

Cranfield University

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**The use of sodium salt deposits in medical and medically
associated industries in Ancient Egypt**

Department of Applied Science, Security and Resilience

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“For the whole body nothing is more beneficial than salt and sun” (Pliny – Natural History Book 31 Chapter 39)

Abstract

The utilisation of minerals in Ancient Egyptian medicine from procurement through to use is examined here in a case study investigating the role of sodium salts. The sodium salts, salt and natron are two of the three most commonly used minerals in the Egyptian pharmacopeia. The results of the project are important to medical historians and archaeomineralogists alike in that they formulate a systematic understanding of the way in which minerals were used in medical and medically associated industries.

Key sources of salt and natron were examined and the Wadi Natrun was identified as the probable main site of natron exploitation. A comprehensive study conducted of this area involved examining sources of a historical geographical nature and analysis of mineralogical samples gathered from fieldwork in the Wadi Natrun.

From the source of exploitation, natron and salt were sold to the Egyptians to be used in a number of everyday industries as well as for their use in medical and medically associated industries. Salt and natron were found to be used for their astringent and cleansing qualities, and are still being used in traditional medical formulations. Prescription replication showed that these substances worked effectively. Additional research into medically associated industries showed commonality between sodium salts use between all three industries investigated.

The results of this research shows that a comprehensive study of the use of minerals in medicine could be established. Primary sites of exploitation of both salt and natron were identified, and minerals from these sites were categorised and identified. The results showed that the chemical nature of these deposits had changed in the last 2000 years. The results also demonstrate reasons why

the language surrounding the term natron needed to be revised. These results have implications for both archaeology and the history of medicine.

Contribution to Knowledge

As an interdisciplinary piece, this work covers the fields of archaeological science, archaeomineralogy and history of medicine. It contributes to each in a variety of ways, namely through the analysis of ethnopharmacological and archaeological samples, analysis of mineralogical specimens and the establishment of a prescription database. The literature survey also forms a big portion of the originality of the project covering not only a study of the historical geography but also a comprehensive analysis of the medical, purification and mummification industries present in Egypt.

One of the major contributions of the project is the prescription database. The database was established to allow the user to search the literature on the medicinal uses of minerals. This allows researchers to either target specific minerals or illnesses or to examine the wider picture. The database is also designed to allow for the future cataloguing of more minerals used in medicine to be conducted which can be added to as new translations and texts are identified.

The literature study ranges across a number of areas. Firstly, it covers the background of medicine, mummification and purification. It is novel in the attempt to identify contemporary ethnopharmacological links with the ancient texts, in the establishment of a chemical history and in the survey of the historical geography of the Wadi Natrun. From this parallels have been drawn between the use of minerals in both modern day Egyptian and Sudanese medicines and their ancient Egyptian counterparts. The establishment of a chemical and geographical history has also allowed for a more comprehensive understanding of the way that the lakes were exploited and modified over time. This in turn gives clues for explaining the perceived change in the mineralogy of the system. As can be identified from a cursory glance at the maps of the Wadi Natrun, a number of features have changed and it is believed that some of

these changes are man-made and that they have consequently impacted on the mineralogy of the system.

A number of small experiments were also conducted in the analysis of ethnopharmacological samples and an embalming jar, and also experimental replication of both mummification and prescription experiments. Perhaps the most novel experiment was the prescription replication which illustrated that replication is the best way to test the actual effect of these prescriptions. This is particularly important as in the past a large number of prescriptions have routinely been dismissed as being wholly symbolic. However, as the replication experiment shows, although a medicine can have symbolic components, there is also a chance that the medicine has an unforeseen level of efficacy.

Analysis of mineralogical samples gathered from the Wadi Natrun were analysed using X-Ray Diffraction, and their complex phases quantified using computer software (TOPAS). These showed that the mineralogies of the lakes were rich in both chloride and sulphate, but not in carbonate which was commonly believed to have been formed in this area. Geochemical modelling of the area was also conducted, showing that the mineralogy model suggested for the system was similar to the actual mineralogy present. This was not always the case however, and there was a decided difference between the mineralogy present within one of the lakes, Lake Fazda, and the software modelling. This suggests that although the chemical nature of the lakes was adept in producing carbonates, biological and other lake interactions may inhibit the production of this substance in practice.

This work contributes to the knowledge of a number of different disciplines and contains a number of new research techniques and methods.

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Dedications

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Glossary

Firstly, the author wishes to note, that she is aware that chemical convention dictates the use of the term sulfate, sulfide and sulfur, but due to the convention of archaeological science that this document will use the dated terms of sulphate, sulphide and sulphur.

Ancient Near East – the area to the East of Egypt made up of a number of nations, ie. the Hittites, etc. (Figure 1)

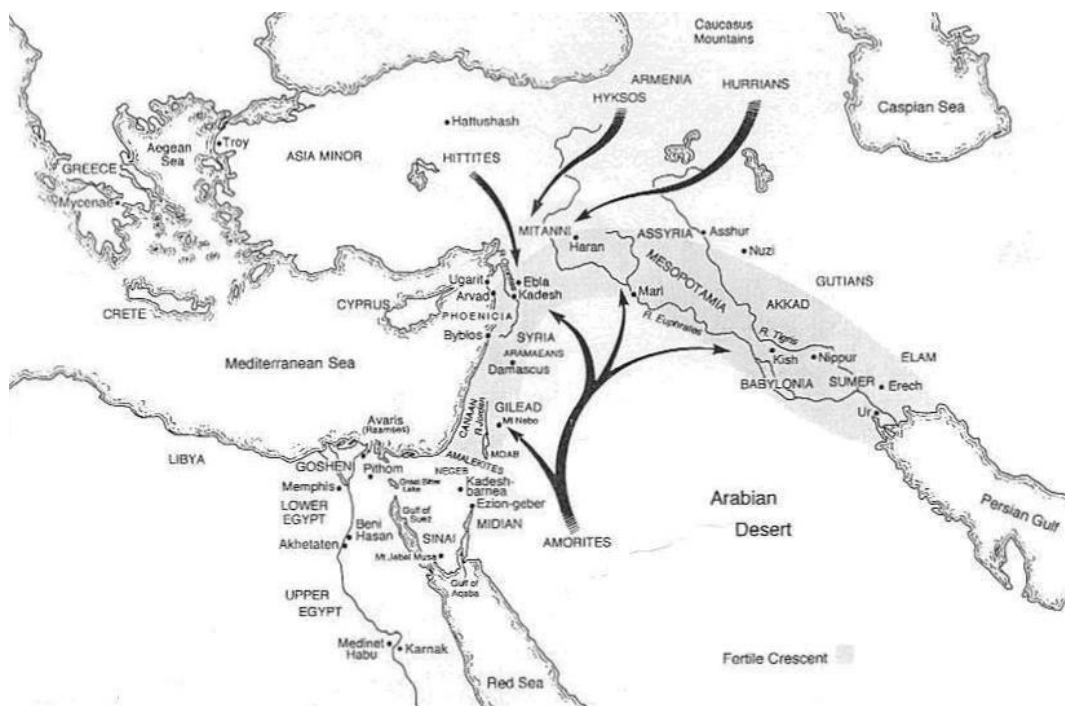


Figure 1: Map showing the location of a number of different Ancient Near Eastern Kingdoms (Astour 1995)

Anion – a negatively charged atom or molecule

Archaeomineralogy - the study of the use of minerals and their exploitation in the past

Astringent – a chemical that has the ability to shrink or constrict bodily tissues

Cation – a positively charged atom or molecule

Cosmeceuticals – a substance that has both cosmetic and medicinal properties

Cubit – an arbitrary measurement used in Ancient Egypt taken between the tips of the fingers and the elbow (approx. 45cm)

Cuneiform – one of the earliest known languages, originated in the Ancient Near East

Demotic – a late form of Egyptian language found between Late Egyptian and Coptic

Drug – a single chemical substance (or natural product) that is used to treat or alter the body

Efficacy – the ability to produce the drugs desired therapeutic effect

Ephemeral – lasting for a short period of time in that state

Ethnopharmacology – the study of traditional medicines

Etymology – a history of words

Evaporite – a rock originally precipitated from a saturated brine by solar evaporation

Hieratic – cursive writing style used in Pharaonic Egypt

Ion – a charged particle

Libation – a ritual of pouring a liquid either for a good or in order to make one ritually pure

Liturgies – a public worship

Medical Anthropologist – an anthropologist who specialises in the study and research of health and wellbeing

Medicine – is a mixture of one or more drugs with additional components such as a vehicle

Middle Egyptian – language spoken between 2000-1200BC

Mineralogy – the study of minerals

Muriate of soda – salt (sodium chloride) (Henry 1810, 4)

Ostraca – (pl.) ostrakon is a piece of pottery (or stone) with writing or drawings on it

Palaeoparisiology – the study of parasites in the past through the study of their presence in human and animal remains

Palaeopathology – the study of ancient diseases

Papyri – (pl.) papyrus is a paper like material used as a writing material by the Egyptians for their documents

Pharmacotherapy – the treatment of a disease or health problem through the use of drugs or medicines

Placebo – a substance or procedure that is given in medical services but that has no therapeutic effect (Macedo et al. 2003)

Stela – a stone slab erected for the dead, generally carved

Syn depositional recycling – the process of redissolving and precipitating minerals

Vehicle – a medium through which the medicine is delivered

Chapter 1: Introduction

The identification of medical knowledge from the past is of prime importance, not only to medical historians but to the study of pharmacology as a whole as it makes it possible to identify new and efficient pharmaceuticals (Tunon and Bruhn 1995). In the 1990s, a campaign was launched to encourage scholars to investigate the medicines of the past (Holland 1994; Sehgal et al. 1994). Ancient texts and folk medicine had been largely ignored despite a study conducted in the 1960s which demonstrated that medicinal plants mentioned in ancient texts had a high efficacy rating for cancer treatment (Tunon and Bruhn 1995). The medical texts also provide a wealth of information regarding environment, trade, faith and even the political structure of the time in which they were written. Of the work that has been conducted into ancient medical texts most have focused on the application of plant matter in medicine and, in particular, have looked primarily at Greek and Roman medical texts. Few studies have been conducted into Egyptian medical texts and the vast majority of work on pharmaceutical knowledge from Egypt has been studies into the plant *materia medica*, whereas few studies have been initiated in the use of minerals. For example even Campbell's (2007) thesis on the efficacy of drugs from four Egyptian Medical Papyri focused on the use of the plants. Manniche (1989a) in her exemplary work also focuses on the identification of plants in the Egyptian medical record. Mineral use touches on many aspects of Egyptian life besides medicine.

Archaeometry can be said to be a truly interdisciplinary subject. There is no other discipline whereby historical research methods would be combined with analytical chemistry in order to answer a research question. It is necessary for the archaeometrist to be familiar with not only analytical chemistry, but other disciplines such as geology and materials science as well as the prerequisite knowledge of archaeology. Within the United Kingdom there are few University

departments that specialise in archaeometry, and even fewer that examine inorganic materials.

The study of the use of sodium salts in medical and medically associated industries in Ancient Egypt is an archaeomineralogical investigation. It combines the analysis of documentary accounts, with archaeological remains, ethnographic work and modern mineralogical samples. It leads to the identification of what minerals were used in the industries discussed as well as a comprehensive account of the changing chemical and geographical nature of one of the sources available to the Egyptians for sodium salts.

Archaeomineralogy is a subject in its infancy and is a subdivision of both archaeometry and the field of geoarchaeology. Archaeomineralogy can be defined as the investigation of minerals in the archaeological record, or even an investigation into the use of minerals within the historical record. It combines analysis of recent mineral formation, to both archaeological remains and the historical record. It plots trade movements, exploitation and processing, and discusses the uses of the minerals. For example the survey of the use of natron in glass, where was it sourced, how was it processed, how was it traded. These questions are commonly investigated by the archaeomineralogist.

The research aim of this project is to develop an understanding of the use and procurement of minerals in medicine and medically associated industries.

The research aim will be tested in a number of ways:

1. The establishment of a prescription database. The prescription database will build a searchable catalogue of all the minerals mentioned in the medical texts
2. Analysis of geological samples. This will enable the identification of patterns of geological formation – this has implications for our understanding of the exploitation, use and source of the minerals.
3. Prescription replication will test for efficacy of the medicines.

4. Analysis of industries related to both the utilisation of minerals and related to the medical profession, allow for the identification of links both between the industries themselves and common usages of the minerals in these industries.
5. Analysis of ethnographic records and samples should show the degree in which the medical tradition of the area has been persevered.

The project covers the use of sodium salts in medicine, mummification and hygiene in Ancient Egypt, covering the 3000 years from the Early Dynastic Period until the collapse of the Roman Empire, although ethnographic evidence is also used covering the period from the 19th century onwards. The three industries examined were chosen due to their close relationship with each other as well as their common feature, that they all use sodium salts. Geological profiling of known sodium salt deposits is an important aspect of the project as it gives a better understanding of how, when and where these sodium salts were gathered and how they were therefore used. Besides this core a comprehensive literature survey was conducted covering ethnopharmacology, historical geography and chemistry. This literature survey is the first of its kind and gives a comprehensive understanding of medical tradition, the changing nature of the lakes and the chemistry of the deposition and formation of sodium salts.

1.1 Ancient Egypt

1.1.1 Introduction

Egypt is unique in terms of her physical geography. The country is surrounded by desert to both the west and east, and protective forts were placed strategically at her changing southern border in order to maintain control over the movement of people and resources between Egypt and Nubia. It is the presence of both natural and man made borders that allowed for the formation of a fairly stable core to the country. Although Egypt did expand to a certain degree through different periods the main populated core of the country, based around the Nile Delta and Valley, has changed very little throughout the country's history (Figure 2). This allowed for a degree of stability that was largely unmatched among other ancient communities and this in turn enabled a sustained development of aspects of "cultured" life, such as science and religion (Kemp 2006).

Egypt has a long history (Table 1) and even by the time of the Greco-Roman Period a degree of commonality and order needed to be found in its history. Mantheo in the time of Ptolemy II devised the system of Dynasties stretching from the Early Dynastic Period through to the Late Period of Egypt's history. It was the work of later Egyptologists that grouped these Dynasties into Kingdoms and Intermediate Periods. Intermediate Periods may indicate either a division in Crown (with one king ruling Upper Egypt and another Lower Egypt), or the ascent of foreign rulers (Baines and Malek 1984). Preceding the historic periods included by Mantheo, lay what is now called the Predynastic era, which includes the cultural groups Naqada, Badarian and Maadi-Buto; each was originally based on the cultural material associated with a given region. The Predynastic is not discussed in any depth in this document and is therefore not further subdivided in Table 1.

The periods with which this project is primarily concerned are the Middle and New Kingdoms and the Greco-Roman Period. These periods provide the most detailed surviving medical literature as well as documentary evidence regarding the geological sources for a number of medicinal minerals, which were written from the Middle Kingdom onwards.

Table 1: Table showing the different time periods of Egypt's ancient history (based on (Baines and Malek 1984, 36-37))

Time Period	Date	Dynasties
Predynastic	Up to around 3000 BC	n/a*
Early Dynastic Period	2920 – 2575 BC	1 st and 2 nd Dynasties
Old Kingdom	2575 – 2134 BC	3 rd to 8 th Dynasties
First Intermediate Period	2134 – 2040 BC	9 th to 11 th Dynasties
Middle Kingdom	2040 – 1640 BC	11 th to 14 th Dynasties
Second Intermediate Period	1640 – 1550 BC	15 th to 17 th Dynasties
New Kingdom	1550 – 1070 BC	18 th to 20 th Dynasties
Third Intermediate Period	1070 -712 BC	21 st to 25 th Dynasties
Late Period	712 – 332 BC	26 th to 30 th Dynasties
Greco-Roman Period	332 BC – 395 AD	n/a

* For an up to date discussion on the periods of the Predynastic see (Hendrickx 2006)

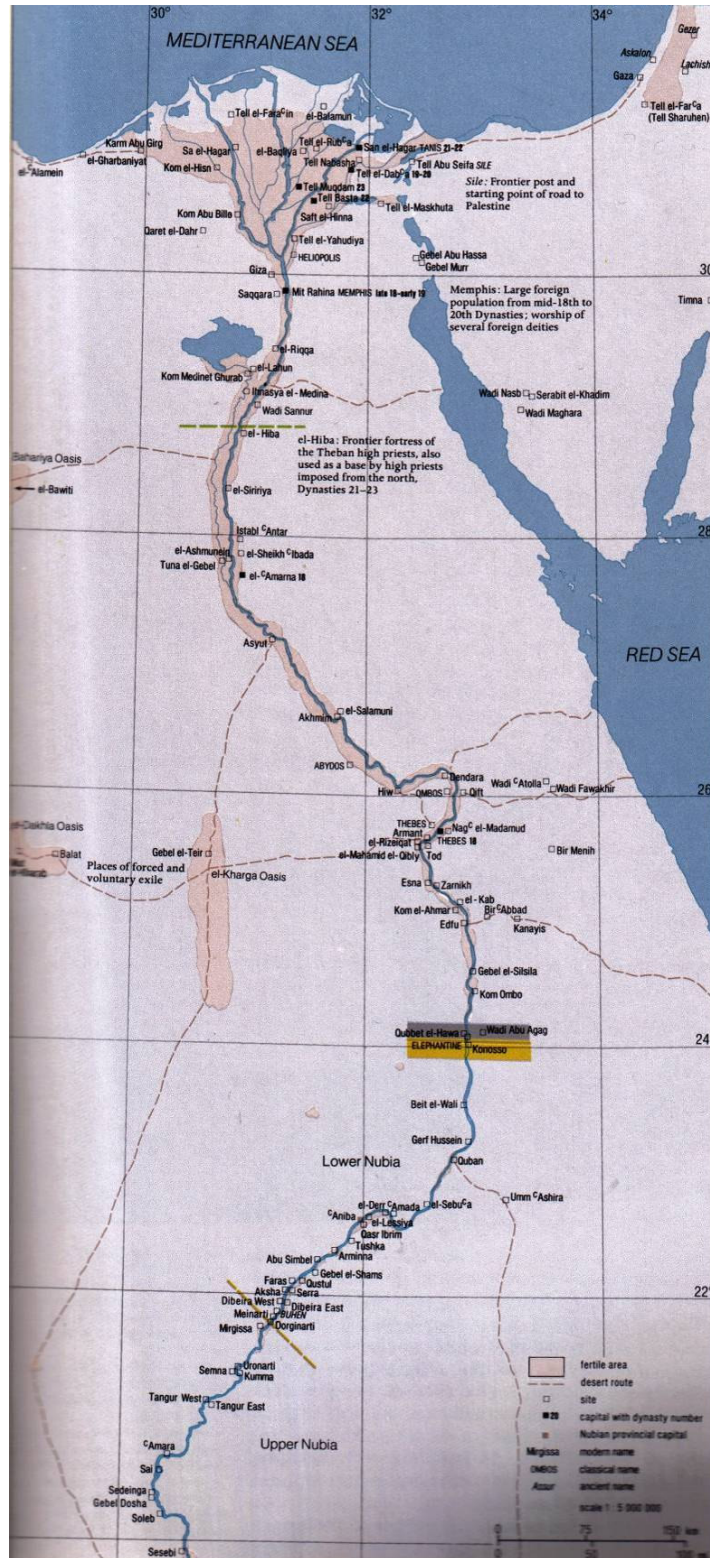


Figure 2: Map of Egypt in the New Kingdom showing borders and desert routes (Baines and Malek 1984, 43)

There was no distinct “race” present within ancient Egypt, indeed it is said that the Egyptians saw themselves not as a race but as a culture (Kemp 2006; Morkot 2005). Those who adopted similar cultural traits were therefore classed as Egyptian and religion was a central part of this cultural life. However the Egyptians had a very strong sense of self as depicted in the art where there are different conventions for the depiction in terms of hair, dress and skin colour between foreigners and Egyptians and this is especially the case in tomb iconography of high ranking officials (Panagiotopoulos 2001). The common convention for the depiction of foreigners is in the way the person themselves is depicted, black for Nubian (Figure 3), generally paler and wearing elaborate clothing for Asiatic (Figure 4), Libyans were often depicted as nude under a leather cloak, and the males uncircumcised (Figure 5) (O'Connor and Quirke 2003; Shaw 2002).



Figure 3: A representation of a Nubian found on a 20th Dynasty glazed tile (Image courtesy of the British Museum)



Figure 4: A tomb painting from the 18th Dynasty tomb of Sobekhotep (TT63). Registers show a scene of Asiatic tribute-bearers (Image courtesy of the British Museum)



Figure 5: Photo of a glazed tile depicting a captured Libyan, dated to the 20th Dynasty (image courtesy of the British Museum)

The head of the country was the King/Queen or Pharaoh and below him were the appointed officials who were delegated regions of control or day to day tasks in the royal court. This led to a highly stratified country with the king at the head, followed by the ruling classes, the craftsmen, farmers, outcasts (van Blerk 2006) and slaves. It is unfortunate however that the full structure of Egyptian government is unknown due to the lack of supportive documentary evidence (Kemp 1983). However some attempts have been made towards ascribing the formation processes behind the social organisation in Egypt, specifically in the Old Kingdom (Roth 1991). An important function of the government was the collection of resources, including taxation, and the administration behind such a task, which were necessary for the court to both survive and to support its projects including military activities and mining expeditions (Kemp 1983).

1.1.2 Religion

Baines and Malek (1984) state that there are three aspects to Egyptian religion. The bias in the archaeological record means that there is a great deal more evidence regarding the organised state religion in the form of temples and the gods worshipped therein as well as a wealth of information regarding the mortuary aspect of religion. The third aspect of day to day practices of the overall population is not so well documented, either in the archaeological record or in documentary accounts.

The king and the priests were an important part of Egyptian society, it was through them that the balance of the country was maintained. The king acted as a mediator between the heavens and the earth and it was his function to maintain good relations between the gods and his people. Official state religion was conducted in the temple, and temples were there in order to care for the images and statues present in the temple, and in turn these figures were believed to become a living image of the god (Baines and Malek 1984). These images were placated through the offering of goods and through the daily fulfilment of ritual practices (David 1981).

There is far less known about private religion than any other form of Egyptian worship. This is due to the lack of settlement information that Egyptologists have. Indeed perhaps the best known settlement is that of Deir el Medina, a workers' village formed in order to build and decorate the tombs in the Valley of the Kings and the Valley of the Queens on the West Bank near Thebes (Figure 2). Even this settlement is not, however, representative of other settlements in Egypt, due to its presence being dependent on the Crown. What is known about private religion is that it was based on aspects of pilgrimage to major temples, to attendance at local shrines, and private "household" worship (Baines and Malek 1984; David 1999; Lesko 2002; Meskell 2002). The household worship was governed by the women of the house and a number of gods and goddesses were worshipped in the hope of helping her fertility and to look after her children (Lesko 2002). Erman (1971) stated that present within each house would be a room dedicated to the worship of a specific god or goddess. In this room daily worship would take place, as well as the administration of offerings (Erman 1971). Less is known about private religion as there were no formulaic texts, and relatively few ancient houses have been excavated, which is in direct contrast to the wealth of information that the public sphere of religion namely the temples left with formulaic texts, imagery within the temple and within the tomb as well as texts from the temple which state religious procedures such as purification rites.

1.1.3 Economy and Trade

Egypt's economy was driven by agriculture. Due to the hostile environment to the east and west, the fertile strip alongside the Nile was where the population of Egypt predominately resided, indeed in many documents the borders between desert and the cultivated area were seen as, figuratively, the border between life and death (Faulkner 1996). Egypt is imbued with a variety of valuable raw materials (Figure 6) and it is known that there were complex foreign "trade" and communication networks established even in the Predynastic period and which continued throughout most of Egypt's history

(Amin 1970; Astour 1995; Avdief 1954; Harrison 1993; Leemans 1960; Mark 1998; Peltenburg 1991; Sperber 1976; Temin 2003).

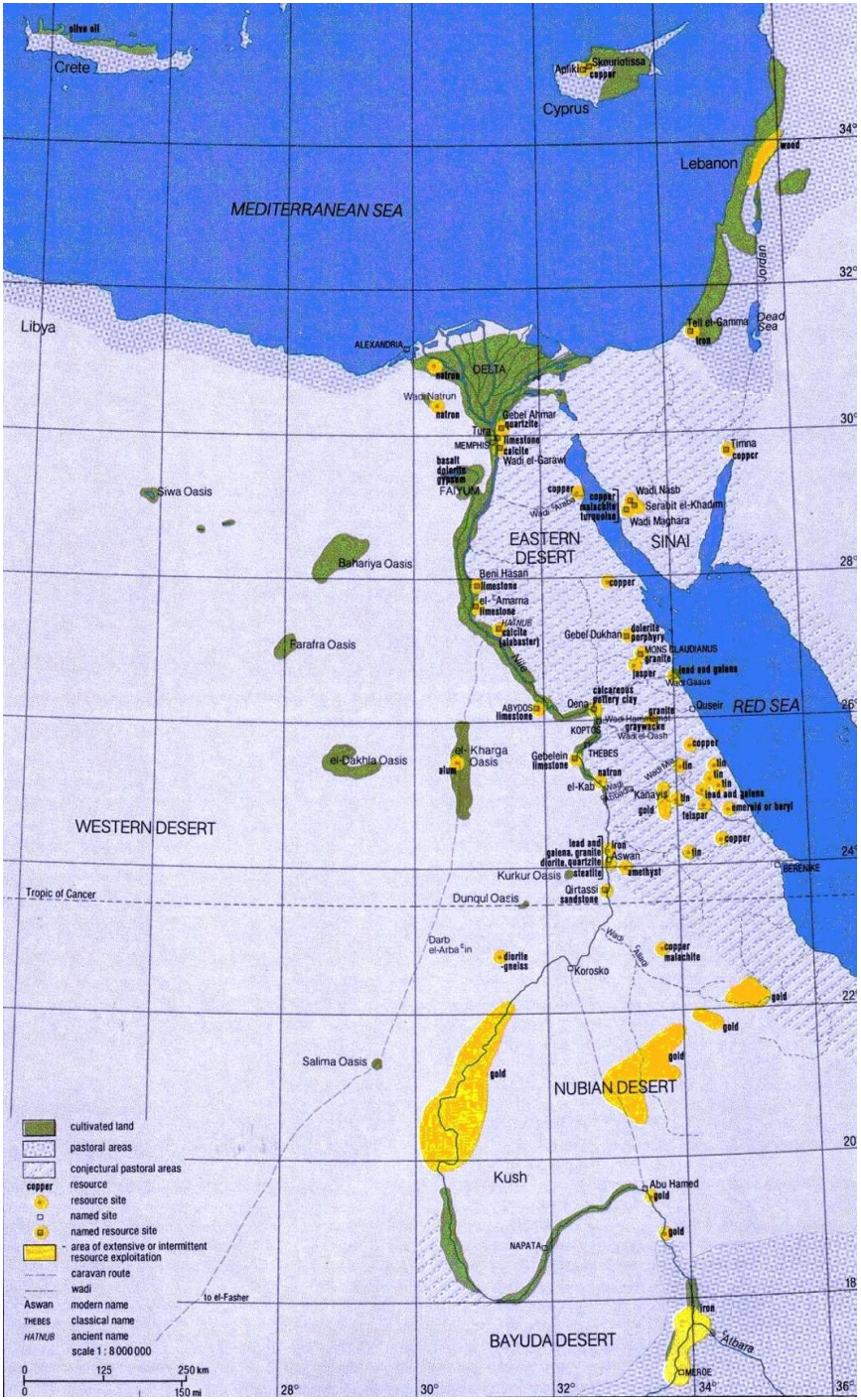


Figure 6: Map of the mineral resources available to Egypt (Baines and Malek 1984, 21)

Trade is an important aspect of any nation. It is based on the identification of a surplus of one good and an unfulfilled demand for another (Saggs 1989). Trade has intrinsically developed from “primitive” society as a form of social progress, which shows the growth of production as well as the beginning of contact between different nations (Avdief 1954). Unfortunately there is an inherent difficulty in establishing trade and the movements of goods, as Catling (1991, 2) states *“trade is not the only possible explanation for the appearance of import”*.

In Egypt specifically, trade was seen not as a fundamental necessity as the country was able to produce its day-to-day requirements, however as society became more complex and the desire for more luxurious goods increased then so did trade. Indeed trade was seen as a means for attaining objects that could be used in ceremonial or religious procedures, or could indeed just be used as a luxury, such as turquoise or lapis lazuli, affordable only to the royal family or the nobility (Ben-Tor 1986). Trade organisation in the form of large scale trading in Egypt was under state control (Ben-Tor 1986; Saggs 1989). This state control even extended into the military encampments of Canaan, where “merchants” were employed to organise the purchase and transport of Canaanite exports into Egypt (Ben-Tor 1986). Trade could be close to home, such as material gathered from Libya or the Sudan, or from established trade networks with other Ancient Near Eastern regions (Figure 1). There is even evidence for trade between Egypt and regions far afield such as the Caucasus and these trade patterns show a well formed communication system as well as a stable economy in the trading process. International trade varied throughout different time periods with examples of trade being completely abandoned between Canaan and Egypt in the Middle Kingdom due to a lack of archaeological evidence (Ben-Tor 1986).

1.1.3.1 Close to home - Sudan and Libya

Egypt is a fairly well isolated community however it is bordered to the South by the Nubia (in modern Sudan) and to the West by Libya. Both of these areas

contained access to high status resources such as gold and consequently ancient trade routes were developed. There is by far less evidence for the trade between Egypt and Libya than for the evidence between Egypt and Nubia. Egypt and Libya had a more difficult trade route over the Libyan Desert and may therefore not have been widely exploited as the land to the south was. However there is archaeological evidence to show that trade between the Egyptians and the Libyans was established in the Neolithic period (Avdief 1954). The identification of forts, built from at least the 12th Dynasty, along these proposed desert routes indicates just how important these routes were and how important maintain trading relations between the two nations were as well.

At certain parts of Egypt's history areas of Northern Nubia were taken as part of the Egyptian Empire. Archaeological evidence has however shown that from the Predynastic through to the end of the Roman Empire, Nubia was an important trade location for such items as gold, ivory, ebony and ostrich feathers (Avdief 1954). There are also documents that detail that a sizeable trade between Egypt and Nubia was conducted (Amin 1970). It is believed that the trade caravans would have followed a route between Egypt and Nubia by following the route of the Nile, allowing for potable water along the way (Amin 1970). In addition to the documentary and archaeological evidence, it is believed that the Egyptians also imported aspects of Nubian religion in the form of the goddess Hathor and the dwarf gods Bes and Patek (Avdief 1954).

1.1.3.2 Trade with other countries in the Ancient Near East

Elat (1978) believed that the reason for Egypt's ability as a commercial trading nation was because of its isolation. This led to other nations being unable to control exports from Egypt through the form of tributes and booty (Elat 1978). Trade between Egypt and a number of Ancient Near Eastern communities is well attested with documentary (the Amarna Letters) and archaeological evidence being found as far away as the Hittite and Assyrian Kingdoms.

Leemans (1960) gives a simplified account of the two potential routes taken by traders between Egypt and the East (Figure 7). The first is a route by road, this route heads north via the Euphrates, Syria and the Mediterranean. The second is a route that goes to the south over the Arabian Sea (Leemans 1960). These routes each proved to have their own problems, but a direct desert route was not appreciable until the advent of camels (Leemans 1960).

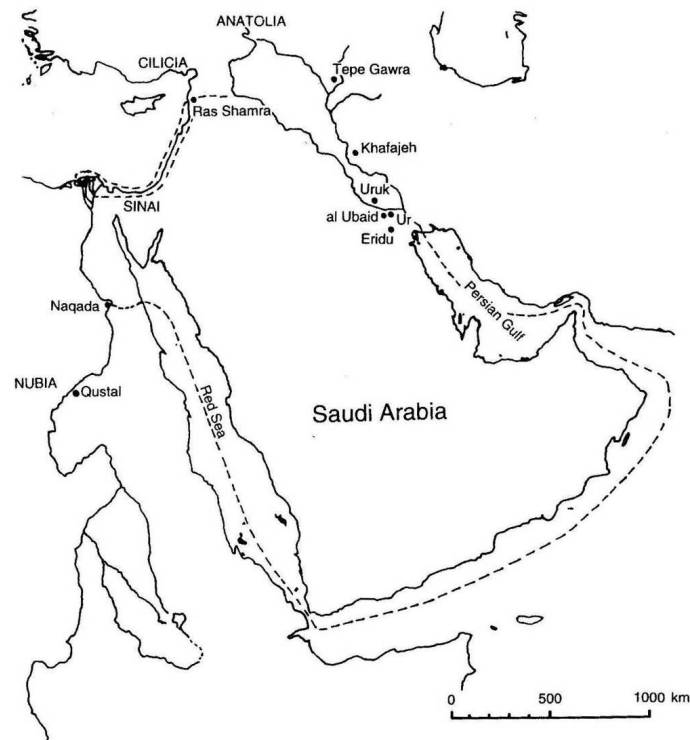


Figure 7: Map showing land and sea trade routes between the Ancient Near East and Egypt (Mark 1998, 4)

There are a number of documentary sources referring to the trade between Egypt and other nations. Bergoffen (1991) states that the records from the Late Bronze Age showed an organised trade network, involving military posts, systems of supply and taxation.

As trade is a two way system, patterns of trade can be found either from the identification of “Egyptian wares” in other nations or from the identification of

“foreign” wares in Egypt. There is also the added complication of “down the line” trading, where objects from one area would be passed between many hands before arriving at in reduced numbers in their final destination.

Egyptian goods have been found in Syria, Palestine and the Southern Levant (Avdief 1954; Beit-Arieh 1984), and “exotic goods” such as turquoise from Western Sinai have been found in excavations in Egypt (Ben-Tor 1982). Trade patterns can also be identified from art, one important depiction are those of Syrian ships entering port, which can be found in a number of tombs (Temin 2003). These pieces of evidence can be dated back, sometimes, thousands of years, and show a confident and thriving trading community both for imported goods and for the export of goods.

Again religion is believed to show links between nations, and the Egyptian god Osiris can be found to be worshipped in Byblos. Avdief (1954) believes that this shows a most ancient and stable trade route between these two countries.

1.1.3.3 Trade with nations outside the Ancient Near East

There is sporadic evidence in terms of trade with nations from outside the Ancient Near East, such as countries within the Aegean. Perhaps the best evidence for trade of this kind is that of lapis lazuli, which is known to come from deposits in Afghanistan (3.9.14). Pottery also gives an indication as to the extent of Egypt’s trade networks, and Egyptian pottery has been found as far away as Crete and other islands in the Aegean (Arnott 2004; Avdief 1954). Similarity in some artistic pieces has also strengthened the belief that there was trade between Crete and Egypt as long ago as the 2nd Millennium BC (Saggs 1989). In addition to this evidence there has been documented cases of Egyptians beads being found in the Caucasus and Azerbaijan, in addition to the find of ancient Egyptian statuettes and amulets in the Caucasus (Avdief 1954).

1.2 Chapter Summaries

Chapter 2- Analytical Techniques

There are a number of analytical techniques that were used in the progress of this project, all are primarily used in the analysis of inorganic materials and a few are readily used in the field of archaeometry. Two main techniques were utilised, X-ray Diffraction (XRD) and Thermogravimetric Analysis (TGA). TGA is well known in the field of materials science and were chosen for their ability to analyse very specific bits of information; however it is not readily identified in the archaeological sciences. X-ray Diffraction is readily used in the archaeological sciences, specifically in relation to the analysis of inorganic materials.

XRD is an increasingly important tool in archaeological sciences by allowing testing for the composition of a range of artefacts whilst having limited destructive drawbacks. Indeed it has been suggested by Schreiner (2004) that the use of XRD in archaeology and even art history allows for a number of questions including where, when and by whom an artefact was made to be answered.

TGA is not a common archaeometric technique, although it is becoming an increasingly popular tool for analysis in both geology and the vitreous materials industry. Indeed in 2000 it was used to determine the manufacturing of a number of Ramesside glasses, through the analysis of gasses given off during a degassing experiment (Heide et al. 2000). TGA was determined to be an effective technique to be used as it is cheap and easy to interpret the data as well as the fact it is a commonly used technique in dermatology.

Chapter 3 – Medicine

The use of minerals in medicine was the primary consideration when this project was undertaken and the use of sodium salts in Ancient Egyptian

medicine examines the way in which these minerals were used in the treatment of the sick. How were these minerals used, was there any symbolism behind their use, where were the minerals gathered, how were they used, what common problems were they used for, how did the formulations work? All these questions are examined in this chapter, alongside these questions a general over view of the way that the medical system worked is also examined.

Chapter 4 – Associated Industries

As two of the three most common minerals used in Ancient Egyptian medicine are related to each other, both being sodium salts, an examination of the way that these minerals were used in medically related industries was undertaken as a case study of the way in which other minerals could have been used in the Egyptians everyday life. The chapter examines the use of sodium salts in two of the most notable medically associated industries, mummification and hygiene. The way in which these minerals were used identifies common themes, and the experimental work hopes to address some questions that have been left unexamined by other research.

Chapter 5 – Evaporite Mineralogy

Chapter 5 covers the chemistry of different sodium salts and also the way in which such non-marine evaporitic deposits form. It is the background chapter for the following more investigatory chapter on the “Wadi Natrun”.

Chapter 6 – Wadi Natrun

The Wadi Natrun is by far the largest source of natron that would have been available to the ancient Egyptians. Consequently it forms the main focus of the historical geography and geological analysis. The analysis of the geological samples gathered from the Wadi Natrun explains formation patterns, mineralogical chemistry and depositional environments. These results coupled

with the information gathered from a historical geography study allow for an understanding of the way in which the lakes were exploited, and overall a better understanding of what was exploited and how it was then used.

The project examines the way in which sodium salts were formed, gathered, sold and then used for at least 3000 years of Egypt's history. Their use in the three industries discussed here are a case study for the way in which these minerals were used in the everyday life of an Egyptian. The results gathered here can build a picture of the way in which these minerals may have been used in different industries, but also allow for an understanding that a deeper knowledge regarding the use of all mineral resources used in Egypt can be attained.

Chapter 2: Analytical Techniques

Due to the interdisciplinary nature of the project a number of different methodologies had to be established, and a number of different analytical techniques utilised. Experimental techniques were designed following a number of factors: firstly suitably supportive literature, secondly the presence of suitable analytical tools available to the department and thirdly the use of pilot studies. The analytical techniques used in the course of this project are described here, however further details regarding the experimental work can be found independently within each supportive chapter, for example the analysis of ethnopharmacological samples can be found in Chapter 3, whereas analysis of geological samples can be found in Chapter 6. The analytical techniques help to answer a number of research questions and cover all aspects of this project from medicine to mineralogy.

This section details the theories which lie behind these techniques as well as discussions on specific instrumentation and sample preparation. The techniques used in the progress of this research are described here and are X-ray Diffraction (2.1); Thermogravimetric Analysis (2.2) and Data Analysis (2.3). The results of these analyses will be discussed in the individual sections throughout the document.

2.1 X-Ray Diffraction

X-ray diffraction (XRD) was identified as a useful analytical technique as:

1. It can characterise mineralogical specimens with a relatively high degree of specificity;
2. Its ability to conduct crystallographic phase analysis;
3. It has the ability to provide quantitative data;
4. It can accommodate a large number of samples to be analysed within a comparatively short time-frame.

XRD is an increasingly important tool in archaeological sciences as it allows testing for the composition of a range of artefacts whilst having limited destructive drawbacks. Indeed it has been suggested by Schreiner (2004) that the use of XRD in archaeology and even art history can address a number of questions including where, when and by whom an artefact was made. XRD is an analytical technique that can only be readily utilised to examine crystalline materials, and although a number of studies have been initiated into its use in the glass industry (Mantler et al. 1999) it is not a readily recognised technique in these industries. It is therefore a useful technique for the basis of this project. XRD is also an available technique within the department, and the inclusion of a number of different XRD machines allowed for specific methods to be established when performing analysis of different sources.

XRD is a crucial element of this project, it is the technique that was most frequently used and was necessary in a number of different experiments; including the mineralogical analysis of samples gathered from the Wadi (6.3), ethnopharmacological samples (3.11) and the analysis of an embalming pot from the Bolton Museum (4.2.4).

Background

There are two main methods of XRD analysis in widespread use; the first is single crystal (crystallography) and the second, and more common, is powder diffraction (known simply as diffraction). This project uses the powder diffraction technique.

X-rays are electromagnetic waves with a high frequency and a short wavelength (λ). XRD uses X-rays of known wavelength to determine the lattice spacing in crystalline structures (Pollard et al. 2007). Crystalline materials have atoms arranged in regular three dimensional patterns (Weymouth 1973). Such crystal structures can be considered to be constructed from planes of atoms, which each have characteristic spacings between them (commonly known as d spacings). Crystals with such regular three dimensional arrangements of atoms are referred to as having long range order. Amorphous materials on the other hand are described as having short range order as they have no regular arrangement of atoms over long distances (Cullity 1978).

X-rays produce both constructive and destructive interference as they are reflected by the crystal lattice (Pollard et al. 2007; Snyder 1999). These constructive interferences lead to high intensities at specific angles and these angles are characteristic of the spaces between the lattice planes. Each peak corresponds to diffractions from the different lattice planes and using Bragg's Law ($n\lambda = 2d\sin\theta^1$) the spacings between the lattice planes can consequently be identified. Crystalline phases are identified from their peak positions and their relative intensities of the diffraction peaks. Crystalline solids are often identified through the relationship of relative intensity versus 2θ (Weymouth 1973). This data is then compared against known databases. Unlike other techniques such as ion chromatography and scanning electron microscopy-electron dispersive spectroscopy, XRD discloses the presence of a compound and its polymorphs not simply the chemical elements (Cullity 1978).

¹ n = an integer normally 1; λ = wavelength of x-rays; d = spacing between planes in an atomic lattice and θ = angle between the x-ray and the scattering plane

The scattering of X-rays occurs when they interact with the atoms present within the crystal, which are described in terms of 2θ . These diffraction patterns are related to the crystal structure found within the crystalline phase (Eiland and Williams 2001). The results gathered from XRD can be likened to a fingerprint, and a diagnostic of the chemical crystalline phase (Eiland and Williams 2001; Snyder 1999). Multiphase materials hold additional complications for the interpreter and indeed it is possible that particular regions of interest within the diffraction pattern may need to be identified. This allows the analyst to confidently identify mineral components provided that data regarding the mineral has already been gathered. This precision can vary depending on the count time for each step. If a rapid analysis is required then this can take as little as ten minutes - however if a more reliable result is required then this time can be increased commensurately. Powder diffraction has a long history in the characterisation of materials (Dinnebier and Billinge 2008) and an ever-growing standing in the field of archaeometry (Pollard et al. 2007).

Inevitably there are both strengths and limitations to XRD. The key strength lies in the quick and simple way that it can be used. However the limitations include the XRD data library which, although large, does not cover every possibility and are produced from results taken from pure mineralogical samples. A second disadvantage is that well-crystallised minerals can lead to inaccurate qualitative data (Pollard et al. 2007).

Experimental Method

A number of samples were analysed using XRD, to identify their mineralogy. The largest sample base analysed using XRD are the mineralogical samples gathered from the Wadi Natrun. Additional samples in the form of a burkeite standard from the Natural History Museum of Belgium, ethnopharmacological samples from the Sudan and samples taken from an embalming pot in the Bolton Museum have all also been analysed using this technique.

A number of methodology protocols were utilised in the analysis of the samples, these methodologies were developed primarily due to sample size constraints (Table 2). There are two distinct groups that can be found in the samples analysed through XRD. Firstly, there are the mineralogical samples that were brought back from the Wadi Natrun. The second group comprises on samples gathered from museums. These ranged from mineralogical samples to ethnographic medicines and embalming salts. The samples gathered from the museums were different in an important respect, only small samples could be taken to preserve the object as much as possible. The second group therefore required a higher analysis time and as they were of uncertain composition the angle range was also greater to ensure no information was lost.

Table 2: Table showing the different methods used to analyse a variety of samples

Sample Type	Machine Used	Angles	Step Size	Time per step	kV	mA
Mineralogical Samples from the Wadi Natrun	Kristalloflex 810 Autoloader	10°-60°	0.02	2	40	30
Ethnographic Samples from the Sudan	Philips 1820	5°-80°	0.02	20	40	30
Bolton Museum Samples	Philips 1820	5°-120°	0.02	20	40	30
Reference Sample from the Natural History Museum of Belgium	Philips 1820	10°-80°	0.02	20	40	30

Although the Diffractometer differed for the analysis of samples, all samples were prepared in a similar manner. The specimen to be analysed was crushed using a pestle and mortar until it was a fine powder and homogeneous. The powder would then be applied to a low background scattering (Philips 1820); or Perspex slide (Kristalloflex 810 Autoloader) using petroleum jelly.

There are a few problems with interpreting data gathered from XRD. Firstly sample preparation needs to be conducted thoroughly to ensure a minimum amount of background or noise. In terms of identification only known mineralogical phases can be identified; organic samples, due to their poor crystallinity are hard to identify and preferred orientation of the crystals also raises problems.

2.2 Thermogravimetric Analysis

For the purposes of this project, mass loss was examined with the TGA. Mass loss occurs when a volatile component is lost. Although the TGA is being used in the replication of an Egyptian prescription it should be noted that TGA is used in a number of industrial applications including glassmaking, compositional analysis, reaction viewing and corrosion analysis.

Background

Thermogravimetric analysis (TGA) is *“a technique in which the mass change of a substance is measured as a function of temperature”* (Heal 2002, 10). TGA relies on the premise that the mass of a substance will change whilst being heated isothermally or non-isothermally. The TGA can be coupled with mass spectrometry in order to register what is occurring in the reaction (this was not available however within the department). There are five main components to the TGA; the inert crucible which is often made of alumina, the furnace which can be fitted in different positions depending on the analysis to be conducted and the type of sample to be analysed; the thermobalance, which registers the change in weight as a function of temperature, two thermocouples - one to measure furnace temperature and the other to measure the constant temperature, and finally the data collection via a computer. The atmospheric control can be either static or inert gas.

Experimental Method

TGA as a method was selected as it was able to record the mass loss of the skin as water was lost. TGA is a technique that is commonly used in dermatology as it is cheap and easy to interpret the data. Although it is not a common archaeometric technique, it is becoming a popular tool in geology and the vitreous materials industry.

A set up was produced that was as close to the Egyptian climate as possible and the proposed number of hours the effect would be monitored set. The experiment used a Mettler M3 TGA and controlled by a TA 4000 control unit and data handling was conducted on a separate PC with Mettler Thermal Analysis Software and graphs were produced using Excel. The experiment parameters were 16 hours at a continuous temperature of 35°C in static air ensure the correct atmospheric conditions, rather than using an inert gas.

There are no specific problems in interpreting data from the TGA. However it is understood that this is an emerging technique in archaeometry and as such needs to be firmly justified in its use.

2.3 Data Analysis

A number of different computer software suites were used in order to facilitate both the quantitative analysis of XRD data or in order to model the chemical system present in the Wadi Natrun. The two software systems that will be discussed here are TOPAS and Geochemist Workbench.

2.3.1 TOPAS

Background

TOPAS (<http://www.bruker-axs.de/topas.html>) is a computer programme specifically designed for powder diffraction line profile analysis. It allows for profile fitting methods such as:

1. Single line fitting up to whole powder pattern fitting
2. Whole powder pattern decomposition
3. Rietveld structure refinement and quantitative analysis
4. Ab-initio structure solution from powder data in direct space

TOPAS is one of a number of programmes (such as RockJock - <ftp://brrcrftp.cr.usgs.gov/pub/ddeberl/RockJock/>) that allow for the quantitative analysis of XRD profiles. TOPAS was used as the method for refinement analysis for a number of reasons: 1) it is freely available within the department and 2) it is readily accepted by both the mineralogical and crystallographic communities. TOPAS R was the programme used for this project and works through the analysis of the powder data with reference to a crystal model, which is accessed through ICSD. There are a further two types of TOPAS (TOPAS manual) that can also be utilised. TOPAS uses all four of the above mentioned profile fitting methods in its analysis and TOPAS P works by refining the data without reference to a model (these models can be found through ICSD or through TOPAS' own database).

TOPAS R was chosen as crystal models for the minerals to be identified were readily accessible through the Chemical Database at Daresbury namely the ICSD database, and through the use of Rietveld method (discussed in depth in Young (1995)) analysis it allows for the collection of quantitative data.

TOPAS is an easy and efficient system to use, however due to the nature of the materials being examined it was important to establish a methodology which could be relied upon to give the most accurate results.

Experimental Method

Data from the diffractometer was saved as a .RAW file and these files can be used without conversion directly by TOPAS. Once the data file has been assessed using SearchMatch (a software database which allows for the identification of phases within a substance) it can be exported into TOPAS. Prior to a refinement being conducted emission profile and instrument details must be inserted to allow for accurate quantification. The minerals examined for the purpose of the study were not available through TOPAS' structure database and had to be imported through the ICSD. Careful notes should also be made on the exact ICSD card required (the number and other details of which are presented in SearchMatch, and can also be found in a number of diffraction journals or through websites such as webmineral - <http://webmineral.com/>). To ensure the most accurate results the most prevalent phase should be inputted first rather than perhaps the more crystalline substance (for example Figure 8 which shows that a more crystalline substance can appear to be more prevalent than the phase that is most prevalent, in this case halite is more dominant in the diffractogram than representing the fact that sample contains high amounts of burkeite). Once each structure profile is entered the system must be refined and spherical harmonics administered. Although the reader should be careful to ensure that the adding of spherical harmonics does not lead to the development

of a negative profile. Once all substances are entered the background order must be increased to improve the fit.

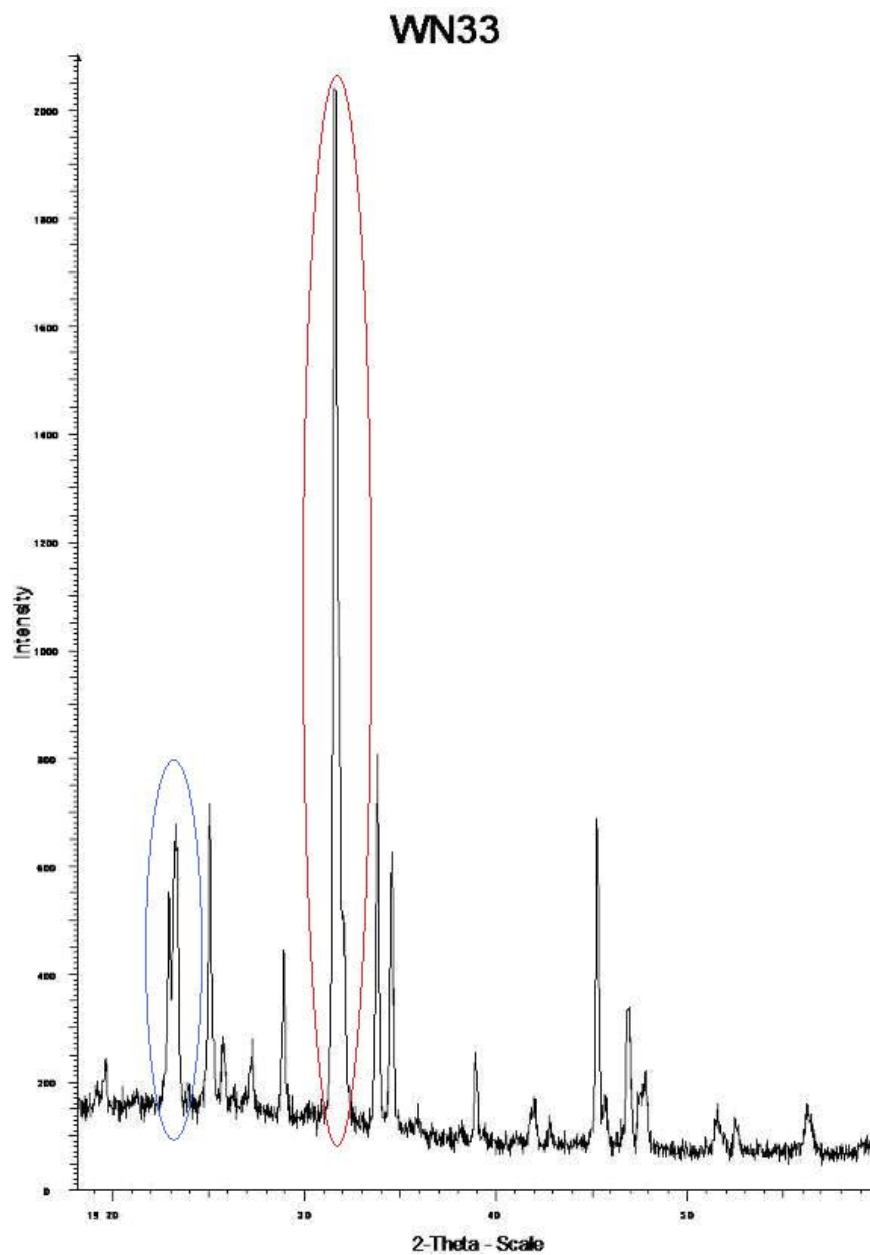


Figure 8: XRD data for WN33 results show that this sample contained high amounts of burkeite (circled in blue), however the most predominate peak is that of halite (circled in red)

2.3.2 Geochemist Workbench

Background

Geochemist workbench is a commonly utilised analytical technique in the fields of geology, geochemistry and mineralogy. It can model different environment types and can generate data in a number of ways. It is a chemical reactor type model which allows for models through “no-flow” conditions (ie. water is not shown to go through an aquifer) (Zerai 2006). Modelling the system in this way can provide insights into the variables that produce reaction progress and reaction products (Zerai 2006). This study was interested in both the quantity of the mineral produced and when it would be produced, ie. the amount of water present vs. minerals (with mass in grammes). The software requires chemical data for the system to be modelled and this data can be generated either through chemical analysis of water samples or mineralogical samples. The system can also be reversed engineered if the chemistry behind the system is unconfirmed.

Experimental Method

Geochemist Workbench version 3.0.2 was used to identify, using the chemical constituents known to be present in the lake water (data gathered by Shortland et al. (2006a)), the proposed mineralogy of the lake. As the results were known per litre, the system was modelled down to almost dryness and at varying temperatures ranging from 10° to 100°C, through 25°C and 60°C. Lake Fazda (the most significant lake) was, modelled between 0° to 100°C at increments of 5°C. The results of these analyses are discussed in Chapter 6.

Chapter 3: Medicine

Historically knowledge of Egyptian medical traditions and abilities were based simply on classical accounts. It was not until Champollion's breakthrough in the decipherment of the Egyptian language in the 19th Century that Egyptian medical texts could be translated and allow for a deeper and more accurate understanding of Egyptian medicine. When this was coupled with the advancement in palaeopathology it widened the understanding of not only the medical traditions but also the health and palaeoepidemiology of the ancient population.

To a medical anthropologist health is frequently defined as being the absence of disease (MacPherson 1995). However health can be a more relative concept and is dependent upon the criteria devised by the culture in question (Winnicott 2003). The presence or absence of ill-health is in practice frequently attributed to whether one can perform ones tasks within a community. As the culture changes, then so does the notion of health; for example women are no longer ostracised with each monthly cycle as a sign of uncleanliness. Consequently, the history of medicine can be an important tool in understanding the functions, and therefore the lives, of people within a community.

A question which needs to be addressed when discussing the history of medicine in Egypt is what is meant by the term 'medicine'? To contemporary Western society medicine is easily defined as the treatment of disease using "conventional" treatments, including surgery and drugs, and the populace is generally able to differentiate between "traditional" and "scientific" healing as well as between religion and medicine. This distinction was more nebulous in the past. As will be discussed later, there is often believed to have been no clear distinction between magic and medicine in Egypt (Karenberg and Leitz 2001; Sigerist 1987). That this tradition continues today can be seen by a number of studies that have been conducted into the effectiveness of prayer in

the treatment of patients (Astin et al. 2000; Cha et al. 2001; Harris et al. 1999) and the importance that traditional remedies can have within a community (Lekouch 2001).

An investigation into the history of medicine in Egypt requires a study of many other aspects of its civilisation and for the medical historian of Egypt there are three main sources: Iconography (3.1), palaeopathology from both mummified and skeletal remains (3.2) and written sources, including the medical papyri (3.3).

3.1 The Iconography of the Egyptians

Egyptian iconography was a manifestation of perfection and most of the surviving iconography comes from a funerary context, in which the artist had to conform to a rigid set of rules regarding the depiction of the human form (Brecklinghaus 2002). This iconography was meant to symbolise the afterlife and how that particular tomb's occupier wished his eternal life to be, indeed there are very few examples of "art for arts sake" (Teeter 1994). As a result of this there are dangers surrounding the use of iconography in understanding the treatment of the sick in Egypt. There are, however glances of medical treatment in Egyptian art such as "religious" birthing scenes (Figure 9), surgical treatment and the treatment of the disabled. In relation to religious birthing scenes, although these aspects of iconography hold spiritual properties, they also divulge information regarding the normal conduct of child birth, such as the use of birthing bricks, and the attendance of the mother by midwives (Chamberlain 2004).



Figure 9: Image from the Temple of Hathor at Denderah. The image is of a squatting woman being assisted by two "midwives". The scene dates from the Ptolemaic period (Faiad 2006)

A number of features are commonly identified as being realistic depictions, although they may actually be conventions used to show status or livelihood. For example, wives were frequently depicted as tall - albeit not always as tall as their husband - and slender (Capel and Markoe 1996). There are also the representations of occupational status and health in tombs and temples and it is believed that these representations suggest that occupation and physical attributes were related in two ways. Firstly, there are the abnormalities that could have been acquired as a direct result of the task; either through associated environmental factors or occupational activity. Secondly, there are those abnormalities from birth or at least those which are unlikely to have been caused by the occupation of the person. Here the relationship is reversed; it is the condition which confines the individual to certain social and occupational roles. For example, dwarfs have been found depicted in more than fifty tomb scenes fulfilling a variety of roles including entertainer, personal servant, and animal attendant as well as jeweller (Figure 10) (Kozma 2006). Dwarfs were clearly identified as being physically different to both children and low ranking officials. They are depicted with typical physical disproportions: a large head; long torso and short limbs (Dasen 1993). Another example is the link between the blind and music (Figure 11).



Figure 10: Schematic showing the representation of dwarfs working as jewellers, from the tomb of Wepemnefert (5th Dynasty - Giza) (Dasen 1993, 120).



Figure 11: Image showing a blind choir and harpist (Amarna Tomb 2 – 18th Dynasty) (Davies 1908, Plate 13)

The earliest known representation of an operation comes from the mastaba of Ankhmahor (located on the northern side of Teti's pyramid), vizier to Teti I (6th Dynasty) (Nunn 1987). The scene is a representation of the process of circumcision (Figure 12) and the inscriptions make no reference to any medical status for the deceased or indeed whether he was the patient (Hebron 2005). The scene may be present in order to fulfil an aspect of religious affiliation not conducted in life. Circumcision is also apparent on the phalli of statues of the King and other males (Shokeir and Hussein 1999) suggesting that this was a necessary rite that took place at an early time in a man's life.

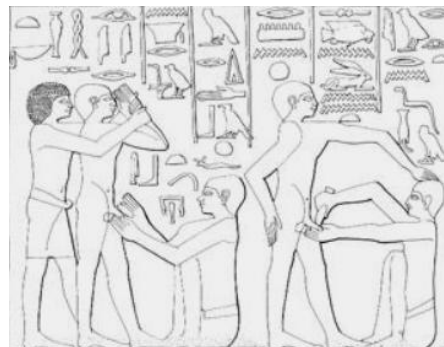


Figure 12: Representation of the circumcision scene found in Ankhmahor's mastaba (Saqqara) (Shokeir and Hussein 1999, 760)

3.2 Palaeopathology of the Egyptians

Probably the best tool available to a medical Egyptologist are the remains of the Egyptians themselves. Palaeopathology, in relation to Egypt, has been studied since at least the late 18th Century (Blumenbach 1794), although it was not until the start of the early 20th Century that more rigorous scientific procedures were introduced (Elliot-Smith 1907; Murray 1910; Ruffer 1910). A wide number of studies have been conducted over the last hundred years to gain insight into the general health of the Egyptians. These studies have covered both visual and scientific aspects, for example: dental studies (Leek 1967), nutritional studies (Hebron 2005) and palaeoparasitology (David 1979; Ruffer 1910).

It can be determined from a purely visual inspection that the earliest Egyptian mummies were circumcised (Dunsmuir and Gordon 1999). A number of the remains from Giza (all non-elite graves) suggest that amputation was a well-performed aspect of surgery (Hebron 2005). Parasitic infestation has been a major part of the study of palaeopathology in mummies since the earliest 20th Century when Ruffer (1910) found evidence for one in mummies from the 20th Dynasty. Besides these mummies studies including analysis from the University of Manchester, analysis of scrotal skin from the Leeds mummy Natsef-Amun and analysis of ROM I (Shafik and Elseesy 2003), have shown the presence of not only schistosomiasis, but of tape and filaria worms.

3.3 Documentary sources and the Medical Papyri

Aside from the medical papyri there are other sources of documentary evidence relating to the history of medicine in Egypt and from which it is possible to understand patterns of disease as well as treatment. Unfortunately information regarding the cause of injuries, types of illness and how the sick were reintegrated in the community is absent from nearly all documentary records (Zucconi 2005).

Of these other sources a number of “prayers of gratitude” indicate some aspect of ritual was required after recovering from an illness (Zucconi 2005) and perhaps suggests it was the ritual rather than the clearing of symptoms which would denote the person as healthy.

From Deir el-Medina and other working towns there are absentee lists which give an invaluable insight into health issues within these settlements. Ostrakon 5634 dates to the 40th year of the reign of Ramesses II (Frandsen 2007), and details a diverse selection of excuses which include illness (eg. ill) alongside other misfortunes (eg. scorpion sting). Unfortunately the text does not always detail the symptoms that lead to the worker’s absence and more often the entries simply specify ‘ill’ (Janssen 1980).

Another source are the amuletic decrees, which are texts on rolled papyrus that were kept within a decorative container. As will be discussed later, amuletic decrees were probably a form of magic based on the written word itself. The written word was believed to hold an intrinsic magical power (Plater 2001) and by wearing such an object the owner would believe that they were protected. The most frequent medical references in amuletic decrees are concerns over blindness and leprosy - although traumatic injuries such as snake bites and work related injuries are also featured (Edwards 1960).

Finally, there are other documents which do not fall into specific categories such as the stela of Neferabut and personal letters. In the stela of Neferabut concerns over blindness are expressed and a reference is made to blindness as being a divine retribution for falsehoods (Hebron 2005). Letters between family members also detail items required for medical treatment as well as health complaints (McDowell 1999).

3.3.1 The Medical Papyri

In 1994 a campaign was launched in *Nature* to resurrect some of the medicines of the past (Holland 1994; Holland 1996a; Holland 1996b; Tunon and Bruhn 1995). Until this point texts and folk medicine had been comparatively ignored despite a study in the 1960s by the National Cancer Institute, of the USA, which revealed that 19.9% of plants used in ancient texts for the treatment of cancer had positive results, when compared against 10.4% discovered through random screening (Tunon and Bruhn 1995). Even so the main scope of work has been primarily focused on the more familiar medicine of the Greeks and Romans (Holland 1996a). The ability to systematically assess and catalogue the medicine of the Egyptians would enable not only a better understanding of the medical system, but would be a starting place to enable scientists to test the efficacy of the preparations.

The Egyptian papyri probably represent the epitome of their medical achievement (Moorad 1937) and date from the Middle Kingdom (2040-1640 BC) to the end of the Greco-Roman Period (332BC-395AD). In addition to the papyri, there are supplementary sources such as ostraca; although it should be noted that only those ostraca with prescriptions rather than simply a list of ingredients have been included in this study.

The actual purpose of the medical papyri is still open to debate because of their widespread absence of archaeological provenance (Hebron 2005). Some have been tentatively identified as being akin to a family medical dictionary

(Jonckheere 1947; McDowell 1999), whereas others are believed to be teaching documents or reference works for the practicing medic (Breasted 1930; Ebbell 1937). Plater (2001) believes that the medical texts were general documents designed for doctors rather than being specific texts drawn up to treat particular cases, whilst Campbell (2007) claims that the papyri are compilations of experiences from doctors over a number of years. Whatever the belief in why the papyri were written it can be assumed that the prescriptions contained within the papyri were tested and were therefore believed to be efficient. There are two ways through which efficacy could be gathered however, either the medication worked due to the medicinally beneficial nature of the ingredients within prescription or it worked as a placebo, that was derived from the belief that one of the ingredients would have worked to aid the sick, it is of course possible that many of the texts may have an additional spiritual dimension that can not be readily identified.

The ostraca which detail medical prescriptions are thought to have been for self instruction, much like a modern prescription, which would be handed out to the patient to self medicate. It is quite possible that these prescriptions were taken from now lost papyri (McDowell 1999).

There are differing definitions amongst scholars as to what texts should be regarded as medical papyri. For the purposes of this study there are 17 medical texts which pertain to medical treatments (Table 3), these documents were identified from literature on medical treatment in ancient Egypt, such as (Ghalioungui 1963; Horstmanshoff 2004; Leake 1952; Nunn 2003; Stetter 1990; Thorwald 1962), in addition to these 12 papyri additional texts such as medical ostraca found through a comprehensive literature survey were also studied.

Table 3: Table showing the different medical papyri examined, their current location and translations examined for this study

Papyrus Name	Current Location	Accession Number	Total # of medical paragraphs	References
Ebers	Leipzig	P. Ebers	877	(Bryan 1930; Ebbell 1937; Ghalioungui 1987)
Hearst	California	P.Hearst.01 or 4970	260	(Bardinet 1995; Reisner 1905)
Berlin	Berlin	Berlin Papyrus 6619	204	(Bardinet 1995)
Brooklyn	Brooklyn	47.218.48 and 47.218.85	100	(Bardinet 1995; Sauneron 1989)
Leyden [sic.]	Leiden	BM10072	81	(Bardinet 1995; Griffith 1974)
Ramesseum	London	EA10756; EA10757; EA10758	77	(Bardinet 1995; Barns 1956)
London	London	BM10059	61	(Bardinet 1995; Leitz 1999)
Crocodilopolus	Vienna	P. Vindob. D. 6257	60	(Reymond 1976)
Edwin Smith Surgical Papyrus	New York	Edwin Smith Surgical Papyrus	51	(Allen 2005; Bardinet 1995; Breasted 1930)
Chester Beatty	London	BM10686	45	(Bardinet 1995; Jonckheere 1947)
Kahun Gynaecological Papyrus	London	UC32057	34	(Bardinet 1995; Collier and Quirke 2004; Griffith 1898)
Rubensohn	Berlin	Papyrus Berlin 10456	20	(Bardinet 1995)
Leyde	Leiden	Leyde I 343 + Leyde I 345	16	(Bardinet 1995)
Louvre	Paris	Papyrus Louvre E.4864	13	(Bardinet 1995)
Qen-her-khepeshef	Unknown	Unknown	6	(McDowell 1999)
Ostrakon Deir el-Medina 1062	Paris	O.DM.1062	1	(McDowell 1999)
Zagreb	Zagreb	Papyrus Zagreb 881	1	(Bardinet 1995)

The dates of the papyri studied covers almost 2000 years and it is hoped that in future work it would be possible to identify a change in the medical system as well as a change within the ingredients used over this period of time. A number of additional papyri were also examined including the Michigan Medical Codex, the Carlsberg Papyrus and the Kahun Veterinary Papyrus (Bardinet 1995; Griffith 1898; Iversen 1939; Jonckheere 1953; Youtie 1996) but proved to have no mention of mineral usage.

3.3.2 Language and the medical papyri

Language is one of the major stumbling blocks in the study of the medical papyri. Many of the papyri are written in Middle Egyptian and while a large number of words can be identified conclusively, a handful appear only in the medical papyri once or twice. This can make it hard to ascertain their exact meaning. In addition to this, a number of well known words may have been misinterpreted as they may have held more than one meaning or perhaps had a special meaning in a medical context.

One of the key problems when working with Egyptian texts is the ability to translate accurate and truthful accounts of the documents. This is made harder by the lack of a common language for translational purposes. However as will be discussed in more depth the language scholars use when referring to the words, or even to the texts themselves, is full of misinterpretation. The terminology used when discussing medical paragraphs is one aspect of this. Most refer to anything found within a medical text as a prescription, and consideration is really only given to the difference between magical and rational treatment; however there is a clear structure in these medical paragraphs which is important. There are a number of methods of treatment and by defining the medical paragraphs in a more specific way it is hoped that it would allow for a better understanding of Egyptian medical treatments and systems. There are four different types of medical paragraph within the Egyptian medical texts:

1. 'Prescription' - this refers to a detailed recipe for a specific medical problem:

e.g. Rejuvenating the face (Edwin Smith Papyrus Prescription 3 (Breasted 1930)) : 'Calcite powder 1; powder of natrun 1; northern salt 1; honey 1; mixed into a compound and smeared on'

2. 'Case' - this refers to a more detailed medical problem which often contains either an incantation or a prescription to aid with the problem. Cases are predominately found in the Edwin Smith Papyrus

e.g. For the treatment of a pulled rib (Case 42, Edwin Smith Papyrus (Breasted 1930))

Title: Practices for a pull in the ribs of his chest

Examination and Prognosis: If you treat someone suffering from the ribs of his chest, and there is no dislocation or break, yet that man is suffering and in very much pain, then you say about him: "One who has a pull in the ribs of his chest: an ailment I will handle"

Treatment: You have to bandage him with alum and treat him afterward with honey every day until he gets well

Explanation: As for the "ribs of his chest" they are bones of his chest, which are pointed like what comes from the shoot of a thorn.

3. 'Incantations' – are pure prayers to the gods and are not associated with minerals. Due to the fact that they are not found in association with minerals they are not encountered within the remit of this project and so are not further discussed, however when a prayer is found associated with a prescription this is defined as a spell.

4. 'Spells' – these are magical rites, and often contain incantations/prayers, and are usually for diseases or ailments that are untreatable in normal medical circumstances. They are also used for "household" tasks such as to drive away fleas and serpents.

e.g. For the treatment of cataracts (Ebers Papyrus Prescription 385 (Ghalioungui 1987)):

'Malachite pounded with honey in *nt hprj*, with them is pounded rush nut, is applied to the eye. The doctor must recite the incantation over

the manufacture and application of the medicine “Come, malachite!
Come, malachite! Come thou green one, come discharge from Horus’
eye, come secretion from Atum’s eye, come fluid that has come out of
Osiris! Come to him and expel for him water, matter, blood, dim sight,
bjdj, blindness, blear eyedness, afflictions caused by a god, by dead
man or woman, all kinds of purulency, all evil things that are in these
eyes”

3.3.3 Principal Papyri

Ebers Papyrus

In 1862 Elliott Smith purchased this papyrus which was subsequently bought by Georg Ebers in 1872 (Bryan 1930; Ebbell 1937; El-Gammal 1997; Hass 1999). One theory surrounding its discovery is that it was discovered between the legs of a mummy in the Assassif area of the Theban necropolis and it is consequently believed to have belonged to a doctor (Bryan 1930), but this is speculative and in truth the only definite thing known is the purchase date of the document and its subsequent history.

The Ebers Papyrus is considered as one of the most ancient pharmacopoeias (Ebeid 1999) and can be dated to the 9th year of the reign of Amenophis I which is around 1534-1536 BC (Bryan 1930; Ebbell 1937; Ruiz 2001; Stetter 1990). However, it is believed to have been a compendium of much earlier prescriptions – although it is not uncommon for the Egyptians to predate their work to give it a better reputation (Bryan 1930; Ebbell 1937; El-Gammal 1997).

The papyrus contains 877 medical paragraphs, the longest of the known medical papyri (Ghalioungui 1987) and it is often used as a starting point for the understanding of the history of medicine in Egypt (Stetter 1990). Whilst it contains some incantations and spells it is primarily a medical document (Nunn 1987). Thorwald (1962) states that the content of the Ebers Papyrus

demonstrates that at the time the papyrus was written that the medical establishment were no longer content with being restricted to the domestic items for healing and so were looking outwards for international sources for some of their *materia medica*. Sneader (2005) believes that there is a correlation between the medical paragraphs present in the Ebers Papyrus and those found in the medical tablets from Nineveh.

There have been a number of issues surrounding the translation of this document. Ebbell's (1937) translation of the papyrus is by far the most commonly referenced and easily accessible (it can be found in 16 libraries in the United Kingdom) but a more "modern" translation in the form of Ghalioungui (1987) is available. Ghalioungui however was not widely published and can only be found in one library (The Wellcome Trust Library for the History of Medicine). The 1937 translation is therefore most used despite identified inaccuracies. In addition to this Ebbell is often seen as "*having given too free a reign to his imagination and medical insight*" (Ghalioungui 1987). For the purposes of this project both Ghalioungui (1987) and Ebbell's (1937) translation were used.

Ghalioungui's (1987) version of the Ebers Medical Papyrus was chosen as the primary source of translation. However comparison was made with the original Ebbell (1937) version and significant differences were identified probably as Ghalingouli (1987) had the benefit of more modern translations of previously unknown words.

Edwin Smith Surgical Papyrus

The papyrus was purchased by Edwin Smith in Luxor in 1862 from Mustafa Agna an antique dealer (Hass 1999; Nunn 2003). There is nothing known about its archaeological provenance, but it is believed to have been found in conjunction with the Ebers papyrus (and possibly also the Rhind Mathematical Papyrus) in a tomb (Breasted 1930). The Edwin Smith papyrus is a typical

example of the lack of provenance involving the sale of Egyptological goods in the late 19th/early 20th Century.

It is believed that the text originated around 2600BC, but was then recopied into the document present today, which is often identified as being a commentary and original text (Breasted 1930), however the papyrus itself has been dated to around 1550BC (Allen 2005; Breasted 1930). It is the oldest known treatise on surgery, and its early date makes it of great importance to understand the development of Egyptian medicine.

Miller (1991) suggests that the Edwin Smith Papyrus is a first aid manual for doctors working on government assignments perhaps quarrying and building schemes. The document contains 48 cases and three prescriptions and there is almost no magic present within the text. However, as Ritner (2000) suggests, the lack of magic may have nothing to do with the time it was written, but more to do with the straightforward nature of the problems dealt with. One aspect which is lacking within the papyrus is how the injuries occurred, it cannot therefore be identified whether it was a treatise on war wounds (Trevisanato 2006) or whether they were injuries caused on major building projects (Miller 1991).

Allen's (2005) version of the Edwin Smith Surgical Papyrus was chosen as the primary source of translation. However comparison was made with the original Breasted (1930) version which differed very little.

3.3.4 Additional Papyri

A stringent selection criteria was applied to the texts themselves. Firstly medical texts were identified and used in the medical database from their Egyptian origins, based on if they were written in an identifiable Egyptian language, namely Hieratic, Demotic or Middle Egyptian. Secondly medical ostraca were also included as texts provided they contained a prescription and not simply a

list of ingredients. Literature relating to ethnopharmacology and geological sources and ranging in date from the Middle Kingdom, through to the 21st Century, were also chosen due to their relevance. The Ebers and Edwin Smith Papyri are the most commonly studied and consequently have the most literature about them. The following papyri have far less information about them, and this is designed to give a basic background to their inclusion in the project.

Berlin Papyrus

The Berlin Medical Papyrus is a document steeped in mystery. The beginning of the document explains it is an ancient copy of an earlier text found under the feet of a statue of Anubis in Letopolis (Breasted 1930). The copy was believed to have formed part of a collection in the library of Memphis which was mentioned by Galen (a Roman physician of some note who lived between 129-216 AD) (Comrie 1909). Unfortunately, the document is difficult to date with some attributing it to the 16th Century BC (Breasted 1930) and others to around 1300 BC (Stetter 1990). Bardinet's (1995) work on this papyrus was used.

Kahun Papyrus

The oldest medical document so far identified from Egypt is the Kahun Gynaecological Papyrus. As its name suggests it focuses on the issue of child birth and pregnancy, as well as other aspects of women's health. It was discovered by Petrie in the 1889 expedition to the Lahun area (Collier and Quirke 2004; Griffith 1898). It can be dated to the 19th Century BC due to the presence of a reference to King Amenemhet III in an arbitrary statement found on the document (Collier and Quirke 2004; Griffith 1898). Both Griffith's (1898) and Collier and Quirke's (2004) translation of this work were examined for the prescription database.

Ramesseum Papyri

The Ramesseum Medical Papyri are a collection of three documents: Ramesseum 3; Ramesseum 4 and Ramesseum 5 which were found with 14 others during Quibbel's excavation of 1896 of a tomb under the brick magazines of the Ramesseum (Barns 1956; Gardiner 1955). From a number of goods within the tomb, it is believed that the owner was a magician or a form of medical practitioner (Gardiner 1955). There is no exact date for the tomb or its contents (Gardiner 1955), although it can be no earlier than 1854 BC due to the presence of Amenemhat III's name in Ramesseum 6 (Barns 1956).

Ramesseum 3 deals with eye problems and Ramesseum 4 with issues surrounding pregnancy and both contain magic. Ramesseum 5 is different in style to the previous two. It contains no reference to magic and consists of prescriptions in the form of recipes. Barn's (1956) seminal work on the document was examined, however the translation comes predominately from Bardinet (1995).

Chester Beatty Papyrus

The Chester Beatty was found during the excavations of Deir el-Medina at the end of the 19th Century (Jonckheere 1947). It is thought to have belonged to the Qen-her-khepeshef family archive, who is understood to have been collector of documents rather than a doctor. The papyrus itself deals mainly with problems of the anus (Jonckheere 1947). The text is believed to date from the 12th to 13th Dynasty (Jonckheere 1947). Both Jonckheere (1947) and Bardinet (1995) were examined for their mineral content.

Leyden Magical Papyrus

The Leyden Papyrus dates to the 3rd Century AD and is believed to be the most recent surviving document to be written in Demotic (Griffith 1974). The papyrus

is split into two manuscripts, one found in the Leiden Museum and the other in the British Museum. It was believed to have been discovered in Thebes and was bought by Anastasi, a Swedish Consul member, based in Alexandria. Lieden i.383 was resold to the Dutch in 1828 and in 1830 it was translated (Griffith 1974). The London Manuscript (10070) was sold to the British Museum in 1857, but it was not until 1892 that it was translated. Griffith's (1974) translation of the Leyden Magical Papyrus was examined.

Hearst Medical Papyrus

The Hearst medical papyrus was given to the Hearst Egyptian Expedition in 1901 by the workforce as a show of thanks (Reisner 1905). It appears that 1/3 of the Ebers text is found within the Hearst papyrus (Reisner 1905). The text is believed to have been found in the remains of a house in the town Der-el-Ballas and, since these date from the 12th to 18th Dynasty, it is presumed that these are the dates for the papyrus (Reisner 1905). A translation of the Hearst Medical Papyrus was made from Bardinet's (1995) work.

London Medical Papyrus

The London medical papyrus is another with an uncertain provenance. It is believed to have been discovered around 1860 (Leitz 1999). It is written in a Hieratic style suggesting that it was written in the 18th Dynasty (Leitz 1999). It certainly dates no earlier than the reign of Amenhotep III (1388-1351BC) as he is mentioned in the text (Leitz 1999). It contains a great many magical rites (El-Gammal 1997) and the most accurate translation can be found in Leitz (1999).

3.4 Doctors

swnw, often translated to mean doctor or physician, has been identified by Ziskind and Halioua (2007) to mean “*the one, of those who are unwell*”. The word *swnw* is readily found on artefacts as well as inscriptions in tombs and temples (Zucconi 2005). The word is also connected with the divine and Amun is referred to as a *swnw* who ‘removes troubles and suffering and makes the eyes healthy’. The word *swnw* was also used in the Berlin Medical Papyrus to mean illness (Bardinet 1995).

From written sources it can be generally assumed that the Egyptian physicians were held in high regard by foreign contemporaries (Güterbock 1962) as well as their kinsmen (Comrie 1909). It is often believed that the reason why Egypt has developed a reputation as a country of great physicians derives from the reports of the Classical writers (Lane 2003). Unfortunately, these Classical writers are only describing the Greco-Roman Period of Egypt and so information regarding the earlier formation of the medical system is limited and must be found from Egyptian sources.

There was a hierarchy amongst doctors and the highest title that can be found is *thrp swnw* which means administrator of doctors (Lorenz 1928; Nunn 2003; Trevisanato 2005). There are also *hry* and *shdj swnw* which can be translated as authority over doctors, and the latter is thought to mean ‘inspector’ (although this only comes from the Old Kingdom) (Nunn 2003). Nunn (2003) suggests however that most of the doctors probably never got above the title of *swnw*.

It has often been assumed that the medical system was founded on the basis of priests acting as doctors (Moorad 1937; Reeves 1984). This idea may have originated from the doctors who look after the temple and its priests - for example the Amherst papyrus (British Museum EA10037) mentions Pahatiou as being a doctor for the temple of Amon, under Ramesses XI (Ziskind and Halioua 2007). Two doctors have also been identified as ‘lector priests’ whose

main role was seen as the reading of incantations and spells (Nunn 2003). Ghaliounghui (1963) even suggested that the *w^cb* priest of Sekhmet might have a special role as a veterinary surgeon. In Egyptian history the modern distinction between science and religion did not exist and in this interwoven state it is unsurprising to find some aspects of religion amongst the healing remedies and the healers; but it does not necessarily follow that the role of the medic was one anchored in religion.

There is a tendency today to differentiate between the three words for doctors mentioned in the medical papyri: *s3*; *w^cb* and *swnw*. The latter word is seen to be connotative with the modern systematic physician, while the others are associated with being part of a “traditional” healing culture. However these lines are blurred and texts commonly associated with the *swnw*, like the Edwin Smith Surgical Papyrus (Allen 2005; Breasted 1930) use incantations whereas those believed to be used by the *w^cb* and *s3* such as the Brooklyn Snake Papyrus, undoubtedly devised for a “traditional healer”, have few incantations show that at least at one stage in Egypt’s medical history the three types of doctor were held in equally high esteem (Sauneron 1989). It is possible that the words are essentially synonymous and the distinction may lie in a distinction between urban and rural areas in naming their physicians.

Doctors are known to have worked not only in the towns and villages but also on expeditions. Inscriptions from the Sinai Peninsula record the presence of Renefseneb ‘chief physician’ among the Middle Kingdom mining expedition administrative personnel (Miller 1991). There are other examples of physicians both travelling with mining expeditions and with the army (Hebron 2005; Miller 1991).

From pay records of the Ramesside necropolis it has been possible to identify the pay system for the physicians on this site. The documents detail that a worker would be paid a monthly ration of 4 khar (sack) of wheat plus 1 ½ khar of barley, whereas the *swnw* received 1 khar of wheat and ¼ khar of barley a

month (McDowell 1999; Miller 1991). It is currently debated as to whether this was their sole allowance or whether this was in addition to the standard worker's rate. If this was their sole allowance it would suggest that healing was the only task the doctor had to perform and he did not do the hard manual labour which may have deserved the higher rates of pay. However the payment for the physician is almost quarter of that of the other workers, and it could also be that they were paid in respect of how much they worked ie. in a weekly shift pattern. Other than these scant pieces of evidence there is little information regarding the remuneration of physicians. The medical papyri never indicate charges next to each medical paragraph. All that can be said is that there appears to be no distinction in payment between the different types of doctor, again suggesting that they were seen in a similar light.

Evidence regarding the position of doctors is not constrained by Egypt's borders. A number of highly regarded doctors were sent to foreign courts. A doctor's attendance at foreign courts was as a response to either a request by foreign kings or from an expansion of the Empire, which saw many doctors established in the vassal courts (Reeves 1984). Doctors from Egypt were held in such high esteem that foreign kings often requested their presence at court and there are letters found between kings which attest to this (Arnott 2002; Arnott 2004; Burden 2005). A letter dated to around 1270 BC from King Ramesses II to the Hittite King requests that an Egyptian doctor in his court be sent on to another King and also requests that the Hittite King to allow two doctors to pass through his Kingdom on the way back to Egypt having served in another foreign court (Güterbock 1962). Zaccagnini (1983) sees this "trade" as part of the gift exchange system, which can be seen throughout many early courts, as physicians were seen as "luxury goods". However, the requests for physicians were not always accepted at first - according to Zaccagnini (1983) some letters mention that a number of requests were made before a formal acceptance or rejection was given. There are also some cases in which the King passes judgement on the use of the physician in a foreign court, for example there is one letter in which the King of the Hittites requests a doctor to

help his wife become pregnant. The request for a doctor is granted as the wife is the King's sister, but a warning is given that the treatment may not work as the lady in question was over the age of biological reproduction (Arnott 2002; Arnott 2004).

Although it is known that doctors travelled to visit vassal states and neighbouring countries, there is little evidence regarding how the more humble patient would have seen a doctor. Although several literary sources make reference to the summoning of a healer, it is often believed that because of the doctor's standing in a community it would be unlikely that they would travel to visit the sick and the patient would have visited them instead (Moorad 1937). Again this may show the difference between a rural and urban situation, but it is difficult to ascertain without more direct literary or archaeological evidence.

3.5 Pharmacy

Pharmacy is the branch of the health sciences dealing with the preparation, dispensing and proper utilisation of drugs (a *drug* is a single chemical substance (or natural product) that is used to treat or alter the body). The term *pharmaceutical* relates to the preparation of medicines according to specific formula (a *medicine* is a mixture of one or more drugs with additional components such as a vehicle). It is believed that the Egyptians themselves monitored the use and efficacy of these medicines and this consequently led to the development of pharmacotherapy (Campbell 2007; Smiltena et al. 2007; Zucconi 2005).

El-Gammal (1997) in her survey of hospital pharmacies in Ancient Egypt believes that the *swnw* were helped by the *wrm*^c. These were specialist technicians that helped prepare and store the drugs within the temple complexes (El-Gammal 1997). There are very few references to pharmacists specifically. It would in certain instances make more sense if the doctor was to prepare his own prescriptions, however one reference, from the 40th year of the reign of Ramesses II, refers to one Pa-heny-pedjet who is not referred to as a doctor, but as someone who is with the sick preparing medicines (McDowell 1999).

In the Egyptian Museum in Cairo, a stove believed to be for the manufacture of medicines can be found. Accession Number 85910 dates to around 1259 BC, and was owned (or presented) to Ramesses II in his 20th year as King (Figure 13). The stove itself is made of bronze, with four holes in the top, which are believed to be temperature regulators (Figure 14). Helmi and Iskander (1985) believe that this stove is one that was used for the manufacture of medicines within a temple complex, and is therefore of great interest, being the only known one to survive.

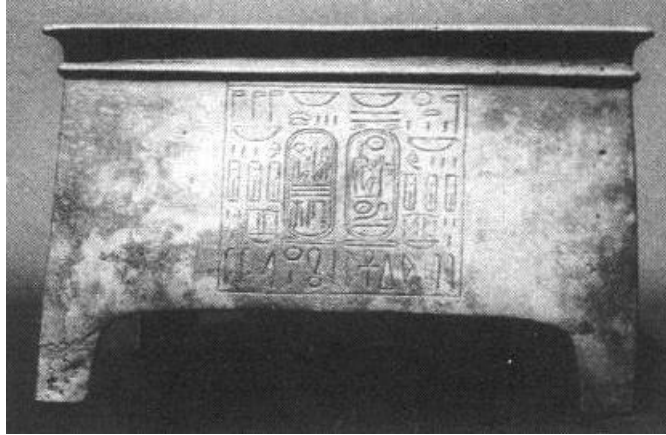


Figure 13: Photo showing the front of a proposed pharmaceutical stove, with the inscription to Ramesses clearly visible (Helmi and Iskander 1985, 29)

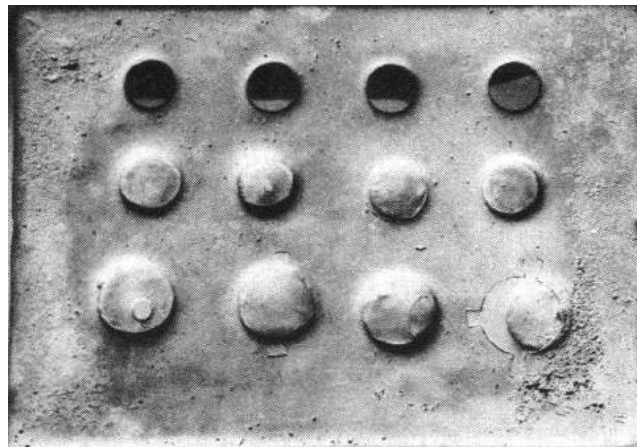


Figure 14: The back side of the top of the proposed pharmaceutical stove, showing the heating plates and the four holes for temperature regulation (Helmi and Iskander 1985, 29)

Using a broad definition there are three types of *materia medica*: plant matter, animal sources and minerals. Ghalingouli (1963) and Leake (1952) both note the lack of organisation within the medical texts which means that large majority of *materia medica* are unidentified. For example, of the 98 minerals listed in the medical papyri, 20 are unidentified. This confusion makes it harder to replicate and therefore test the efficacy of prescriptions. Some believe that the *materia medica* reflected in the Ebers and Edwin Smith Papyrus differ in the

procurement of ingredients, with the Edwin Smith being a more locally based papyri and Ebers having foreign influences (Campbell 2007). This difference is probably due to it having a more practical and accessible focus contrasted with the “luxurious” medicines seen in the Ebers. Overall from this study it is not possible to determine a more foreign bias in medical ingredients within the papyri.

One of the most important aspects of the medical paragraphs is the dosage associated with the material, as it can aid in a scholar’s understanding as to whether a material would be efficient and also identifies whether known toxins such as orpiment were understood to be of a dangerous nature. Dosages themselves were based on the eye of Horus, with each portion of the eye representing a different measurement in relation to a dose (Figure 15). These were then determined in relation to metric measurements (Figure 16). From the measurements we can see that the ro is equivalent to a mouthful or 14.5ml (Leake 1952).

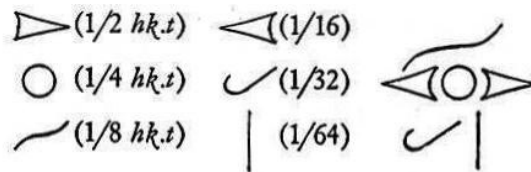


Figure 15: Image showing the break down of dosage in the form of the eye of Horus (Leake 1952)

One of the rarely discussed aspects of pharmacy is that of cosmetics. Many cosmetic formulations have been described in the medical papyri, and as has previously been commented “*vanity alone does not account for the large use of cosmetics even in later times in Egypt*” (David 1981). In the modern mind it is easy to differentiate between the cosmetic and the medicinal, however these distinctions were not so readily identifiable in Egyptian society. Indeed a number of ethnopharmacology specialists call the blurring between the two “cosmeceuticals”, showing that they hold both cosmetic and “medicinal”

properties (Hardy 2008; Lev 2007). For example, creams to maintain a “youthful skin” were probably perceived as being a drug to stop ageing and ward off death. Cosmetics could have also acted as a visible warning to people to their disease, specifically those more contagious diseases involving the eyes, for example conjunctivitis.

<i>Hnw</i>		<i>Hk.t</i>
10	□	1 (4.5 liters)
5		1/2 ▷
(5/2) 2 1/2	□	1/4 ○
(5/4) 1 1/4	○	1/8 ↗
(5/8) 1/8 plus 1/2	○□	1/16 ▷
(5/16) 1/16 plus 1/4	○	1/32 ↗
(5/32) 1/32 plus 1/8	○	1/64

1/64 *hk.t* equals 5 *ro* (kd.t?)

1 *ro*, ○, was a mouthful, or 14.5 cc.

Figure 16: Table showing the different prescription doses (Leake 1952)

Lastly the use of minerals in pharmacy should be examined. Many see the use of minerals as acting like a charm or a means of protection, rather than them acting efficiently as a pharmaceutical (Gyory 2000). The idea that the minerals were used as a charm probably derives from the belief that every mineral was associated with a god (Gyory 2000). Consequently, even though the prescriptions themselves have a therapeutic core, the use of the mineral might be thought as acting as a placebo, giving the patient confidence with the treatment because a certain god was looking out for them (Gyory 2000). Indeed the use of minerals as a medicinal aid are so often overlooked that Gomes and Silva (2007, 6) state that “*the assessment of both the positive and negative effects of minerals requires further research by in vivo and in vitro experiments and well-planned and systematised epidemiological studies*” leading to the identification of potentially beneficial natural mineral medicines.

3.6 Prescription database

The medical papyri are an under used resource, from which a lot of data can be gathered, not only in relation to the medical system in Egypt, but also in the belief and political systems at the time the documents were written. Nevertheless, it can be misleading to investigate certain aspects of the Egyptian medical system purely from the medical texts; such as an examination into the efficacy of Egyptian diagnostic methods (Hebron 2005).

Table 4: Table showing the different medical papyri that contain reference to a text, the number of different minerals that are referenced within said text and additional information such as any declarations of working ability, special instructions for application or any associated incantations

Papyrus	# of medical paragraphs containing minerals	Total # of medical paragraphs	# of different minerals	Declaration of working ability	Special instructions for preparation or administration	Incantations
Ebers	284	877	63	11	7	5
Hearst	79	260	18	0	1	1
Berlin	45	204	12	3	0	0
Brooklyn	36	100	15	6	0	0
Edwin	18	51	9	1	0	0
London	11	61	12	1	4	4
Chester Beatty	10	45	5	0	0	0
Crocodilopolus	8	60	9	0	0	0
Ramesseum	8	77	9	0	0	0
Leyden	7	81	7	0	0	0
Leyde	4	16	3	0	0	0
Kahun	3	34	3	1	0	1
Qen-her-khepesh-ef	3	6	3	0	0	0
Rubensohn	3	20	3	0	0	0
Louvre	1	13	1	0	0	0
Ostrakon Deir el-Medina 1062	1	1	1	1	0	0
Zagreb	1	1	5	0	0	0

In light of this the prescription database was established as a means of easily cataloguing and interrogating the data to answer a number of questions in

relation to this research. Table 4 shows the number of medical papyri found to contain a reference to minerals, along with the number of different minerals they contain, and other basic information. Before a discussion on the use of minerals, it is worthwhile here to discuss briefly other types of information that the prescription database can generate.

3.6.1 Magic and Minerals

The prescription database is able to determine the relationship between the use of minerals and magic. It is well established (Ghalioungui 1963; Karenberg and Leitz 2001; Leake 1952; Stetter 1990; Zucconi 2005) that there are two clearly distinct causes of illness within the medical texts. The first are the “natural causes”, such as trauma. Other natural problems also include some types of stomach and eye problems. These causes are quite frequently visited in such papyri as the Edwin Smith Surgical Papyrus, and follow a systematic approach with few incantations. Hebron (2005) stated that there should be no surprise that the cases dealing with trauma show a greater degree of “confidence” than those treating diseases, as for example different types of stomach ailment can be treated in different ways, either magical or medical. Illnesses, such as stomach ailments, in this natural group tend to be treated by prescriptions and described in cases, rather than resorting to more magical remedies.

The second group are those illnesses thought to have a “supernatural cause”. When no obvious signs of trauma or a reasonable cause for the illness were evident, the Egyptians sought an explanation for the illness in the manifestation of supernatural forces such as the gods or the dead (Karenberg and Leitz 2001; Plater 2001). The primary course of treatment for afflictions with supernatural causes was the magical incantation. Nunn (2003) describes how there seems to be a lack of magic or magical reasoning within the medical paragraphs of the earlier medical papyri, whereas in the later ones there is an increasing dependence on magic, which has tentatively been put down as a sign of a loss of confidence in the ability of the King to maintain order between the heavens

and the earth. However Barns (1956) disputes this and claims magic was equally present in early medical texts like the Ramesseum Papyri.

Table 5: Table showing the number of spells in relation to minerals

Papyrus	Paragraph Number	Incantation	Problem	Minerals
Ebers	48	It shall be said oh <i>htw</i> -animal! Oh <i>htw</i> animal! Is repeated backwards: oh dn! Oh <i>dnjt</i> ! Is repeated backwards	Diahorrea	Ochre (Yellow)
	203	<i>iw t3-n ir-n dp</i> followed by first remedy berry juice and ammi strained and drank for four days	Appendicitis	Salt
	356	I have brought this which was applied to the seat of yonder and replaces the horrible suffering. You must recount this twice.	Blindness	Black kohl and Ochre (Red- <i>mnst</i>)
	385	Come, malachite! Come, malachite! Come thou green one, come discharge from Horus' eye, come secretion from Atum's eye, come fluid that has come out of Osiris! Come to him and expel for him water, matter, blood, dim sight, <i>bjdj</i> , blindness, blear-eyedness, afflictions caused by a god, by dead man or woman, all kinds of purulency, all evil things that are in these eyes	Cataracts	Green kohl
	776	Oh thou lighting one who stands still, <i>*h3 r3 itm</i> , beware thou of the master of my crown	Spotted baldness	Alabaster and Ochre (Red)
London	16	<i>sk</i> (twice) <i>šmnib</i> <i>Isttr wi</i>	<i>hmkt</i> disease	Ochre (Red)
	25	Back, companion of Horus! Back companion of Seth! Repelled is the blood that comes from Hermopolis. Repelled is the red blood that comes forth at the hour. You are ignorant of the dam. Back before Thoth!	Remedy to repel blood	Carnelian
	31	The <i>m3r</i> -demon is to be seized by the <i>nht</i> -demon. The <i>nht</i> -demon is to be seized by the <i>m3r</i> -demon, yet it is the <i>m3r</i> -demon that is to smite the <i>nht</i> -demon. This against this.	Wound	Ochre (Red)
	43	Charcoaled is the body with charcoal and the water of a red water. Hacking your Do not debilitate, do not debilitate, O vile one, make no sting, make no whitenings, make no maggots!	Burn	Ochre and Red pigment
Hearst	174	This is an evil I can treat	Vermin	Mineral <i>sj3</i> from the north from the south
Kahun	Kahun/ Lahun UC32271RI- f	I pluck [...] me against anything. A man should say this formula, his protection while passing around. "I am the one who is in the blinded wedjat-eye. I am its protection" A man should say this formula writing an eye on his hand in red ochre when he has added his name to the pupil in writing; then he [...] it	Pain	Ochre (Red)

There are three forms of magic in the medical texts. The first is the use of the written word and it is believed that the written word held magical power (Plater 2001) and this could suggest that the medical papyri in their written form are

already aiding the patient. The second is manual rites: there are examples of this within the Ebers papyrus and they are frequently coupled with the third form of magic which is the incantation. When an incantation is coupled with a medical recipe, this type of medical paragraph has been defined as being a spell, and it is believed that the purpose of these incantations are to change the integral nature of the ingredients within the prescription (Zucconi 2007). It has been known, however, for incantations (or prayers) to stand alone within the papyri. There is, also, the possibility of a fourth branch of magical medicine which is the use of like-for-like ingredients in the treatment of certain problems - such as the use of a fish head in the treatment of headaches.

There are only 11 paragraphs out of 522 that are classed as spells showing that minerals were used in an overtly rational manner (Table 5).

3.6.2 Types of Administration Method

The method of administration of the treatment is another important aspect that is often overlooked. Only one study could be found regarding this in Egyptian medicine (Karenberg and Leitz 2001). There are 20 different forms of administration, with 61% of them being a form of external treatment.

Table 6 shows that by far, the most common method of administration is that of the bandage, indeed it was used three times more than the next most prevalent known method. Administration is an important aspect in the way that these minerals were used. It is possible that by examining their method of administration to identify whether there were any ideas about potency or toxicity of certain materials. For example, as will be discussed later (3.9.1), red ochre is never taken internally, perhaps suggesting that, red ochre was perceived as having a high level of toxicity.

Table 6: Table showing the different types of administration method present in the papyri (in relation to minerals) and the percentage they represent as a whole

Method of administration	Number of times mentioned	Percentage (%)
Bandage	170	33
Applied Specific	61	12
Digested	39	7
Applied	37	7
Anointed	27	5
Suppository	20	4
Emetic	9	2
Fumigate	8	2
Anointed Specific	7	1
External	6	1
Injection	5	1
Rubbing	3	1
Mouth Rinse	2	<1
n/a	2	<1
Applied and Fumigated	1	<1
Digested and Bandaged	1	<1
Inhalation	1	<1
Internal	1	<1
Poultice	1	<1
Unknown	121	23

3.6.3 Minerals in the prescription database

From the prescription database it was possible to determine that 98 different minerals were used and that these can be grouped into 29 different categories (Table 7). The minerals most commonly used were the earthy minerals of salt; ochre and natron. Salt and natron form the core of this project due to their popularity in usage as well as their close geological and chemical relationship.

Table 7: Table generated from the prescription database showing the different types of mineral present within the medical texts

Mineral group	# of mentions	# of types	Mineral name	# of mentions
Salt	175	7	Salt (Northern)	79
			Salt (Sea)	79
			Salt	11
			Salt (Eastern)	3
			Salt (Delta)	1
			Salt (Oasis)	1
			Salt (Fresh)	1
Ochre	171	7	Ochre (Red)	50
			Ochre	43
			Ochre (Yellow)	37
			Ochre (<i>stj</i>)	24
			Ochre (Red – <i>mns</i>)	14
			Ochre (Red – <i>tjr</i>)	2
			Ochre (Red – <i>prs</i>)	1
Natron	92	5	Natron	72
			Natron (Red)	14
			Natron (Northern)	2
			Natron (Oasis)	2
			Natron (Pure)	2
Unknown	80	22	<i>trw</i> red mineral	15
			<i>dd</i> mineral	12
			<i>sβ</i> mineral from Upper Egypt	12
			<i>htm</i> mineral	6
			<i>nr spd</i> mineral	5
			<i>qušebet</i> mineral	4
			<i>kzntj</i> mineral	3
			<i>wšbt</i> mineral	3
			<i>bjβ</i> mineral	2
			Dessicative powder	2
			<i>m3d</i> mineral	2
			Powdered blood stone from Elephantine	2
			<i>sβ</i> mineral	2
			<i>sβ</i> mineral from Lower Egypt	4
			<i>ʿt</i> mineral	1
			<i>hdjt</i> mineral	1
<i>htw3</i> mineral	1			
<i>ksw</i> mineral	1			
<i>ssjt</i> mineral	1			
<i>w3h-nhbt</i>	1			
Kohl	71	4	Kohl (black)	51
			Kohl (green)	18
			Kohl (galena/black)	1
			Kohl (malachite/green)	1

Mineral group	# of mentions	# of types	Mineral name	# of mentions
Galena	32	3	Galena	29
			Galena (male)	2
			Galena (<i>gsfn</i>)	1
Malachite	30	3	Malachite	24
			Malachite (<i>hp3w</i>)	2
			Malachite (metallic)	2
Alum	26	2	Alum	25
			Alum (Heated)	1
Copper	16	5	Copper (slag)	6
			Copper (flakes)	5
			Copper	3
			Copper (Heated)	1
			Copper (Sulphate)	1
Working Stone	12	4	Alabaster	6
			Granite	3
			Calcite	2
			Gypsum	1
Clay	9	3	Statue clay	5
			Male clay	3
			Clay of the potter	1
Glass	7	4	Frit (green)	4
			Faience	1
			Frit	1
			Glass powder	1
Earth	6	5	Dirt from the courtyard	2
			Mud	1
			Mud from the water carriers	1
			Nile earth from the washerman	1
			Nubian earth	1
Pottery	6	3	Hin-vessel	4
			<i>bd3</i> vessel	
			<i>dw</i> vessel	
Flint	5	2	Flint (Black)	4
			Flint (Splinter)	1
Minium	5	2	Minium	4
			Minium (bread)	1
Hematite	5	1	Hematite	5
Pigment	5	4	Pigment (Green)	2
			Pigment	1
			Pigment (Red)	1
			Pigment (<i>rjt</i>)	1
Semi-Precious Stones	4	2	Lapis Lazuli	3
			Carnelian	1
Lead	3	2	Lead (white)	2
			Lead	1

Mineral group	# of mentions	# of types	Mineral name	# of mentions
Cadmia	2	2	Cadmia	1
			Cadmia (Heated)	1
Ammoniac salt	2	1	Ammoniac salt	2
Calamine	2	1	Calamine	2
Chalk (red)	2	1	Chalk (Red)	2
Orpiment	2	1	Orpiment	2
Stibium	2	1	Stibium	2
Brick	1	1	Brick	1
Pumice	1	1	Pumice	1
Sulphur	1	1	Sulphur	1

Although 98 minerals have been identified as used, a number of “important minerals”, such as gold and silver, are noticeably absent. Even today gold is used for its healing properties in the treatment of rheumatoid arthritis, and as a number of semi-precious stones were utilised it is surprising that this material, well known to the Egyptians was not used. It could be that the use of gold simply hasn’t been identified due to the medical word for the substance being disguised among the group of unknown minerals. Other reasons for the lack of inclusion could be the high cost of this material to be placed within a medicament. As has already been discussed (3.6.1) the relationship between minerals and magic has shown that in actuality minerals were used in more rational than irrational treatments, thereby negating the use of this clearly spiritual material (Lucas and Harris 1962). Other than the lack of use of these highly prized materials, no other notable material is obviously missing from the Egyptian’s mineral *materia medica*.

The 29 mineral groups were selected for their ease in both cataloguing and documenting. Other categories such as earthy minerals (which would have encompassed salt, ochre natron and alum), metals (for lead and copper) could have been just as identified, or the categories could have been based on colour, or preparation method. The 29 mineral groups however allow for the researcher to easily identify the most common minerals used as well as discern specific groups such as semi-precious stones.

Although not the largest group, unknown minerals are quite a significant proportion of all minerals identified from the prescription database. A number of aspects surrounding unknown minerals will be discussed in section 3.9.25, and as new translations are published the unknown minerals may become known and allow for further clarification of the groups produced.

This document will discuss all minerals that are mentioned in the medical paragraphs, and in relation to unknown minerals, possible new translations for their identity.

3.7 Salt

The chemistry and geology of salt will be discussed in depth in Chapter 6. This section investigates the use of salt in Egyptian medicine, as well as the possible locations from which salt could have been exploited.

3.7.1 Language

Salt has today a number of meanings; on the examination of one dictionary alone 18 can be found, with definitions ranging from experienced sailor to a dry wit. Not only this but the term salt in chemistry can mean the product from an acid-base reaction, as well as being a colloquialism for the material known as halite, it can thus be defined as the cubic crystal of sodium chloride. Many of the definitions of salt that can be found are in reference to salt's use in everyday life, although there are also sayings in reference to salt such as "*to rub salt into someone's wounds*" or "*salt of the earth*" (Matthew 5:13). In this way salt acts not only as a physical entity but as a metaphor, which has previously been commented on by Slaje (2001) and Parman (2002). Salt is commonly found referred to in religious texts, most notably in reference to those derived from Ancient Near Eastern sources such as Judaism and Christianity. Parman (2002) believes that there is an intrinsic link between salt and religion and that those groups that have access to a large amount of salt generally have a more negative attitude towards it than groups who have little. In the Ancient Near East, salt was seen as a universal purifier, a view carried into the Old Testament, as can be identified from God's instruction to Moses in the manufacture of religious incense "*Add salt to keep it pure and holy*" (Exodus 30:35). Indeed this manufacture of religious incense is still seen today within the Christian church (Burge 2005). Perhaps the most symbolic use of salt is in the punishment of Lot's wife (Genesis 19:26), indeed the idea of this punishment was so heartfelt that it occurred again within the teaching of Jesus (Luke 17:32).

hm3t is the Egyptian word often associated with salt and is closely related to *hsmn* (or natron) (Harris 1961). Harris (1961) in his comprehensive study of the language of minerals shows that most of the evidence surrounding the word(s) for salt is derived from the medical papyri.

3.7.2 Salt in Medicine

In total, there are 175 mentions of salt as a group, making it the largest mineral group in the prescription database. This mineral group is divided into seven different mineral types (Table 8):

- Sea Salt
- Northern Salt
- Salt
- Eastern Salt
- Salt from the Delta
- Salt from the oasis
- Fresh Salt

As Pliny (Book 31) stated in his Natural History, *“there is nothing more beneficial to the body than salt and sun”*. Today salt is so common and so inexpensive to purchase that it is easily forgotten how important a commodity it was. Indeed as McDougall (1990) points out *“man can live without gold but not without salt”*. It is hard to remember that, specifically in Africa, salt has had more of an impact on the control and colonising of areas than one of the world’s most sought after metals (McDougall 1990).

Table 8: Table showing the use of salt

Salt Type	# of mentions	Administration Method	# of mentions	Type of Problem	# of mentions	Body Area Treated	# of mentions
Salt (Sea)	79	Bandage	25	Animal	12	Internal	4
		Suppository	12	Swelling	5	Anus	3
		Emetic	8	Cosmetic	2	Face	3
		Applied	6	Injury	2	Bladder	1
		Applied Specific	6	Tumour	2	Finger	1
		Fumigate	2	Pain	1	Legs	1
		Anointed	1	Urinary	1	Lungs	1
		Digested	1			Toe	1
		Digested and Bandaged	1			n/a	36
Unknown	17	Unknown	54	Unknown	30		
Salt (Northern)	79	Bandage	37	Cosmetic	4	Limbs	13
		Anointed	9	Blisters	3	Stomach & Digestion	9
		Applied	7	Injury	3	Anus	6
		Digested	7	Sexual Problems	3	Knee	5
		Injection	3	Cough	2	Chest	4
		Suppository	3	Fever	2	Penis	4
		Rubbing	1	Fungal	2	Skin	3
				Bewitched	1	Bladder	2
				Burn	1	Digested	1
				Dejection	1	Ear	1
				Epilepsy	1	Face	1
				Parasite	1	Female	1
						Sexual Organs	
				Prolapsus	1	Finger	1
				Trembling	1	Sexual Organs	1
		Ulcer	1	Stomach & Chest	1		
		n/a	2	n/a	20		
Unknown	12	Unknown	53	Unknown	6		
Salt	11	Applied	3	Animal	1	Anus	1
		Digested	2	Fever	1	Anus & Bladder	1
		Anointed	1	Leaky ear	1	Ear	1
		Bandage	1			Eye	1
		Suppository	1			Head	1
						Stomach & Digestion	1
Unknown	3	Unknown	8	Unknown	4		
Salt (Eastern)	3					Anus	2
		Unknown	3	Unknown	3	Unknown	1
Salt (Delta)	1	Bandage	1	Injury	1	Chest	1
Salt (Oasis)	1	Bandage	1	Sexual Problems	1	Penis	1
Salt (Fresh)	1	Digested	1	Unknown	1	Female	1
						Sexual Organs	

The two most commonly used salts, northern salt and sea salt, are both commonly applied with bandages. Indeed 70% of medical paragraphs which feature northern salt require some method of external application. Among the most common reasons for its use is in the treatment of problems related to wounds and as a cosmetic. This coupled with the fact that salt is most notably used externally suggests that the Egyptians valued it for its astringent qualities rather than has been suggested as a flavourer (Campbell 2007; Nunn 2003).

Salt was seen as a positive agent as it was known to inhibit putrefaction and treat diarrhoea (Cirillo et al. 1994) and consequently a number of medical formulations build on these positive effects. It is therefore no surprise to see that salt is used in the treatment of wounds and in the process of mummification (4.2). One important use of salt in Egypt would have been that as a measure against dehydration. Salt is lost in intense heat through sweating, leading to the risk of fever, diarrhoea and vomiting, all of which would exacerbate dehydration (Cirillo et al. 1994; Orr 1934).

The most common problem treated by the salt group is animal bites and stings and with the limbs being the most commonly treated body area. There should be little surprise at this relationship as a survey conducted by Feldman et al. (2004) showed that 71% of bites on adults (over the age of 10) occurred on the limbs. In turn the use of salt in relation to the treatment of animal bites and stings is also a well thought out treatment. Indeed 92% of paragraphs that call for salt to be used in the treatment of animal bites requires the use of sea salt, and 58% of these paragraphs require the patient to be treated with an emetic. Sea salt is a well known emetic, and the use of an emetic suggests the knowledge that the animal that had bitten or stung them was of a poisonous nature, and that this treatment was therefore carefully considered.

Most problems treated with salt fall into the natural category; however there is one instance in which salt is used to treat a supernatural condition – a bewitching of the ear (Ebers 769). This treatment calls for a remedy to be

infused in the ear and indicates the use of northern salt. Interestingly there is no incantation associated with the remedy which suggests that although the cause was supernatural the manifestation was deemed more natural. There is one instance in which a problem is treated with a spell utilising salt (Ebers 203). However the salt remedy is only to be used if the incantation and preliminary medical paragraph has failed. Unfortunately the problem is not translatable and so it cannot be readily established whether this was a primarily a supernatural problem, or a natural problem where spells were believed to be more efficient.

Some of the more varied uses of salt are of those salts which are relatively rarely used. Eastern salt and salt from the oasis are only found in the medical texts a total of four times. Both these salts are always used in conjunction with other types of salt, which is highly unusual. The three medical paragraphs for Eastern salt also contain sea salt, and the one medical paragraph for salt from the oasis also contains Northern salt. The reason for using two salts together is unclear, but perhaps one may have been seen as inferior in quality to other salts, but a necessary requirement for some undisclosed spiritual purpose.

The use of salt is still quite common among traditional folk remedies and this can supplement the data from the ancient sources already discussed. Ethnographic studies can help further aid our understanding of the transition from ancient medicine into the modern world and allows for a comparative study of uses throughout history. Many traditional folk remedies may have had their origin within ancient medicine and use the same ingredients and method of application. Some parallels between folk and ancient medicine can be direct, for example a Siwan medicine for the treatment of ear problems, which uses salt, oil and a fragrant resin, which is very similar in content to a medical paragraph from the Ebers medical papyrus.

Ear trouble: A mixture of salt, oil, onion juice and myrrh is used in the form of drops (Stanley 1912b)

Remedy for a bewitched ear (*w^sf nf rjt*): *shpt*, resin, northern salt (Ebers 769) (Ebbell 1937)

There are a number of myths regarding the use of salt in medicine. One is the belief that salt and fertility were intrinsically related (Cirillo et al. 1994; DeSanto et al. 1997a; DeSanto et al. 1997b; Kurlansky 2003). This could be due to the notion that those animals living on a salt supplemented diet produced more offspring (Cirillo et al. 1994; DeSanto et al. 1997a; DeSanto et al. 1997b; Kurlansky 2003); that fish have more offspring than land dwelling animals (Cirillo et al. 1994; DeSanto et al. 1997a; DeSanto et al. 1997b; Kurlansky 2003); that ships carrying salt had a large population of mice on board (for centuries sailors believed that the mice in their hold reproduced asexually simply by being in the salt) (Kurlansky 2003). Or the more direct suggestion regarding salt's link with fertility is that salt was associated with semen and consequently salt would aid its potency (Kurlansky 2003).

3.7.3 Salt deposit localities

One of the largest sites from which the Egyptians could have potentially exploited salt is that of the Wadi Natrun (3.8 and Chapter 6). Sea salt was probably harvested from salt pans in the Mediterranean (Pliny Book 31 39.81). Another major source of salt in Egypt was the Oasis of Siwa. The Oasis of Siwa lies within a geographical depression which reaches for over 30 miles and contains a number of lakes (Stanley 1912a; Stanley 1912b) (Figure 17).

The principal lakes are Zeitoun; Koraichin; Khamisa and Maraghe (Stanley 1912a; Stanley 1912b). It was reported in 1911 that the town near the Oasis of Siwa was built entirely of locally mined rock salt (Stanley 1912a). The earliest record of Siwa is found in the biography of Harkhuf who travelled along the caravan route between Elephantine and Darfur and dates to around the 6th

Dynasty (Fakhry 1950). Much like the Wadi Natrun (6.2) the Oasis of Siwa was not a fully integrated part of the Egyptian Empire (Fakhry 1950), and possibly acted much like a vassal state or a trading nation. It is known that the "Ammonites" sent a tribute of salt from the oasis to the King of Persia to be used in special religious ceremonies (Belgrave 1923) and there is also evidence dating from the Ur III Period (2119-1940 BC) for the trade in "Ammonite salt" (Potts 1997). There is no mention of the oasis in the accounts of the Egyptian-Libyan wars either with Merenptah or Ramesses III and this suggests that the oasis was actually a Libyan territory rather than an Egyptian one (Fakhry 1950). Archaeologically speaking the main find in the area is the Temple of Jupiter-Amon (26th Dynasty), and whilst the temple was in a state of disrepair artefacts such as the "Fountain of the Sun" could still be distinguished (Stanley 1912a). The oasis was well known for its salt and Arab writers discuss the mines, and that salt was readily picked off the ground in the vicinity (Belgrave 1923). According to Stanley (1912b) tradition dictated that the entire years supply of salt was collected on the Eve of the Courban Bairam (a Muslim festival of sacrifice, held in accordance with Islamic law), and labourers vied for the best salt deposit which was concentrated around Lake Khamisa.

Salt was a commodity to be traded and consequently could have been imported from outside the borders of Egypt. It is known that salt was imported into Egypt from the Sinai Peninsula (Nenquin 1961) and there are a number of famous salt works known outside Egypt and these include the production of sea salt in Larnaka, Cyprus (Bass-Becking 1931); the presence of purple salt in Libya and Sicily (Bass-Becking 1931; Herodotus Book II; Pliny Book 31; Wilson 1988). There are known salt deposits in Anatolia and Armenia with a large quantity of rock salt being mined near Lake Van (Karajian 1920).

3.8 Natron

The chemistry of natron and geological formation will be discussed in Chapter 5 and a detailed description of the Wadi Natrun can be found in Chapter 6.

3.8.1 Language

The language issue surrounding natron is complex, and was acknowledged back in the 18th Century with Monro (1771, 567) commenting "*it is well known that the nitre, or natrun of the ancients which they used for making glass and in their baths and other uses was not the salt which now goes by the names of nitre of salpêtre; but a salt of alkaline nature which at present is commonly called the natrun of the ancients*". Nitron is the Coptic/Greek corruption of the Egypt *ntr* (Gibbs 1938; Harris 1961; Josset 1996; Stillman 1924) and occurs in both Greek and Coptic texts. It is known that this word nitron refers specifically to soda/natron - a sodium carbonate. Nitron was then Latinised and the word nitrum was also used to mean sodium carbonate and has been found in the context of the manufacture of glass (Gibbs 1938).

Gibbs (1938) believed that the confusion over the correct terminology was the fault of early modern mineralogists who did not conform to the chemical convention and referred to salpêtre as nitrum, and chemical nitrum as soda. The specific word natron is of Arabic origin and probably originated at the same time as the change in name of the Wadi Natrun (Chapter 6). This word arrived into Europe in the 16th century and came through Prosper Alpinus' account of Egyptian medicine (Gibbs 1938). One prescription urges for the use of *nitrum nubrum* which was corrupted to natrun (Gibbs 1938). This type of soda was believed to have been obtained from water which was coloured by red algae, perhaps a reference to the Wadi Natrun.

This arises from the large number of Egyptian words which refer to this substance and also the modern misuse of terms such as nitre, natron, natrum,

natrun, soda and nitrum. For the purpose of this document natron will be used to mean the specific mineral sodium carbonate decahydrate ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$), and natrun will be used to mean a “usually complex, often polyphase evaporitic deposit rich in carbonates of sodium” (Shortland 2004, 500).

According to Harris (1961) there are ten versions for the word natrun although only two are used in reference to medicine; *ntryt* which is an undisclosed form of the substance, and *ḥsmn*. *ḥsmn* is one of the most commonly associated words in respect to natrun. The word *ḥsmn* is closely related to purity (Faulkner 1988), although which came first is hard to establish: ie. whether the word for purify was born out of the intricate relationship between natron and purification, or whether the word natron was born out of its use in purification. There are two words however which differ only by determinative which are very closely linked. Firstly the word for bronze *ḥsmn* (Faulkner 1988) differs by the presence of a crucible as a determinative, and in addition to this is rarely used within texts. Secondly the word for menstruation is also *ḥsmn* (Faulkner 1988), the formation of this word is again closely linked to purification as a menstruating woman would have to become ritually pure to be accepted back into society at the end of her period.

3.8.2 Natron in Medicine

Natron was mentioned 92 times in the prescription database, and is the third largest mineral group to be used. It is divided into five groups:

- Natron
- Red Natron
- Northern Natron
- Pure Natron
- Natron from the Oasis

From the prescription database it is possible to determine that the use of natrun in medicine follows very similar patterns to salt (Table 9). The most common method of administration is bandaging and 83% of the known administration methods are external. There is no real discernible trend for a particular type of problem or body area treated, although animal bites, stings and limbs are mentioned in a significant proportion of the medical paragraphs.

Table 9: Table showing the use of natron in the medical papyri

Natron Type	# of mentions	Administration Method	# of Mentions	Type of Problem	# of mentions	Body Area Treated	# of mentions
Natron	72	Bandage	39	Swelling	6	Limbs	8
		Applied	9	Animal	5	Stomach	5
		Anointed	6	Cosmetic	3	Anus	4
		Applied and Fumigated	1	Fever	3	Legs	3
		Applied Specific	1	Nail	2	Face	2
		External	1	Blisters	1	Head	2
		Fumigate	1	Injury	1	Toe	2
		Suppository	1	Pain	1	Anus/Digestive	1
				Pus	1	Chest	1
				Sex	1	Eye	1
				Tumour	1	Finger or toe	1
						Knee	1
				Mouth	1		
				Nail	1		
				Penis	1		
				Skin	1		
		n/a	2	n/a	1	n/a	20
		Unknown	11	Unknown	46	Unknown	17
Natron (Red)	14	Anointed	3	Cosmetic	3	Eye	3
		Applied Specific	3	Blisters	2	Digestion	2
		Bandage	3	Parasite	2	Skin	2
		Applied	2	Trachoma	2	Face	1
		Digested	2	Animal	1	Knee	1
		Rubbing	1	Poor Eyesight	1	Legs	1
							n/a
				Unknown	3		
Natron (Northern)	2	Bandage	2			Limbs	2
				Unknown	2		
Natron (Pure)	2	Bandage	2	Animal	1	n/a	1
				Unknown	1	Unknown	1
Natron (Oasis)	2	Bandage	2	Animal	1	n/a	2
				Unknown	1		

Sodium carbonate in various forms is still being utilised in the medicinal industries of many African nations. Sodipo (1993, page 1181) comments that the “popularity of trona is ranked next in importance to common table salt”. Its uses in medicine cover mainly digestive problems and studies have also shown that sodium carbonate can help alleviate fatigue in warm climates (Davey 1996; Sodipo 1993). These instances of modern usage aid the understanding of how natrun and other sodium carbonates were used in the past.

A commonly referred to use of natrun is in contraception (Campbell 2007; Haimov-Kochman 2005; Harayama et al. 1998). This is primarily based on Kahun Column 3 which prescribes

Hin of honey, sprinkle over her vagina, this to be done on natron bed

Many have seen this as evidence for natrun’s use as a contraceptive. Indeed ethnographic records from the Sudan show that natrun produces violent diarrhoea that can lead to the miscarriage of an unborn child, and studies have shown that the presence of sodium carbonate in a contraceptive agent caused head to head agglutination, which meant that fertilisation could not occur, thereby acting as a spermicide (Harayama et al. 1998). This evidence discounts the idea suggested by Guiter (2001) that it was the mixture of the honey and natrun that caused the contraceptive effect.

However evidence from the papyrus itself and from external sources suggests that the conclusion of its contraceptive qualities is not as concrete as previously imagined. The statement itself is located among procreation aids and natrun is a well known purifying agent (Chapter 4). If the statement itself is examined the use of the term ‘bed’ was translated from an influence of embalming texts (Quirke 2008), with another link being drawn to purification rites. In addition to this the bed in ancient Egypt was not only used for sleeping but was a very specific concept in terms of womanhood. Indeed Meskell (1998) states that the bed was seen as a ritual place for sexual intercourse and conception. Additional

evidence in the form of ostraca show women nursing newborns on what was perceived as birthing beds (Meskell 1998). From a study of business transactions it has been possible to identify a number of bed purchases (eg. O Gard 105 rt 1; O Varille 13 1.2) and in one case (O Gard 91.5) a bed was purchased with the addition of a birthing amulet (Meskell 1998). This perhaps supports the idea that rather than natrun being used as a contraceptive it was actually a procreation aid.

3.8.3 Location and Trade of Natron

Trade networks and locations for natrun deposits both within and outside Egypt's borders have been identified from surviving Egyptian records and accounts from the Classical to the Modern Period. The Wadi Natrun is believed to be the main source of natrun within Egypt and using documentary sources covering almost 4000 years a clear idea of the chemistry, exploitation and history of the Wadi Natrun has been gathered. The Wadi Natrun will be discussed in more depth in Chapter 6.

The Libyan Desert contains the Wadi Natrun together with a number of other sources for natrun. Haynes (1979) reported that in the 1970s the Bedouin still made a living by collecting "trona" from a source near the Kharga oasis (Figure 18). Another source is that of Barnugi (Lucas 1911; Shortland 2004), unfortunately there is no known reference in either ancient or classical texts to these deposits. A "modern" deposit in Hottara in the Western Delta is also known, but like Barnugi, no pre-modern reference to this can be found (Habashi and Bassyouni 1982). Yet Pliny also commented on the use of Nile water in which to manufacture natrun artificially (Pliny Book 31 46.109). Two other deposits are thought to have been used for natrun extraction in the medieval period, namely in the city of Abyar and the al-Fasquesiyya in the Sharqiyya province (Rabie 1972). A 19th Dynasty ostraca shows natrun and salt workers coming under the jurisdiction of the temple of Amon in the Delta (141 O Gardiner 80 (Wente 1990)).

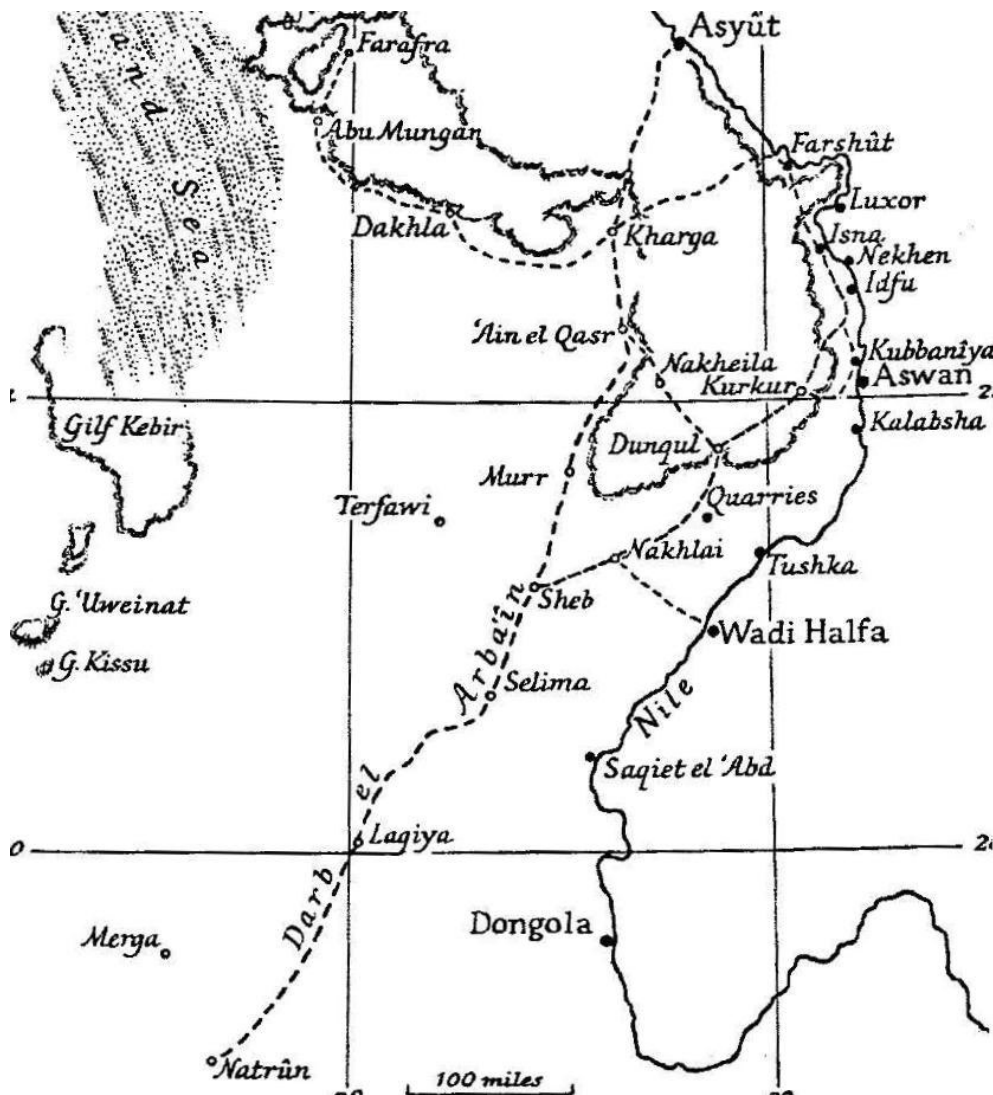


Figure 18: Map showing the location of the Kharga oasis (Murray 1939)

Another notable natrun deposit is at El Kab in Upper Egypt (Figure 19 area V on the map). Examination of modern satellite images of the area (Figure 20) shows that these deposits are no longer present. It is plausible that the temple complex of El Kab was built as a result of this location next to a large natrun deposit and would thus allow for the purification of people/objects (4.1) within the temple complex. Clarke (1923) also mentions that these deposits were considerable and that they were in much repute in ancient times.

Although Egypt had its own supply of natrun a number of external sources can be identified. The Sudan has sources of natrun and these deposits would have been available to the Egyptians. Hume (1912), stated that even in the early 20th Century when large scale exploitation of the Wadi Natrun was being conducted by the Salt and Soda Company that natrun was still imported from Sudan. Indeed Budge (1914) noted in his survey of liturgies that there was incense and natrun that are “mixed by the Nubians”, this suggests that Nubia was indeed, at some stage in Egypt's history a potential site of natrun exploitation. It is also known that during the reign of Thutmosis III (18th Dynasty) tribute was paid in part by natrun from Syria (Breasted 1906), whether this was either before or after a regular trade link was established is unknown, but the evidence of trade links will be discussed later. It is known from Pliny's Natural History (Book 31) that the best natrun to be found was Lydian, but there were also sources in Macedonia, in Media and also in Thrace near Philippi.

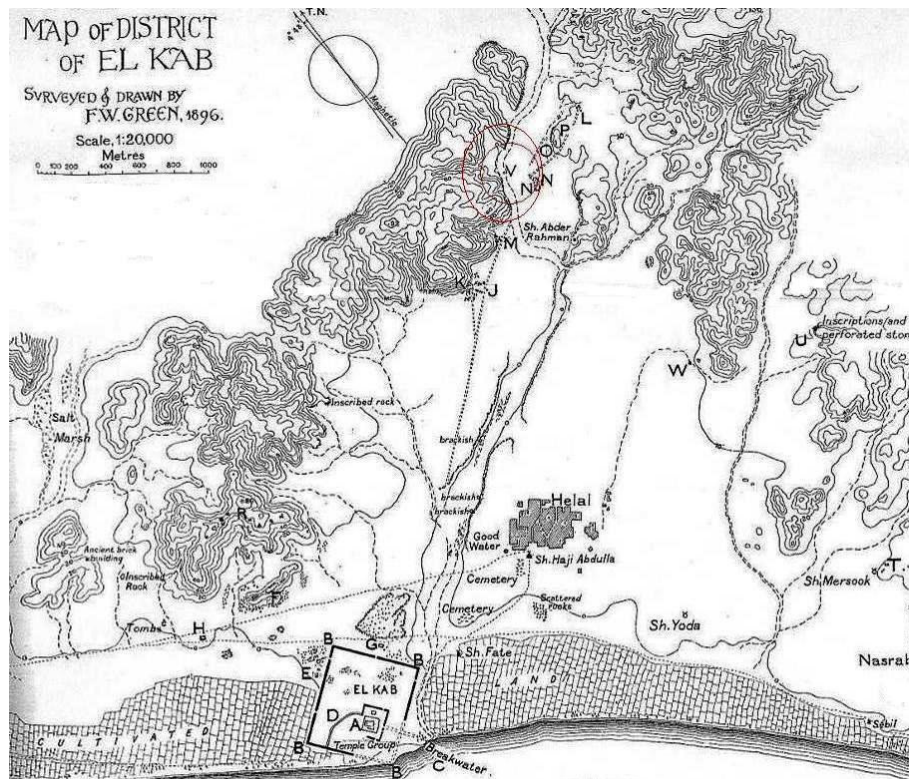


Figure 19: Map of the el Kab district, with the natrun deposits represented with a V and a circle (Clarke 1923)



Figure 20: Modern satellite image of the area surrounding the "natron deposits", marked with a V and a circle (Courtesy of Google Earth)

3.9 Other minerals

As has already been shown there are many other minerals which were used in the medicine of the Ancient Egyptians. These minerals will be discussed here in detail.

3.9.1 Ochre

Language

As can be seen from the table (Table 10) ochre has a number of different types, although they are predominately based on the two colours of ochre, red and yellow. One thing which is easily identifiable is that there are four different reds. There is also the presence of *stj*, an ochre which has no colour readily associated with it. Of these ochres the language of *mnšt*, *prš* and *stj* will be discussed in greater depth.

The term *stj* is believed to refer to yellow ochre. Evidence for this comes primarily from its function as a pigment. Both Harris (1961) and Iversen (1955) show that *stj* is a form of yellow ochre through its relationship with the Boat of Re, which is meant to be painted with *stj* and is depicted in the Book of the Dead as yellow.

Both the words *prš* and *mnšt* are used in relation to red ochre. Faulkner (1988) believes that the term *prš* relates to the red mineral minium (3.9.11), although due to its relationship with the Coptic word for red ochre it can be suggested that this is a more accurate term (Iversen 1955). Harris (1961) makes it clear that this type of red ochre is not a regularly used pigment and is relatively rare in the textual record. *mnšt* is often translated as a red ochre (Harris 1961; Iversen 1955), however Harris (1961) is more specific when he states that he believes *mnšt* is a product of the oases, hence the specific word for this mineral.

Table 10: Table showing the use of ochre in the medical papyri

Ochre Type	#mention	Administration Method	# mentions	Type of Problem	# mentions	Body Area Treated	# mentions
Ochre (Red)	50	Bandaged	22	Burn	3	Eye	5
		Applied Specific	7	Alopecia	2	Toe	4
		Applied	4	Animal	2	Finger or toe	3
		Anointed	2	Injury	2	Stomach& Digestion	3
		External	1	Pain	2	Digestion	2
				Parasite	2	Ear	2
				Swelling	2	Hair	2
				Trachoma	2	Nail	2
				Blood	1	Finger	1
				Fever	1	Knee	1
				Poor Hearing	1	Limbs	1
				Sexual Problems	1	Penis	1
				Trembling	1	Scalp/head	1
						n/a	17
		Unknown	14	Unknown	28	Unknown	5
Ochre	43	Bandaged	13	Animal	3	Nail	10
		Digested	6	Burn	2	Internal	3
		Applied Specific	5	Swelling	2	Stomach& Digestion	3
		Applied	1	Catarrh	1	Anus	2
		External	1	Diarrhoea	1	Bladder	2
		Suppository	1	Nail Problem	1	Legs	2
				Pain	1	Finger or toe	1
				Unconscious	1	Heart	1
						Lungs	1
						Toe	1
				n/a	9		
		Unknown	16	Unknown	31	Unknown	7
Ochre (Yellow)	37	Digested	9	Blood	3	Heart	4
		Bandaged	4	Cough/Asthma	2	Stomach& Digestion	3
		Applied Specific	3	Trachoma	2	Bladder	2
		External	2	Alopecia	1	Eye	2
		Mouth Rinse	2	Diarrhoea	1	Toe	2
		Applied	1	Nail Problem	1	Tongue	2
				Trembling	1	Tooth	2
				Ulcer	1	Bladder& Digestion	1
						Finger	1
						Finger or toe	1
						Gums	1
						Hair	1
						Head	1
						Heart and Mind	1
				Limbs	1		
				Mouth	1		
				Stomach& Digestion	1		
			n/a	1	n/a	5	
		Unknown	16	Unknown	24	Unknown	5
Ochre (stj)	24	Applied Specific	6	Poor Eyesight	2	Eye	8
		Bandaged	5	Animal	1	Female Sex Organs	2
		Anointed	1	Blisters	1	Chest	1
		Applied	1	Injury	1	Gums	1
		Injected	1	Jaundice	1	Liver	1
		Rubbing	1	Sexual Problems	1	Penis	1
				Tumour	1	Toe	1
						Tongue	1
						Tooth	1
						n/a	3
		Unknown	7	Unknown	14	Unknown	1

Ochre Type	# of mentions	Administration Method	# of mentions	Type of Problem	# of mentions	Body Area Treated	# of mentions
Ochre (Red – <i>mnšt</i>)	14	Applied Specific	4	Injury	1	Eye	9
		Bandaged	2	Poor Eyesight	1	Penis	1
		Applied	1	Sexual Problems	1		
				Tumour	1		
		Unknown	7	Unknown	10	n/a	2
Ochre (Red – <i>tjr</i>)	2	Bandaged	1			n/a	1
		Unknown	1	Unknown	2	Unknown	1
Ochre (Red – <i>prs</i>)	1	Unknown	1	Unknown	1	Unknown	1

Ochre's use in medicine

Ochre is the second most frequently mentioned mineral group in the texts, with 171 medical paragraphs requiring its use. However ochre is the most likely mineral to be associated with a spell. Whilst only 5% of all medical paragraphs containing ochre make mention of spells this still means that around 60% of the medical spells which use minerals use ochre (Table 5). This shows that ochre had use in sympathetic magic as well as in medicine and as a pigment as red ochre is also important in having a symbolic meaning and therefore has a use in sympathetic magic. Red ochre was used in the treatment of wounds and blood problems, presumably because it is the colour of blood and therefore believed to be able to heal this area quicker.

From Table 10 it is possible to identify that there are seven different types of ochre mentioned within the medical texts. Red ochre is the most commonly utilised ochre, followed by ochre. There is no clear colour definition made with this material and it could have been left to the doctor's discretion in prescribing the one he saw most fit. The types used are:

- Red ochre
- Ochre
- Yellow ochre
- Ochre – *stj*
- Red ochre – *mnšt*

- Red ochre – *tjr*
- Red ochre – *prš*

Table 10 shows that again bandage is the most commonly used form of administration, with 32% medical paragraphs (47 medical paragraphs) requiring it. Most methods of administration are external and in only 12% of instances is it digested or used as a suppository. Interestingly the proportion of different types of administration of the ochres is very similar to that of salts. Table 10 also shows that the eye was the most commonly treated body area with a total 24 medical paragraphs, although there are also a similar number of paragraphs on limbs and the digestive tract.

One medical paragraph (Kahun/Lahun UC32271RI-f) stipulates the use of red ochre in drawing on the flesh (Collier and Quirke 2004). This is directly paralleled in Pliny (Book 33) where he stipulates the use of iron to draw a protective circle to ensure the patients health and wellbeing. Lucas (1938) also notes the use of ochre in other areas of Egyptian sympathetic magic and shows that there was a clear link between blood and red ochre, this is most pronounced in aspects of hunting (and is found in respect to this across all cultures which rely on hunting) and Lucas (1938, 198) states that the Egyptians used red ochre on arrow tips to *“draw the arrow to the blood of the animal”*.

The four red ochres are only ever administered externally, which is in contrast to yellow ochre which is administered through a variety of means including digestion. The most common method of application for yellow ochre was for the remedy to be digested. It can perhaps be proposed that the Egyptians perceived yellow ochre as being safer, or maybe even less potent, therefore required the medicine to be digested.

Chemistry and Sources of Ochre

There are two main types of ochre, red and yellow. Red ochre is Fe_2O_3 , it is coloured through the presence of hematite, the principal colouring material of yellow ochre is the presence of goethite, $\alpha\text{-FeOOH}$ (Eastaugh et al. 2004).

The best known use of ochre is probably that of a pigment and ochre in this context is amongst the most common minerals found in archaeological excavations (David et al. 2001). Red ochre has been used since the earliest time and even by the time of Pliny (Book 33) ochre had an ancient reputation.

Ochre is a readily available mineral within Egypt's borders. Found principally near Aswan and in the Western Desert (Lucas and Harris 1962). Evidence for its procurement from Aswan can be found in Dend. Mar. I. 71 where it is cited as a source (Harris 1961). It is also available in the North-Eastern Desert near Wadi Abu Marwat (Buckley and Weatherhead 1988). There are classical references to ochre coming from Egypt, and specifically red ochre, in both Pliny (Book 33) and Dioscordies (2000). Indeed Dioscordies (2000) remarks that Egyptian and Carthaginian red ochre are the best available.

3.9.2 Kohls

Kohls are a cosmetic which is applied to the eyes in the form of an eye shadow. They are quite often separated in the study of medicine both ancient and ethnographical as it is a commonly held belief that kohls were cosmetic first and foremost with any additional medical benefits being purely coincidental. The role played by kohls in Egyptian medicine is in effect a cosmeceutical, as a substance which holds both cosmetic and medicinal properties. It is interesting to note the change in favour by translators over reference to kohls. In the early half of the 20th Century kohls were referred to by their proposed mineralogical identity such as galena or stibium, however in more modern translations of texts the formula has been to describe these substances as kohls referenced by their

colour ie. instead of galena the translator would use the term black eye paint. This is significant for the ultimate understanding of what minerals were used in these cases. Alongside the kohls, galena and malachite will also be discussed here.

Unsurprisingly kohls, not including galena and malachite, were used to treat the eye with 94% of all prescriptions calling for its use. Unfortunately only 31% of the medical paragraphs have the eye problems identified, causing a gap in knowledge as to what the common eye problems might have been. The most common type of kohl used was black.

Black kohls

Language

The term *msdmt* is often found in connection with black kohls (Harris 1961). The term is often indiscriminately used to mean either black kohl or galena, depending not only on the context of the prescription but also on the translator, consequently there is a sufficient link between black kohl and galena to believe that the latter is indeed the former. Besides the term *msdmt* to describe galena, an additional type of galena known as galena *gsfn* has been identified from the medical texts (Harris 1961). As both *msdmt* and *gsfn* were found within the same medical paragraph it is presumed that they refer to different sources of exploitation or even a different manner of manufacture. It is not possible to build a clearer understanding of the term galena *gsfn* as it is rarely found outside of the medical texts, and in them not that often (Harris 1961), perhaps suggesting that *gsfn* was chosen for its specific medical properties rather than the colour it would produce. Couple this linguistic evidence with the fact that galena is commonly identified from the kohls of Egypt (Shortland et al. 2000; Stos-Gale and Gale 1980; Wiedemann 1892) and the wealth of archaeological evidence regarding galena's use in Egyptian life dating from the Predynastic through to

the end of the Greco-Roman period. It is suggested here that the term black kohl refers to galena.

Use

There are 51 mentions of the use of black kohl and perhaps unsurprisingly the common problem to be treated with black kohl was problems in relation to the eye. Indeed 94% (48 out of 51 medical paragraphs) of medical paragraphs that require the use of black eye paint are to be used on the eye. Poor eyesight is a common reason given for its use. The relationship between black eye paint and the eye can also be found in religious texts, in conjunction with the term "*for opening of the eyesight*" (Wiedemann 1892).

Galena has 32 mentions and can be divided into three types, galena, male galena and galena *gsfn*. Although there is no distinct problem or treatment which requires galena, over 70% of medical paragraphs utilising this mineral are external, in application.

Source

Black kohl in the form of galena has been found dating back to the Predynastic. Galena is a lead sulphide (PbS) and can be found within Egypt's borders, for example in sites near Aswan (although in limited supply (Hume 1912)) and the Red Sea (Saleh 1972). Along the Red Sea coast galena can be found at both Um Anz and Zog el Bohar (Hassan and Hassan 1981). There are other well known sources of galena such as a source near Wadi Hammamat (Hassan and Hassan 1981) and there is also evidence to suggest that galena was sourced from the Western Desert.

Evidence also suggests that some galena was gathered from outside of Egypt, indeed Stos-Gale and Gale (1980) believe that during the early part of Egyptian history black kohl was obtained from far outside Egypt's borders and may have

been imported from as far away as Asia. Evidence for the importation of *msdmt* can be found at Deir el-Bahari where in the Pwenet scenes it is recorded that *msdmt*, a precious commodity, was brought to Egypt by the 'Aamu (or Amu) (Saleh 1972). The Amu were also represented trading the substance in a scene at Beni Hasan within the 12th Dynasty tomb of Khnumhotep II (BH3) (Bloxam 2006) (Figure 21). The Amu are believed to have been Semites (people who originate from the Near East such as the Phoenicians) (Saleh 1972). Evidence from the 18th Dynasty also suggests that *msdmt* was imported from Naharin (Naharin was the Egyptian word for the kingdom of Mitanni (Figure 1) (Saleh 1972).



Figure 21: A scene from the tomb of Khnumhotep II showing the presence of the Amu traders

A number of scientific projects have been conducted to identify the source of galena used in Egypt for the production of kohls. From Stos-Gale and Gale's (1980) work on the chemical analysis of kohls from the Predynastic and Protodynastic only five of the 11 sampled can be conclusively ascertained to have originated from the mines in the Eastern desert, suggesting that galena for cosmetic purposes may have come from both local and foreign sources, however Stos-Gale and Gale also stipulate that due to the Egyptian sources size that it would be unfeasible to think that this was not a primary source of galena throughout Egyptian history (Stos-Gale and Gale 1980). The evidence for the procurement of galena from Gebel Zeit is further compounded by the relationship that can be found there between religion and mining where Hathor

is designated as the 'Mistress of Galena' on votive offerings, fertility figurines and stela from the mines at Gebel Zeit (Bloxam 2006). A clear relationship between this site and kohls can be identified linking the procurement of galena with the site of Gebel Zeit (an Eastern Desert site) (Shortland et al. 2000). It was an expensive commodity as can be shown from an unnumbered IFAO (Institut français d'archéologie orientale) papyrus (Fragment A1 Line 11) where galena is identified as being among a number of items requested for a type of poll tax (Janssen 1991).

Green kohls

Language

The term *w3d* is often found in relation to "green stones" and is believed to be a reference to the green kohls and the mineral malachite (Harris 1961; Iversen 1955). It is believed to be found within a number of different literary contexts, such as lists of precious stones, and as reference to a pigment within the Book of the Dead (Iversen 1955).

Use

Green kohl can be found in 18 medical paragraphs. Again the use of green kohl in the treatment of the eyes is well attested with 88% (16 out of 18 medical paragraphs) requiring being administered to the eye in some manner. Cataracts, poor eyesight and being bleary eyed are all reasons given for the use of green kohl.

Malachite is mentioned 30 times and can be split into three types, malachite, *hp3w* malachite and metallic malachite. Most would believe that malachite would be used in the treatment of eye disease, due to its close relationship with green kohl; however, it is by no means the most common body area to be treated. 11 other body areas are treated with malachite and six different problems have

been identified. External administration makes up 57% of malachite's medical paragraphs with bandages being the most common form.

Chemistry and Sources

Malachite is a copper compound with a chemical formula of $\text{Cu}_2\text{CO}_3(\text{OH})_2$ and it can be found in a variety of places, in Egypt and elsewhere. Malachite was important to the Egyptians not only because its colour held religious significance (MacKenzie 1922) but also because of its importance in copper manufacture (Barrois 1932; Lucas 1927a). The word *w3d* has been found in reference to a number of sites within Egypt, such as the Gebel Zebara on the Red Sea (Iversen 1955). Archaeological evidence has however suggested that malachite was also mined in the Eastern Desert at Timna and the Sinai Peninsula at Wadi Maghara, Serabit el-Khadim and Bir Nasib (Aston et al. 2000). Harris (1961) believed that during the Old Kingdom the Eastern Desert rather than the Sinai Peninsula was the main source of malachite. The earliest known record of a mining expedition for malachite is from the First Dynasty (Lucas 1927a) although malachite has been found in graves dating from the Predynastic suggesting a much earlier usage (Debb et al. 2004; Diamandopoulos 1996; Ead 2006; Lucas 1927a).

The Egyptians attached a special significance to the colour green (MacKenzie 1922). It is believed that the colour was associated with life itself, as across almost all ancient cultures, green is associated with the propagation of healthy plants and crops. It was also seen as a sign of resurrection and early Egyptian texts refer to the afterlife as the "field of malachite". The colour is also closely associated with water (Wilkinson 1843a). Consequently the colour green was highly prized in both natural and manufactured "stones".

3.9.3 Alum

Language

The importance of documentary evidence in the determination of the use of alum cannot be underestimated. Today the word alum has a specific meaning, it is a hydrated double sulphate of potassium and aluminium with the chemical formula $KAl(SO_4)_2 \cdot 12H_2O$. However it has also been used to mean a hydrated double sulphate that contains aluminium with or without another type of alkaline/alkaline earth mineral (Shortland et al. 2006b). The Egyptian word for alum, *ibnw* has been predominately identified from the medical texts such as the Berlin Medical Papyrus (Harris 1961).

Use

Alum is mentioned 26 times in the medical papyri and is most commonly found in the medical papyri as a method of treating wounds, and consequently is primarily found in the Edwin Smith Surgical Papyrus. The way it is administered is what would be expected for the treatment of wounds, namely in the form of a bandage, and again the body areas to be treated are those most commonly associated with fractures and wounds, such as the chest or neck. Although its use in the treatment of wounds date back as far as 1550BC, later it was predominately used by the Greeks as an abortifacient and to halt abnormal growths (Dioscorides 2000) in the genitals, ears and mouth. No parallels can be identified in its use in Egyptian medicine.

Sources

Alum comes from the Western Desert, namely the Dakhla and Kharga Oasis (Lucas and Harris 1962; Shortland and Eremin 2006; Shortland et al. 2006b) and it was said that every kind of alum can be found within the alum mines of Egypt (Dioscorides 2000). The area in which alum can be found is known to

have been attached to Egypt in the 12th Dynasty, around the same time as the proposed annexation of the Wadi Natrun (6.2.1) and was such a hostile environment that by the time of the 21st Dynasty it had become a place of banishment (Caton-Thompson and Gardner 1932). Pliny describes a number of sites along the Mediterranean where alum could easily be sourced (Hall and Photos-Jones 2006), but Egyptian alum was believed to be among the best in the classical world. There are even documents detailing the price of this commodity in Mesopotamian trade and it is known that alum was being sold in Mesopotamia in the first millennium BC (Levey 1958a; Levey 1959). Cuneiform tablet YOS 6 168 states that 233 minas of Egyptian alum would cost 1 mina $17^{2/3}$ shekels (Oppenheim 1970).

3.9.4 Copper

Language and Use

The word for copper is identified as *hmt* and is closely related to the Egyptian word for salt (Faulkner 1988). Copper is mentioned 16 times and there are five different types of copper mentioned within the medical paragraphs. Unfortunately there is no clear discernible use for the metal and it covers all areas of the body, and a number of problems are untranslatable.

Source

Most Egyptian copper ores, which have been analysed are found to be malachite (Barrois 1932; Lucas 1927a). Copper ore can be found in a number of areas in Egypt, primarily in Sinai and the Eastern Desert (Lucas 1927a). where there is additional evidence in the form of ruined mining settlements (El Gayar and Jones 1989; Lucas 1927a). A few studies have focused on these settlements, one of the largest studies focused on the Old Kingdom town of Buhen (now submerged by Lake Nasser) (El Gayar and Jones 1989). From the excavation at Buhen three smelting furnaces were found and the remnants of

the ore used to be smelted where also found in the excavation. From this evidence it is believed that the source of the copper ore was from the nearby gold mine of Kush (El Gayar and Jones 1989).

Egypt has a long history of trade in copper. The mines of Sinai have long been exploited, and the settlements in this area suggest that copper was traded to Canaan as well as within Egypt (Beit-Arieh 1984). Besides exploiting its own resources, Egypt also acquired copper through “international” trade, and through booty (Shortland 2007). Probably one of the major sources of copper from outside Egypt's borders was that from Cyprus. Indeed communications between the ruler of Cyprus and the King suggest that the trade in copper was of a ceremonial nature (Panagiotopoulos 2001). Although Mesopotamian texts suggest that copper could be exploited in South-East Arabia, there is little archaeological evidence to support this activity occurring in Egypt (Carter 2001).

3.9.5 Working Stone

The mineral group of working stones has 12 mentions and there are four types, alabaster, granite, calcite and gypsum.

Alabaster

Language

Like many minerals in Ancient Egypt, Egyptologists and geologists use the same term to mean different things. Technically alabaster is the chemical compound $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, gypsum, whereas “Egyptian alabaster” actually refers to, travertine or calcite (Aston et al. 2000; Hester and Heizer 1981). Considering there is this confusion between calcite and alabaster in Egyptology, it is right to discuss in this section reference made to calcite in the Edwin Smith Papyrus (Allen 2005), since in this case Allen (2005) was using the correct geological term to describe the mineral rather than the pseudonym of alabaster.

The Egyptian word for alabaster *šs* (Gardiner 1931; Harris 1961) has been identified not only from its use in the medical texts (Harris 1961), but also because of its identification on a number of alabaster reliefs, such as the alabaster shrine of Amenophis I at Karnak (Gardiner 1931).

Use

Calcite is mentioned twice in the medical papyri and in both instances is used to treat old age problems such as wrinkles, indeed very similar in content as to the way in which alabaster was used.

Source

Alabaster has a history of being a commodity gathered through booty as well as being known to have been found within Egypt's own borders. One of the more important alabaster sources in Ancient Egypt was at Hatnub (Aston et al. 2000; Gardiner 1931; Hester and Heizer 1981). Indeed the fame of these quarries is believed to have been spread throughout Egypt since earliest times (Griffith and Newberry 1893). There are inscriptions and graffiti in the area of Hatnub that suggest that the site was exploited intermittently for around 3000 years (Aston et al. 2000). Griffith and Newberry (1893) prove that there were a number of frequent expeditions to this area for alabaster in the Middle Kingdom by both the number of tombs in el Bersheh as well as the graffiti present in the quarries. There are a number of additional references to alabaster from this site, including the belief that Unas obtained the altar for the pyramid of Merenra from this area and in the 18th Dynasty Thutmosis III dedicated some alabaster from this area to Amen in the temple of Karnak (Griffith and Newberry 1893). The sites of Wadi Gerrawi (near Helwan) was also an important alabaster quarry exploited in the Old Kingdom (Aston et al. 2000). Classical authors also suggest that Yemen was well known for its alabaster (Weisgerber 2006), and this could have been a possible location for Egyptian trade in this substance.

Granite

Language

There are a number of different variants of granite available to the ancient Egyptians, however the term *m3t* commonly believed to be the word for the red variety of granite is the one found in the medical texts (Harris 1961).

Use

Granite is only mentioned three times and only in the Ebers Medical Papyrus. Its predominant use was in the treatment of eye problems, indeed in one instance it is the only item to be used (Ebers 382 (Ebbell 1937; Ghalioungui 1987)). There are no known reasons why granite would be an efficient treatment for eye problems, but it could be to do with the symbolic colour of the material.

Source

Granite is a well known building material used since the Protodynastic (Lucas and Harris 1962), there are two types of granite known within the Egyptian province of Aswan, the first is red granite and the second is a dark grey granite, both were used frequently (Lucas and Harris 1962).

Gypsum

There are four words which are believed to refer to gypsum, only one has been positively identified however and that is *kd*, identified due to its inscription on two lumps of gypsum (Harris 1961).

Gypsum is mentioned only once in the medical papyri, and is in medical paragraph Ebers 510 as a cure for an unknown problem “to expel stripes from

striking” (Ebbell 1937; Ghalioungui 1987), which is perhaps a reference to a burn.

Even today gypsum is an important economic resource for Egypt. It can be found in the western desert (Hume 1912) where it can be specifically found in the Mariout region to the west of Alexandria and in the Fayum, as well as being plentiful near the Red Sea (Lucas and Harris 1962). Archaeological work on the Umm es-Sawan gypsum quarries of the Northern Fayum has found evidence for the extraction and manufacture of gypsum products on site from the Old Kingdom (pottery records indicate a strong presence in the 3rd to 4th Dynasties) (Heldal et al. 2006), suggesting that this could have been the site for the gypsum being used in the medical texts.

3.9.6 Clay

Language

Clay has nine mentions from three different types, statue clay, clay from the potter and male clay. There is a clear link between statue clay and clay from the potter as both are artistic uses of the material, and it could be concluded that these types of clay are of a sufficiently high quality.

Statue clay has been identified with the word *k3h*, which has also been found to be a reference to Nile alluvium (Harris 1961). Statue clay was identified from the Ebers Papyrus by the term *im* (Harris 1961). Unfortunately there is no geographical or geological identification alongside. Male clay is rather ambiguous, reference to male clay can be found in other African countries where this type of clay is prepared for specific pottery purposes, the male clay is generally used to form the basis of the object whereas female clay is used to form the delicate and external appearance of an object (Gosselain and Smith 2005).

Use

Like several minerals discussed in this document, clay has no discernible use due to incomplete paragraphs or an inability to translate key words. From the information that can be gathered clay was used externally to treat a number of ailments like the eye and snake bites. Clay probably would have been used like a poultice thereby negating any possible microbial attack. Clays have also been found to be beneficial when applied topically as they can promote an antiseptic action and form a water proof barrier (Carretero 2002). They can also be used cosmetically as they can reduce inflammation and remove grease and additional toxins from the skin, such as in the process of a face mask (Carretero 2002).

3.9.7 Glass

Language

The Egyptians do not appear to have a specific word for glass, rather they speak of true and artificial stones (Stern 2007). One word often found in relation to glass is *hsbd* which meant blue stone and is applied to lapis lazuli and glass (Shortland 2007). Unfortunately, one of the key areas of research available to the glass historian, namely that of documentary evidence, is not available in relation with Egypt (Stern 2007). Although there are a number of texts referring to Ancient Near Eastern production of glass there are no known texts for the Egyptians.

There are three types that are found in the medical texts, frit, faience and glass. Faience and glass have a common stem in the term *ṯhn*, which is defined as “to sparkle or to be dazzling” (Gardiner 1994, 505 S15). Faience uses the word *ṯhnt* (Faulkner 1988; Harris 1961). Harris (1961) indicates that frit (which he believes is a reference to green frit) can be identified by the word *ḥmt*.

Use

Glass was used in medicine in three different forms, frit (sometimes “green frit”); glass powder and faience. In total glass or glass products were mentioned seven times. They were only used externally and the problems and body areas are unknown. Glass could have been used in medicine as an alternative to lapis lazuli. Its use in medicine is probably due to its “mystical” properties.

Source

Glass artefacts including industry related items, are commonly found in temple complexes throughout the ancient world (Peltenburg 1991; Stern 2007). One of the earliest documents regarding the vitreous materials industry is acknowledged to have been written by a priest (Peltenburg 1991). Henderson (1985) states that in the 2nd millennium BC glassmakers were strongly associated with religion and temple worship and Shortland (2007) suggests that the reason behind glass inclusion in temple context as well as within religious documents is relate to the belief that glass was a magical substance with great healing properties.

One of the most interesting mentions of glass in an ancient document is in Job 28:17 *“it [wisdom] is worth more than gold, than a gold vase or finest glass”*. This passage can lead to the assumption that glass was an expensive commodity. Indeed glass is placed alongside precious metals of silver and gold; and alongside the precious stones of ruby and topas, showing that glass is considered as precious as these substances. This may appear strange, as today glass is so ubiquitous, that, much like salt, it is taken for granted that at one time this was a precious commodity. Indeed it was even the subject of correspondence between kings in the Amarna letters and formed 1% of the letters (Shortland 2007). It was not until the Roman period, that glass became more easily accessible (Shortland 2007). All these factors suggest that glass was an expensive, high status, commodity to the Egyptian people.

Glass is believed to have been produced in a regular manner, first in 16th Century BC Mittani (Figure 1) (Brass 1999; Shortland et al. 2007; Shortland 2007). The first securely dated glass from Egypt dates to the reign of Tuthmosis III who is believed to have brought the glass trade to Egypt through a series of successful series of campaigns in the Near East (Brass 1999; Nicholson et al. 1997; Shortland 2000b). The use and manufacture of glass was therefore first imported in Egypt from the Near East (Nicholson et al. 1997; Shortland and Eremin 2006).

Once glass had become an established commodity in Egypt it was necessary to establish how it was manufactured and worked. It is readily agreed that there are two producers in the glass industry, there are the glass makers and the glass workers (Shortland 2007). Biek and Bayley (1979) suggest that it was a possibility that glass as a raw product was never formally manufactured in Egypt but was still imported and just reworked there. Although there are more glass reworking sites in comparison to glass manufacture factories, this is the nature of the industry (Freestone 2005). Indeed a number of glass factories of Egyptian date have been found, for example at Qantir (Rehren and Pusch 2005) and Amarna (Turner 1956). There is also evidence for the manufacture of glass on a major scale at the Roman glass factory sites along the Wadi Natrun (Hanna 1966; Saleh et al. 1972). Evidence for glass workers is probably best exemplified at the site of Amarna which has been discussed in the literature since the time of Petrie (Shortland 2007).

3.9.8 Earth

There are five different types of earth mentioned in the medical paragraphs:

- Dirt from the courtyard
- Mud
- Mud from the water carriers
- Nile earth from the washerman
- Nubian earth

These minerals were used infrequently with the two mentions for dirt from the courtyard being the most common.

Dirt from the courtyard is found referenced solely in the Ebers papyrus and is identified from the medical texts as *ḥ*. It is believed that the same material described in the medical texts is found in reference to the manufacture of bricks, and could just be another form of the word for clay (Harris 1961). Unfortunately no clear use of “dirt from the courtyard” can be found.

“Nile earth of the washerman” and “mud of the water carriers” is presumably just a difference in translation style and could refer to the same type of material. It could mean either that it is earth gathered from an area near them and is consequently contaminated with cleansing products such as natrun, or it could be a reference to the use of clay in laundry process. Clays have been shown to be beneficial in the cleansing process, most notably as a bleach (Habashy et al. 1982). *ḥ* has been identified as being a reference to Nile earth, this term has been applied to other meanings but at its most basic is a reference to the type of material gathered from along the Nile. Both Nile earth and mud of the water fetcher are used in the treatment of burns, again suggesting their close link. Both are applied externally to wherever the burn occurred.

The use of lumps of mud in the treatment of a vaginal discharge is for a purpose unknown, it could be that the discharge was as a result of a miscarriage and thereby by sitting on the mud that it results in a cooling and antiseptic purpose and symbolically allows the woman to recover. The term *ḥ n pns* was identified by Ebbell (1937) to refer to lumps of mud/earth.

3.9.9 Pottery

There are three types of vessel mentioned in the medical paragraphs *hin*, *dw* and *bd*. Their uses cover a number of aspects of the body and a number of problems, although they are predominately used external to the body.

3.9.10 Flint

The term *ds* refers to flint, and black flint is *ds km* whilst a splint of flint is *3st nt ds* (Faulkner 1988). Flint was used sparingly in medicine, only five mentions, and was always externally applied. It is interesting that it treated both the eye and the penis, but no known symbolism can be accounted for its use in either.

Flint is closely related to the mineral chert, indeed flint is purely a darker form (Aston et al. 2000). Like many minerals discussed in Egyptology, Egyptologists “*have tended to make arbitrary distinctions between the two [flint and chert]*” (Aston et al. 2000, 28). It is believed to have been exploited in the Eastern Desert, around 30 miles from the Nile, near the Wadi el Sheik (Seton-Karr 1898). It can also be found between Esna and Cairo (Aston et al. 2000).

3.9.11 Minium

Like many minerals in Egyptology, minium has a number of meanings. To a chemist minium refers to lead tetraoxide (Pb_3O_4), however it has also been used to describe mercury sulphide (cinnabar). They share similar characteristics, particularly their colour. King (2002) notes its confusion may have arisen due to the use of minium to adulterate cinnabar in the time of Pliny.

Consequently it is difficult to ascertain the meaning of “minium” in the medical papyri. It has been positively identified in five medical paragraphs, and there are two types, minium and minium bread. The latter perhaps suggesting the form it took, or a specific preparation method. Miniums major use in Egypt was as a pigment (Huhnerfuß et al. 2006) yet so was cinnabar (Aloupi et al. 2000; David et al. 2001; Edwards et al. 2004). Its main use as a pigment is in the Greco-Roman Period, however this does not coincide with its main use as a medicine.

3.9.12 Hematite

Hematite has been identified in five medical papyri and is applied externally. Unfortunately, like many of the minerals being discussed the problem it is used to treat is not readily identifiable, so little information regarding its use can be gathered. Hematite is well known as a pigment (Ambers 2004; Uda et al. 2000), however again there is confusion surrounding the name, as red ochre is often called hematite, however in Egyptology hematite refers to the black metallic-looking mineral employed in the manufacture of beads (Lucas and Harris 1962). Hematite is found throughout geological environments (King 2000) and in Egypt is found amongst other places in the Bahria Oasis and the Eastern Desert (Buckley and Weatherhead 1988).

3.9.13 Pigment

There are four types of pigment mentioned in the medical papyri, a total of five times. It is probably not surprising that the most common pigment to be used is the colour green. One medical paragraph calls for a red pigment but the other two have no known colour determinative. This document deals with a number of different minerals that were used as pigments (ochre 3.9.1; malachite 3.9.2; minium 3.9.11; hematite 3.9.12 and orpiment 3.9.20). Additional information regarding the use of pigments in Ancient Egypt can be found in (Ambers 2004; Baines 1985; Barnett et al. 2006; Buckley and Weatherhead 1988; Burgio and Clark 2000; Clark 2003; David et al. 2001; Davy 1815; Eastaugh et al. 2004; Edwards et al. 2004; Hatton et al. 2008; Hradil et al. 2003; Huhnerfuß et al. 2006; Iversen 1955; MacKenzie 1922; Pages-Camagna and Colinart 2003; Pradell et al. 2006; Ragai 1988; Rivers 1901; Uda et al. 2000; Waller 1692; Welcomme et al. 2006; Wouters et al. 1990).

Pigments were used predominately externally, and although most are used for unknown purposes, one, red pigment, is used to treat a burn. This is probably in

direct relation to the use of red ochre in the treatment of burns and wounds, as a method of symbolic healing.

3.9.14 Semi-Precious Stones

There are two types of semi-precious stone mentioned in the medical papyri, lapis lazuli (three mentions) and carnelian (one mention).

Lapis Lazuli

Language

As lapis lazuli is such a precious commodity, a lot is known about its language. In the Temple of Karnak in the festival hall of Thuthmosis III column 51 the word for lapis lazuli is *hsbd* (Gardiner 1952) and it is from this that the term was initially identified (Faulkner 1988; Harris 1961).

Use

Lapis lazuli is mentioned three times within the medical papyri and it is applied in a very specific manner, and is predominately used in the treatment of eye problems, two of which are identified as the treatment for poor eyesight and the treatment for bleary eyes.

Source and Chemistry

Lapis lazuli is the mineral $[\text{Na, Ca}]_4[\text{AlSiO}_4]_3[\text{SO}_4, \text{S, Cl}]$ (Aston et al. 2000) and is one of the more commonly utilised and highly prized of semi-precious stones (Harris 1961), however lapis lazuli does not occur within Egypt (Harris 1961; Lucas and Harris 1962). The most likely source of all lapis lazuli in the ancient world is in Badakshan, in the North-East corner of Afghanistan (Herrmann 1968). It is known to have been paid as part of booty from war to a temple,

through a relief in Karnak (Shortland 2007). Lapis lazuli was traded between Mesopotamia and Egypt, through both sea and land routes (Figure 22) (De Waele and Haerinck 2006; Herrmann 1968). Letters also show lapis lazuli was used as diplomatic gifts (ie. Letter 3; from Burraburiyash, King of Karaduniyash to Amenophis IV) (Bezold 1893).

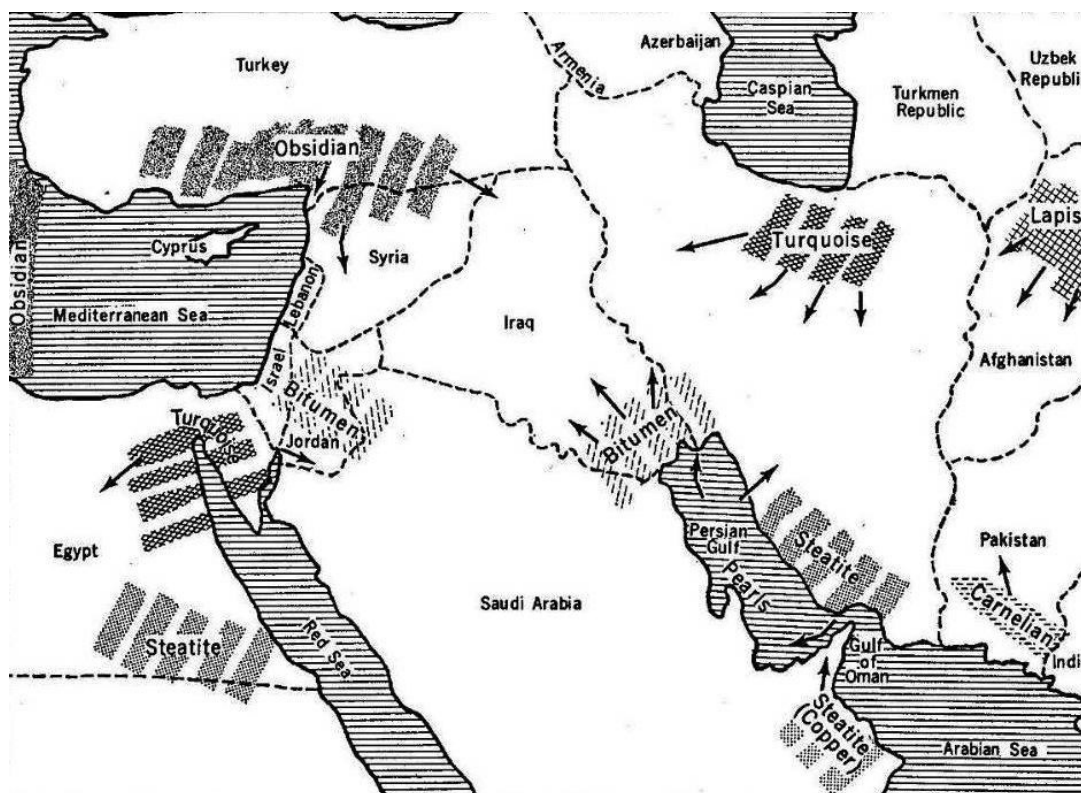


Figure 22: Map showing the trade in semi-precious stones, including lapis lazuli in the Ancient Near East (Wertime 1973)

Carnelian

Language

There is disagreement over the identification of the word for carnelian Faulkner (1988) believes that the word is *ḥm3gt* whilst Harris (1961) believes that the term *tr ḥrst* better describes the gem. According to Harris (1961) the textual evidence

for the use of *tr hrst* is considerable. This is supported by Gardiner's (1952) translation of Columns 20-43 in the Festival Hall of Thutmose III in the Temple of Karnak where he translates *hrst* as carnelian.

Use

Carnelian is only mentioned once in the medical papyri and much like the use of red ochre in sympathetic magic, carnelian is used in the treatment of blood problems. It is not used with any additional substance and there is no preparation associated with the gem. Its use is internal in the form of a suppository and all these facts could suggest that the cost of carnelian was high and that the fact it is not prepared and that carnelian was an expensive commodity that it could suggest that it was reused if the problem ever recurred.

Source

Carnelian is a translucent form of chalcedony which can be found with a yellow, orange or red hue. The colour is produced by the inclusion of iron oxide (the more iron oxide present, the redder the colour) (Aston et al. 2000; De Waele and Haerinck 2006). It is known to have been used from Predynastic times (Bloxam 2006). Carnelian is known to have been a valuable commodity, indeed some see it as being second only in importance to lapis lazuli (De Waele and Haerinck 2006). Although the presence of carnelian can be attested within Egypt's own borders, it is also known to have been "imported" from Palestine and Syria, and is also known from places such as Germany, India, Iran and Yemen, as well as Asia in the area around Afghanistan (Figure 22) (De Waele and Haerinck 2006; Magnus 1967; Weisgerber 2006). Carnelian is known from the Eastern and Western Deserts (Lucas and Harris 1962), and in Lower Nubia in an area known as Stela Ridge (Bloxam 2006). Stela Ridge is known to have been exploited from as early as the 2nd Dynasty (Murray 1939), and were heavily exploited during the 12th (Bloxam 2006). From the slag heaps it is

suggested that the darker (redder) stones were the more highly prized (Bloxam 2006).

3.9.15 White Lead

White lead is mentioned in the medical papyri twice, and in one instance was used in the treatment of a burn. It is used both internally and externally, and unfortunately the body areas it was used to treat are either unknown or undisclosed. The definition of white lead is uncertain, modern translators appear to believe that white lead is actually a reference to tin (Gladstone 1892; Leitz 1999; Pliny 1979), although Gladstone (1892) goes on to note that there is no known word for tin in hieroglyphs and it is unknown as to where the tin would be obtained. Harris (1961) believes that the term for lead itself is *dhty* and it may also be the *dhwy* found in the Ebers Papyrus. However Celsus (1977) and Dioscorides (2000) all note on the manufacturing process of white lead by adding vinegar to some form of lead (ie. Celsus (1977), lead shavings).

3.9.16 Cadmia

Cadmia (zinc oxide) is mentioned twice, once heated and once untreated. They are used in exactly the same way, both on undesignated body areas in the treatment of tumours, the only thing that is not known is how cadmia was administered. They are both utilised with alum, but heated cadmia is also used in conjunction with ammoniac salt (Reymond 1976). Its only reference in a papyri that dates from the Greco-Roman period is not surprising considering that cadmia was a well known medicinal mineral in Greek medicine (Dioscorides 2000). Much like the way in which cadmia was used in Egypt, cadmia was utilised for the treatment of all different sorts of tumours (Dioscorides 2000)

The Greeks defined cadmia as a product deposited in smelters flues (Taylor 1930), although it could also be found geologically, however the nature of the

material changed depending on where the substance was sourced (Taylor 1930). Cadmia could be found in Cyprus, and was in fact imported to Roman Egypt from here (West 1917), and according to Dioscorides the Greek (2000), the best cadmia came from Cyprus. Although it was also known to come from Macedonia, Thrace and Spain, Dioscorides (2000) however determined that these were useless.

3.9.17 Ammoniac Salt

Ammoniac salt is mentioned twice in order to treat tumours, but the body area and administration are unknown. The term ammoniac salt has very different connotations to the way it was presumably used by the ancients. Ammoniac salt is ammonium chloride (NH_4Cl). Like many of the minerals present within this thesis, the term ammoniac salt can be used loosely in different contexts. The phrase which is translated as ammoniac salt is *wršk*. It is believed that the ammoniac salts of the ancients actually refers to rock salt (Celsus 1977; Moore 1859) rather than sal ammoniac or ammonium chloride. Indeed it is even more specific in that it is rock salt that comes from Egypt (Moore 1859) and specifically in the region of the temple of Jupiter Ammon in Libya (Celsus 1977). It is known that this area borders the evaporitic lake, Siwa Oasis, and indeed the source of ammoniac salt may in turn be the evaporates produced from this deposit. This could have implications on the identification of ammoniac salt in a number of, not only ancient references to the substance but, translations of medieval Arabic texts.

3.9.18 Calamine

Calamine is mentioned twice and is believed to be related to the word *htm*. Unfortunately the problems calamine is believed to have been used on are unknown; both uses of this material are external. According to Campbell (2007) however there is a problem with this translation as calamine is used to treat eye

problems and it is believed that this is erroneous as calamine is unsuitable for such an activity.

3.9.19 Red Chalk

Red chalk is known from the medical papyri in two instances, where it is used to bandage an unknown body area for an unknown problem. Consequently little can be inferred in relation to its use in medicine. Little is known about chalk, specifically red chalk in ancient Egypt. It is known that chalk could be gathered from the chalk pinnacles found in Farafra (Waltham 2001). Other than that no clear source can be identified.

3.9.20 Orpiment

The word for orpiment is believed to be *ḳntj* although Iversen (1955) comments that the evidence surrounding this translation is purely circumstantial, but orpiment fits the profile of *ḳntj*. The stem of the word *ḳnt* is the word for yellow (Faulkner 1988). Although no clear problem or body area can be seen the interesting use of orpiment is that to form a medicine it is heated. As orpiment is arsenic sulphide (As_2S_3) the health effects are an immediate concern. Indeed the health effects of heating orpiment are potentially fatal; as it acts as a carcinogen and can also cause lung irritation. The evidence for orpiment in Ancient Egypt comes primarily from a study of Egyptian pigments. Although the most commonly found yellow pigment is an ochre, orpiment has also been identified in the past (David et al. 2001; Uda et al. 2000). There is only one location within easy reach of Egypt that is known for its production of orpiment and that is at Siah Rud on the Araxes River (Turkey) (Fischer et al. 1993).

3.9.21 Stibium

Stibium, or antimony sulphide, has long been believed to be the source of the black eye paint so commonly employed by the Ancient Egyptians. Probably

confused due to its use in the Greco-Roman period, stibium has very rarely been found in connection with cosmetics of Ancient Egypt (Hardy 2008; Lucas and Harris 1962; Myers 2003; Wiedemann 1892). Antimony is known to occur in the Near East (Fischer et al. 1993; Halse 1925; McCallum 1999; Shackley 1977). In classical times stibium was chosen for its brightness, but it was also known to be adulterated with lead oxide and charcoal (Gladstone 1892; Pliny 1934; Dioscorides 2000). Perhaps surprisingly stibium was used in the treatment of stomach problems as well as eye problems. With more up to date translations only two medical paragraphs are believed to actually have contained stibium.

3.9.22 Brick

Brick is used only the once and is bandaged externally. There is no mention within the prescription of the brick being crushed which suggests that it was already in small enough pieces to be used. *dbt* is the term used for brick, and although no specific materials are mentioned in its manufacture, Lucas and Harris (1962) state that the basic manufacture of bricks would be from Nile alluvium, and it should be noted that the brick to be used in the medical paragraph is not one of a magical nature.

3.9.23 Pumice

From the prescription database pumice was mentioned only once and unfortunately for unknown problems. It was however anointed, perhaps suggesting a more spiritual administration that is commonly found. There is little documentary evidence regarding the use and presence of pumice in Ancient Egypt, however chemical studies have identified sources for pumice. Most come from the Aegean with pumice being identified from Thera, and Cappadocia (Anatolia) (Rapp et al. 1973; Steinhauser et al. 2007), although evidence from Pliny (Book 31) also suggests that Syros was another potential source. Chemical analysis of pumice is sufficiently accurate to be able to

pinpoint the eruption from which they were created (Steinhauser et al. 2007). It was a major source of trade (Rapp et al. 1973; Steinhauser et al. 2007) presumably due to its use in medicine as well as its use as its apparent use as a religious artefact (Steinhauser et al. 2007). Its use in medicine can be attested by Pliny (Book 31) who states that it was used mainly in eye salves, but was important as it has a reducing and drying effect.

3.9.24 Sulphur

There is only one recipe which calls for the use of sulphur. It is used in the form of a poultice on the limbs for the treatment of gout. In fact even today sulphur is used in the treatment of gout (Leslie et al. 2004). Classical authors state that sulphur was a well known and well used drug (Celsus 1977; Dioscorides 2000; King 1999; Moore 1859). Sulphur can be found within Egypt, within the limestone surrounding Cairo and in the sulphur springs of Helwan (Hume 1912; Lucas and Harris 1962). It also occurs alongside the red sea coast (Lucas and Harris 1962) as well as within Yemen (Weisgerber 2006) and in Greece on the islands of Melos and Lyara (Dioscorides 2000).

3.9.25 Unknown Minerals

There are 20 types of mineral which have thus far remained unidentified within the Medical Egyptology community. They have been identified positively as minerals by the inclusion of the papyri authors of the mineral determinative. However, perhaps the most important breakthrough in the philology of minerals is the potential identification of *wšbt* mineral. As can be seen from the table it is mentioned three times. According to Harris (1961) the term is unknown outside of the medical text, which is why it was difficult to translate. Harris proposed that *wšbt* could be a form of alum, but was not wholly certain. Kaczmarczyk (1991) however believes that alum is indeed the correct identification for this mineral. He believes that it is used in relation to the cobalt-bearing alum that can be found in the Dakhla and Kharga Oases (Kaczmarczyk 1991; Shortland et al.

2006b). No literary evidence has clarified the meaning as the term is also found in connection with a number of texts on colour, and *wšbt* is said to be used for a blue pigment (Kaczmarczyk 1991). This would mean that in total alum would have 29 references and three variants, but as no medical specialist has thus far acknowledged this development it has been retained within the unknown section.

3.10 Experimental Section

3.10.1 Prescription Replication

Introduction

So far this document has dealt with deductions about Egyptian pharmacy based on analysis of the prescription database. One aspect that is, however, often overlooked in relation to medicine from the past is that of efficacy. Some have compared the use of certain ancient drugs against a modern day pharmacopeia (Campbell 2007), although this has certain merit, the mixture of these drugs in itself can change the very nature as to their use and efficacy. A number of medicines found within the medical texts are believed to have worked primarily on the basis of a placebo, rather than have any actual benefit medicinally. Although knowledge surrounding the use of placebos was unknown to the Egyptians the belief in the spirituality behind certain substances was also of importance and would have been considered in the process of manufacture. In addition to this the materials used can be chosen for their medicinal properties or additional functions such as spiritual benefits, ease of application or even perhaps, as a flavour. All these need to be taken into consideration when examining the medical texts. Unfortunately however the reasons behind use can not always be identified from the literature. One way in which this can be examined is through the establishment of prescription replication experiments. For this to be conducted the identification of all ingredients within the medical paragraph must be identified, including all dosages and problems treated.

The aim of this experiment was to identify not only the efficacy of a prescription as a whole but of the individual components. Investigations were also to assess the potential of placebo effect and symbolic use of materials.

The prescription chosen for replication was Hearst 154:

“Alabaster powder, natron powder, sea salt; honey. Mix it and make it a homogeneous mass with honey. Coat the skin with it” (Bardinet 1995, 395)

The prescription itself has parallels with Prescription 3 from the Edwin Smith Surgical Papyrus and 716 in the Ebers Papyrus. This prescription was chosen for several reasons. Firstly the prescription is fully translated and all the ingredients are identifiable. Secondly, although no specific measurements are indicated in Hearst 154, Breasted's (1930) theory is that if no measurements were given then they were all equal and an examination of Prescription 3 from the Edwin Smith Surgical Papyrus means that it is known that each substance was measured in ro, with each one being measured as one ro. Thirdly the use for the prescription is known and the effect can be anticipated.

The prescription itself contains a number of ingredients; firstly it contains the minerals alabaster, natrun and salt. It also includes honey which is thought to be the vehicle through which the medicine is delivered. The prescription is for “making the skin perfect” it is believed therefore that the medicine was used was as an anti-wrinkle cream.

Hearst 154. A remedy to make the skin perfect: Alabaster powder, natron powder, sea salt; honey. Mix it and make a homogeneous mass with honey. Coat the skin with it (Bardinet 1995, 395).

Ebers 716. A remedy to beautify the body: Powder of alabaster, powder of natron, northern salt, honey, are mixed together with this honey and the body is anointed therewith (Ebbell 1937, 101).

Edwin Smith 3. A prescription for rejuvenating the face: Calcite powder 1, powder of natron 1, northern salt 1, honey 1, mixed into a compound and smeared on (Allen 2005, 113)

Today antiwrinkle cream is seen as just a cosmetic measure. However old age in any culture is associated with death and so an anti-wrinkle cream may have been identified as a way to longevity. Premature aging of the skin is mainly as a consequence of the UVA and UVB rays emitted by the sun (Pillai et al. 2005). This form of aging is known as photoaging and can include symptoms such as wrinkles, skin roughening and blotchiness (Pillai et al. 2005; Tszuboi 2005). The predominant cause of these symptoms is moisture loss (Hefford 2006; Tagami et al. 1980).

The choice of ingredients shows the power of symbolism in medicine. Alabaster is a mineral admired for its endurance and natrun was used in the heb-sed festival, which was a festival held after 30 years of a king's reign and was held to rejuvenate the king's strength. It would appear that the minerals were used in order to recapture both beauty and youth. It was anticipated that due to the inclusion of at least two desiccants (natrun and salt) that Hearst 154 would not be able to retain moisture.

Methodology

Moisture retention is most easily assessed by determining weight loss (Adamy 2003). Thermogravimetric Analysis (TGA) was chosen as it easily and accurately records moisture loss over a prolonged period of time and sustained temperature. The parameters of a run were set at 35°C for a period of 16 hours. The length of time and temperature were selected as figures for both an average daily temperature in Egypt and it was determined that 16 hours would be the longest any remnants of the formulation would be expected to be used.

The chemicals used in both the pilot study and the longitudinal study were defined by the prescription. However a number of aspects need to be addressed; firstly alabaster chemically is gypsum but based on the analysis of heritage items from Egypt is actually found to be calcite; natrun as has already

been discussed is often confused when discussed by Egyptologists and there are a number of different honeys available on today's market.

As Egyptian alabaster is frequently identified alongside calcite the decision was made to analyse the results of calcite in the formulation but that a control of gypsum would also be conducted. Natrun was determined to mean sodium carbonate and this chemical was consequently used through all experiments. Honey was more complicated to determine. Beekeeping in Egypt has been known in Egypt since the Old Kingdom (Allsop and Miller 1996; Lucas and Harris 1962) and although honey is discussed in a number of texts (Lucas and Harris 1962; Manniche 1999) none stipulate the type of plant the honey was made from. However of the varieties available acacia honey was deemed the most appropriate as acacia has been known to have been used in Egypt since the Predynastic and was especially used in sacred unguents (Manniche 1999). This evidence suggests that honey derived from this context is the closest available to ancient honey.

Porcine skin was chosen as a substitute to human for a number of reasons: it is readily available and also a well known human substitute in the forensic sciences (Haskell et al. 2002), it is also an established medium in the cosmetics industry (Richert et al. 2003). Pig and human skin are very similar in their morphology (Lawson et al. 1997; Richert et al. 2003) and biochemistry (Adamy 2003; Simon and Maibach 2000). The pigs' heads were obtained from Pat Thomas butchers of Faringdon, on the morning of which they were slaughtered and they were kept chilled for no more than 24 hours before being destroyed using conventional biohazard treatment.

The prescription stipulated that each ingredient was 1 ro or 14.5ml in volume, to begin with all solid substances were placed into the pestle and mortar and crushed into a homogeneous powder, and the honey was then mixed. Once this had formed a homogeneous paste, the paste was then applied to the cheek of a

pig until it had been absorbed. The skin was then sectioned and a small piece was placed inside the alumina crucible and analysed using the TGA.

Results

A pilot study was instigated to assess the effectiveness of the formulation in retaining moisture in porcine skin. The pilot study tested the overall manufacture of the formulation and using the parameters already discussed, determined that the formulation aided in the skin's ability to retain moisture (Figure 23 and Figure 24).

These results showed that the formulation was able to retain moisture to an effective level. From these results a longitudinal study was derived whereby the ingredients would be independently assessed for their ability to retain the skin's moisture content.

The longitudinal study followed the same methodology as already discussed for the pilot study. The results (Table 11) showed that as expected sodium carbonate acted as a strong desiccant. The formulation was also able to retain moisture to the extent of at most 22% although, the average for retention was 11%. Perhaps the most surprising result was that for the short period of time that the formulation was applied that salt acted as a retainer. The honey and alabaster also acted as retainers. The honey was the biggest retainer with only 6% of moisture being lost in comparison to the 23% moisture loss from the control. When all the ingredients were blended together and applied to the skin and analysed the medicine was found to retain moisture to a significant degree (on average 10% more moisture retained).

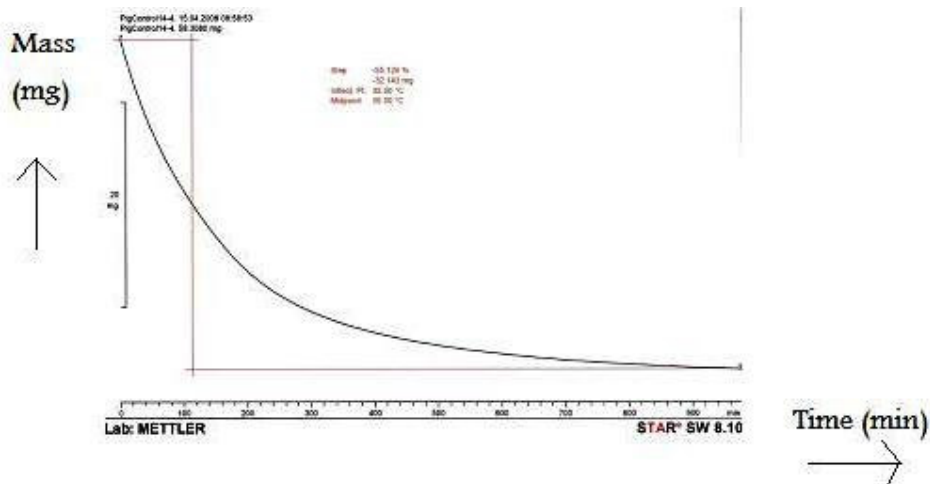


Figure 23: Graph produced by TGA showing the porcine skin control and the amount of moisture lost. From the graph it can be seen that there was a vast amount of moisture lost (over half of the original mass) which produces a nice diffusion curve.

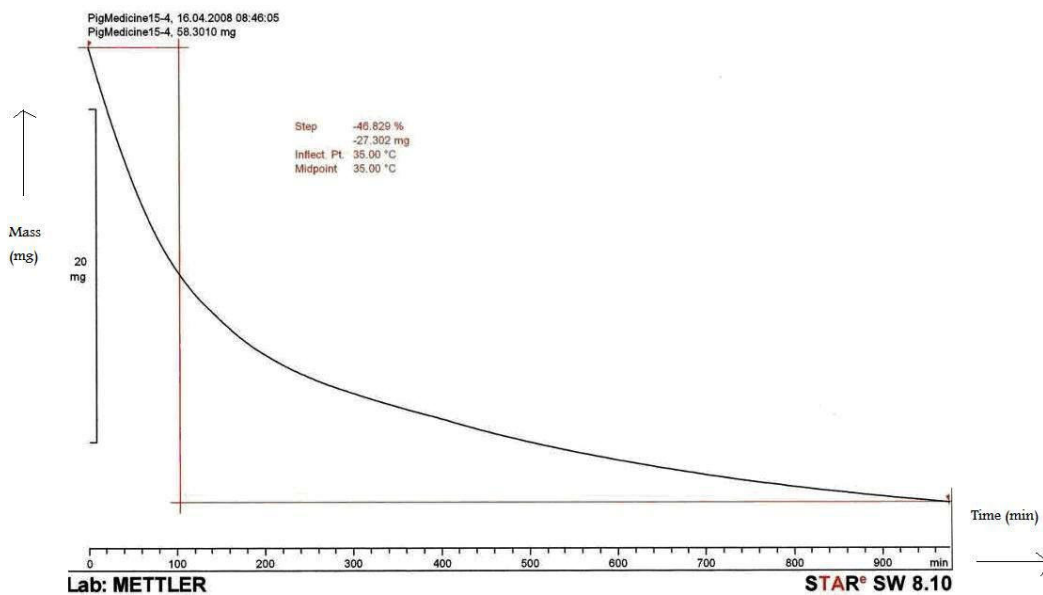


Figure 24: Graph produced by TGA showing the prescription's affect on porcine skin. From the graph it can be seen that moisture is retained over a longer period of time, and indeed that less moisture is lost.

Of the four ingredients used in this prescription over the 16 hour period that they were tested three of them were determined to be moisture retainers, whilst sodium carbonate was determined to be a desiccant. These three therefore had an overwhelming effect on the formulation enabling the skin to become moisturised, and for a short while after would have allowed the skin to look plump and less wrinkled.

Table 11: Table showing the results of the prescription replication

Substance	Weight at beginning	Weight at end	Total Loss	% loss	% difference	Comparison with control
Control 1	57.9267	46.0752	11.8515	20.5		n/a
CaCO ₃	66.477	55.6989	10.7781	16.2	4.3	Retained
Control 2	124.9948	95.7814	29.2134	23.4		n/a
Honey	143.67	134.48	9.19	6.4	17	Retained
Control 3	108.3578	88.1388	20.219	18.7		n/a
CaSO ₄	102.393	89.9153	12.4777	12.2	6.5	Retained
Control 4	93.645	87.7355	5.9095	6.3		n/a
NaCl	93.7152	90.6281	3.0871	3.3	3	Retained
Control 5	124.901	115.09	9.811	7.9		n/a
NaHCO ₃	97.8848	88.1016	9.7832	9.9	-2	Desiccant
Control 6	101.814	93.6797	8.1343	7.9		n/a
Honeycomb	109.379	94.086	15.293	13.9	-6	Desiccant
Control 7	49.76771	23.4181	26.34961	52.9		n/a
Sea salt	55.7821	39.5259	16.2562	29.1	23.8	Retained
Control 8	47.8608	37.5913	10.2695	21.5		n/a
NaCO ₃	42.7968	26.1058	16.691	39.0	-17.5	Desiccant
Control 9	58.2922	26.1494	32.1428	55.1		n/a
Prescription Attempt 1	58.289	30.9871	27.3019	46.8	8.3	Retained
Control 10	51.2561	17.547	33.7091	65.8		n/a
Prescription Attempt 2	69.4737	38.9311	30.5426	43.9	21.9	Retained
Control 11	44.93771	31.12996	13.80775	30.7		n/a
Prescription Attempt 3	45.2118	32.3106	12.9012	28.5	2.2	Retained

From the results it can be seen that the formulation was variable effective and it is believed that the reason as to why Hearst 154 was so adept at maintaining moisture was because of the presence of honey. The honey acts as a barrier enabling the moisture to be retained, and the inclusion of the additional retainers of salt and alabaster counteract the highly desiccant ability of the sodium carbonate.

As already discussed, a number of the ingredients such as alabaster and natron may have been included due to their status in Egyptian society as enduring and purification properties. Although natron was included in the formulation and was determined to be highly desiccative, it had no detrimental effect on the overall efficacy of the remedy and was probably included to fulfil some spiritual or physical aspect, such as its ability to cleanse.

Hearst 154 was chosen as a prescription to be replicated because it was 'simple' and it was expected to be of symbolic rather than medicinal value. The results have shown that, while there may have been a significant symbolic reason behind the inclusion of a number of the ingredients, the overall prescription has high efficacy.

3.10.2 Analysis of Medicinal Salts from Sudan

Ethnopharmacology is a relatively new discipline and combines ethnographic research with pharmacological testing. Few studies have been conducted into either the efficacy or usage of minerals in traditional medicine. In studies that have been conducted the analysis of minerals has been secondary to research of other types of medical materials (Lev 2002; Lev 2007; Lev and Amar 2000; Lev and Amar 2002). The aim of this analysis is to identify key terms and identify what minerals are used medicinally in the Sudan and any potential medical knowledge transfer between communities and through history.

Sudan is bordered by Egypt, Ethiopia, Libya and Chad. It (Sudan) is the Kush of the Egyptians and it may have acted as a trading post for natrun and salt into Egypt. Minerals have been employed in medicine for thousands of years and many, such as salt and natrun, are major items of trade. This still holds true in the Sudan where traditional medicines still have an important role to play in the community.

Natrun and salt have been traded in Sudan for at least 4000 years. Natrun was of major economic importance and the major sources were exploited by the Kabbash Arabs of Kordofan who traded deposits in both the Bir el-Malha and Bir Natrun (Figure 25) (Carlisle 1975; Newbold and Shaw 1928). They would travel great distances and Kabbash Arabs would frequently make a 30 day round trip to the deposits at Bir el-Malha (Carlisle 1975). Similar long distances are reported in other tribes such as the Zaghawi of Darfur whose exploitation of natrun was first recorded by Browne in the 18th Century and was honoured by them in a number of traditional songs (Browne 1799; Carlisle 1975). The rewards are great for those who successfully exploit the deposits with prices in 1928 being recorded at 50-60pt per kantar (around 100 pounds) (Newbold and Shaw 1928). Kawar natrun was exploited from the mine in Ankalas which has been famous for natrun since the 12th Century (Palmer 1929; Viktor 1982). There were other sources of the minerals which have been utilised in different industries, for example Tequidda salt was seen as highly prized, whilst natrun from Kawar was mixed with tobacco to give a sweeter flavour (Lovejoy 1984; Lovejoy 1985).

The uses of these minerals in Sudanese medicine have been recorded back to the 15th Century and cover a range of complaints, but mainly focus on digestive aids. Alvise de ca'da Mosto (15th Century) explained that in order to combat the effects of intense heat, salt was dissolved in warm water and drunk everyday (Jarcho 1958). It was believed that when natrun was dissolved in water and drunk the effects would be almost immediate in relieving the bowels; however it was also mixed with flour or food and cooked to stop diarrhoea – although this

may have been less for medicinal purposes and more for flavouring (Lovejoy 1984). Besides the use of treating humans salt and natrun were also used to treat livestock, most notably to reduce diarrhoea. Estimates from Lake Chad suggest that camels consume 10-15kg of natrun a year (Lovejoy 1985).

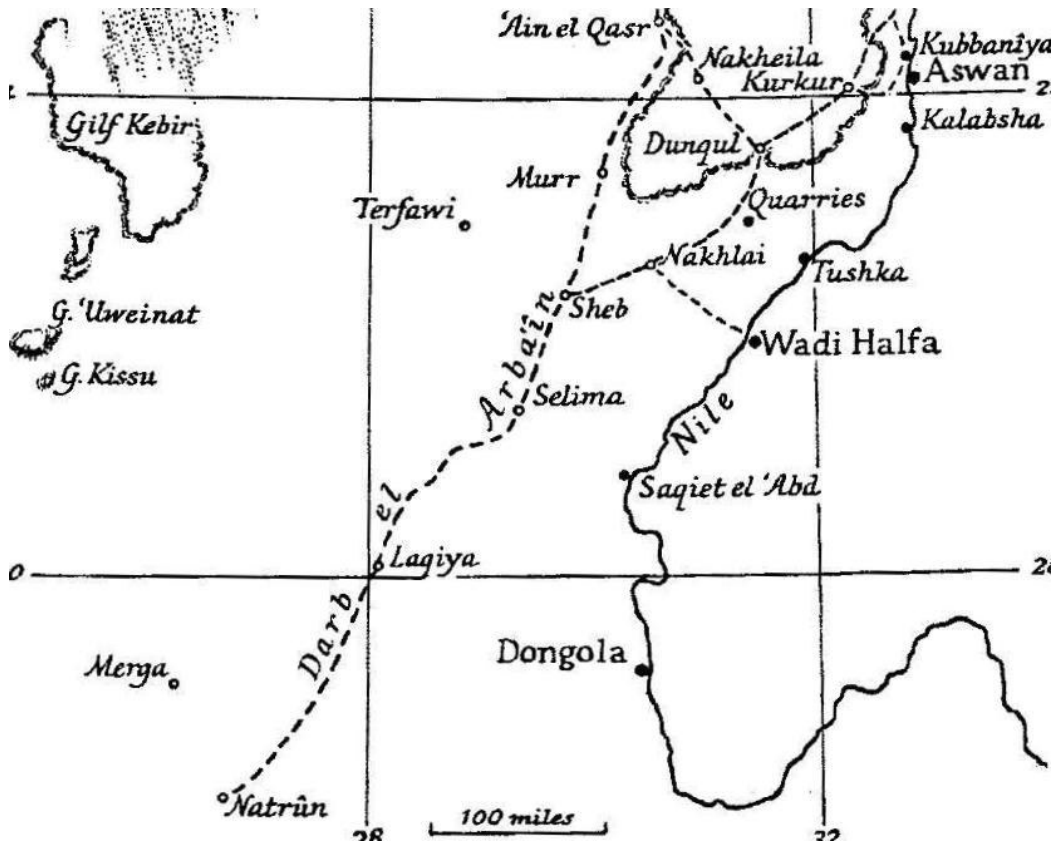


Figure 25: Map showing location of Bir Natrun (Murray 1939)

Once again there is much debate over the language used to discuss minerals used in medicine. The most important ones are atrun, shabb and wariza. These minerals have very different meanings such as:

atrun – has been used to describe rock salt as well as natrun (Newbold and Shaw 1928).

wariza – used to describe red natrun (Lovejoy 1985)

shabb – has been used to describe both alum and natrun (Lovejoy 1985; Viktor 1982)

Four ethnopharmacological samples were purchased in Khartoum market on behalf of the British Museum. These samples were described by the vendor and labelled with the samples at the time of purchase by the collector and they included two samples of atrun; which were designated for use with camels and in snuff, one sample of Kedada (named after a location in Darfur); used by goats and humans to treat digestive problems, and a sample of sha'ab which is used to purify water. These samples were analysed using X-Ray Diffraction (XRD) following the method discussed in Chapter 2.

These results (Table 12 and Appendix A) show the mineralogical components present within the ethnopharmacological samples. The two atrun samples appear to come from different sources due to the presence of other material within them. Atrun and sha'ab have been discussed in the literature as being names associated with sodium carbonate and alum, and the results here chemically identify this relationship. The results have implications as to the source of these materials, the idea of medical transfer between communities and to their uses. Further work would be necessary to categorically state what was meant by the different terms used, to identify the locations of the sources for these materials and identify whether they have always been used to access so material and finally to test the efficacy of these materials used.

Table 12: Table showing the results of the XRD analysis performed on the ethnopharmacological samples

Sample #	Sample Name	Potential Mineral	Major Phase	Minor Phase
BM1	Atrun	Sodium Carbonate	Trona	Sodium carbonate; halite; nahcolite
BM2	Kedada	Unknown	Syngenite	Anhydrite; Gypsum; Calcium carbonate; Quartz
BM3	Sha'ab	Alum or natron	Alum	n/a
BM4	Atrun	Sodium Carbonate	Trona	Quartz

3.11 Chapter Summary and Conclusion

Chapter 3 gives a comprehensive background to the history of medicine in ancient Egypt. As has been established, the Egyptians had a comprehensive medical system, which relied on doctors and pharmacists. In terms of minerals this document, is the first to comprehensively identify the minerals used as *materia medica* and the first to assess the way in which they were used, including the identification of 20 different forms of administration. The analysis of links between spells and minerals has also shown that minerals were often used in a rational manner.

From the research conducted into the use of minerals in Egyptian medicine it has been possible to identify the most commonly used minerals, the common ways in which they were used, and their consistency of use. Although there are a number of uncertainty over word meanings in this document it has never the less shown just how beneficial the prescription database is. This has an impact on the way in which minerals are viewed not only in the Egyptological record but in archaeological and history of medicine research. The way in which these minerals were used in the highly specialised branch of medicine also has an impact on the understanding of the way in which they were used in everyday life.

Analysis of ethnopharmacological samples and analysis of the prescription database prove that minerals were utilised in a rational way, that 99% of medical paragraphs contain local natural resources which would have been easily exploited and that there is a medical tradition for the use of these minerals both in Egypt and the Sudan. The replication of Hearst 154 also showed the link between symbolism and efficacy.

Chapter 4: Associated Industries

The use of sodium salts in Egypt is not solely restricted to the medical industry, consequently the research examined the role played by sodium salts in two medically associated industries: purification and mummification. In addition it should be noted that sodium salts were used in a variety of other industries such as food preparation (Ikram 1995); glass manufacture (Hanna 1966; Henderson 1985; Shortland 2004) and artistic materials production (Hatton et al. 2008; Pages-Camagna and Colinart 2003; Pradell et al. 2006) to name a few.

Firstly the hygiene/purification industry is investigated. Hygiene is an important aspect of medicine and ancient Egyptian hygiene was identified as a link to medicine through the use of sodium salts in both ritual and personal cleanliness. The second industry investigated is that of mummification. This was chosen as it is often identified as helping with the development and understanding of medicine in ancient Egypt. Mummification is possibly the most well known Egyptian industry and utilised large amounts of sodium salts. The link that binds these activities together is not only their relationship with sodium salts, but also their relationship with each other, as purification is commonly identified within mummification rituals, and aspects surrounding the treatment and afterlife of the dead are seen in ritual purification texts.

4.1 Purification and Hygiene

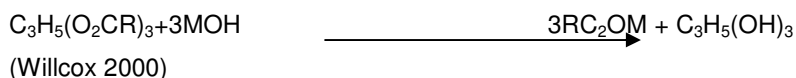
4.1.1 Modern Day Hygienic Science

Today there are many products that are designed to help maintain a good level of personal hygiene from toothpastes to deodorants. In today's society there is a higher level of personal hygiene than has ever been experienced before (Larson 2001) and new products are constantly being developed.

Soap

Soap is *“a cleansing agent made by reacting animal or vegetable fats or oils with potassium or sodium hydroxide. Soaps act by emulsifying grease and lowering the surface tension of water, so that it more readily penetrates open materials such as textiles”* (Collins English Dictionary)

Today the formation processes behind soap are understood and an equation can express the basic soap reactions in which a fatty material combines with a metal radical (often sodium) and forms a soap and glycerol.



Where R is an undefined hydrocarbon chain and M represents a metal with a valency of one (ie. sodium).

Scientific investigations have shown that when a soap is above a pH of 9.6 inflammation of the skin can be identified (Gfatter et al. 1997). Consequently modern soaps are specially formulated to be more balanced to the pH of the skin, as soaps which are too alkaline can damage the protective layer of skin, known as the acid mantle, and any soap of a more alkaline nature could leave the skin irreversibly damaged.

Mouthwash

Another aspect of modern hygiene is cleansing the mouth. Although developed/processed toothpastes are not known in the archaeological record, such things as masticatories and mouth rinses were and are used to ensure good hygiene of the oral cavity. Although masticatories are solid and mouth rinses are liquid they share a common function and a common technique, both are placed in the mouth with the intention to spit them out.

Modern mouthwash achieves its functions in three ways:

1. the mechanical effect of rinsing debris from the mouth
2. the effect of flavour
3. the effect of an agent specifically added to deliver a benefit (eg. anti-bacterial)

(Mason 2000)

Detergent

A detergent is a water soluble cleansing agent which combines with impurities and dirt to make them water soluble, it is both chemically and reactively different to soap. Chemically a detergent is defined as RSO_4Na (where R represents a long chain alkyl group) and in hard water detergent does not form a reaction with the ions present in the water, unlike soap (OED).

Laundry

Laundry is the action of washing clothes. Clothes are generally washed using some form of detergent. Laundry in the past however could also refer to the use of soap, and the term laundry itself is multifaceted and can refer also to the clothes to be washed (OED).

4.1.2 Ancient Egyptian Personal Hygiene

Personal hygiene is an important aspect of life within warm countries as without it disease can spread rapidly. Unfortunately, knowledge of the manufacture of cleansing aids in Egypt has been heavily clouded by Classical sources eg. Pliny (Levey 1959).

Hygiene

The most basic cosmetic is the detergent, as cleanliness is identified with beauty (Diamandopoulos 1996). It is believed to be Pliny who firsts mentions soap (Lutz 1923), however aids in the form of cleansing creams, or as straight natrun had been known throughout the Ancient Near East for thousands of years (Adamson 1969; Diamandopoulos 1996; Forbes 1955; Levey 1959; Manniche 1994). There are also artistic representations of women using these items, such as from the fragmentary stela of the Lady Ipwet (Figure 26) where there is an image of the deceased rubbing her face with a cloth in front of the mirror - this could be a reference to either the application of a perfume or cosmetic, or the process of washing ones face (Edwards 1937). The Egyptians traded these cleansing agents - in the form of natrun from the Wadi Natrun - with the Phoenicians (Lutz 1923) and possibly with the Yemen (Pringle 1998).

Washing was seen as important and people generally washed before and after a meal, as Blackman (1918a) puts it "*Washing, therefore must have been one of the common acts of daily life in ancient Egypt*". Linguistic evidence gives more direct evidence for the use of natrun in washing as it is believed that women washed themselves with water containing natrun during their periods, and indeed the Egyptian for 'menstruate' is *ir ḥsmn*, or 'to make a purification with natrun' (Blackman 1918a, 476). This is perhaps related to the fact that women were seen as outcasts and unclean during their monthly cycle, and that this was one of the rituals required to be reaccepted by the community.

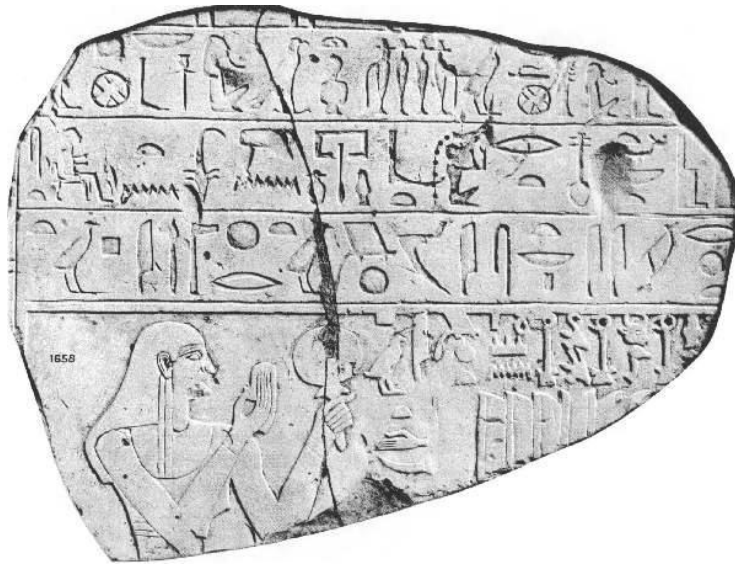


Figure 26: Fragmentary Stela of the Lady Ipwet. Showing a woman possible cleansing her face in a mirror (Edwards 1937, Plate XX)

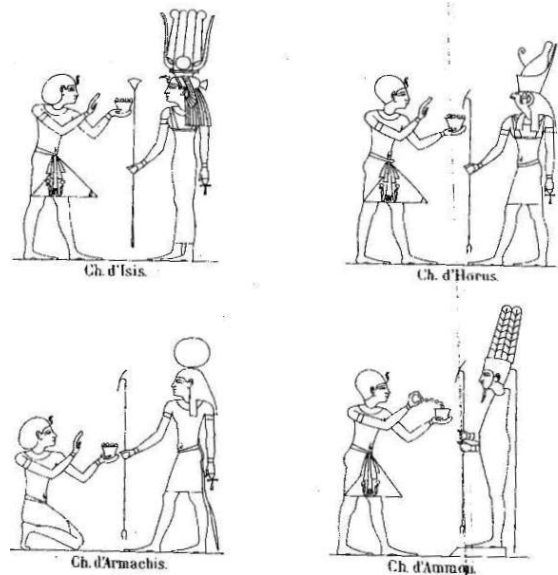


Figure 27: Schematics showing the presentation of balls of natron to a number of gods (Maspero 1882)

The use of masticatories in Egypt is one aspect of society which leaves very little archaeological evidence and so as much information as possible has to be gathered from documentary sources as well as ethnographic studies. A

masticatory is 'any substance that is chewed to increase the secretion of saliva' (OED). Dixon (1972) however disagrees with this definition and believes a better one would be 'any substance chewed without the intention of ingesting'. It is believed that to maintain fresh breath lumps of natrun were chewed (Manniche 1994) and although its use in a religious setting (Figure 27) is known, it was also presumably also used in a secular context (Blackman 1918a).

Laundry

As today laundry was an important social aspect of Egyptian society. Herodotus makes mention of it as a unique characteristic of the Egyptians

"They wear linen clothes which they make a special point of continually washing (Herodotus Book Two: 37)."

The laundry was conducted by the men of the village (McDowell 1999), something unparalleled today in modern Egypt. Laundry was not just an activity but an industry in its own right, as can be attested to by documents from Deir el-Medina (McDowell 1999). Laundry was important because of the ritual significance of purity and the fact that the colour white was most closely associated to purity. Ragai (1988) even discusses the disappearance of colour from clothes from the Middle Kingdom, and is believed to be related to the 'desire for absolute cleanliness of the body'. In the apocalypse 'fine, linen, clean and white' is a symbol of righteousness (Rennier 1827) and priests had to be clean in every respect. However laundry was not always associated with religion (Adamson 1969) and the fashion was to dress in crisp white clothes (Manniche 1994).

Some believe that clothes were cleansed using only water (Manniche 1994), and it is known that flax and hemp when dried in the sun, even with just water, can become visibly whiter (Anon 1824). However, documents detailing the role

of the laundrymen, suggest a use for natrun in the cleaning of garments (Davies and Toivari 2000; Rennier 1827). From accounts of Deir el-Medina and from other documents up until the Greco-Roman period, laundry as an industry can be identified. In addition to these domestic accounts, literature from the period also discuss the role of the laundryman and it is from these documents that the identification of a laundryman's status can be made (Janssen and Janssen 2002). An example of this is from the teaching of Duaf's son Khety, a New Kingdom story.

*“And the washerman washes on the shore
Nearby is the crocodile
‘Father I shall leave the flowing water’
Say his son and daughter
‘for a trade that one can be content in
More so than any other trade’
While his food is mixed with shit
There is no part of him clean
While he puts himself amongst the skirts of a woman who is on her period
He weeps, spending the day at the washing board
He is told ‘dirty clothes!’
Bring yourself over here’ and the river edge overflows with them”
(Parkinson 1991)*

This section clearly shows that the launderer was not an enviable job. The profession was, and equipment were, provided by the state. The laundrymen did an average of eight households per day, and evidence from Deir el-Medina shows that laundry lists were written to ensure that the right clothes went back to the correct households (McDowell 1999). The laundry was conducted at the riverside (Davies and Toivari 2000; McDowell 1999; Parkinson 1991) although it is unknown as to whether the laundry was collected by the washers or there was an intermediary who brought the clothes to the riverbank. There are many documents regarding the procurement of natrun - which was controlled

centrally through government (Davies and Toivari 2000; Edgar 1928; Janssen and Janssen 2002; Wente 1990). Other than these literary offerings there is little other evidence regarding laundry in Egypt. There are only two artistic representations of laundry being conducted, TT217 (Figure 28) and TT254 (Figure 29) (Griffith and Newberry; Janssen and Janssen 2002; Manniche 1989b). Few laundrymen have been identified from the archaeological record, however in the northern cemetery of Abydos a stela known as Hepet's stela (Cairo CG 20281) was discovered. The stela contains a prayer to Ptah from his faithful son Hepet. Hepet identified himself as a laundry worker and he is believed to have lived in the 13th Dynasty (Parkinson 1991).



Figure 28: Laundry scene from TT217 (Griffith and Newberry 1893)

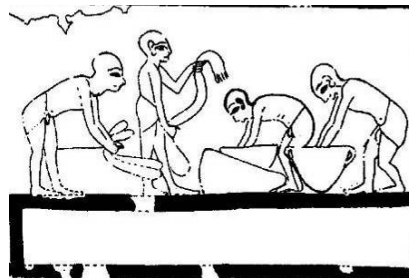


Figure 29: Laundry scene from TT254 (Manniche 1989b)

Rare archaeological evidence also shows the use of natrun and salt as a cleanser. Marsh-Letts (2002) in her study of garments found within tomb complexes suggest that there was a degree of mineralisation from their continued cleansing with natrun. Her analysis of garments showed clearly the crystal structure of sodium salts, suggesting their usage as a detergent.

4.1.3 Ancient Egyptian Ritual Purification

To the western world the concept of purity is intertwined with the concept of sin and guilt and it is therefore difficult to differentiate between the two, whilst this is not the case in Ancient Egypt (Bleeker 1966). Cleanliness was highly regarded in Egypt so anyone who worked in the service of the gods had to be ritually pure (Manniche 1994), and, as already discussed, dressed in pure white clothes. For the most part it is difficult to discern between ritual and physical purity (Unal 1993) and a number of religious and secular practices such as cleansing the mouth contain elements of both. There is evidence regarding the role of ritual purity in Egyptian society, varying from mortuary texts, prayers, temple art and royal inscriptions (Yoo 2005). Two of the biggest influences behind Egyptian ritual purification was the belief that the divine realm was extended to common people upon death and that moral purity could be acquired through a ritual process (Yoo 2005). Since the time of the Old Kingdom the Kings had been regarded as gods on earth and able to enter the divine realm with little difficulty upon death, provided they maintained ritual purity whilst they were alive. This concept was then extended in the New Kingdom to include non-royals as long as they followed moral rules, and were morally pure, as this was the condition of the human realm (Yoo 2005). Ritual purity however should be seen in a wider context than it often is in our modern society (Fallaize 1918; Routledge 2001). Purity was required to enter a sacred space (Gee 1998). There are three groups of people who needed to be ritually pure in order to perform their appropriate functions: priests, the King and the dead (4.2).

Temples and Priests

A great deal of information regarding the role of purification in religion comes from ritual areas such as tombs and temples and the priests which served them.

Temples were regarded as pure places and purification rituals were conducted in them to maintain this realm of purity (Gee 1998). The term 'pure place' is

often used to describe a temple, however the etymology suggests the meaning comes from the term for an unoccupied space, and indeed it was similarly used in this way in old English (Lefebvre 1939) and could refer instead to the large open spaces present within the temple.

It has been suggested that the levels of purity required for visitors and the priests who serve within these temples are the same (Baines and Lacovara 2002), however visitors cover a broader spectrum such as women, servants and children. There was a common warning over the entrance to the temple which read “everybody who enters the temple, must be pure” (Bleeker 1966). Purification could be established by burning incense, by using libations either of water or of water containing natrun and by changing one’s clothes (Bleeker 1966; Gee 1998). These acts of purification are represented in scenes within or near the entrance to the temple, although they are generally only found in New Kingdom or later temples (Gee 1998). The earliest purification scene to have been discovered comes from outside Egypt’s borders in the Levant and dates to the Middle Bronze Age, however there are early references to purification in temples from the Pyramid Texts (Gee 1998). Although there is evidence that suggests what was required in order that one is ritually pure what is not clear is the detail of the process of cleansing and there are discrepancies regarding the time in which one ritual purified oneself. Some people believe that the cleansing took place outside the temple whereas others, such as Gee (1998), believe from archaeological evidence that ritual cleansing took place within the temple. Some temples have purification basins present within the hypostyle hall, such as the temple of Ptah in Memphis (Gee 1998). There is also literary evidence in the form of the Amarna letters which state that the nations of Babylon and Mittani present the nation of Egypt with gold, silver and bronze purification basins as part of diplomatic relations and as dowries (Gee 1998). These purification basins would have been placed within either a purification chapel or within the entrance to the temple itself, in which visitors would cleanse themselves and their offerings. However inscriptional evidence from Edfu also supports the idea that priests purified themselves within the sacred lakes which

lie to the east of the temple and this is also present within Spell 420 of the Pyramid Texts.

“I have gone down so that I may wash myself in the Lake of Natron since I have entered into the pillared hall so that I may see the god, the lord of the gods” (Faulkner 1978)

To ensure the purity of the temple and the smooth running of the heavens and earth, priests had to maintain their ritual purity. As has previously been discussed this could be conducted either within sacred lakes or purification basins. Herodotus (Book II: 37) details the purification rituals of the priests in the temple of Amun at Karnak as “they bathe in cold water twice a day and twice at night and cleanse their mouth with natron”. The term *w^cb* can often be found in association with priests and is commonly translated as pure or clean. This term was reserved for anyone who worked within the temple complex and was seen as ritually pure (Zucconi 2005; Zucconi 2007). Besides being physically clean through washing, priests were also expected to shave all their hair, be circumcised and be celibate (Herodotus Book II; Zucconi 2005; Zucconi 2007). It was important that the priests followed all of these directions as otherwise the gods could be offended and abandon Egypt (Zucconi 2007).

A 20th Dynasty document shows that in order to come into “close quarters” with the god one must be ritually pure, and to be ritually pure meant to have drunk natron water for a set period of time. The document itself is a legal document listing charges levied against a number of people (Peet 1924). One case regards a priest carrying out a service before he was ritually pure:

“Charge concerning his coming into the inside of the fortress when he has only done seven days of drinking natron. Now the scribe of the treasury, Mentuherkhepeshe made this prophet of Khnum take an oath by the Ruler saying, I will not let him enter with the god until he accomplish his days of

drinking natron. But he disobeyed and entered with the god when he had three days of drinking natron still to do” (Peet 1924, 121)

The case shows that there was a prescribed ritual behind becoming ritually pure and secondly it shows the immense importance of natrun in this process.

A crucial first stage in the life of a temple was the foundation ceremony. Some of the earliest documentary evidence for a foundation ceremony are the 5th Dynasty Palermo Stone and a reference to a ceremony that can be found at the 5th Dynasty Sun Temple of Niuserre at Abu Gurab (Lower Egypt) (Greenwell 2005). The foundation ceremony included aspects from both the daily temple ritual and the opening of the mouth ceremony. The King performed these ceremonies (Greenwell 2005) and every statue and relief had their mouth opened and each room was censed to bring to life every part of the temple (Fairman 1954).

King

The purity of the King is vital as he is the link between the heavens and the earth and it is his responsibility to maintain the stability of Egypt. The first point of the King’s purification comes at his coronation (Blackman 1918a). Although there is little documentary evidence regarding the coronation, it was clearly of huge significance as the main purpose was to restore the unity between heaven and earth, which would have been disrupted upon the death of the last King (Fairman 1958). The first and most important of the steps was the coronation purification, also known as the Baptism of the King (Blackman 1918a; Fairman 1958). This baptism was seen as being a renewal of the baptism conducted in infancy and was designed to transfer the power of the gods into the new King (Blackman 1918a; Fairman 1958). The ceremony was conducted by two priests impersonating Horus and Thoth, or Horus and Seth (Blackman 1918a), and consisted of being sprinkled with libation water, which could either be pure or contain natrun (Blackman 1918a; Fairman 1958). He would also be presented

with natrun to chew and would be fumigated with incense before being offered food and drink (Blackman 1918a).

Although the King was seen as semi-divine the same rituals of being pure had to be conducted before he could officiate in temple. This lustration was believed to allow him to be reborn as his divine prototype (Blackman 1918c), this was in addition to repetition of the fumigation and the chewing of the balls of natrun (Figure 27). This act would be conducted in front of the false door - which bridged the land of the living and the dead - and not in front of the deity of the temple (Blackman 1918d). Although the Piankhi (Piye) Stela does not describe in detail the practice of the purification of the King it describes how Piankhi (752-721BC) re-established the religious community in Memphis and purified the entire city with natrun before he himself was purified in the temple of Ptah which he had just restored (Breasted 1962).

The role of the King once he has died is as important as when he was alive. Indeed if the King was ill, this was thought to cause ill-health and problems within the entire nation. If the King recovered from an illness the entire palace had to be cleansed to signify the cleansing of the Empire (Baly 1930) and it is likely that this same ritual would be conducted upon the death of a King. As already stated the death of the King caused problems as it was believed to disrupt the unity between heaven and earth and the King had to be purified before he could enter the solar Kingdom (Blackman 1918a). The King was therefore purified by being washed, like the god Re-Atum who was washed every morning before appearing in the eastern horizon, and this was meant to signify his rebirth (Blackman 1918b). The lustration water itself in this context was seen as divine and associated with Nun or of a sacred pool dedicated to the sun god (Blackman 1918b).

Formulae

Some parts of the opening of the mouth ceremony have already been discussed in relation to the foundation ceremony of the temples. The opening of the mouth ceremony was a crucially important aspect of the religious life of the Egyptians. It encompassed nearly all aspects of life from birth through to death and the ceremony is directly related to the re-creation of the birthing ceremony. This explains not only its importance but also its use as part of the foundation ceremony of temples. The process evokes the gods to life allowing for the temple to become a living space. This section will discuss the formulae behind this important ceremony in relation to the use of natrun. The ceremony is depicted in a number of temples (Blackman and Fairman 1945) and has a number of stages, some cover aspects such as touching the statues, whilst the ones to be discussed here cover the aspects of purification in relation to the use of natrun, consequently this document will be examining the 5th, 6th and 7th ceremonies.

All three involve the process of “censing” and prayers in which the object to be purified is made pure. The 5th ceremony is possibly the one which shows the use of natrun in such a practice. The term *seman* incense is repeatedly used with the prayer “*pure is the seman incense, pure is the seman incense which openeth thy mouth*” (Budge 1909). Many believe that *seman* is natrun, although this has not yet been satisfactorily confirmed, however the language of the prayer is similar to that of other prayers in which natrun is used, even within the opening of the mouth ceremony itself. The 6th ceremony involves censing of the statue with incense from the north, which is brought from the *štp.t* area, which is known from other texts to refer to the Wadi Natrun (6.2). This ceremony involves the process of reiterating prayers and presenting the statue with five grains of the incense. The 7th ceremony follows the exact lines of the 6th except the natrun is presented in a vessel to the statue, the prayers are also identical (Budge 1909). The purpose of this ceremony is to ensure the purity of the

object, predominately statues. Natrun is a primary requirement to ensure this purity.

A number of purification rituals are for the dead and are used in relation to the treatment of the deceased soul rather than the process of mummification or the protection of the corporeal body. Natrun and salt are key concepts in the protection of the deceased. Indeed both natrun and salt have been found in funerary contexts (Manniche 1994). Perhaps one of the biggest discoveries in relation to natrun, were the finds inside Tutankhamen's tomb. Natrun was found within a number of containers, in one area, two faience cups were found, one filled with natrun and one filled with resin (Carter 1927). Presumably placed within the tomb in order to perform ritual cleansing. A number of dishes were also found to contain relatively 'crude' natrun and these are all believed to hold some use in the mummification ritual. However the most interesting find in the tomb was a chest (Figure 30) which contained natrun, that when analysed was 95% pure sodium carbonate (Carter 1933; Lucas 1933). This was the purest natrun found in the entire tomb and shows how closely followed these texts were, as this chest fulfils Spell 592 from the Pyramid Texts.

"Spell for a chest of natron. O all you gods who are in the snwt-shrine, come, that you may see this foe; he is one trodden down and bound in the presence of my father Osiris for I have killed his foes whose slaughtering has been effected, and my father Osiris is triumphant O lector, O sm-priest, bring a chest of natron and let the gods offerings be issued" (Faulkner 1969)

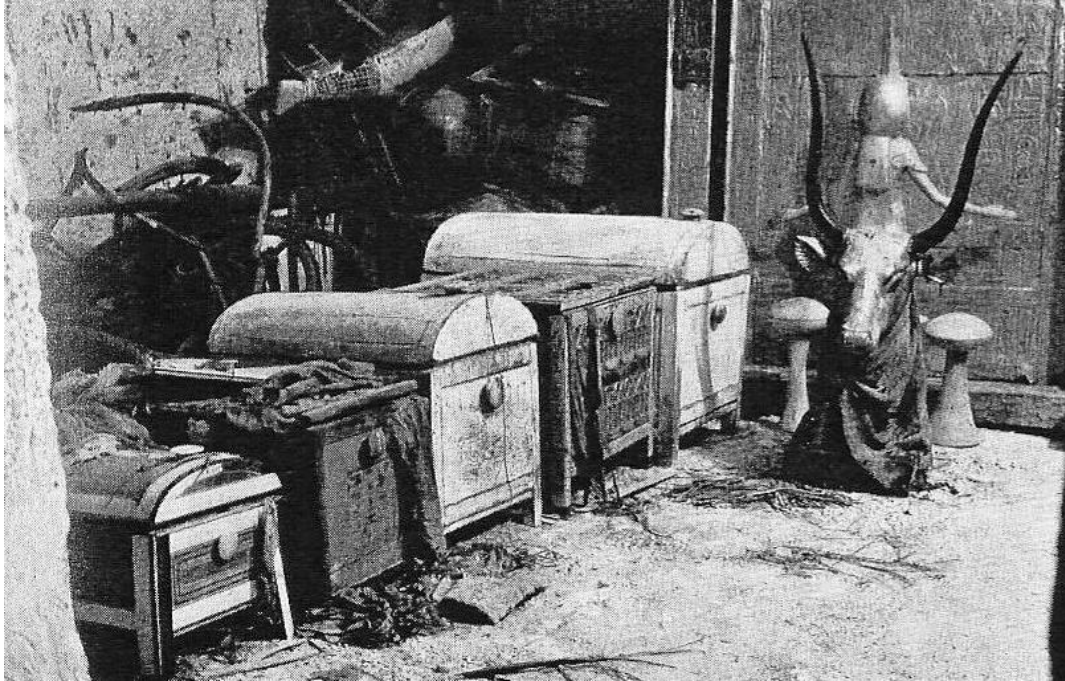


Figure 30: Photo showing the layout of a number of chests in the tomb of Tutankhamen. The chest closest to the wall contained large amounts of almost pure sodium carbonate (Carter 1933)

As already discussed the King, priests and even the temple were maintained as ritually pure. The living also required prayers and spells, although most, much like Jewish and Christian faith, are passed on social niceties, such as Spell 926 *“wash yourself, sit down at the meal”* (Faulkner 1978). Once ritually pure the Egyptians believed that the gods would favour them *“Spell 385 - [...] as one who is favoured thereby in sky and earth”* (Faulkner 1978). There are a number of spells and utterances which stipulate the use of natrun and salt in maintaining this connection of the living and the heavens, as well as in maintaining personal hygiene.

4.2: Mummification

It must be noted that whilst the terms mummy and mummification were derived in relation to the process and result of the Egyptian form of desiccation, that today the term mummy relates to any faunal remains, in which organic remnants (ie. skin) have been preserved. In relation to this there are two broadly defined mummification categories. The first and probably the least well documented is the production of a mummy through a natural process. Natural mummification occurs when the environment excludes micro-organisms which would aid decomposition (Janaway 2002). There are three main environments in which natural mummification can be expected to occur, the cold such as Otzi, who was preserved in ice (Figure 31) (Bahn 1996; Spindler 2001) or John Torrrington, who was preserved in a burial environment on Beechy Island, on his search for the North-west Passage (Janaway 2002). Cold environments work as they suppress micro-organism activity and help to desiccate the remains (Janaway 2002). Bog environments also help to preserve flesh, although additional organic material such as muscle tissue can decompose, an example of which is Tolland man (Figure 32). In the past it was thought that the bog preserved skin by being acidic, the presence of a natural antimicrobial substance and by facilitating anaerobic conditions, however it is now believed that due to the conditions found within the bog that it may just be that the body becomes tanned, much like in the leather industry (Janaway 2002). The last environment discussed is that of the dry environment where by the rapid drying out of bodily tissues, and the inhibition of decomposition bacteria allow for the preservation of the human remains, although to varying degrees (Janaway 2002). Natural mummies have been found in the Tarim Basin and were preserved due to the extremely dry and saline soil they were buried in (Mallory and Mair 2008).



Figure 31: A photo of Otzi as he was found (Spindler 2001)



Figure 32: Tolland Man (Glob 2004)

The second category refers to the production of a mummy through an artificial process, such as the Egyptian mummies themselves. An artificial process can be defined as one in which means were used in order to preserve the remains knowingly. Conversely a natural process is one in which nature enables the preservation of the remains, but unknowingly. In a number of cultures there could be a certain degree of cross-fertilisation determined, such as the Incas,

who preserved a number of their dead in the arid, cold environment of the mountains (Douglas 2001), or the Iron Age Europeans who in wetland areas preserved bodies in bogs (Figure 32) (Coles and Coles 1995; Glob 2004). However this relies on the premise that the cultures and the people within them understood that this process of artificial preservation was occurring using natural means, and unfortunately to a certain degree this is not always known.

The Egyptian method of mummification began in less than auspicious circumstances. For most of Egypt's history the dead were disposed of in the surrounding desert. The deceased were interred in the foetal position with limited provisions for the afterlife (Figure 33) (David 1978). These remains were preserved in a natural way through the heat of the sand, which drained the body of moisture, and also inhibited microbial growth. It is commonly believed that chance discoveries of such preserved remains (David 1978), enforced the notion of corporeal preservation and spiritual survival. As the custom for burial developed from the crudeness of burial in the desert, with the addition of funerary goods, such as coffins, or even the tombs built to house the dead themselves, the corpse being placed within a tomb setting, it would have been noted that the flesh was no longer being preserved. It is believed that this spurred the movement towards artificial mummification in the beginning of the Early Dynastic Period, although it should be noted that evidence for the use of desiccants is unknown until around the Fourth Dynasty.



Figure 33: A photo of Ginger, a Predynastic natural mummy (Courtesy of the British Museum)

The desiccants that have been identified as being used in the mummification process are salt and natrun. It is believed that the process behind the desiccation of the body was based on a similar process to that of preserving meats, although the preservation techniques will be discussed later, the understanding about preservation was probably derived from the food processing industry (Ikram 1995; Ikram and Dodson 1998). It is due to natrun's clearly identifiable ritualistic properties, that natrun was chosen as the primary desiccant rather than salt due to these religious relationships. However, both are effective desiccants and work by drawing out the moisture within the tissue. Once the moisture is withdrawn there is a limited amount of decomposition that can occur, add to this the ability of both salt and natrun to inhibit the growth of microbial communities, and it means that decomposition is unlikely to occur unless the procedure is performed incorrectly, for example the period given to desiccation is not long enough. Once an effective method had been established, the procedure remained unchanged for around 3000 years.

The first context that needs to be addressed is just why mummification was conducted. One important consideration is that the disposal of the dead is a

necessity in any society (Merrifield 1987), none more so than a hot, arid climate such as Egypt. Like many of today's religions, death was seen as the beginning of a new life as well as the end of the corporeal one (Jansen et al. 2002). The soul would be sustained by the preservation of the body as well as from the depictions within the tomb (Jansen et al. 2002). Though many see it as a means to an end, the use of natrun was not just used to enable the preservation of the remains, as natrun held a deep religious significance throughout Egypt's history.

4.2.1 Ritual

This section will focus on the ritual behind the process of mummification and put into context the importance of this aspect of Egyptian life. The Egyptians, like most cultures, found the most terrifying aspect of life was death (Hartland 1911). However Gardiner (1935) believes that this fear of death and of the dead did not drive the funerary rituals now commonly associated with Egypt. The funerary rituals were born out of a "normal" society whereby death was revered and the dead mourned. Consequently elaborate funerary rites were developed in order that the bereaved were given a sufficient time for the grieving process as well as sufficient preparation for the afterlife.

It could be argued that the Egyptian beliefs about death and the dead were an aspect of ancestor worship. The role of ancestor worship can be identified through a number of different cultures, probably most notably Chinese (Addison 1924a) and Iron Age European cultures as well as some within the African continent (Addison 1924b; Driberg 1936). When this is taken into consideration the role of mummification was not only a religious practice but was the duty of a family to preserve the memories, as well as the remains, of the ancestor. Indeed once the dead were interred the families either visited the tombs themselves or paid priests to say prayers and give offerings (Ikram 1995; Ikram and Dodson; Wilson 1988). Many tombs had tomb-chapels attached where these ceremonies could take place more easily (Malek 1988). Diodorus of Sicily

(Book 1: 91.7 and 93.1) also comments on what can be perceived as ancestor worship prevalent in Egypt at the time.

According to Egyptian myth the first King to be mummified was Osiris. The myth focuses on his death and his subsequent rebirth, and his subsequent ability to procreate (Budge 1973). Most evidence surrounding this myth comes from the New Kingdom, however one of the Pyramid Texts has the intriguing statement “[.....] *Thou hast union with her, thy seed entereth her. She conceiveth in the form of the star Septet*” (Budge 1912, 40). The consequence of this union was the birth of Horus and a belief that the preservation of the body was tantamount to an existence in the afterlife.

Textual Evidence regarding rituals in the Mummification Process

There is little direct textual evidence regarding the process of human mummification from the Egyptians themselves. Most documentary evidence is derived from the information gathered by classical authors in the Greco-Roman period. However, Egyptian evidence regarding the process of mummification can be found in relation to **animal** mummies as well as through myths. The most important literary document preserved regarding mummification is the Apis Embalming Ritual (Papyrus Vindob 3873) (Vos 1993), which focuses on the preservation on one of the sacred **animal** mummy groups, namely the Apis Bull. The Apis Bull was a sacred animal commonly worshipped from the Second Dynasty onwards in and around Memphis.

The papyrus that examines the Apis Embalming Ritual is currently housed in the Kunsthistorisches Museum in Vienna and it was believed to have been found in the Memphis area. The document details the practices involved in the embalming of the **sacred bull**. The document is dated to around the Ptolemaic period. From this document it can be established what ritual practices were conducted to ensure the transition from death to the afterlife in the bull. The first ritual aspect of the embalming ritual was the purification of the embalmers (Vos

1993). Then the bull is anointed, with ritual ointments which allowed for the purification of the bull. The mummification is carried out by an overseer and four priests (Vos 1993).

In reality mummification is an expansion of a number of ritual ceremonies which culminate in the probable preservation of a body. The whole process of preservation could be an extension of the purification ritual where the body is purified using natrun containing water as well as natrun in solid form and in turn these minerals would preserve the flesh. The papyrus of Ani even mentions that Ani was purified with natrun and salt (Rowling 1961). There is a symbiotic relationship between the aspect of ritual purification and the ability to preserve the remains. To obtain entrance to heaven the correct ritual and religious processes needed to be conducted, and this was the necessity and the preservation was a bonus (Baines and Lacovara 2002).

Many of the aspects of ritual within mummification can be found in documents such as liturgies and within the art from temples and tomb complexes. One of the most important ritual practices surrounding the formation of the mummy is the Opening of the Mouth ceremony. This ceremony can be found throughout Egyptian religious practice including the foundation ceremonies of temples as well as in funerary rites. The Opening of the Mouth ceremony is based on aspects of the birthing practice. This view can be supported by archaeological and literary evidence. It is believed to have stemmed from the practice conducted on a newborn shortly after birth when the fluid from the amniotic sac was cleared from the mouth and nose, and in the past this practice of clearing the airway was generally performed by the midwife using her two little fingers. A number of aspects about the Egyptian funerary practice could be seen as being related to the whole idea about rebirth.

The Opening of the Mouth ceremony enabled the deceased to become living in the next world and more importantly to receive sustenance. In relation to the deceased the ceremony was performed, by the use of the priests little fingers.

Although in some cases this practice was superseded by the use of the *ntrwj* blades, which have been found in a number of archaeological contexts (Roth 1993).

A number have commented on the idea that the ancient Christian belief of resurrection was based on the Egyptian practise of mummification (Bostock 2001). Egyptian myths and faith had by the time of the First Century AD been accepted in the classical world and it is therefore not surprising that the early Christians associated Christ with Osiris and his resurrection (Bostock 2001). Indeed Coptic Monks also performed mummification until they were persuaded by St Anthony, who proposed that Christ would resurrect the body in a glorified state, without the need for corporeal preservation (Bostock 2001).

4.2.2 Embalmers

Embalmers are one of the most important aspects of the process of mummification, without them there would be no mummy and no eternal life. It is therefore surprising that embalmers themselves are fairly infrequently mentioned. Indeed no one person has as yet been identified as being an embalmer.

What can be gathered from textual evidence, by Diodorus of Sicily, is that there were clearly two ranks in the embalming classes: the “slitter” and the “embalmer”. It is believed to be the slitters who were seen as the lowest of the low, and whom dwelt within the poorer area of the city (Comrie 1909). Indeed slitters were unpopular members of society, with them even being cursed and threatened with physical violence by members of the deceased's family (Comrie 1909). This is because some aspects of the embalming process were seen as unnatural and unjust, specifically the cutting of the flesh to remove the viscera which was seen as committing “*harm to someone in the flesh*” (Diodorus Book 1 91.3-6). Once the cut was made, the “slitter” would be forced to flee to escape the curses and stones hurled at him (Diodorus Book 1 91.3-6). According to

Brier and Wade (2001) to make an incision in the human figure was prohibited as it was seen as being defilement. In the process of mummification however it was a ritual necessity to ensure the preservation of the deceased and in this context could be seen as a paradox. However in contrast, it is also known that some members of the embalming tradition were revered as being almost priestly (Comrie 1909; Pettigrew 1834):

“[embalmers were] considered worthy of every honour and consideration, associating with the priests and even coming and going in the temples without hindrance as being undefiled” (Diodorus Book 1 91.3-6)

4.2.3 Practice

As already discussed the necessity in disposing of the deceased is great. This is primarily a public health issue, but the disposal of the dead also allows for an appropriate period of grieving. The religious reasons behind the entire process have already been discussed, and this section is designed to give an understanding in the way in which the desired effect was achieved.

Classical References

Herodotus and Diodorus of Sicily are two of the key authors who discuss mummification in the Greco-Roman Period. Both describe the availability of three levels of mummification, ranging in price and standard (Herodotus Book II 86-88; Diodorus Book 1 91.1-3). The most expensive involved the active removal of the viscera and brain. The body was then placed in natrun and then wrapped in linen. The second involved the removal of the viscera through the use of cedar oil “emetic” and the body is then ‘pickled’ in natrun. Whilst the cheaper option was to purge the body and then place the remains in natrun.

Evidence from the Mummies

One of the most important resources in understanding the process of mummification is the mummies themselves, as already discussed there is little documentary evidence from contemporary authors, and the classical scholars are only aware of processes conducted in the Greco-Roman Period, which is known for its poorly preserved remains.

Scientific examination of mummies began in the late 18th Century (Blumenbach 1794) but even by 1754 authors such as Rouelle were commenting on the use of natrun as a mummification aid (Rowling 1961). However it was not until the early 20th Century that a more rigorous examination of the mummies, as well as the processes behind their manufacture, was begun. Most modern studies focus on palaeopathology, what evidence the bodies hold about everyday life, rather than how those bodies were preserved. Indeed, few mummies have been unearthed in the last 10 years, and most museums will only allow for the examination of human remains under a strict number of provisos, the most important of which is that it will not damage the deceased. This has led to more constrained research, and indeed some of the most important work in this field came before the 1950s. Some work has been conducted on supposed “embalming caches” but there is concern surrounding their exact use in the mummification procedure (4.2.4). Indeed until the recent discovery of the embalming cache in KV63 around two years ago, Egyptologists were not interested in this aspect of Egyptian life (Eaton-Krauss 2008). There is consequently no definitive idea surrounding what an embalming cache is or what its purpose was, however it can be determined from an examination of a number of proposed “embalming caches” that they contain the refuse from the mummification process and have been found to include soiled strips of linen and rags, sacks of natrun, and these can be packed in jars, boxes or coffins (Eaton-Krauss 2008).

In almost all cases where the removal of the organs is through the formation of an incision, the incision itself is found on the left side (Granville 1825), possibly as a means of ensuring the heart remained in tact. Indeed the only organs that are commonly found to remain inside the body are the heart and kidneys. The heart was maintained as the seat of wisdom. The removal of the organs is a fundamental aspect of preserving the remains as these organs contain the bacteria which aid in the decomposition process. Experiments have shown that decomposition is slower when the internal organs are removed in a normal burial environment (Sapsford 2003). The brain was also removed (Cappabianca and de Divitiis 2007) and although a number of additional organs were removed, the liver, intestines, stomach and lungs were preserved within canopic jars. Canopic jars are the guardians of the internal organs. Each canopic jar is associated with one of the four sons of Horus (Figure 34). The liver was protected by the human headed son Imseti, the lungs were placed within a baboon headed canopic jar representing Hapi, the falcon headed canopic jar (Qebehseuef) preserved the intestines and the stomach was protected by the jackal headed son, Duamutef. The brain, however, was not preserved either within canopic jars, or within any additional funerary kit, thus suggesting that the brain was identified as an unnecessary object. The fact that the face of the deceased was risked in order to remove the brain although it makes no significant contribution to the decomposition of the remains (Ith et al. 2002), suggests that the removal of the brain was an important feature, even if the considerations are today not understood.



Figure 34: Image of the four canopic jars found in the tomb of Neskhon, a 21st Dynasty female (courtesy of the British Museum)

Internal Packaging

Once the incision had been made, and the internal organs removed, packing materials were inserted into the body cavity. These packages were present for a number of reasons. Firstly, it would allow for the desiccation of a body internally, secondly it would dry up any decomposition products and thirdly, it would give the body a more realistic shape once the desiccation process had been concluded. Internal cavities would be filled with temporary packing materials such as fragrant plants, natrun and resins (Iskander and Shaheen 1964; Iskander and Shaheen 1973). Internal packaging materials of natrun have also been found in Tutankhamen's embalming cache (Figure 35) (Lucas 1933; Winlock 1941).

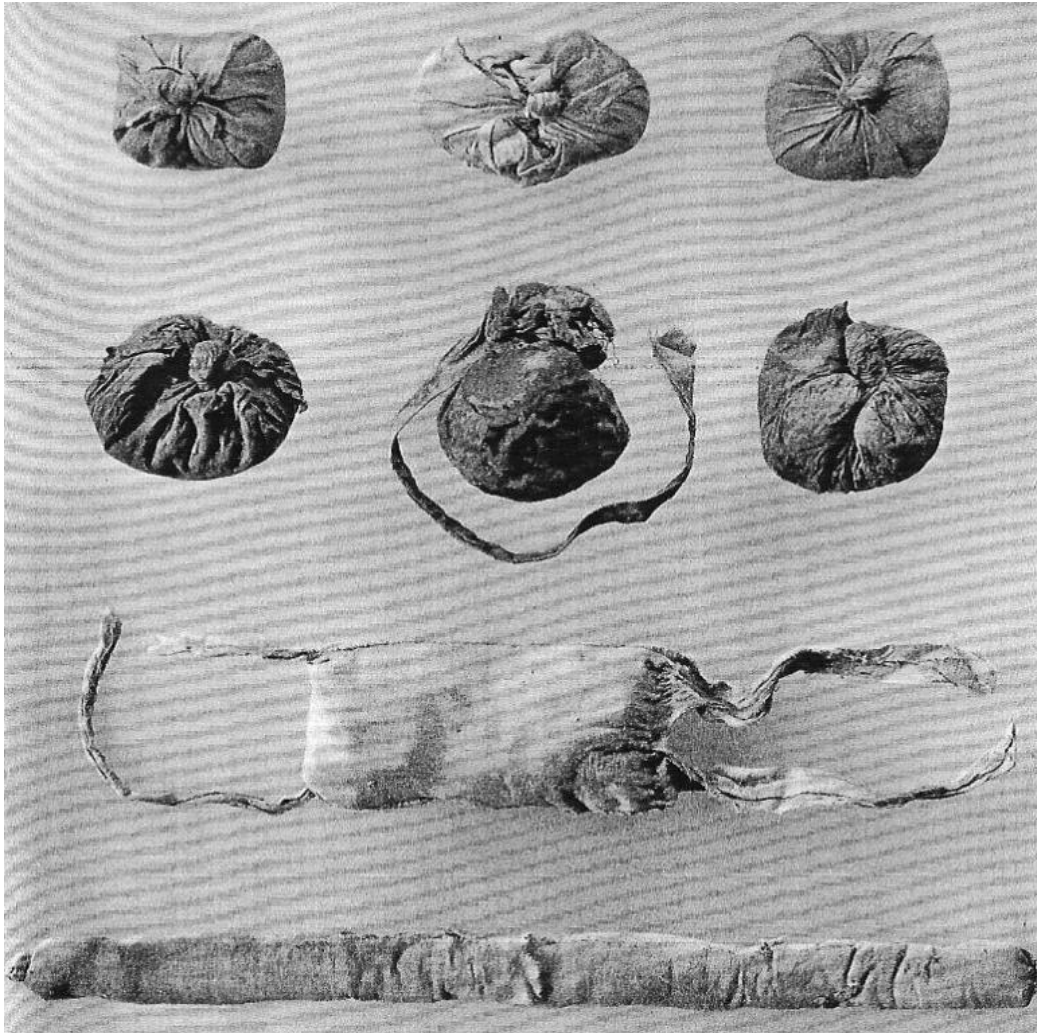


Figure 35: Image showing a number of the internal packing materials found within Tutankhamen's embalming cache (Winlock 1941)

Time taken

The length of time that it took for the entire process of mummification, from death to internment, has been described as anywhere from 40 to 272 days. Indeed the time it would take depended greatly on the amount the family could afford. The prescribed 40 days was associated with the preservation period rather than with any additional ritual process necessary before internment. The

length of time is discussed in the Old Testament through the treatment of Jacob upon his death.

“Joseph gave orders to embalm his father's body, and they did so, finishing the task in 40 days, which was the usual time for embalming. The Egyptians mourned him for 70 days” (Genesis 50: 1-3)

The information that can be gathered from this quote, shows that the time taken for the mummification process to be conducted was 40 days, but including the time for ritual processes and the time for mourning the whole event would take up to 70 days. This corresponds to Herodotus' statement that it took 70 days and could be the reason why many early scholars of mummification believed that the mummies were created over such a length of time. The longest time period mentioned in relation to the entire process is 272 days, and comes from the Fourth Dynasty tomb of Queen Mersankh III (Giza 7530-40) (Wilson 1944).

Transitions in style

The Old Kingdom was a period of experimentation for the Egyptians in their pursuit of preservation. Indeed Derry (1941) was scathing in his account of mummies of the Old Kingdom, suggesting that during the Old Kingdom the Egyptians were incapable of preserving their deceased. Evidence has shown that early experiments primarily involved the use of linen bandages and little else, although some skeletons have been shown to have been treated with sodium salts and wood tar (Salter-Pedersen 2004). Unfortunately there are very few mummies that survive from the Old Kingdom, due not only in part to their lack of expertise but also because of the reduced numbers of mummies caused by the Egyptians only mummifying the Royal Family and the religious elite (D'Auria 1988). The oldest intentional mummies are believed to date from the late 4th Dynasty.

There are many discrepancies over when the Egyptians reached the peak of their ability in the process of mummification, whilst some believe that the Middle Kingdom was the height of excellence (Edwards and Munshi 2005) others see the 18th Dynasty as being its peak (Salter-Pedersen 2004; Sandison 1969). Meskell (1999) in her survey noticed that at the end of the Amarna period there was an increase in the complex nature of mummification practices. There is also believed to have been an increase in the number of mummies produced in the New Kingdom (Sandison 1963), which could be due to the increase in the number of women or children being interred (Murray 1956), or could be due to the ability for “commoners” to enter heaven as well.

Although transitions in mummification are not readily identifiable one of the greatest changes in trend was between the Egyptian Dynastic and the Greco-Roman period. The Greco-Roman period is often identified as being a time of poor attempts at preservation, where the external appearance of the body was of more concern than the preservation. Aufderheide et al. (2004) in their survey of the Greco-Roman burial site of Kellis, discovered that a number of the remains had little evidence of an attempt to preserve the remains with a desiccant.

The use of natrun or salt?

Although natrun is widely referenced as being the main desiccant in the mummification process (Brier and Wade 1995; Brier and Wade 1997; David 1979; Dawson 1927; George 1828; Lucas 1932b; Ruffer 1917; Sandison 1963; Zimmerman et al. 1998), it was by no means the only desiccant used. Indeed evidence suggests that after Pinodjem III (Twenty-First Dynasty) the use of natrun was discontinued in favour of salt (Lucas 1911). The confusion between the use of salt and natrun in the literature is brought about by several authors through mistranslation, poor analysis and general belief that salt was used instead of natrun. Since salt is an impurity in natrun it is unconsciously used, whilst this is in contrast to the use of salt in the mummification of the early

Copts, where salt was used (Lucas 1908b). This is because salt is an Ancient Near Eastern purifying agent and as Christianity is born out of a Semitic culture; salt is used as the ritual purifier rather than natrun.

Lucas (1911) detected the presence of halite and sodium sulphate and free alkali on the soles of a 21st Dynasty mummy. The mummy of Menephtah is not evidence enough that salt was used as it could have come from impurities (Lucas 1932b). Elliott-Smith (1907) found bodies encrusted with salt, and found no evidence for the use of natrun (Linder 1910). Lucas (1933) didn't find any evidence for natrun on Tutankhamen's body just salt and sulphate. Petersen et al. (2003) noted that in places with high sulphate degradation was evident.

Winlock (1925) believed solution was used. The idea of liquid natrun probably arose from the fact natron occurs in solution in the Wadi Natrun (Engelbach 1941). Brier and Wade (1997) question why a solution was used if the purpose was to dehydrate the body. No jars large enough to hold a body have been found (Sandison 1963). Sandison (1963) believes the reasons behind a belief in the use of liquid natrun are 1) epidermis loss 2) that body hair is sometimes found to be missing 3) nails occasionally tied on 4) dismemberment has been found and 5) in the 21st Dynasty it was popular to pack limbs. A pottery figure (Figure 36) from the Rustafjaell Collection is of a man in a contracted posture in a large jar (Dawson 1927). Lucas (1908b) believed that evidence on the use of natrun solution are Amenhotep III; Ramesses IV and a prince found in Amenhotep II's tomb. Sandison (1970) showed in his experiments that epidermal loss was not always the case in fluid natrun. Natrun has been found in many archaeological contexts in reference to mummification, most notably Tutankhamen's tomb. In relation to Tutankhamen's embalming cache 24 bags of natrun were found along with five cloth cylinders all filled with natrun (Winlock 1941). Dawson (1927) states that the "salt bath" took place in a large jar.



Figure 36: Image of a pottery mummy placed within what is believed to be a salt bath, the piece belonged to the Rustafjaell Collection which was sold in 1913 (Dawson 1927, Plate XVIb)

Evidence from other sources

Pottery plays an important role in the understanding of the use of natrun and salt in mummification. There are two distinct types of pot that can be found in relation to mummification: firstly there are salt/natron pots (Figure 37) and secondly there are libation vessels (Figure 38), commonly identified in depictions of purification rituals, and would be used to ritually clean the deceased during the embalming process. There is then the evidence of

embalming refuse pots, which are natron/salt pots which are refilled with refuse from the embalming process, such as used natron and bandages. Engelbach (1923) in his report on the town of Harageh (near Kahun) reported finding natrun pots dating from the 12th Dynasty all marked inside the neck. Harter (2003) refers to the recent discovery of 20 large jars containing natrun dating to the 25th Dynasty in the south-west sector of Akhtheteps mastaba. In an 18th Dynasty chamber for embalming refuse pots were found marked with the words, natrun or salt (Figure 39) (Winlock 1922). Pottery is important as once embalming was concluded the refuse was placed in jars and buried within the necropolis but not within the tomb. In the Deir el Bahri quarry hundreds of large round bellied jars were found containing such refuse (Figure 40) (Winlock 1928).

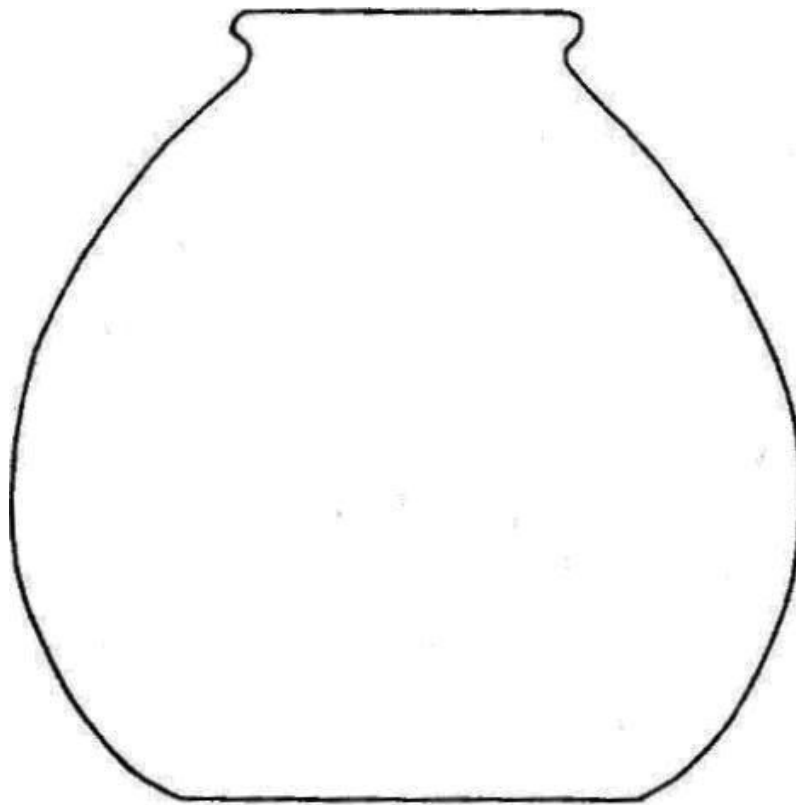


Figure 37: A schematic of a natrun/salt pot found at the site of Harageh (Engelbach 1923)

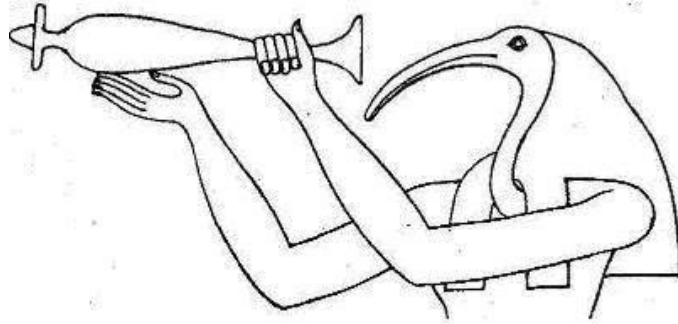
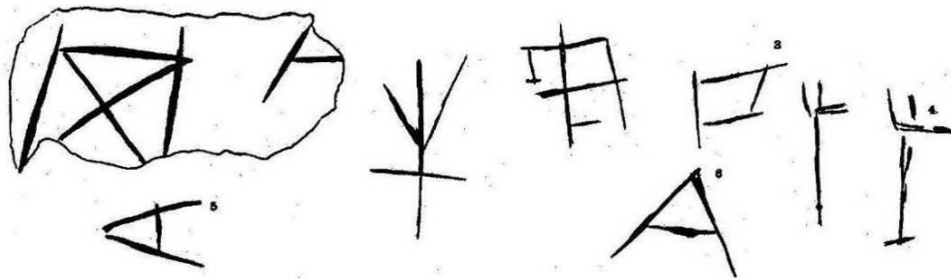


Figure 38: A schematic of a libation vessel being used, Denderah (Mariette-Bey 1870)



POTTERS' MARKS INSIDE NECKS OF SALT JARS, TYPE 67 e.

Figure 39: Marks found inside the necks of the natrun/salt pots (Engelbach 1923)

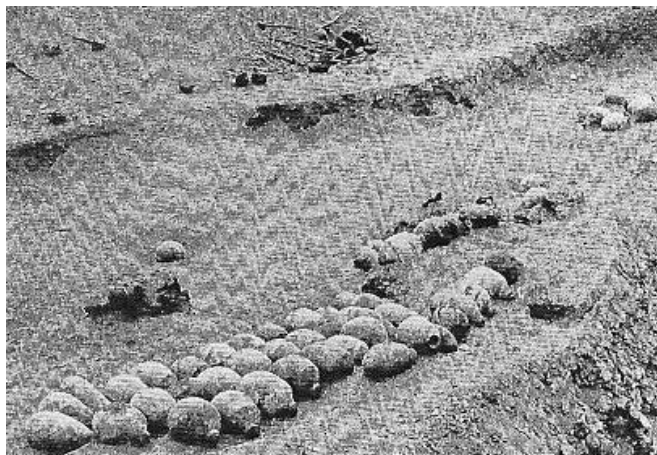


Figure 40: A photo of some of the embalming refuse pots found in an excavation of Deir el Bahri (Winlock 1928)

Evidence from the Ancient Near East also suggests that mummification was practised outside of Egypt. Evidence of a foetus preserved in salt and Assurbanipal's statement 'put the body of the Nabu-bel-shumak [a captured King] in salt with the head of his shield bearer' (Levey 1958b).

4.3 Experimental Section

4.3.1 Analysis of an “embalming pot” (1983.1.253) from Bolton Museum

An “embalming pot” (Object 1983.1.253) in the Bolton Museum (Figure 41 and Figure 42) forms part of the Wellcome Collection of the same museum was investigated to identify what the “pot” contained and also to identify its use in the embalming industry.

Wellcome Collection

Sir Henry Wellcome is well known for three things; the establishment of the Wellcome Trust, the formation of a major pharmaceutical company (now GlaxoSmithKline and his avid collecting of “medical” paraphernalia from around the world (Anon 2008). Upon his death Wellcome’s collection was split between a number of institutions most notably the Wellcome Collections at the Science Museum, the British Museum and the Wellcome Trust. A number of items were also sent to “provincial” museums such as the Bolton Museum.



Figure 41: Photo showing the Bolton vessel on its side



Figure 42: Photo of the opening of the Bolton vessel which shows pitting caused by erosion

Embalming vessels

As already discussed pottery plays an important role in the understanding of the use of sodium compounds in mummification. There are three types of vessel that are used in the embalming process. The first is the natron pot (Figure 37). The natron pot is the vessel in which either natron or salt was stored in prior to being used in embalming or other purification rites. Evidence for these pots are generally found in town settings such as Harageh. These same pots were also reused at the end of the embalming process and filled with embalming refuse such as used natron and used bandages (Figure 40), these pots would then be buried near tombs or graves. Thirdly there are the refuse pots which appear similar in structure to the natron pots, being large and round bellied, and lastly

there are the libation vessels which would have been used in the process of the purification rituals (Figure 38 and Figure 43).

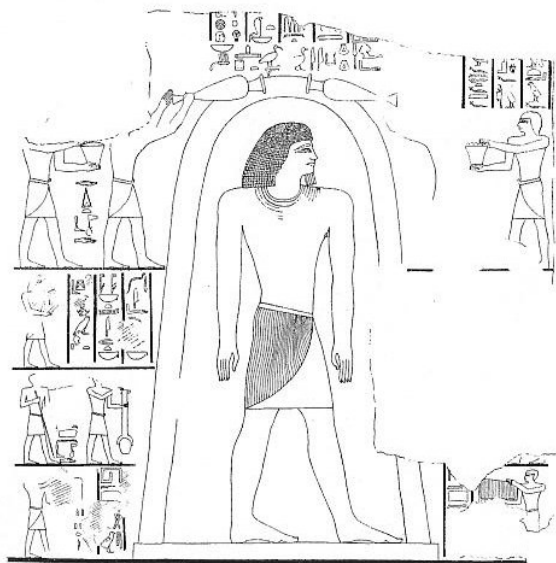


Figure 43: Representation of a libation scene from el Bersheh (Griffith and Newberry 1893; Newberry 1893)

The Object

The pot is tall and round bottomed. Janine Bourriau (2008) of Cambridge University assessed images of the object and dated it to around the 8th to the 1st Century BC. As can be seen from the photos (Figure 41 and Figure 42) the pot itself is a large round bottom flask, and appears to be similar to depictions of libation vessels, although not wholly identical. From its size and shape it also does not match any identified natron or embalming refuse pot.

The pot was sampled for external salt, internal salt and pottery. At the base of the pot, the base is open and the salt accessible. The shape however is maintained by the salt found in the base. These samples were then analysed using SEM and XRD (Appendix A), the methodology of which is discussed in Chapter 2.

Although a number of studies have been conducted into the practice of mummification, very few, especially in the last 50 years have investigated the remnants of embalming, found in the embalming refuse. Embalming refuse holds a wealth of information not in the least about the minerals used. The aim of this analysis was to identify the way in which this pot would be used in mummification as well as to identify the chemical make-up of the remains.

Results

The results of the XRD analysis showed that the contents of the pot were high in halite and had detectable traces of sodium sulphate present within them (Table 13). There was also little difference between the salt taken from inside the pot and the salt taken from the exterior of the pot. The lack of a detectable amount of carbonate is not surprising as it is often commented on that embalming refuse contains high traces of both halite and sulphates (Lucas 1908b; Lucas 1908c; Lucas 1910; Winlock 1932).

Table 13: Table showing the different minerals present within the "embalming pot" and concentration

Sample	Major Phase	%	Minor Phase	%
Bolton Internal Salt	Halite	82.68	Sodium Sulphate	17.32
Bolton Salt	Halite	88.28	Sodium Sulphate	11.72

Through the analysis of the SEM no discernible traces of decomposition products, or bandages could be identified.

Conclusion

The analysis of a proposed embalming pot is important for a number of reasons. Firstly, it allows for the possibility that a source for the natrun used

could be identified. Secondly the examination of material associated with the mummification process can give a better understanding as to the procedures and rituals that had to be undertaken in order for the deceased to be prepared for the next life.

Due to the shape of the pot and the material found within it is proposed that rather than being an embalming refuse pot that instead it is a jar used in the practice of giving libations. If a provenance of the object had been known a clearer understanding as to its true use would be possible, as it is, it cannot be ascertained whether it had any direct use in the embalming process or whether it had been deposited in the tomb as a way for the deceased to perform libations, or whether in fact it was found in a temple. The lack of any discernible traces of decomposition products also aids in the proposal that object 1983.1.253 is in fact a libation vessel rather than a vessel used to store the refuse after the embalming process.

The fact that there was no trace of sodium carbonate present within the jar is not surprising as it has often been commented on at how sodium chloride and sodium sulphate are often found in relation to embalming refuse, however no known chemical analysis of a known libation vessel has taken place and therefore no comparisons can be made. However the analysis of objects of a ritual use such as those objects analysed by Lucas (1927b; 1933) in relation to the burial of Tutankhamen has shown a wide variety of results with some being almost pure sodium carbonate to others being high in sodium chloride content. There is consequently no reason as to why this vessel could not have been used in the more ritual side of the embalming process, in aiding the deceased to be washed and become pure upon his entrance to the afterlife.

4.3.2 Mummification Experiments

One of the enduring images of Egypt is the mummies of the ancient population. Questions have been asked since the beginning of scientific studies into the mummies as to how they were made, discussion on this has already taken place in section 4.2.1 and 4.2.3, and questions have been raised regarding the types of materials used (whether natrun or salt) and to the nature of these materials (solid or liquid).

Background

There have been a number of experiments into identifying the materials used in the mummification process. Perhaps the most pertinent of these experiments have been conducted by Garner (1979) and Brier and Wade (1995; 1997). Brier and Wade's (1995; 1997) experiments were the first of their kind as they replicated the mummification procedure using a donated human cadaver.

Brier and Wade Experiment

Brier and Wade (1997) based their experiment on an embalming table (Figure 44) found by Winlock (1922) in the tomb of Ipy. Using the same dimensions the human body was placed on a replicated board and covered with 273 kg of solid natrun (Brier and Wade 1997). After 35 days the body was removed from the table and investigated, the natrun used was dark brown and had clumped and there was a strong odour, but not of decomposition. The flesh was identified as being dark brown, almost black and *“As the natron was removed and the hands, feet and head emerged, we were struck by how similar they were to those of an ancient mummy”* (Brier and Wade 1997, 97) (Figure 45). The experiment served to prove that natrun was an exemplary desiccator and also the vast quantities of natrun that would be required in order to effectively mummify a body.

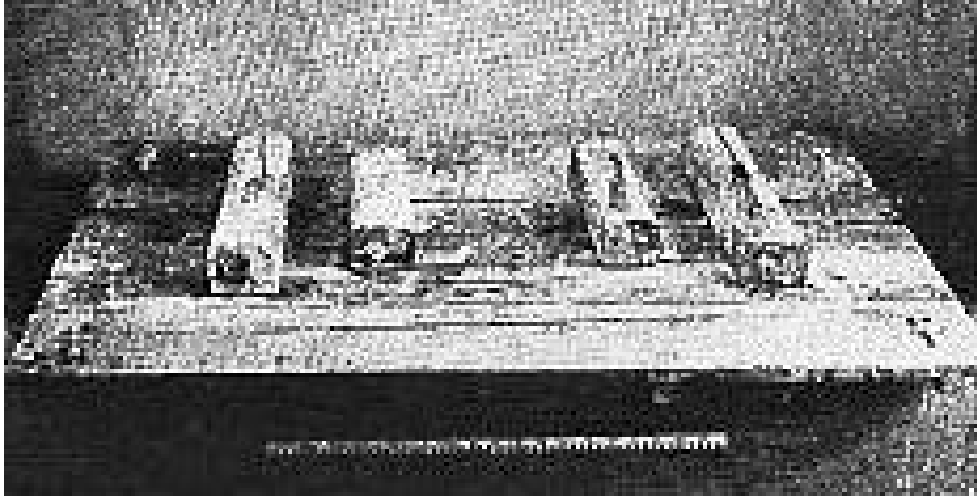


Figure 44: "Embalming table" from the tomb of Ipy (Winlock 1922, 34)



Figure 45: Photo showing the flesh of the mummy once it was removed from the natrun (Brier and Wade 1995, 9)

Garner Experiment

Garner (1979) was employed in investigating the material used for mummification. Using mice and measuring weight loss for 40 days he showed that sodium carbonate was the most useful desiccator and would take between 30 and 40 days to become sufficiently desiccated (Garner 1979). The experiments conducted also investigated additional treatments as described by Herodotus when he discussed mummification. In addition a number of solution experiments were conducted but having left them in the solution for 70 days Garner (1979) found the flesh to be poorly preserved in comparison to the body preserved using solid constituents (Figure 46 and Figure 47). These results form the basis of most modern studies of mummification and consequently have major implications for the way we understand the way flesh was preserved. However earlier studies conducted by Lucas (1908a) showed that a preservative bath could have been used:

“There is nothing in the results obtained to indicate that a natrun solution might not have been used by the ancient Egyptians for soaking the body previous to burial” (Lucas 1908a, 423)

Evidence discussed in 4.2.3 also suggested that this could be the case.

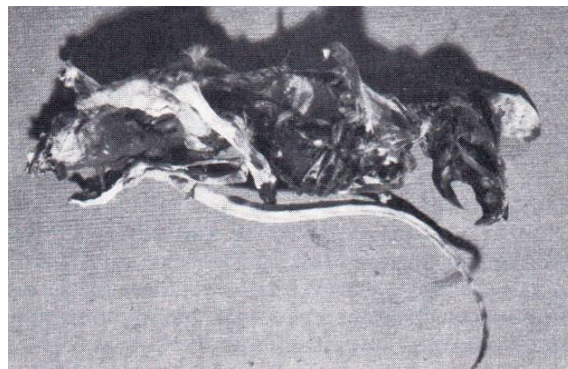


Figure 46: Mouse preserved in natrun solution. Decay has set in and the body is considerably damaged (Garner 1979, 20)

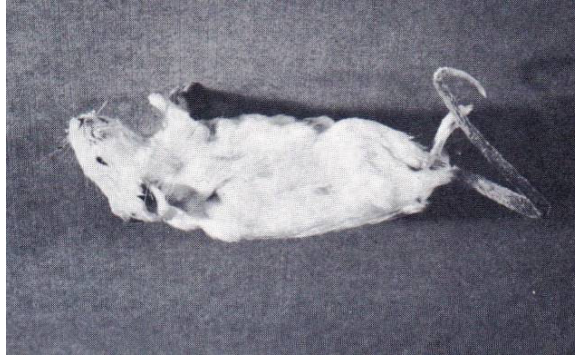


Figure 47: Mouse preserved in solid natron, little shrinkage and little loss of fur (Garner 1979, 20)

Purpose of Experiment

The purpose of the current mummification experiments were three-fold, firstly to identify an accurate animal model, secondly to determine whether there was any discernible difference between solid and solution and thirdly whether there was any difference between the three key minerals sodium carbonate, sodium sulphate and sodium chloride.

The three minerals sodium carbonate, sodium sulphate and sodium chloride were chosen as examples as they form constituents within both within geological samples and from the analysis of archaeological samples. The experiments were to identify how each reacted with the flesh of the deceased, whether they were preserved and how much moisture was removed through the process. A period of 40 days was chosen for the study as this date is commonly identified as the length taken to mummify a corpse and previous experiments by Brier and Wade (1997) and Garner (1979) had also identified this time period as a satisfactory one.

The choice of animal model is an important consideration when examining the process of mummification in humans. Besides the use of a human, the ideal animal model would be that of a pig (for reasons that have already been discussed in 3.10). This was not feasible however for the purpose of this

experiment, because of lab constraints and expense. In the past there have been two main animal models; mice (Garner 1979) and pigeons (Lucas 1908a; Lucas 1932b). A preliminary experiment was instigated using a pigeon (already defeathered) and a mouse. These animals were eviscerated and were placed within containers containing sodium carbonate both below and above the body. The bodies were removed after 40 days and the flesh of the animals were compared to each other to determine which was the most efficient. The fur from the mouse had begun to fall out although there was no obvious sign of decay. The pigeon fared a lot better with no obvious signs of decomposition and no obvious problems regarding preservation. In addition to these results the consideration of flesh versus fur was also examined and it was decided that the pigeon was the preferable animal model due to it both replicating the nature of mummification (ie. skin against the preservative, rather than the added barrier of fur) and due to the preferential results from the experiment.

Methodology

The reagents chosen were lab grade sodium carbonate, sodium sulphate and sodium chloride. There were not enough geological samples to have been utilised in these experiments and this would form a good portion of potential future work. Pigeons were bought defeathered and freshly killed from Pat Thomas Butchers of Faringdon, they were then eviscerated just prior to being covered in the chosen reagent or solution.

In the case of the solution experiments solutions were created using the reagent and 600ml of deionised water. Deionised water was chosen so as not to place any unknown detrimental or positive agents into the system. This involved dissolving 26g of reagent in the water (the amount required to make a saturated solution).

There was a series of three experiments, pigeon versus mouse (discussed above), sodium carbonate versus sodium chloride and sodium sulphate and the last experiment group was solid versus solution.

Pigeon versus Mouse

Once the animals were eviscerated they were placed in 1 litre beakers which had been partially filled with sodium carbonate reagent. They were then held in a central position whilst more reagent was added until it covered the body entirely, this ensured that the sodium carbonate surrounded the corpse and would therefore have no external environment that could not be accounted for. The containers were then moved to a fume hood, where they were stored for 40 days. The fume hood was used in order to prevent any decomposition smell contaminating the lab. They were kept at an ambient temperature of 19°C in natural sunlight. The animals were weighed prior to being placed in the containers and were weighed at the end of the forty days once they had been removed from the containers.

Different Sodium Compound Comparison

The methodology for this experiment is identical to the one above save for the difference in reagent. There were three pigeons one was placed in a beaker full of sodium carbonate, another sodium sulphate and another sodium chloride.

Solid versus Solution

Four pigeons were used for this experiment and were eviscerated. The pigeons to be placed in beakers containing a solid substance were placed following the methodology described above. Those placed in a solution were placed once a supersaturated solution had been formed for both sodium carbonate and sodium sulphate. The supersaturated solution was formed at room temperature with 26g of reagent in 600ml of deionised water. The containers were then

moved to a fume hood, where they were stored for 40 days. The fume hood was used in order to prevent any decomposition smell contaminating the lab. They were kept at an ambient temperature of 19°C in natural sunlight. The animals were weighed prior to being placed in the containers and were weighed at the end of the forty days once they had been removed from the containers and patted dry.

Results

Different Reagents

Table 14 shows the results of the experiment and shows that all the reagents were able to produce a desiccatory effect although to varying success, with sodium carbonate being the most successful.

Table 14: Table showing the results from a preliminary mummification experiment

Sodium compound	Mass of pigeon before (g)	Mass of pigeon after (g)	Difference in mass (g)	Difference (%)	Description after mummification
Sodium carbonate (solid)	441.1	339.8	101.3 (Loss)	23 (Loss)	Very fragile, limbs broke off on moving. Skin damaged
Sodium chloride (solid)	425.8	378.1	47.7 (Loss)	11 (Loss)	Eyes missing, skin damaged solid to the touch
Sodium sulphate (solid)	440.9	420.8	20.1 (Loss)	5 (Loss)	Very withered, terrible smell. Bloated to size of vessel. Very discoloured and substance crystallised to body

Solid versus Solution

Table 15 shows the results of experiments comparing solid sodium carbonate and solid sodium chloride versus the results of sodium carbonate solution and sodium chloride solution. The experiment shows the difference between solid and solution is that the pigeons placed in a solution gained mass whilst the ones placed in solid substances were desiccated.

Table 15: table showing the results of solid versus solution experiments

Sodium compound	Mass before	Mass after 1 day (g)	Mass after (g)	Difference in mass (g)	Difference (%)	Description after mummification	Figures
Sodium carbonate (solution)	340	400.8	424.6	23.8 (Gain)	7 (Gain)	No obvious decomposition, skin supple. Eyes preserved, damage to chest, skin soft to the touch	48, 49 and 50
Sodium chloride (solution)	349.6	407.7	473.8	66.1 (Gain)	16 (Gain)	Eyes present, skin supple. Body bloated. No sign of decay, no obvious skin damage	51, 52 and 53
Sodium carbonate (solid)	321.9	n/a	209.2	112.7 (Loss)	35 (Loss)	No overall discolouration to the salt. Carbonate formed a solid mass around the corpse. No eyes preserved. Feathers poorly preserved. Biological tissue reacted with carbonate to form a yellow fat	54, 55 and 56
Sodium chloride (solid)	368.3	n/a	274.6	93.7 (Loss)	25 (Loss)	Hard to the touch, eyes are not preserved. Feathers in good order, skin brittle. Well desiccated. No potential of limb movement. No insects	57 and 58



Figure 48: Before shot of pigeon prior to being preserved using sodium carbonate solution



Figure 49: After shot of pigeon once it has been removed from the sodium carbonate solution



Figure 50: After shot of pigeon once removed from sodium carbonate solution, showing the preservation of the skin, feathers and eye



Figure 51: Before shot of pigeon prior to being preserved using halite in solution



Figure 52: After shot of pigeon once it is removed from halite solution



Figure 53: Photo showing the preservation of the flesh and eye of the pigeon once it has been removed from the halite solution



Figure 54: Before photograph of pigeon preserved using sodium carbonate solid



Figure 55: After photograph of pigeon preserved using solid sodium carbonate



Figure 56: Photograph showing after effects of being preserved by sodium carbonate. See similarity to Brier and Wade's (1995) experiment (Figure 45)



Figure 57: Before shot of pigeon to be preserved by solid halite



Figure 58: After shot of pigeon once preserved in solid halite

Discussion

This experiment was designed to answer three separate questions; the first to identify the best possible animal model for mummification experiments, the second was to compare the desiccative ability of the three most commonly identified sodium compounds in association with mummification and mummies, the third set of experiments was to compare the preservation ability of solid sodium compounds versus sodium compound solutions.

The results of the first study showed that pigeon was a better animal model than that of mouse. There were a number of reasons for this finding. Firstly pigeon has no barrier between the flesh of the model and the sodium compound, unlike the mouse which has fur as a barrier and secondly pigeon is available fresh to those researchers who do not work or have the ethics approval for experimentation on mice. In all the most preferential animal model to be chosen would be a pig if the facilities allowed, but pigeon would suffice for the smaller scale mummification experiments often encountered.

The results of the second study showed that of all the preservatives used sodium sulphate was by far the poorest, with obvious states of decomposition seen and a smell of decomposition identified. In contrast sodium carbonate was by far the best preservative, although the observations of both the pigeons preserved using sodium carbonate and sodium chloride showed that there was damage to the skin and that the flesh was very brittle, indeed the remains were so brittle that on moving the leg of the one preserved in sodium carbonate the leg broke off. These results are of interest as it poses the question how would the embalmers be able to wrap the deceased once desiccated if the remains were in such a fragile state. Even the work of Brier and Wade (1997) (Figure 45) showed that the flesh looked dry and quite brittle and would have therefore made it more difficult to wrap the body than if the body was fresh.

The third set of experiments were conducted to identify which method preserved the flesh better. The results of these experiments were surprising in that a solution of sodium carbonate showed an increase in weight, and that the bodies unlike those seen in results of other experiments, were well preserved (including in the case of sodium carbonate the preservation of the eyes) (Figure 48 and Figure 50), and the flesh and body remained soft and pliable. Indeed they looked very life like and there was no outward sign of decomposition. The results of the experiment showed that the solution experiments preserved the pigeon in a life like state with no dehydration. The solid substances were again the better desiccators, with sodium carbonate being the most effective. The birds preserved using solid salts were preserved in a mummy like state (Figure 56 and Figure 58), with skin withered and slightly shrunken.

The results of this study show that the use of natrun went far beyond its use in religious rites and purification practices, and was used as an effective desiccant that would have had additional spiritual properties. Salt was also a reasonable desiccant, however sodium sulphate was not, and significant quantities of this substance would have cause for poor preservation and would have led to the start of decomposition in the deceased. The study also showed that the use of sodium salts in solution had the potential to be an effective mummification agent.

The experiment was important to identify key preservers and to identify key ideas about what was actually used and why in the mummification process. Unfortunately the results can not answer such fundamental questions as; what were the Egyptians looking for when they preserved the flesh? Were they looking for a "mummy like state" where the flesh looked desiccated and drawn, or were they after a more "life like" body? These questions are important, once the flesh was removed from the solution it began to dry and if the body had have been wrapped and then buried there is no reason as to why it would not look like a mummy upon its discovery some 3000 years later. It is also known that the body would remain within the embalmer's workshop for a further 30

days in order to perform all the necessary religious processes and indeed by the time the body was removed to be buried they would have been solid enough to be moved. In addition to this the dissolution of the solid into a solution would have allowed for the removal of impurities such as sodium sulphate which would have impeded the process, and this could even explain the difference in findings between the mummies themselves and embalming pots, whereby little sodium sulphate is found on a corpse, but embalming pots are often found to include such a material. In addition to this the work by Brier and Wade (1997) showed that 273kg of natrun was required to preserve a human corpse, results of this experiment shows that less than 5% of the solid required for this would be needed to preserve the flesh in a natrun bath.

Although some questions cannot be answered from these results validation can be given to the Egyptians choice of natrun as a desiccant showing that it wasn't only due to its religious connotations that natrun was chosen. Salt was also an effective desiccant and unlike sodium sulphate would not have effected the preservation of the flesh.

Conclusion

In conclusion the bulk of the results have confirmed earlier experiments in that sodium carbonate was identified as the better desiccant in comparison to sodium chloride and sulphate, and in turn sodium sulphate was a poor desiccant that had negative effects on the preservation of the flesh. Contrary to a number of earlier experiment however, the results of this study showed that preservation using a solution was entirely possible and would have led to a more life like corpse prior to being bandaged than if a solid component was used. This aspect of the ritual should not be ignored, the whole purpose of the mummification process was to retain a connection between the deceased and their life and the ability to produce a life like mummy would have been far more beneficial to the Egyptians than has previously been considered. The results of these experiments was intended to reopen the wider debate surrounding the

formation processes behind the manufacture of a mummy, rather than to conclusively prove either way whether liquid or solid is the better mummy producer.

4.4 Conclusion

Mummification is by far the most commonly identified aspect of ancient Egyptian society and from the experimental work and literature studies undertaken it was identified that mummification is a complicated necessity. The work has shown that mummification and purification are intertwined through the identification of a number of parallel texts and that the use of natrun as a desiccant is primarily based on its role in religious purification.

As has been shown from this research, purification and mummification are intrinsically linked. The purification rituals of the ancient Egyptians can still be seen today in many of the Semitic faiths, however the role of natrun and salt has little been discussed and the work here showed how both were used in order to maintain both personal and religious purity. Archaeological evidence showed the presence of both salt and natrun crystals in laundered clothes, and the presence of high purity natrun from Tutankhamen's tomb, fulfilling prayers set out in the Pyramid texts. This is highly significant as it showed that not only were the prayers/spells identified as a religious practice but were taken to a practical level whereby the prayers were followed by the letter, showing how deeply religious and seriously funerary practices were taken.

Natrun and salt are known to be highly desiccative and have been identified on both mummies and from embalming caches. There is little documentary evidence regarding Egyptian mummification and most information gathered comes from mummies themselves and other archaeological evidence. Experimental mummification is also a key way to understand the practicalities of mummification, the results from the experimental mummification here have wide ranging implications. Like many archaeological subjects ideas around mummification have changed quite dramatically, from the belief that mummies were produced in a natron bath through to the use of solid desiccants. The experiment tested these two key ideas, and noted that although sodium carbonate is a very effective desiccant that when it was in a liquid the

preservation was by far more acceptable, especially in the terms of life like forms, pliability and preservation (ie. eyes were well preserved). The amount of sodium carbonate needed to preserve the body was also a key implication, Zimmerman et al. showed in their study that 273kg of sodium carbonate would be needed per body, require a huge amount of natron every year, at least 273,000kg if only 1000 mummies were produced a year. There is no doubt that natron would not be reused, for two main reasons. Firstly embalming refuse was buried near to the remains of the human that they helped serve, and secondly once used it would take longer to preserve the remains and would cause poor sanitation.

Therefore there are major implications in Egyptology in understanding both mummification and purification.

Chapter 5: Evaporite Mineralogy

The uses of salt and natron have been discussed in depth in the previous two chapters. Chapters 5 and 6 investigate the formation of these minerals since this chemistry and mineralogy is an integral part to understanding further, the reasons behind their uses. In addition to salt and natron this section also covers additional salts; namely burkeite, thenardite and trona - which are associated with deposits of salt and natron.

Sodium salt evaporites can form in three distinct situations. The first, and probably the most studied, are the marine evaporitic deposits, second are the non-marine deposits and the third type of formation takes place as a result of mixed (or hybrid) brines (Warren 1997). The Wadi Natrun, along with many other continental salt/soda lakes, falls into the second category. Consequently this chapter will focus on the basics of non-marine evaporitic settings (5.1) and detail the most common sodium compounds in these environments (5.2-5.5). Section 5.6 will concentrate further on the mineralogy of some of these non-marine evaporitic deposits.

5.1 Non-marine evaporitic deposits

Before a discussion on the nature of non-marine evaporitic systems can begin the term “evaporite” needs to be defined. A simplistic definition is that an evaporite is *“a deposit that was originally precipitated from a saturated surface or near surface brine by hydrologies driven by solar evaporation”* (Warren 1996, 115). Accordingly the phrase ‘non-marine evaporitic deposits’ can refer to any deposit formed through the solar evaporation of non-marine brines (Warren 1999). There are few published studies which model non-marine systems, although recently there has been a resurgence in interest in these environments

as a means of studying patterns of climate change since changes in deposits can give clues as to the climate in the area over time (Benison and Goldstein 2001; Smoot and Lowenstein 1991).

Non-marine environments are found throughout the world in arid, semi-arid or sub-humid regions (Hardie and Eugster 1970; Schreiber and El Tabakh 2000; Smoot and Lowenstein 1991). As well as these different environments there are five diverse chemical types of nonmarine basin that have been identified (Hardie and Eugster 1970; Warren 1997) (Table 16):

- 1) Na-CO₃-Cl;
- 2) Na-CO₃-SO₄-Cl;
- 3) Na-SO₄-Cl;
- 4) Na-Mg-SO₄-Cl and
- 5) Ca-Mg-Na-Cl.

Table 16 shows the typical mineralogy that is expected from deposits that have the brines discussed above. It also shows an example of a typical brine deposit. These typical mineral formulations show that in all instances halite is produced, whilst minerals such as natron and thenardite are only produced in a handful of cases. It is interesting to note however that some minerals only form in some type of brines, such as burkeite, which only forms under Na-CO₃-SO₄-Cl brine conditions. These minerals are of interest as it acts much like a fingerprint in allowing the geochemist or mineralogist to identify the type of brine that a lake contains and would therefore allow for a comprehensive identification of the brine system.

Table 16: Table showing the minerals formed from five different brine types, (based on (Warren 1997, 152))

Brine Type	Primary Minerals	Chemical Formula of Minerals	Primary Key Deposits
Na-CO ₃ -Cl	Halite Nahcolite Natron Thermonatrite Trona	NaCl NaHCO ₃ Na ₂ CO ₃ .10H ₂ O Na ₂ CO ₃ .H ₂ O NaHCO ₃ .Na ₂ CO ₃ .2H ₂ O	Lake Magadi
Na-CO ₃ -SO ₄ -Cl	Burkeite Halite Mirabilite Nahcolite Natron Thenardite Thermonatrite	Na ₂ CO ₃ .2Na ₂ SO ₄ NaCl Na ₂ SO ₄ .10H ₂ O NaHCO ₃ Na ₂ CO ₃ .10H ₂ O Na ₂ SO ₄ Na ₂ CO ₃ .H ₂ O	Searles Lake
Na-SO ₄ -Cl	Gypsum Glauberite Halite Mirabilite Thenardite	CaSO ₄ .2H ₂ O CaSO ₄ .Na ₂ SO ₄ NaCl Na ₂ SO ₄ .10H ₂ O Na ₂ SO ₄	Death Valley
Mg-Na-SO ₄ -Cl	Bischofite Bloedite Epsomite Glauberite Gypsum Halite Hexahydrate Kieserite Mirabilite Thenardite	MgCl ₂ .6H ₂ O Na ₂ SO ₄ .MgSO ₄ .4H ₂ O MgSO ₄ .7H ₂ O CaSO ₄ .Na ₂ SO ₄ CaSO ₄ .2H ₂ O NaCl MgSO ₄ .6H ₂ O MgSO ₄ .H ₂ O Na ₂ SO ₄ .10H ₂ O Na ₂ SO ₄	Saline Valley
Ca-Mg-Na-Cl	Antarcticite Bischofite Carnallite Halite Sylvite Tachyhydrite	CaCl ₂ .6H ₂ O MgCl ₂ .6H ₂ O KCl.MgCl ₂ .6H ₂ O NaCl KCl CaCl ₂ .2MgCl ₂ .12H ₂ O	Dead Sea

Eugster and Hardie (1978) developed a schematic in order to help determine the type of brine seen. These ions and their concentrations are the chemical constituents which allow the non-marine deposits to be formed. These are the common types of parent brines found within non-marine evaporite settings, and the proportion of chemicals within the brine determines the formation of specific minerals (Figure 59). These show again a typical example of the type of lake for a certain type of brine, but also show how these brine types have evolved, depending on the concentration of three different chemicals, HCO_3 , Ca and Mg. When there is less Ca and Mg to HCO_3 brines such as can be found at Searles Lake are produced. If HCO_3 and Ca and Mg are equal to each other then brines such as the Dead Sea are found. If Ca and Mg are of greater concentration than HCO_3 then lake brines such as at Death Valley are found. Although there are intermediate steps within these systems to determine the exact brine formed, such as sulphate reduction of an $\text{Na-CO}_3\text{-SO}_4\text{-Cl}$ brine system forms a $\text{Na-CO}_3\text{-Cl}$ brine system such as seen at Lake Magadi. Both Table 16 and Figure 59 give a basic overview as to how these brines evolve and typical examples of these lake systems.

Evaporites form where evaporation rates exceeds inflow (Schreiber and El Tabakh 2000; Smoot and Lowenstein 1991). This means that the salt concentration continues to build until the saturation point where the precipitation of the salts within the system will occur (Shortland 2004). The system is heavily reliant on a delicate state of balance between inflow and evaporation (Eugster and Jones 1979) and if the rate of inflow greatly exceeds evaporation then dilution or flooding can take place which changes the chemical nature of the deposits (Smoot and Lowenstein 1991).

In mineralogical terms the same types of deposits are often found in both non-marine and marine settings, for example halite can be found in both. However the formation processes for these deposits often differ. One difference is that in a marine system the deposits are generally uniform, whereas in non-marine

systems the deposits can vary markedly even within a single lake system; as will be demonstrated when discussing the Wadi Natrun. Tucker and Cann (1986) also suggest that the use of trace element analysis helps differentiate between marine and non-marine environments since marine deposits tend to have a much higher concentration of Br (Bromine) than non-marine deposits.

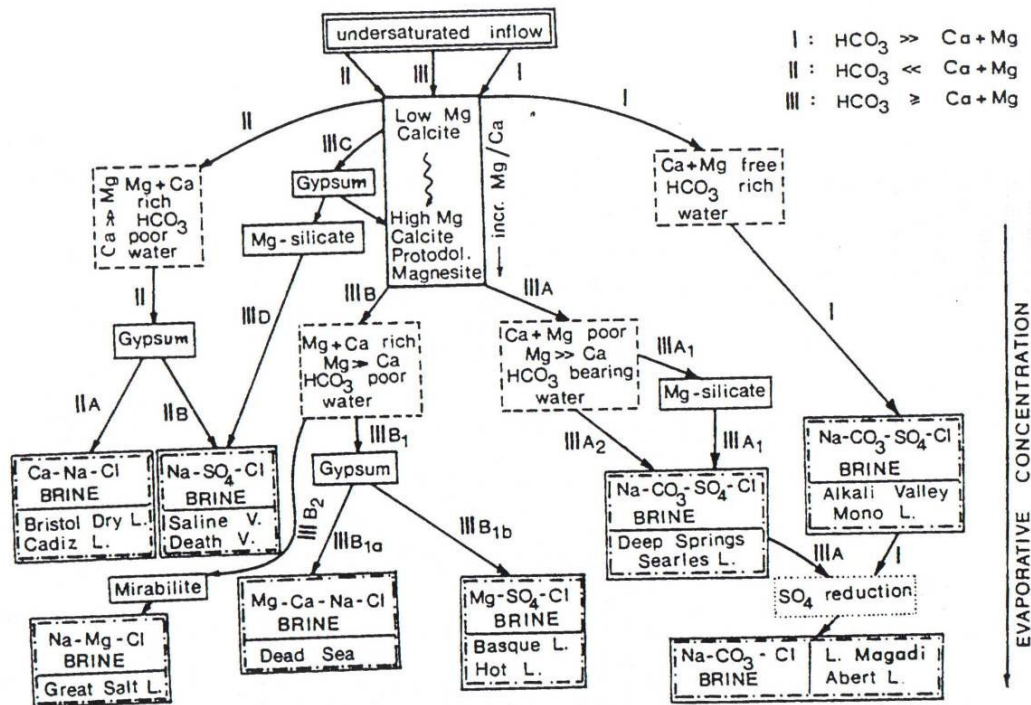


Figure 59: Image showing the brine evolution pathways of continental lake waters (Eugster 1984, 239)

The presence of the particular salts found within a non-marine system are dependent on two things: firstly the chemical nature of the inflow waters and secondly the mechanisms by which the water becomes a brine (Eugster and Jones 1979; Sinha and Raymahashay 2004; Smoot and Lowenstein 1991; Tucker and Cann 1986). The order in which the various salts precipitate is also a function of these same two factors (Smoot and Lowenstein 1991). For example a brine whose main constituents are Na-K-HCO₃-CO₃-SO₄-Cl may

form trona, natron, nahcolite, halite, mirabilite or thenardite, depending on concentration of the salts and the evaporation rate (Eugster 1966; Hardie 1984; Smoot and Lowenstein 1991). As individual salts precipitate out this changes the chemical nature of the brine and allows for new minerals to form rather than what might have been expected from an analysis of the inflow (Eugster and Jones 1979). Moreover non-marine systems are also complicated by mineral recycling (or “syndepositional recycling”); these are back-reactions which occur when the inflow water redissolves previously deposited minerals. Smoot and Lowenstein (1991) state that the bulk of salts found within ephemeral environments may be derived from this recycling process and this is where the preferential dissolution of more soluble salts such as halite occurs (Eugster and Jones 1979; Goodall et al. 2000; Smoot and Lowenstein 1991; Warren 1997). Warren (1997) states that these back-reactions occur both at the sediment-brine interface and within shallow brines. These salts can then be redeposited in either their original form or a modified form, and this causes difficulties when analysing the stratigraphy of nonmarine deposits. However it is possible to identify some of these redeposits by the presence of “pseudomorphs” and “relic” mineral cores (Warren 1997).

Despite the complication of back-reactions stratigraphy is the best basis on which to identify the order in which the salts precipitate. This should follow the pattern of least soluble salts - such as calcium carbonate (Warren 1997) - being precipitated first (Shortland 2004) and the most soluble - such as halite - being precipitated last. Indeed Jenyon (1986) states that in order for halite to form as an evaporite within the system the brine needs to be reduced to around one-tenth of its original volume. This means that it is possible to devise models to predict which minerals should be present and where in the system they should appear. However, according to Jenyon (1986), the precipitation order and the distribution of evaporite minerals within the deposit is often quite different to that which are predicted by these models when looking at non-marine deposits evaporating to complete dryness. Shortland (2004) comments on the

inaccuracies of trying to utilise a simplistic model to explain a complex formation pattern such as that seen in the Wadi Natrun.

The environment of lakes which form non-marine deposits is high in both temperature and pH. This is caused by the brines trapping the infra-red radiation from the sun, the consequent absorption of this radiation causes the temperature of the water to rise as high as 55°C (Schreiber and El Tabakh 2000). The additional presence of a microbial community within the system can lead to a further increase in temperature and, according to Schreiber and el Tabaleh (2000), this can account for around 3-6°C. The high concentrations of CO_3^{2-} and Cl^- in these lakes as a product of the evaporation mean that the pH value is typically between 8 and 12 (Jones et al. 1998).

Introduction to 5.2-5.5

Besides the obvious economic value of salt there is also a demand for sodium compounds such as sodium carbonate and sodium sulphate. One of key uses of these compounds is in the detergent industry. Meenan (1995) explains that this is due to their ability to crystallise to a high form which has both a high surface area and which is highly porous which enables them to be an effective basis for detergents.

5.2 Chemistry of Salt

Halite or common salt is one of the most common evaporitic minerals and is found across the world and in both nonmarine and marine systems. Pure salt is rare in nature as it often contains inclusions, these inclusions being dependent on the system in which they are found. One common form of salt is that of “rock salt” which refers to massive, compact substances which are coarsely granulated (Kaufmann 1960).

Salt crusts are believed to form through two main processes, namely efflorescence (the loss of water from a salt on exposure to air) and precipitation (formation of a salt from a supersaturated solution whereby a solid is formed and leaves the aquatic chemistry system) (Goodall et al. 2000), and these two processes affect the shape of the halite crystals. For example efflorescent crusts are determined by their powdery texture and occur by direct crystallisation onto sediment grains - these can form at either the sediment-air interface or within the sediment itself (Goodall et al. 2000). Precipitated crusts forms by direct evaporation and forms layered crusts as it sinks through the water-air interface (Goodall et al. 2000).

Salt is known to occur in a number of locations although major deposits are known in the Dead Sea and the Great Salt Lake in Utah. Other locations for salt formation are discussed in section 5.7. There have been few studies into the solubility and evaporation of salt, however it is known that 35.9g dissolves in 100ml of water. Akridge (2008) conducted a survey of evaporation methods for the production of salt using the three most common methods deduced from archaeological and ethnographic records, being; solar evaporation; evaporation through the immersion of a heated object and from the brine being warmed in a heated pan.

5.3 Chemistry of Sodium Carbonate Minerals

Sodium carbonate minerals are commonly formed through an evaporitic process. The table below details these sodium carbonate minerals together with their chemical formula and a summary of where they most commonly occur in nature. Of the sodium carbonates the only ones discussed in depth in this document are natron, burkeite and trona. This is because natron, burkeite and trona are commonly found within the Wadi Natrun and are the most economically important.

Table 17: Table showing the names of common sodium carbonate minerals, their formula and the place in which they are most commonly found

Mineral	Formula	Commonly found
Thermonatrite	$\text{NaCO}_3 \cdot \text{H}_2\text{O}$	Russia
Trona	$\text{NaHCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$	Searles Lake, California
Nahcolite	NaHCO_3	Searles Lake, California
Bradleyite	$\text{Na}_2\text{PO}_4 \cdot \text{MgCO}_3$	Green River, Wyoming
Pirssonite	$\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$	Searles Lake, California
Tychite	$2\text{MgCO}_3 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$	Searles Lake, California
Northupite	$\text{Na}_2\text{CO}_3 \cdot \text{NaCl} \cdot \text{MgCO}_3$	Searles Lake, California
Natron	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	Nevada; Canada
Dawsonite	$\text{NaAl}(\text{CO}_3)(\text{OH}_2)$	Canada
Gaylussite	$\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 5\text{H}_2\text{O}$	Searles Lake, California
Shortite	$\text{Na}_2\text{CO}_3 \cdot 2\text{CaCO}_3$	Green River, Wyoming
Burkeite	$\text{Na}_2\text{CO}_3 \cdot 2\text{Na}_2\text{SO}_4$	Searles Lake, California
Hanksite	$2\text{Na}_2\text{CO}_3 \cdot 9\text{Na}_2\text{SO}_4 \cdot \text{KCl}$	Searles Lake, California

5.3.1 Chemistry of Natron

Natron, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, refers to a specific mineral, known chemically as sodium carbonate decahydrate. Unfortunately, however, natron is a word used differently in different contexts. 'Natron' has been used to describe any product

derived of the Wadi Natrun (Shortland 2004) and has been used to describe a mixture of sodium carbonate-sodium bicarbonate (Lucas and Harris 1962). For the purposes of this document the term 'natron' will refer to the specific mineral sodium carbonate decahydrate; and the term 'natrun' will be used more generally to refer to "a usually complex, often polyphase evaporitic deposit rich in carbonates of sodium" (Shortland 2004).

One of the primary complications surrounding an analysis of the formation of natron is that it is highly temperature dependent. According to Heikkinen natron is never found in environments where temperatures reach 35°C (Heikkinen 2005). This leads to an assumption that the precipitation of natron occurs during the winter months rather than summer (Eugster 1966). The formation of natron at low temperatures has been substantiated by work done by Libowitzky and Giester (2003) and Suner et al. (2003). If the brine is above 35°C then the minerals thermonatrite or trona will be formed in preference (Heikkinen 2005; Libowitzky and Giester 2003; Suner et al. 2003). Another controlling factor of natron precipitation is the presence of carbon dioxide. This appears to combine with a rise in temperature to determine whether it is trona or thermonatrite that is deposited (Suner et al. 2003).

Chemically natron is thought to be pseudo-centric, with the centric symmetry being disturbed by the presence of the carbonate groups. It is also believed that there is hydrogen bonding between the hydrate and carbonate units which form in a sodium chloride arrangement (Libowitzky and Giester 2003). The solubility of natron is less than that of salt at 30g per 100ml of water at the temperature of around 20°C.

5.3.2 Chemistry of Trona

Trona is a sodium carbonate mineral and is also known as sodium sesquicarbonate ($\text{Na}_3\text{HCO}_3\text{CO}_3 \cdot 2\text{H}_2\text{O}$). The term trona is derived from the Arabic word for natron. Trona can be found in various locations throughout the

world, some of which are discussed here, and some of which are discussed in section 5.7.

Trona is an important economic deposit in Africa where it has been reported to be the second most commonly utilised mineral in most African households (Nielsen and Dahi 2002). Like many minerals trona goes under a host of names. Trona is also frequently cited in the literature in reference to Magadi. It is believed that the term *magadi* is a development of the Masai word *magad* meaning bitter (Nielsen 1999). Unfortunately this term can often lead to be confusion with the mineral magadite.

The chemical structure of trona was first derived using X-Ray Diffraction by Brown, Peiser and Turner-Jones (Choi and Mighell 1982), and it has been found to be monoclinic-prismatic (Pabst 1959). Trona is a sought-after resource due to the ease by which it can be converted to sodium bicarbonate. From studies into the transformation between trona to sodium bicarbonate it was discovered that trona can remain in a stable state until 57°C and transformation between trona and sodium bicarbonate cannot take place at lower temperatures (Cho et al. 2008). This inability to transform between the two compounds at lower temperatures is due to the presence of structural variation within trona at lower temperatures (Cho et al. 2008). The structural variation does not allow for the CO₂ or water vapour present within the reaction system to react as there is less surface area than is found at higher temperatures (Cho et al. 2008).

Trona is rarely discovered in a pure state and is often found together with other compounds such as halite and thenardite (Sodipo 1993). The primary theory regarding the formation of trona in natural environments is that trona is evaporated from water rich in Na⁺ and HCO₃⁻ which is produced by silicate hydrolysis (Earman et al. 2005). However in recent years there has been an increasing belief that trona could be formed through “excess” carbon dioxide input (Earman et al. 2005). This “excess” is formed through the decay of organic

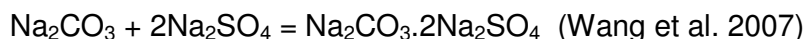
matter within the deposit. This is a theory which still needs to be examined in more detail before it can be firmly established.

Deposits include Sweetwater County, USA (Mendenhall 1940) which was discovered in the 1930s. Another famous deposit, also in America, is the Green River formation. These thick monomineralic beds were formed by three main processes which together combined to allow the trona to precipitate. These three processes are 1) The addition of carbon dioxide into the system 2) a decrease in the surrounding temperature and 3) a constant evaporation temperature. As these conditions appear to occur wherever there is trona then it is supposed that they are the mechanisms which allow its formation. Trona is also found in a number of major deposits in Africa, such as Lake Magadi (Kenya), Lake Natron (Tanzania), El-Atrun (Sudan), Lake Katwe (Uganda); India (see section 5.6) and also Turkey - such as the deposit in Beypazari-Ankara (Ustundag et al. 2007).

5.4 Chemistry of Burkeite

Burkeite ($\text{Na}_2\text{CO}_3 \cdot 2\text{Na}_2\text{SO}_4$) is a naturally occurring double salt (a salt which contains more than one anion or cation) of sodium carbonate-sodium sulphate. Burkeite can be found in some lake deposits but is probably most famous for its discovery in Searles Lake. The mineral was discovered, named and characterised by Foshag (1935).

It has the chemical structure orthorhombic-dipyramidal (Meenan 1992), although it is occasionally reported in the literature as orthorhombic (Foshag 1935). It is formed through the crystallisation of a brine which contains both sodium carbonate and sodium sulphate (Heikkinen 2005; Meenan 1992; Shi and Rousseau 2003).



It is believed that burkeite is formed as a result of the reduced stability of both sodium sulphate and sodium carbonates at higher temperatures (Shi and Rousseau 2001). Heikkinen (2005) reported that sodium sulphate's solubility increased with temperature but that this was disrupted with the addition of sodium carbonate into the system.

Besides Searles Lake, there are a number of other deposits which contain burkeite, these are Lake Turkana (Kenya) and in lakes in the Konya basin in Turkey (Giuseppetti et al. 1988).

The main focus of work on the chemical nature of burkeite has been conducted by Shi and Rousseau (2001; 2003), Giuseppetti (1988) and Meenan (1992; 1997; 1995).

5.5 Chemistry of Thenardite

Thenardite (Na_2SO_4) is named after Louis Jacques Thenard. It is a sodium sulphate compound often found in conjunction with mirabilite - another sodium sulphate (Wiedemann and Smykatz-Kloss 1981). It is an evaporative mineral and has been found in a number of deposits, including the Wadi Natrun (Cole 1926; Garrett 2001; Wiedemann and Smykatz-Kloss 1981). Indeed in the early 20th Century Lake Beida was mined for its thenardite deposit (thenardite is used in the paper industries, and is also utilised in the soda manufacturing industry). In Lake Kuchuk in Russia the chloride rich nature of the brine allows for the transformation between mirabilite and thenardite (Garrett 2001).

Thenardite is a useful for determining the temperature of the brine in which it formed as it is only deposited above 33°C (Cole 1926), although if the brine in which thenardite exists is highly chloride rich then it can precipitate in temperatures of >9°C (Garrett 2001). It is highly soluble with 20g dissolving per 100g of water at 20°C, increasing to 50g in 100g at 32.4°C (Fahey 1986). Thenardite's chemical structure is orthorhombic-dipyramidal.

5.6 Other Deposits

Although this project examines the mineralogy and the formation processes within the Wadi Natrun (Chapter 6) it is relevant to discuss other non-marine evaporitic deposits throughout the world which present similar mineralogies.

5.6.1 Americas

Possibly the most intensively studied non-marine saline deposit is that of Searles Lake in California. This is notable for being the place where burkeite was discovered and is also an economic trona deposit (Eugster and Smith 1965; Foshag 1935). Besides burkeite and trona, nahcolite is also formed there (Eugster and Smith 1965). Consequently the lake system has been defined as being $\text{NaHCO}_3\text{-Na}_2\text{CO}_3\text{-H}_2\text{O}$ (Eugster and Smith 1965). The presence of trona suggests that the brine temperature is between 32°C and 35°C (Eugster and Smith 1965). Trona forms somewhere between 40% and 70% of the overall mineralogical deposit present within the lake system (Eugster and Smith 1965).

In British Columbia, there are five areas of non-marine evaporitic lakes: Osoyoos; Kamloops; Basque; Chilcotin Plateau and Cariboo Plateau (Renaut 1990). Of these five the last is perhaps the most studied and best understood. In this system natron precipitates freely (Renaut 1990), perhaps because of the low temperature range (13°C to 17°C in July). Halite, thenardite and trona also precipitate indicating that the brine is of the $\text{Na-CO}_3\text{-SO}_4\text{-Cl}$ type (Renaut 1990).

5.6.2 India

Scant work has been conducted on the non-marine deposits of India, however one important site - due to its impact of the bioproductivity of the land - is that of the Indo-Gangetic plains (the flood plains of the Ganges) in Uttar Pradesh State (Datta et al. 2002). Efflorescent crusts of trona and thermonatrite have been found in these areas and this is believed to account for the soil having a pH of

10.5. The minerals form through the fast evaporation which occurs after the rainy season (Datta et al. 2002). According to Datta et al. (2002) the formation of these deposits can only occur once the system has degassed itself of carbon dioxide, a factor often cited in the literature.

5.6.3 Turkey

Natron, as has already been discussed, is a rare mineral as it forms only under a relatively limited set of conditions. One deposit which has been studied is that of the Baypazari deposit in Turkey, near Ankara. In this system natron has been found within trona deposits and is also found in connection with themnatrite, this lends further credence to the theory that at higher temperatures natron decomposes to form themnatrite (Suner et al. 2003). The trona deposits were not known about until they were chanced upon by a 1979 expedition for coal (Nasun-Saygih 2003).

There are further non-marine deposits in Turkey, including the Tuz Gölü basin (the salt lake basin) which is both rich in carbonate and sulphate (Camur and Mutlu 1996). The basin itself is in central Anatolia and covers 16000km², it is fed by three major rivers the Peçeneközü, the Uluiрмаk and the Insuyu, and is surrounded by mountains (Camur and Mutlu 1996). It is believed that syndepositional recycling occurs within the system, and that this is accounted for by the evolution of the waters from a sulphate rich system to a chloride rich one (Camur and Mutlu 1996). There are thought to be two zones within the deposit which each exhibit different mineralogical formations and the main salt formed is sodium chloride (Camur and Mutlu 1996).

Tuz Gölü is also renowned for the formation of “salt biscuits”, where halite is precipitated and larger crystals form on the lower side of a mineralogical formation and smaller crystals form on the top (Muller and Irion 1969). These “biscuits” occur separately but have been known to merge and form due to the nature of salt precipitation in the upper layers of the brine until such time as the

crystal formations become too heavy to be suspended and they fall to the bottom of the lake (Muller and Irion 1969).

5.6.4 Africa

Africa has a variety of deposits of non-marine origin although for the purposes of this project the Wadi Natrun, Egypt and Al-Natrun, Sudan are discussed elsewhere. Perhaps the two most well known deposits are Lake Magadi (Kenya) and Lake Natron (Tanzania). Both of these deposits form trona (Day 1993; Jones et al. 1977; Monnin and Schott 1984; Nielsen 1999). There are some deposits in southern Africa, although these are rarely studied due to the comparative ease in studying the larger and better-known deposits in East Africa (Day 1993). The deposits in southern Africa are typically chloride rich; in contrast to the carbonate/bicarbonate rich systems present in East Africa (Day 1993). Besides the presence of trona in Lake Natron, thermonatrite has also been discovered, suggesting that the brine was undersaturated in terms of carbon dioxide (Nielsen 1999). A non-marine evaporitic lake from Northern Namibia has shown the presence of both thenardite and burkeite with a small inclusion of halite (Mees 2001). Lake Logipi is the most northern lake in the Kenyan East Rift (Castanier et al. 1993) and its microbial community allows for the formation of carbonate and bicarbonate ions - sodium carbonate crusts within the lake are also quite common along with forms of sodium silicates (Castanier et al. 1993). A study of a non-marine deposit in Tunisia, Chott el Djerid, showed that halite was the most common mineral formed, and that the inflow waters become more concentrated in respect to halite due to mixing of inflow and surface evaporation (Bryant 1993).

Lake Magadi in southern Kenya is possibly the best known and most extensively studied system in Africa. It produces trona and has been known to have trona deposits up to 40m thick (Jones et al. 1977) and is described as an "ephemeral saline lake" (Monnin and Schott 1984). The brine present within the system is Na-Cl-CO₃ and it is believed that these ions form 98% of the total ions

present within the lake (Monnin and Schott 1984). According to Eugster and Jones (1977), Lake Magadi has the most concentrated brines known in the African Rift Valley. The sources of inflow into the system range both in temperature (28°C and 85°C) and in ion concentration (Jones et al. 1977; Monnin and Schott 1984). The lake waters come from “lagoon” brines, as there are no rivers or streams which feed the deposit directly (Jones et al. 1977). The system within the lake means that trona is formed first, followed by halite and then thermonatrite, although natron has also been known to precipitate in preference to thermonatrite and this is dependent on temperature (Monnin and Schott 1984). There is no evidence to suggest syndepositional recycling occurs within the deposits (Monnin and Schott 1984).

5.7 Conclusion

This chapter examined the chemistry of a number of minerals that form in non-marine environments. These minerals continue to be of economic importance today and an understanding of their chemistry is crucial to discerning the processes by which they form. Although Chapter 6 focuses on the Wadi Natrun - the source identified as being the largest source available to the Egyptians for their natrun and also for their salt – there are other non-marine sources for these minerals. These additional examples of non-marine evaporitic mineral formation add to our understanding of the geochemistry and mineralogical formation that occurs in the Wadi itself.

Chapter 6 focuses on the historical and chemical nature of the lakes found within the wadi, and it is through these and the formation of the minerals that a better understanding of the use and exploitation of the minerals can be gained.

Chapter 6: Wadi Natrun

Sodium chloride and sodium carbonate have a long history of exploitation and use across the world, not least in Egypt. Although a number of ancient sites of exploitation of these minerals in Egypt can be identified, the Wadi Natrun is by far the one most discussed both in the archaeological and literary records. The Wadi Natrun is an important case study through which to understand both the formation processes behind the deposition of these economically important minerals as well as the changing chemical and geographical history of the system due to exploitation.

The Wadi Natrun forms a major portion of this research, for a number of reasons. Firstly, it has been identified as a potential source of both natron and salt from the Middle Kingdoms onward, and the resources from within the wadi are believed to have been utilised in all three industries dealt with in this research. Secondly, the identification of sites of archaeological sites of industrial importance along the Wadi Natrun's shores indicates its importance as a resource. An understanding of the formation of the minerals within its system will help to give a better understanding of the substances used in the glass making industry, what the lakes produced and how it was exploited.

The Wadi Natrun is a geographical depression which lies around 70km from the centre of Cairo, along the "Desert Road" which links Cairo and Alexandria (Figure 60). Within the wadi are a series of ephemeral evaporitic lakes of non-marine origin. These lakes precipitate a variety of sodium salts and the chemistry, deposition and exploitation of these salts form part of the focus of this project. The chemistry of these salts has already been discussed in Chapter 5 and the mineralogy of the lakes as a whole is discussed in 6.1; section 6.2 examines the historical evidence present for the changing use and geography

of these lakes and the analysis of geological samples taken from the wadi and other experimental work will be discussed in 6.3.

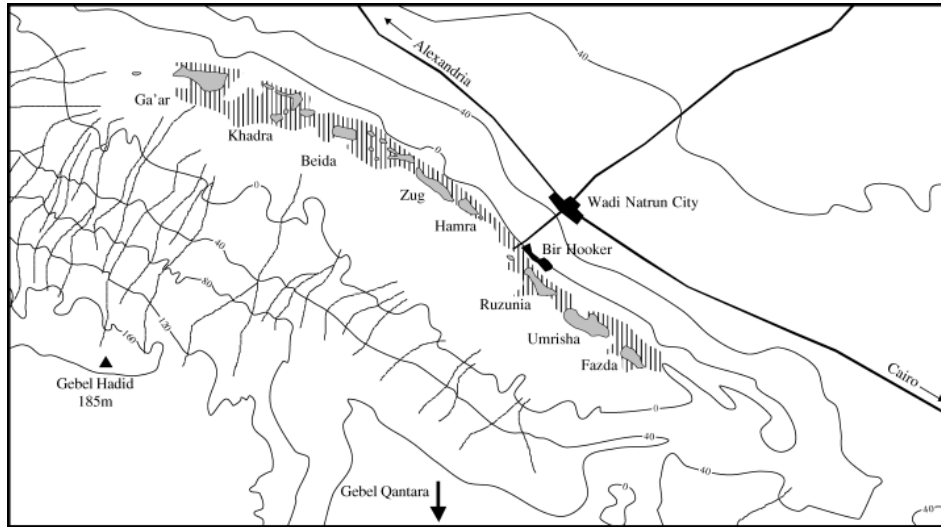


Figure 60: Map of the Wadi Natrun area (Shortland 2004, 498)

When looking at the lakes today eight major lakes can be identified although between these lakes are a series of smaller unnamed ponds or birkets. These eight lakes form the basis of the modern analytical work. Running along the northern shore of the lakes is a major town, and the desert around the area is beginning to become cultivated under the new Egyptian irrigation scheme, which uses the ground water that supplies the lake system. On the bottom edge of Lake Hamra lies a newly established eco-tourist hotel which hopes to one day use the lakes as a natural spa. The Lakes are also surrounded by ancient buildings in the form of the ruins of three glass factories (Roman in date) and a number of monasteries which were established in the area due to its remoteness, as well as for its religious significance. As will be discussed in depth later the lakes themselves change in features, such as size, “location” and shape. However one constant to have remained in sources dating from at least the 1st Century AD is that the lakes have a red tinge to them. This red colour is due to the presence of a microbial community that inhabits the lakes, but it was not until the 19th century that the colour was examined in depth.

From the observational fieldwork conducted in 2006 other details of the lakes were noticed, for example the presence of large islands of burkeite (Figure 61 and Figure 62) and that a number of the lakes are currently exploited to varying degrees both by hand (Figure 63) and by mechanical digger (Figure 64). These were then piled alongside the lake (Figure 65).



Figure 61: Photo showing burkeite islands in Lake Fazda



Figure 62: Photo showing the presence of a burkeite island in Lake Fazda



Figure 63: Exploitation by hand at Lake Fazda



Figure 64: Photo showing the over exploitation of one of the lakes by mechanical diggers



Figure 65: Image showing the piles of exploited "salt" in one of the lakes

This chapter therefore examines the lakes today, as well as conducts a comprehensive chemical and geographical history of the lake system for the last 4000 years.

6.1 Mineralogy of the lakes

The lakes have been subject to a series of studies over at least the last three hundred years (Lister 1685) (6.2), however other than Lucas's systematic investigations in the early 20th Century, the lakes were only really scientifically assessed after the 1950s. The geology of the lakes is of intrinsic importance for understanding both the formation of the mineral deposits and for understanding of the way that these lakes were exploited in the last 3000 years. The mineralogy can be separated into four key areas; firstly the source of the water in the wadi (6.1.1); secondly the microbiology of the lakes (6.1.2); thirdly the underlying geology of the wadi (6.1.3) and fourthly the evaporites themselves (6.1.4 and 6.1.5).

6.1.1 Source of water in the wadi

The Wadi Natrun is a non-marine evaporitic deposit and these deposits are more complex to model than marine deposits since non-marine evaporitic deposits tend to be open systems (an open system is one in which the water can freely circulate throughout the lake). The Wadi Natrun is itself an open system (Imhoff 1979; Shortland 2004) and one of the biggest factors which control the deposits in the wadi is the source of the water.

One aspect of water entry, rainfall, can be largely discounted as a significant source of water since the average annual rainfall in the region lies between 30 and 55mm (Adeel and Attia 2002; El-Hinnawi and Atwa 1973). This leaves only two further methods of water entry, the first being springs within the lakes, and the second are the small streams around the lakes (Abd-el-Malek and Rizk 1963; Atia et al. 1970a; Atia et al. 1970b; Imhoff 1979; Taher 1999; Taher and Soliman 1999). Both these methods of water entry rely on an original groundwater source.

This groundwater is currently highly stressed because in the last 50 years there have been increased demands for water in the wadi. The largest demand comes from the Egyptian Government, which established an agricultural programme in the area. The success of the arable farming policy relies on the local groundwater for irrigation (Aly et al. 2004). The water has also been affected due to the emergence of a large sedentary population around the lakes, which has caused an increased demand on the system (Taher and Soliman 1999). A number of factories have also been opened in the area causing an increase in polluted waters entering the system (Taher and Soliman 1999).

All these human factors impact on the mineralogy of the system and indeed on the survival of the lakes themselves.

6.1.2 Microbiology of the lakes

One aspect which is often overlooked by geologists and studies of the lakes is the part that microbiology plays. The lakes have been part of a much larger study into sulphur-reducing bacteria and it is believed that microbiology plays a major role in the formation of many of the mineralogical deposits present in the lakes. One of the primary indicators of an active microbial community in the wadi is the colour of a number of the lakes (Atia et al. 1972; Shortland 2004; Taher 1999).

The microbial community is made of extremophiles – organisms that live in extreme environments, such as a high temperature, in this case the high pH present in the wadi (Grant et al. 2004). Three different families of bacteria have been identified in the lakes – these are *firmicutes*, *bacteroidetes*, *alpha* and *gamma proteobacteria* – there were also two groups of *archaea* (a type of single celled micro-organism with no cell nucleus) identified (Mesbah et al. 2007).

It is this microbial community which can lead to the varying mineralogical deposition of the lakes (Taher 1999). There are two routes for the formation of carbonates through microbial activity. The first is the formation of the carbonic acid and a second is the carbon dioxide traps present within the lakes themselves due to the high alkalinity within the brines (Imhoff 1979; Taher 1999).

The bacteria inhabit vents in the lake bed in colonies and ingest the organic matter present within the lake. The lakes are rich in this organic matter and its decomposition can be detected by the pungent odour of hydrogen sulphide.

6.1.3 The Underlying Geology of the Wadi

The underlying geology of the wadi is another important consideration when discussing the formation of the mineral deposits within the wadi.

Most scholars note the fact that the area is covered by Quaternary lake deposits (El-Hinnawi and Atwa 1973; Shortland 2004; Taher 1999). These Quaternary deposits are underlain by Pleistocene and Pliocene sedimentary rocks, with Tertiary limestone as the bedrock, which are found to influence groundwater composition (El-Hinnawi and Atwa 1973; Shortland 2004).

Shata et al. (1967) in their study of the underlying wadi geology ascertained the following chronology of the wadi. Firstly in the early Pliocene the area was flooded by the sea. The formation of what could be recognised as the Wadi Natrun today was established in the Holocene (Shata and El-Fayoumy 1967).

6.1.4 Mineral Deposits formed

The three main types of sodium salt that are formed are chlorides; carbonates and sulphates. Section 6.3 will discuss the frequency of each of these minerals in the samples analysed for this project, this section will cover previous

analyses and their results. Their chemistry has already been discussed in Chapter 5.

Sodium chloride, in the form of halite, is the most abundant mineral present within the lakes (Atia et al. 1970a; Atia et al. 1972; Shortland 2004). Halite forms in a number of places, one of which is a crust that forms at the surface while others are found within the layer structure of the mineralogical deposits. The formation of the sodium chloride occurs in two ways. One is through the formation of crystals which precipitate at the air-brine interface and sink in the brine (Atia et al. 1970a; Taher 1999), the other is by the formation of crystals which also form at the surface of the brine and aggregate to form crusts which float upon this brine (Taher 1999).

Although the Wadi Natrun is named after the purported presence of the mineral natron, there has actually been very little of this mineral identified in the mineralogical record (Shortland 2004). Indeed trona is the most common carbonate found within the lakes and a survey by Atia found it present in all lakes other than Beida (Atia et al. 1970a; Atia et al. 1972). Nahcolite is also occasionally found within Ruzunia (Atia et al. 1970a).

Of the sulphates the most common mineral formed is the double crystal salt – burkeite. The formation of this salt is believed to occur because of the interaction between sulphate crystals and a carbonate rich water system (Atia et al. 1970a; Atia et al. 1970b). However Atia stated that thenardite was the most common sulphate present in the lakes (Atia et al. 1970a; Atia et al. 1970b).

There have been two models put forward for the formation of the deposits in the wadi. The first is the simple model - this proposes that the wadi system is a closed one and, although this is now known to be erroneous, is an important consideration as some of the same concepts in the closed model also apply to the open model. In a closed system two distinct seasons can be identified, winter and summer. During winter the rate of evaporation is far slower than the

rate of water inflow and consequently the lakes become filled with water. In the summer the resulting rate of evaporation becomes faster than the inflow of water. During this period the lake waters become more saturated with ions and at certain points within the evaporation process this ion concentration leads to the precipitation out of the evaporitic minerals that can now be identified.

The second, more complex, model is based on an open system. Not only does the water act in a similar way as in the closed system model but it further allows for the realisation that the water can circulate throughout the lake. This circulation system explains the way in which minerals precipitate, where they precipitate, how they precipitate, and what precipitates.

6.1.5 Previous analyses of the lakes

Atia et al. (1970a) conducted a series of studies into the lakes of the Wadi Natrun. A number of lakes were examined and their results are discussed here. A number of the lakes have a differing composition to the results published in the report and to later analyses (Atia et al. 1970a; Shortland et al. 2006a; Shortland 2004; Taher and Soliman 1999).

Beida Lake is one of the largest lakes in the wadi and is known to contain an economic deposit of thenardite (Nakhla et al. 1985). The lake was also found to contain a high concentration of salt (5 to 20% in the north and 50 to 65% in the east), and to a lesser extent a concentration of the carbonates: trona and nahcolite, which were found in the more northerly aspects (Nakhla et al. 1982; Nakhla et al. 1985). This presence of salt is also detected in recent analysis, with thenardite formed as an additional phase (6.3).

Taher (1999) conducted geochemical analysis of the Wadi Natrun in the late 1990s, focusing on the concentrations of ions found within the groundwater of the Nile Delta and within the lakes themselves, she concluded that the differences found within the lakes was due to the presence of differing microbial

communities within the lake sediments, rather than any chemical difference present within the groundwater sources. She also concluded that the presence of these microbial communities have lead to the creation of a unique environment (Taher and Soliman 1999). Unfortunately no mineralogical studies were conducted, although her analysis of major ions show that the lakes were high in the presence of chloride and that at the present time sulphate is higher in concentration than carbonate. Using her analysis Geochemist Workbench was used to identify what minerals would be formed from such concentrations, the results of which can be found in section 6.3.

In the last few years Shortland has investigated the lakes in order to ascertain the impact of mineralogical composition on archaeological understanding. Only a few lakes were examined and samples gathered, and it is these samples were analysed in the process of this study (6.3). In both 2004 and 2006 the lakes showed the presence of only one type of carbonate and that is the formation of trona. The lakes have very similar composition to that proposed by both Atia et al. and Nakhla (Atia et al. 1970a; Atia et al. 1970b; Nakhla et al. 1985), however the strong presence of burkeite is not commented on by others and this could be due to the way in which they assess mineralogical data rather than any significant increase in the presence of this substance (Shortland et al. 2006a; Shortland 2004). The results of these two studies, coupled with the others show the predominance of halite within the system, showing a complex depositional environment. There are major archaeological implications for these results and these will be discussed in depth in 6.4.

In the last 30 years a number of lakes have been the focus of much study. From the perspective of this project, Lake Fazda has been a primary concern. This is due to its prominent location near an industrial archaeology site, which is believed to have utilised the lakes deposits in the manufacture of glass. Consequently more information about the mineralogy and depositional environment of Lake Beida and Lake Fazda is known.

6.1.6 Chemical History of the Wadi Natrun

As can be seen from Table 18, a number of lakes (5) have had changing chemistries in the last 100 years. As can be clearly identified halite is the dominant species. From the table it can also be seen that there were a number of carbonates identified in both 1970 and 1912. This could be due to the season in which the samples were collected, rather than a directly different chemistry. There is no doubting the presence of some form of carbonate in at least two of the lakes, Lake Zugm and Lake Hamra and it could suggest that at some point carbonate was formed rather than the double sulphate-carbonate crystal. One of the more interesting aspects of this table is the distinct lack of burkeite. Although XRD shows the presence of a significant proportion of burkeite within the system, it is surprising that few have discussed it.

Table 18: Table showing the variation of major chemical phases between past analyses of certain lakes

Lake	This study	Shortland 2004	Wenigs. 1988	Atia et al. 1970	Lucas 1912	Berthollet 1800	Lister 1685
Fazda	Burkeite	Halite	Halite	Thenardite	Halite		
Umrisha		Halite	Halite	Halite	Halite		
Ruzunia				Halite	Halite		
Hamra	Halite	Halite		Halite	Natron		
Zugm	Halite	Halite	Halite	Trona	Natron		
Beida	Halite	Halite	Halite	Trona	Halite		
Ga'ar			Halite	Trona			
Lake 3						Natron	
Unknown							Ammoniac salt

Besides an analysis of the literature surrounding the lakes, modelling of the mineralogy of samples analysed and published by Taher (1999) was also conducted and found that halite would be the dominant species in all lakes, and it also shows the typical minerals of burkeite and trona (Table 19).

Table 19: Table incorporating Table 1 (Taher 1999, 161) and results from Geochemist Workbench

Sample #	pH	Temp (C)	Na+ (g/L)	Cl- (g/L)	SO4 2- (g/L)	CO3 2- (g/L)	HCO3- (g/L)	Major Phase Modelled	Additional Phases	Queries and Corrections
1	8.89	22.2	279.68	86.4	43.4	33.2	5.3	Halite	Burkeite; Trona	n/a
2	9.26	22.2	295.21	93	44.9	36.26	0.64	Halite	Burkeite; Trona	n/a
3	9.22	24.4	291.53	92.3	40.1	36.65	2.02	Halite	Trona; Burkeite	n/a
4	9.34	25.5	281.41	81	37.8	36.75	1.97	Halite	Trona; Burkeite	n/a
5	9.28	23.3	274.05	85.8	48.1	37.93	0.79	Halite	Burkeite; Trona	n/a
6	9.2	23.3	270.37	91.2	41.7	36.45	2.07	Halite	Trona; Burkeite	n/a
7	9.45	23.8	154.45	74.5	27	17.93	n.d.	Halite	Burkeite; Trona	n/a
8	9.25	22.2	155.37	56.6	24.8	50.68	n.d.	Halite	Trona; Burkeite	n/a
9	9.27	22.2	155.37	59.2	27.5	20.4	n.d.	Halite	Trona; Burkeite	n/a
10	8.16	20.2	30.2	12.7	9	0.2	0.09	Supersaturated	Supersaturated	No minerals precipitated, software states supersaturation
11	9.28	20	144.33	54.6	24.7	22.87	n.d.	Halite	Mirabilite; Trona; Burkeite	Mirabilite = thenardite
12	8.51	23.8	271.29	118	50.4	5.32	3.45	Halite	Mirabilite; Burkeite	Mirabilite = thenardite
13	8.51	24.4	291.53	125.7	61.1	7.19	1.97	Supersaturated	Supersaturated	No minerals precipitated, software states supersaturation
14	8.54	25.5	279.57	110.2	51.8	7.59	1.82	Halite	Mirabilite; Burkeite	Mirabilite = thenardite
15	8.52	24.4	273.13	115.3	48.5	4.14	0.19	Halite	Mirabilite; Burkeite	Mirabilite = thenardite

These models were based on the water temperature taken by Taher and are in the low to mid-twenties, from the analysis performed on the mineralogical

samples gathered from the Wadi Natrun in 2005 and other mineralogical analysis (Nakhla et al. 1982; Nakhla et al. 1985; Shortland et al. 2006a; Shortland 2004), thenardite is known to be found within the deposits of the Wadi Natrun, therefore suggesting a higher temperature present at the time of solution formation (around 60°C), than that recorded by Taher. Consequently for the purposes of this body of research where the model has proposed mirabilite, thenardite has been substituted. There were also a number of samples which the model could not support, claiming supersaturation of a number of the anions. Minerals are known to form in all lakes, and consequently it is proposed that this is just an error in the model rather than a lake which does not precipitate, potentially caused by the lack of ability of modelling a living system.

6.2 Historical Survey

6.2.1 Egyptian References

There are very few references directly related to the Wadi Natrun available from pre-Classical times. A number of Egyptian sources regarding the area however can be gathered from less likely sources. These sources allow for a better understanding regarding the Wadi Natrun within the Egyptian Empire as well as within the economic and trade structure of the ancient world.

The Egyptian term *štp.t*, which is commonly translated as the “salt field” and has been identified in a number of texts, is often presumed to refer to the Wadi Natrun (Lichtheim 1973; Paton 1922; Ritner 1986; Schulman 1978; van Blerk 2006).

The area surrounding the wadi is believed, by some, to have been the centre of worship for Osiris, the god of the Underworld (Hanna 1966). It was also seen as the “world’s end” (Osburn 1844) and was therefore regarded as a spiritual place, thus explaining the use of natron from this specific deposit in the process of mummification (4.2) as it would aid the deceased to transcend to heaven through the use of this “mystical” substance.

The Wadi Natrun produced a number of commercially viable commodities and it is known that natron as well as salt, was traded across Egypt (Fakhry 1940; Hanna 1966; Lichtheim 1973). These items were traded for corn, which was not locally available. The Complaints of the Peasant (also known as the Eloquent Peasant (Parkinson 1991)) is one such text which shows this trade relationship. The Complaints of the Peasant not only shows pattern of trade but also shows where the Wadi Natrun was in relation to the state of Egypt. The story was preserved in four papyri (P. Berlin 3023; P. Berlin 3025; P. Berlin 10499; P. Butler 527=P. British Museum 10274) and, although, there is no single complete edition of the text these four together yield the full text (Lichtheim

1973). The story itself suggests that the Wadi Natrun was not part of Egypt, the phrase *"I am going down to Egypt"* suggests that the wadi was not considered part of Egypt's direct control, but was perhaps a client state.

There is other documentary evidence that natron was a commodity of significance (Chapters 3 and 4 discussed industries in which salt and natron were utilised in more depth). In a model letter (Kahun 111.2) dating from the 12th Dynasty and addressed to Amenemhat IV there is a plea for the King to send the writer natron *"this is a communication to the lord about sending me natron"* (Wente 1990). This letter and others suggest that natron was a royal monopoly by this period, a trait which continued until the end of the Ptolemaic era. Each household would require a supply of natron although whether this is for medical or hygienic purposes is unclear. Indeed in 170 Ostraca Cairo 25670, an inventory of a house sitting states that there were 12 bricks of natron present (Wente 1990), and Papyrus Moscow 127 shows that some workers were paid with both salt and natron (Allam 1975).

Bricks were the common unit of measurement for both salt and natron, although their exact volume cannot be fixed. Evidence from Deir el-Medina suggests that a brick varied in size between 720 and 1840 cm³ (Bruyere 1939). There is scant documentary evidence as to the cost of one of these bricks but Janssen (1975) states that 15 bricks of salt would cost around 5 deben, but unfortunately the natron inscription is damaged and it is therefore impossible to say how much a brick of natron would have cost. One of the largest users of natron and salt were the temples and every year a donation would be made to a temple on behalf of the Pharaoh which included these commodities. In one of these tributes, made to the Temple of Amun 44,000 bricks of natron and 44,000 bricks of salt were donated (Breasted 1906; Ezzamel 2008 (In Proof)).

Archaeological evidence shows that the area surrounding the wadi was fortified in the reign of Amenemhat I (Arnold 1991; Fakhry 1940) in what could have been a possible attempt to maintain control over the watering holes in the Wadi

Natrun from “marauding” Libyans (Arnold 1991). Control over this area possibly rested with a diplomat of sufficiently high standing. From the Complaints of the Peasant there is a reference made to a governor or mayor of the area (Lichtheim 1973; Simpson 1973). There is also a prayer stela (Philadelphia E.13068) which refers to the “King's son in the Wadi Natrun” (Schulman 1978). This document dates from the New Kingdom, perhaps implying that the area was never formally absorbed into Egypt. It is believed that the term “King's son” refers to the position of vizier, rather than an actual prince (Schulman 1978), however Schulman (1978) and Török (1998) state that when that phrase is used in relation to Kush, it translates as viceroy. There is little doubt however that the discovery of this prayer stela shows that there was a high ranking official in the area, perhaps to ensure continuing trade relations with the region.

6.2.2 Classical Sources

The Greco-Roman period saw an increase in the written documentation regarding the lakes. Evidence from the *Aḥiqar* scroll shows that natron was exported in vast quantities from Egypt's ports (Yardeni 1994). The *Aḥiqar* scroll was found in Elephantine, and is a customs account, which covers ten months of the year 475 BC (Yardeni 1994). From these lists it was easy to identify that natron was by far the largest commodity exported.

Although two types of ship are recorded on the scroll there is only an export list for Ionian ships (Yardeni 1994). The way the scroll is organised shows that there were specific formula to record both the export and the importation of commodities. The formula for the exportation of silver follows as such:

“Ionian ships: In (day) of (month) they inspected for the sea one ship, Ionian. The silver – customs – the price of the natron they took out to sea in it” (Yardeni 1994, 76)

Unfortunately there is no reference as to how much was exported in these ships, but during the period of ten months and a total of 42 ships, 36 apparently departed the port laden with natron (Yardeni 1994). There is also no clue as to where the substance was being exported but it is presumed that due to the nature of the ships leaving the dock that it was headed into the Mediterranean. Unfortunately this cannot be confirmed as there is no reference for a specific port from which these ships left (Yardeni 1994).

From Herodotus' account it can be shown that salt was gathered from the oases of the Libyan Desert (Orr 1934) and it is presumed that the Wadi Natrun could be one of these oases. Pliny gives the most comprehensive Classical account of the lakes

“The soda beds of Egypt used to be confined to the regions around Naucratis and Memphis, the bed around Memphis being inferior. For the soda becomes stone like in heaps there, and many of the soda piles there are for the same reason quite rocky.....in this region are soda beds from which red soda also is taken owing to the colour of the earth” (Pliny Book 31 46.111)

Although there is no specific mention of exploitation in any classical source, the fact that Pliny designates one lake as being inferior suggests the presence of some form of working, otherwise there would be no need to comment on which lake was inferior in quality. The description also suggests that there were at least two lakes and that at least one was red in colour.

One of the most commonly referred to accounts of the Wadi Natrun dating from the Classical period is from the author Strabo. Unfortunately Strabo describes the location of the lakes in relation to towns, which no longer exist, and this description has caused the most confusion and debate amongst scholars. His account describes the presence of two lakes which lie above Momemphis (Strabo The Geography of Strabo VIII). Unfortunately Momemphis no longer exists but was displayed in maps of the 19th Century positioned below

Naucratis. If this is the case then Strabo was describing the location of the Wadi Natrun, and not as some have commented the more northerly deposit of Barnugi (Lucas 1912; Lucas 1932a; Lucas and Harris 1962). However Lucas believes that the cartographers of the 19th Century would have been unfamiliar with the natron deposits at Barnugi and consequently would have then fixed the position of Momemphis in relation to the more “famous” natron deposits (Lucas and Harris 1962). Using Wilkinson’s information regarding the area – which was published before the maps – and is based on conversation with local natron workers, it could be deduced that Momemphis is the town known as Terraneh where the natron workers inhabit (Wilkinson 1843b). The term Terraneh itself can be translated as “natron lake” (White 1932). The town itself has archaeological evidence dating back to the Roman period, but is believed to have dated to much earlier (Wilkinson 1843b). This is plausible as it would make sense that Strabo would comment on the location of the worker’s town as well as the lakes they exploited.

6.2.3 Pre-19th Century Sources

There are few references to the lakes of the Wadi Natrun during the intervening 1500 years between the end of the Roman Empire and the 19th Century. The wadi saw a program of building as monasteries were established. The lakes were seen as being religiously significant due to the belief that the wadi was the hiding place of the Holy Family when they fled from King Herod (Matthew 2:13-15). Due to this religious connection the area became famous for pilgrimages, and consequently a number of accounts regarding the lakes were derived.

White claims that the term Wadi Natrun was unknown before the 15th Century AD and the term for the area prior to this was the Wadi Habib; named after one of the Arab conquerors who settled in the area (White 1933). This could explain the lack of knowledge surrounding the area in the medieval period. However even searching for the term Wadi Habib draws few results (except in regard to the monasteries), and it could just be that little was actually documented in this

time. It is known that natron was still gathered in the medieval period (Lane-Poole 1968; Rabie 1972; White 1932) and there are also sources detailing the fact that this area was famed for bandits (White 1932), and this evidence suggests that the natron deposits were still economically valuable.

As already stated there are few references to the Wadi Natrun in the medieval period, however there are some economic accounts on the exploitation of natron as a whole. Indeed the finance minister Ibn-Mudebbir (9th Century AD) established a number of new taxes including a tax on natron “mines” (Lane-Poole 1968; Rabie 1972). This system of taxation was maintained until well after Maqirizi’s death in 1442 and it was ultimately after his death that the decline in natron exploitation occurs (Rabie 1972). Other evidence suggests that certain industries ceased using natron by the end of the 9th Century AD, for example the decline in the use of natron as a flux in the glass industry (Rabie 1972; Shortland et al. 2006a). Indeed the last natron glass found dates to 833-842 AD, as this does not correlate with the cessation of exploitation, it can only be concluded that the natron was being exploited, until the end of the 15th Century AD, for other industries, such as linen manufacture. Table 20 shows the cost of natron per weight and the weight used.

Table 20: Table showing the amount of natron exploited and the amount of revenue generated

Century	Amount exploited (in tonnes) per year	Money generated (in gold) per year	Cost per tonne
15 th	1360	70,000-105,000	51
17 th	1632	54000	33
19 th	1293	Unknown	Unknown

Economic accounts suggest that the selling price of natron in Cairo (internal trade) and Alexandria (external trade) was 70 dirhams (one dirham was the equivalent of three grams of copper (Shoshan 1986)) per quintal. The dirham had been changed to be valued against copper rather than silver in the

beginning of the 15th Century (Shoshan 1986). A dirham has been identified to be valued at between 30 dirhams to 1 gold equivalent and 20 dirhams to 1 gold equivalent (Shoshan 1986). This coupled with the huge amounts of natron exploited – around 30,000 quintals (3,000,000 pounds or 1360 tonnes) a year (Rabie 1972) means that around 2,100,000 dirhams (or between 105,000 and 70,000 gold coins) was collected per year just by exploiting natron. As the cost of the exploitation of natron was only two dirhams per quintal this enabled the traders to make a massive profit of 3400%.

In 1672 the annual revenue of the natron lakes was 18,000 French Crown (equivalent of 54,000 French Livre) from 36,000 quintals (the equivalent of 3,600,000 pounds or 1632 tonnes) (Sicard 1845; White 1932). Egyptian natron was famed in Europe and was specifically used in the French linen industry (primarily for bleaching) (Andreossi 1800; Anon 1814; Boullaye 1657; Browne 1799; White 1933).

One of the enduring myths of the wadi was still in relation to the nearby Bahr-bela-ma. Were as in the Classical period the myth had been propagated by the belief that King Menes had dammed the river to ensure that Memphis would not flood through the annual inundation (Herodotus Book II), by the early Christian period the presence of this geological formation could be explained through the hagiography of Saint Macarius. The high value of natron exploitation can be determined through the story, and parallels with “modern” groups, such as the tribes from Darfur (3.11), can also be drawn. It was believed that at the time of Saint Macarius the river, which once ran in the Bahr-bela-ma, was populated with pirates, and that the Saint prayed for the river to run dry in order that they did not attack his natron expedition (Boullaye 1657; White 1933). This theme of pirates in the dried river was common even among later visitors to the area.

The earliest published chemical analysis of the natron from the Wadi Natrun dates to the 17th Century (Lister 1685). Whether Lister (1685) ever visited the

lakes themselves is unknown, but he comments on the distinctive red colour of the lake water and names the area from whence it came.

The best record regarding the Wadi Natrun at this time comes from the records of the French Priest Sicard who visited the area in the winter of 1712, whilst on sabbatical, and commented on the presence of one lake in the vicinity. The presence of one lake however should not be dismissed, as it was winter the lakes were filled with water, and in addition due to the location of the monasteries he would not have seen the whole chain. He did not notice the lakes being exploited himself, however from discussion with the monks and other local inhabitants determined that the lakes were indeed exploited (Sicard 1845).

The best account of the exploitation of the lakes, prior to the 19th Century, is Browne's description of two lakes (Browne 1799). After discussion with the workers of this area he determined: that the natron that was collected was never larger than a cubit (a relatively derived measurement measured between one's fingertips to the elbow – around 45cm) in size, and the salt crust had a thickness of 15cm (Browne 1799, 41), suggesting that even in the 18th Century the lakes were sufficiently stratified to easily tell the difference between the two minerals.

6.2.4 19th – early 20th Century References

With travel becoming easier and Egypt becoming part of the French then British Empire in the 19th Century, more people travelled to the area and recorded what they saw. The types of people visiting the wadi varied between the “tourist” and the scientist, and a great many accounts from this period, both in the form of scientific papers and travel guides have survived to this day.

Although the wadi has been known from documentary accounts from at least the last 4000 years, it is true to say that it has only been in the last 300 that

impressions in the form of maps, of the wadi have been known. The maps show not only the geographically changing nature of the lakes, but also reflect the changing nature of the cartography of this period.

A clear distinction can be drawn between the “tourist” and the scientist, the former is generally on a tour, visiting the areas of interest in Egypt, and in the case of the wadi, this means a trip to the monasteries. The scientist however comes under a number of guises; a few are interested in the geological history of the area, others are interested in the basic chemistry that can be identified within the lakes in addition to the importance that the lakes have within the history of physical chemistry (discussed later) and then a number are interested in the economic benefits that can be reaped from a careful study of the depositional environment.

In Europe the Wadi Natrun was of huge economical importance. The largest importer of natron from this area was England with around 40% of all natron exploited being exported to its shores. Although it should be noted that natron was also important in both French and Venetian industries (Andreossi 1800).

Due to all these factors a number of references exist. One of the earliest references from this period is that of the French expedition to the area in 1798 (published in 1800). This expedition could be classed as the earliest “scientific” study of the area, examining, not only the chemistry of the deposits, but the typography of the lakes, and a history of the surrounding environs.

The leader of the expedition was Andreossi (Andreossy), General of the Artillery, and the group was made up of both the army and scientists – most notable is the inclusion of Berthollet (later famous for developing a number of fundamental principles behind the discipline of physical chemistry, and is believed that these were derived from his study of the lakes (Gillispie 1989)). The presence of the military was due to *“protecting their researches in a district*

open to the incursions of the wandering Arabs” (Andreossi 1800, 255), again showing the economic importance of this area if bandits were still present.

The wadi that the expedition saw was moderately different to the wadi reported in the literature in the previous 3500 years. Although there was the continued presence of water “the colour of blood” (Andreossi 1800), the number of lakes had increased from two to six. Andreossi (1800) also commented on the fact that earlier maps contained a number of inaccuracies. For example Sicard’s map shows the presence of only one lake and that was depicted in the wrong orientation, and the later D’Anville map was drawn using Strabo’s account of the lakes, and is also drawn in the wrong orientation (Figure 66).



Figure 66: Map showing a close up of the depiction by D’Anville (1794) of the Wadi Natrun. Note the presence of only two lakes.

Both Andreossi and Berthollet commented on the fact that the lakes held different concentration of minerals (Andreossi 1800; Berthollet 1800). The minerals which make the vast majority of the deposits were identified as being muriate of soda (halite (Henry 1810)), carbonate of soda (natron) and sulphate of soda (an unidentified form of sodium sulphate) (Andreossi 1800; Berthollet 1800). The concentrations of these minerals vary, with sulphate of soda always being found infrequently, and some lakes with a high predominance of carbonate of soda and others with muriate of soda being the most prevalent

(Andreossi 1800; Berthollet 1800). Berthollet (1800) even stated that varying concentrations of the minerals could be found within different areas of the same lake.

Table 21: Table showing the descriptions and positions of the lakes in the Wadi Natrun from Strabo to today

	Author and Date									
	Today	Liddle 1915	Lucas 1912	Bryant 1903	Wilkinson 1843	Andreossi 1800	Danville 1794	Sicard 1712	Pliny 1st Century AD	Strabo 1st Century BC-1st Century AD
# of Major Lakes	8	12	12	11	8	6	2	1	2	2
Lake Name and relative position NW-SE	Ga'ar Khadra Beida	Ga'ar Khadra Beida	Ga'ar Khadra Beida	Ga'ar Khadra Beida	e' Ja'ar e'Rasunieh El Gunfadiah	1 - Beida 2 - Ponds between Beida and Zugm 3 - Zugm and Hamra				
Notes				Muluk is in a different position to later maps	No lake Fazda. The position of lake e'Rasunieh is also questionable as it sounds like Ruzuniah which is found farther down the chain	No descriptive names, the names next to the numbers are potential ids from comparisons of maps	No lakes names. Danville also bases his maps on Sicard and Strabo and draws them in an incorrect SW-NE position	Winter visit could account for the small number of lakes noted	No accurate description	Location determined by no longer existing towns and cities, is therefore prone to error

As Table 21 shows Andreossi describes the presence of six lakes, with Lake Six being located at the Northern end of the chain (Andreossi 1800). Only one lake was studied in any detail and this was Lake Three (determined to be in the position of Zugm and Hamra), and Berthollet identified two areas within the

lake, to the eastern side (Figure 67, the eastern side being closest to the Kasr) the lake contained a high percentage of salt, whilst to the west natron was to be found (Andreossi 1800; Berthollet 1800).



Figure 67: Close up of the lakes from the Andreossi map (Andreossi 1800) (Figure 68)

However natron was occasionally found as small islands amongst the waters of the eastern side:

“In that part of Lake No.3 which I have said only contains sea salt is found a circular island covered with natron” (Berthollet 1800, 307)

Berthollet's comment about islands of natron resting among the waters of the lakes is extremely pertinent to today's study and understanding of the mineralogy. From the fieldwork conducted in 2006 a number of burkeite islands were noted (Figure 61 and Figure 62), no other mineral was identified in such a similar manner. Therefore the islands which Berthollet described, rather than have been natron could have been burkeite. The reason that this is of such interest is that it could lead to an understanding regarding the ancients' belief in what natron is.

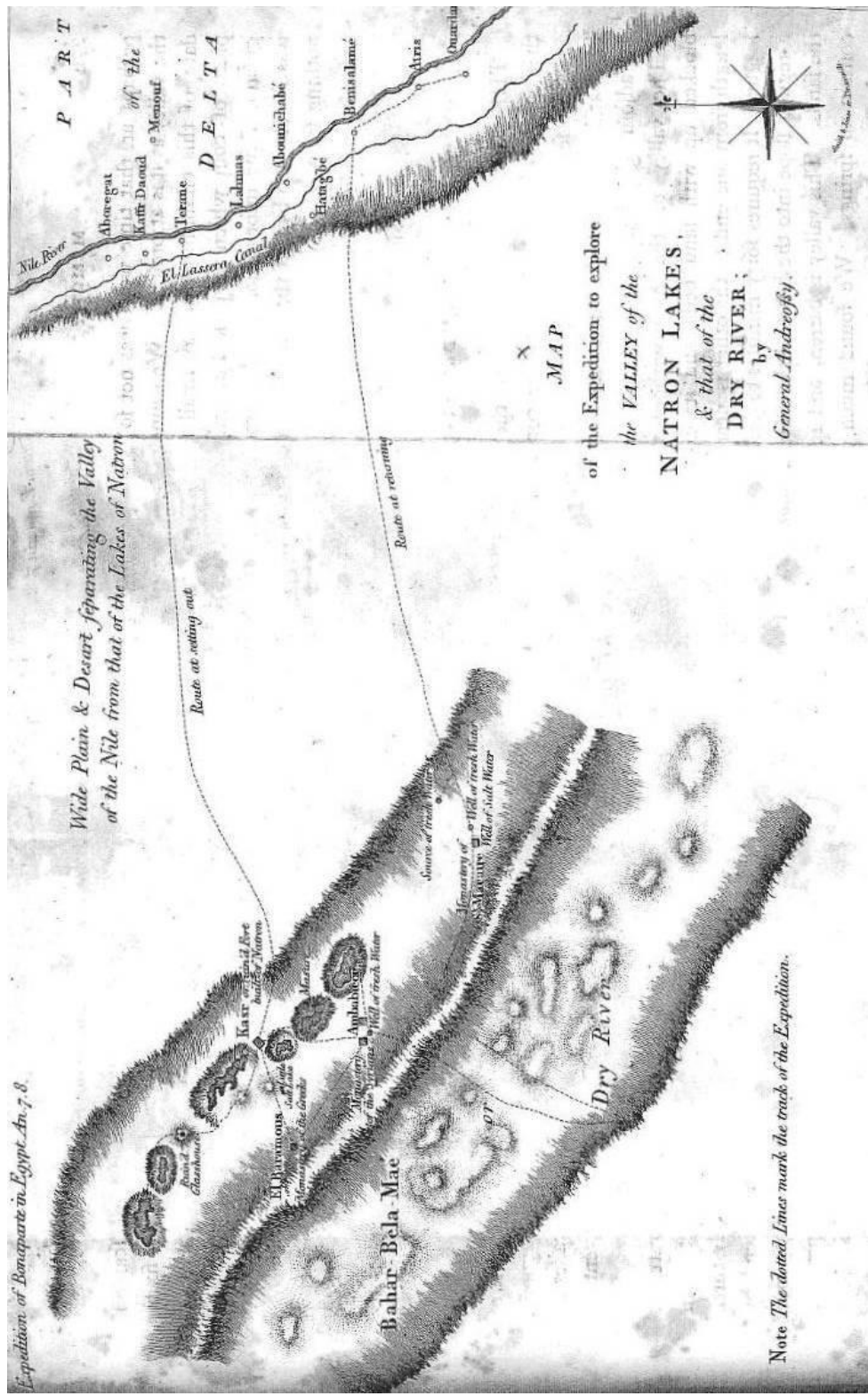


Figure 68: Map of the French Expedition to the Wadi Natrun in 1799. Showing the presence of six lakes (Andreossi 1800)

These chemical analyses were important, because, as has already been discussed a number of times throughout this chapter the French were heavily reliant on the natron from Egypt, in a number of their industries. Indeed it was only the advent of war in France (and then throughout Europe) that ensured the continued supply of natron from Egypt to France (Andreossi 1800).

The “local” village of Terraneh is still the home of the natron workers, and the village from which most natron caravans began their journey (Andreossi 1800). Besides this legal trade in natron, an illegal trade was conducted by the Sammalou Arabs (a group of nomadic shepherds). The Sammalou Arabs exploited the natron of Lake Six (Figure 67) and exported the minerals to Alexandria (Andreossi 1800). The Sammalou were the only ones to exploit Lake Six, the natron workers of Terraneh exploited Lake Four (Figure 67) for its natron, and although Andreossi only notes the presence of six lakes, the “legal” workers commented on the fact that normally there were seven lakes, but a dyke in Lake Four had recently been breached (Andreossi 1800). The two most southerly lakes (Lake One and Lake Two) are the only two to be named, and go by the name Birket al-Deouara or Lakes of the Monasteries (Figure 67) (Andreossi 1800).

The lakes themselves were only worked between “seed and harvest time” (Andreossi 1800, 263). Between seed and harvest time would have been a time in which farmer labourers could be used in additional industries such as the gathering of natron. It also coincided with the hottest time of year, when most of the mineralogical deposit would have been formed. Once the workers struck soil the lakes were left to recuperate for a period between four and six years, depending on whether the seasons had been moist or dry (Berthollet 1800, 309):

“When the natron which covers any soil has been carried off, it requires, as we have been informed, four years for its reproduction, if the seasons have been moist, and six if they have been dry”

The natron was extracted from the lakes by hand and the natron would then be loaded onto the waiting caravan which consisted of 150 camels and 500-600 asses, and are believed to carry 600 “kanthars of 48 okahs each” (an okah is the equivalent to 935g) of natron (Andreossi 1800). This means that each caravan carried around 950,440 pounds, the equivalent of 431 tonnes, of natron. There are no indications as to how many caravans were utilised through the summer, however using information from earlier sources regarding natron exploitation 100 years previous to this account it can be expected that there must have been at least three caravans a year.

Although Andreossi gives a comprehensive account of the lakes and their deposits, a number of artists on a later expedition capture images of the lakes, which had hitherto only been described. The image (Figure 69) found in the *Description of Egypt* (Anon 1822), show the presence of around six lakes (although the distinction between each lakes is blurred), as well as the camel caravan which was there to take the natron away for sale. Although the image does not clearly show the extraction of the minerals from the lake it shows the presence of a number of buildings which were described by Andreossi, including the fort which was built out of natron. Although glass factories aren't marked specifically on this “map” ruined buildings are (Figure 70), suggesting that they are the ruined glasshouses as described by Andreossi.



Figure 69: "Map" from the *Description de l'Egypte* showing the Wadi Natrun, with six lakes and a camel caravan (close up can be found in Figure 70) walking across one of its lakes (Anon 1822)

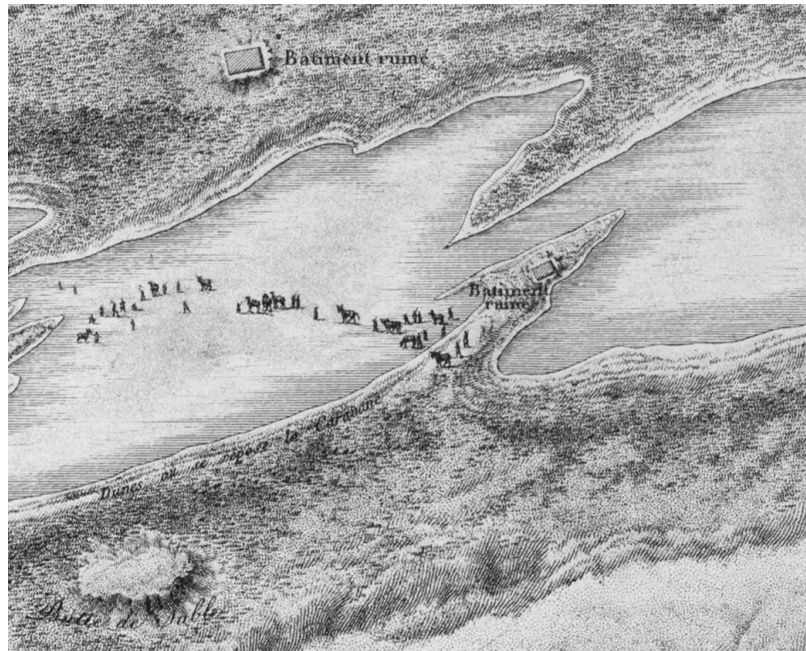


Figure 70: Close up (of Figure 69) of the camel caravan present on one of the lakes, also showing the presence of at least two ruined buildings which are potentially glass factories (Anon 1822)

The most highly sought after natron for the Egyptians was the red natron referred to as the “Natron of the Sultan” which was extracted from Lake Four (Berthollet 1800), however for the glass and linen industries in France a high quality carbonate was required (Andreossi 1800; Berthollet 1800). Both Berthollet and Andreossi agree that the natron from the lakes, which was established to be a mixture of two main minerals, need to be purified in some manner (Andreossi 1800; Berthollet 1800). This was seen as a technique which was preferential to the villagers attempting to identify between the two (Andreossi 1800):

“It will be seen by the table hereto annexed that there are some samples of natron which contain much carbonate of soda, and therefore may be looked upon as a very good soda, but that others are of a much inferior quality, so that in order to establish the use of this article in Europe with confidence, it would be

necessary to have an intelligent agent on the spot to select the salt and to fix different prices according to the goodness of the natron [...] What would be still more advisable is to purify the carbonate of soda on the very spot where it is worked, or at Terraneh [...] so that it should be quite free from earth, contain but little sea salt and be manufactured in a uniform manner” (Berthollet 1800, 311)

The account given by both Berthollet and Andreossi can be seen to be believable for a number of reasons. 1) The report that they gave was of huge economic importance to their country, and they would have therefore done everything within their power to ensure that the report regarding extraction, and nature of the lakes were accurate. 2) A number of fundamental physical chemical principles are based on the findings of Berthollet and his analysis of these lakes. Although their analysis of the mineralogy may not be, to modern standards, good, their descriptions and identifications can be believed.

Prior to the advent of the 19th Century the number of lakes present within the wadi was always described as two or below, the dawn of the “scientific” age saw descriptions of the number of lakes rise from anywhere between six and 11 (Andreossi 1800; Anon 1825; Bryant 1903; Long 1846; Malte-Brun 1825; Moore 1859; Russel 1842). Names for lakes start appearing in the 1840s and a number of lakes are named, after the colour of their waters (Hamra = red; Khadra = green and Beida = white (Taher 1999; Shortland 2004)). The main focus of colour descriptor for the 19th to early 20th Century was in regard to the red colour present within the lakes (Bryant 1903; D’Arcet 1844; D’Arcet 1845; Dewitz 1899).

This variance in the number of lakes could be due to many reasons. The lakes are ephemeral and so in summer there are a higher number of lakes than in winter. Indeed an extreme view of this is commented on by Murray who stated that in the summer there were seven lakes but in winter the water formed one large system (Murray 1818). The water is at its highest in April and it’s lowest in September (Bryant 1903) and this could in turn explain the description by

Sicard, who visited the lakes in November, and only noted the presence of one lake. However there are other reasons behind the large discrepancy in lake numbers. From a number of accounts it can be seen that El Gara, the lake furthest to the north-west was not included in the lake system (Anon 1825). Another reason for the low number of lakes could be that a proportion of the visitors only went to the lakes in the immediate vicinity of the monasteries and these monasteries were only in a small number of locations so a lake or lakes could have been missed. The change in the number of the lakes from the Classical period till the 19th Century could also be explained by the account from Andreossi where he details a damming program by the Arabs exploiting the resource.

The 19th and 20th centuries were no different in terms of the level of export and exploitation of the lakes. It is known that the caravans of natron would leave the lakes for Terraneh (Curzon 1849; Wilkinson 1847; Yates 1843). According to Wilkinson the village was the site of natron preparation before its journey to the markets at either Cairo or Alexandria, and this is in direct contrast to the findings by Andreossi and Berthollet, who were dismayed at the lack of processing (Andreossi 1800; Berthollet 1800; Wilkinson 1847). The natron was:

“prepared for use at the village by first washing and dissolving it in water and then exposing it to the sun in an open court; from which it is removed to the oven and placed over the fire in a trough till all the moisture is extracted”
(Wilkinson 1847, 240)

The substance was then stored and exported to either Alexandria or Cairo - depending on whether it was being kept inside Egypt or exported.

The method of extraction changed little and was conducted by a number of different groups and by the 1820s the extraction was conducted by the Jovaisi Arabs (Anon 1825) under the direction of an Italian, Carlo Rosetti (Curzon 1849; Yates 1843), whom worked for the Pasha (D'Arcet 1845; Yates 1843).

In the beginning of the 19th Century only one lake was exploited, and this was Lake Four (Figure 68) (Andreossi 1800). By 1814 two lakes were being exploited, but the identity of the lakes was not mentioned in the original report (Anon 1814). However, from an 1847 account it could be presumed that the reference refers to, el Gronfedeeh and el Hamra (Figure 71) (Wilkinson 1847).

Either due to the economic importance of the area or due to the interest generated from the realisation that this could be the area from which the ancients gathered their natron a number of studies were made in the 19th and early 20th Century to focus on the deposits, specifically their formation and chemistry.

One of the more interesting features of the Malte-Brun (1825) study is his comments on the nature of the lakes, stating that even within the same lake the deposits can vary, this phenomena was also described by both Andreossi (1800) and Berthollet (1800). The identification of this feature could explain the damming practice commented on by Andreossi (1800). Perhaps this can be seen as an attempt at engineering the lakes to ensure a simple method of extraction of the desired economic product.

From a survey of the literature regarding the Wadi Natrun it could be potentially suggested that the dynamics of the lakes have changed over time. As already discussed in 6.1 sulphates are quite common within these lakes and this would seem to be a recent phenomena only occurring in the last 200 years, as Andreossi's survey shows a lack of sulphates (Andreossi 1800; Berthollet 1800). This could be attributable to a variety of causes; not least the poor level of analytical techniques available or the absence of a systematic survey and collection of samples.

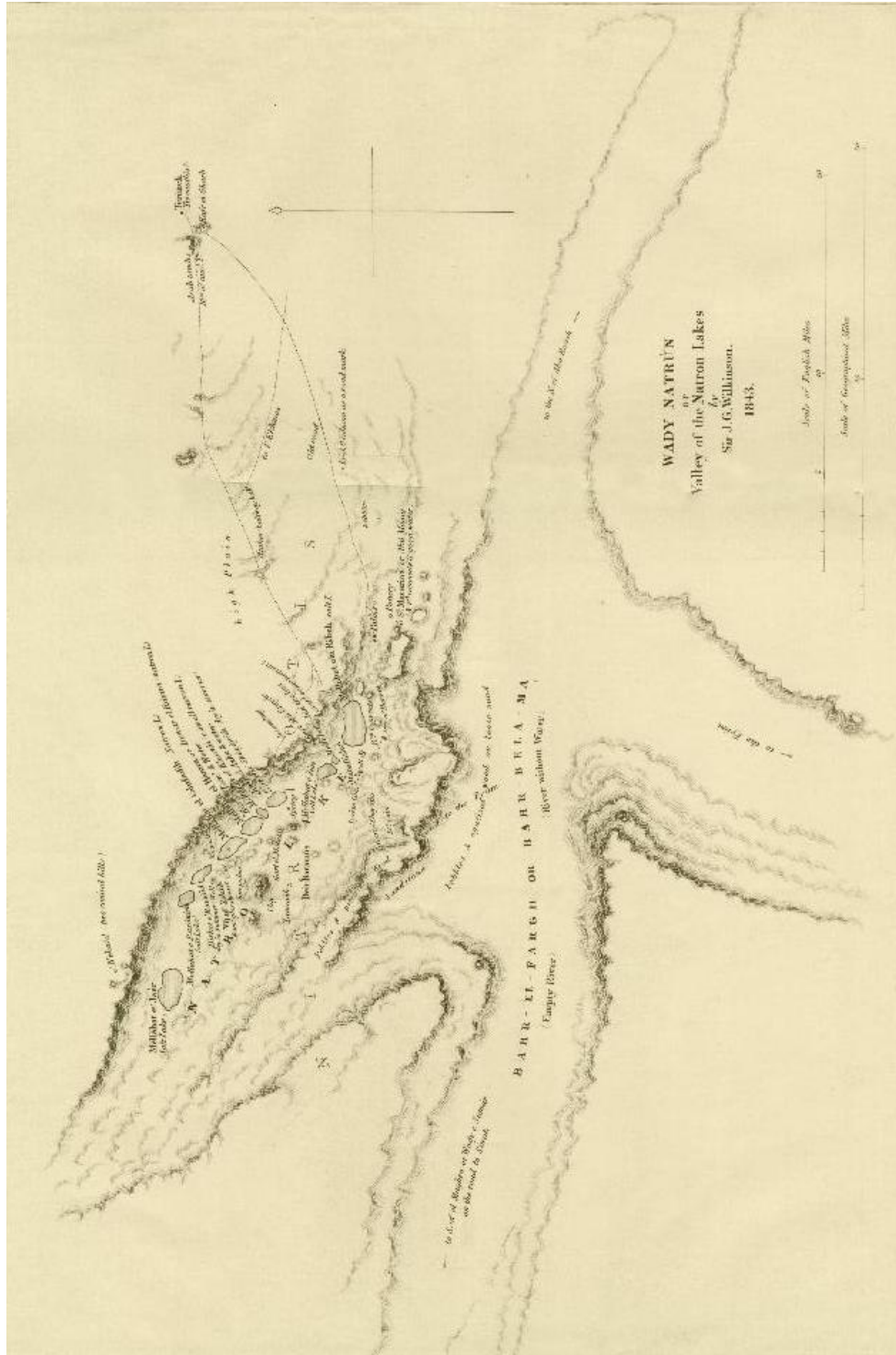


Figure 71: Map of Wilkinson (1843a) of the Wadi Natrun showing the number of lakes and "ponds" in the vicinity. There are also descriptions as to the quality of natrun from each one

An 1825 (Malte-Brun) survey suggests that the only two deposits present within the lakes were salt and natron. It could be that Malte-Brun's survey was again not rigorous and focused only on these two economically desirable products, however the fact that carbonates were present in a high enough quantity to be identified is different from lakes today. By 1845 sulphates were being detected in the form of magnesium sulphate (D'Arcet 1845), alongside the more commonly described minerals of sodium chloride and sesquicarbonate of soda (trona) which are still present in abundance. An increase in presence of sulphate is seen by 1903, although salt is still highly abundant and makes up a quarter of the lake deposits. Sulphates and carbonates were in relatively stable proportions with the sulphates being approximately the same percentage as the carbonates (Bryant 1903). These results and the results from the experimental work (6.3) suggest that the sulphate is more likely to be formed by an organic system than a geological one.

Due to the stratigraphic nature of the deposits it is known, or at least assumed, that the deposits crystallise at different times. This stratigraphy was not overlooked in the 19th Century with a number of theories being suggested as to a time frame of these depositions (Bryant 1903; Chatard 1890; Malte-Brun 1825; Wilkinson 1843a). One proposal was that the salts were precipitated in different seasons of the year; Bryant (1903) suggested that natron was deposited in the winter with salt following in the summer. His proposal is based on facts which are very much present in the formation of these lakes, rise and fall of temperatures, which lead to an increase and decrease in solubility (Bryant 1903).

The first study to name the lakes is the 1843 publication by Wilkinson. He visited the area twice in the 1840s, firstly as a geologist to discuss the lakes and secondly as a "tourist" writing about his visits to Egypt (Wilkinson 1843a; Wilkinson 1847). Although Wilkinson (1847) only designated eight deposits as being lakes, the map shows that there are a large number of birkets and ponds these latter are believed to contain "natron of a bad quality".

The lakes run in a northwest to southeast position and start with e'Ja'ar in the north-west, and moving in a southeast direction the lake is followed by e'Rasunieh, El Gunfadih, El Hamra, El Khortai, the two Jun lakes and then Om Riseh (Wilkinson 1843a). There are a number of lakes which maintain similar names today, Umrisha (Om Risheh), Hamra, Ga'ar (e'Ja'ar) and Ruzunia (e'Rasunieh). Ruzunia is an interesting case as today this lake is in a different location to where Wilkinson plots, suggesting the naming system at this time was fairly arbitrary, perhaps based on physical characteristics which could be attributed to a number of lakes. Further surveys added additional names to the lakes, with Nehele being named as the largest (D'Arcet 1845). Besides the report by Chatard (1890) this lake disappears from the documentary and oral record. Indeed, although Chatard's work is identified as the seminal work on the Wadi Natrun from the pre-Lucas era (Lucas 1912; Lucas 1932a; Lucas 1932b; Shortland et al. 2006a; Shortland 2004), Chatard never visited the wadi and based his report on D'Arcet's. By 1903, the presence of a number of well known names are identified. The lakes therefore run in a north-west to south-east pattern with Gaar; Khadra; Beida; Zukum; Hamra; Abu Ma'ma; Abu Gebara; Ruzaniah; Un Risha; Fazda; Muluk (Bryant 1903).

The use of cartography also changed in the early 20th Century, no longer were the lakes being documented by "amateurs" for expedition accounts, or for geographical understanding, but were mapped for business and military purposes. Lucas' (1912) map (Figure 72) of the area is perhaps one of the most basic maps of the area, and is primarily there to allow the reader to understand the layout of the valley as well as the location of the Salt and Soda Company, by now a well established force in the area.

More important maps were however developed during both World Wars when the area became a strategic holding, due to the presence of drinkable water in the need of a retreat, or indeed if in the wrong hands for the enemies advance. Consequently the United Kingdom produced a significant study of the area in the early 20th Century in order to understand the lay of the land (Figure 73).

These maps are highly accurate and show all the lakes from Gaar in the Northwest to Lake Fazda in the Southeast. They follow a similar pattern to the map drawn by Lucas in 1912, including the drawing of a little lake further to the west of Gaar, which is neither named nor examined in any document. Few maps have been produced of the area since but it is believed that the area, besides the increase in population, would not look that different cartographically.

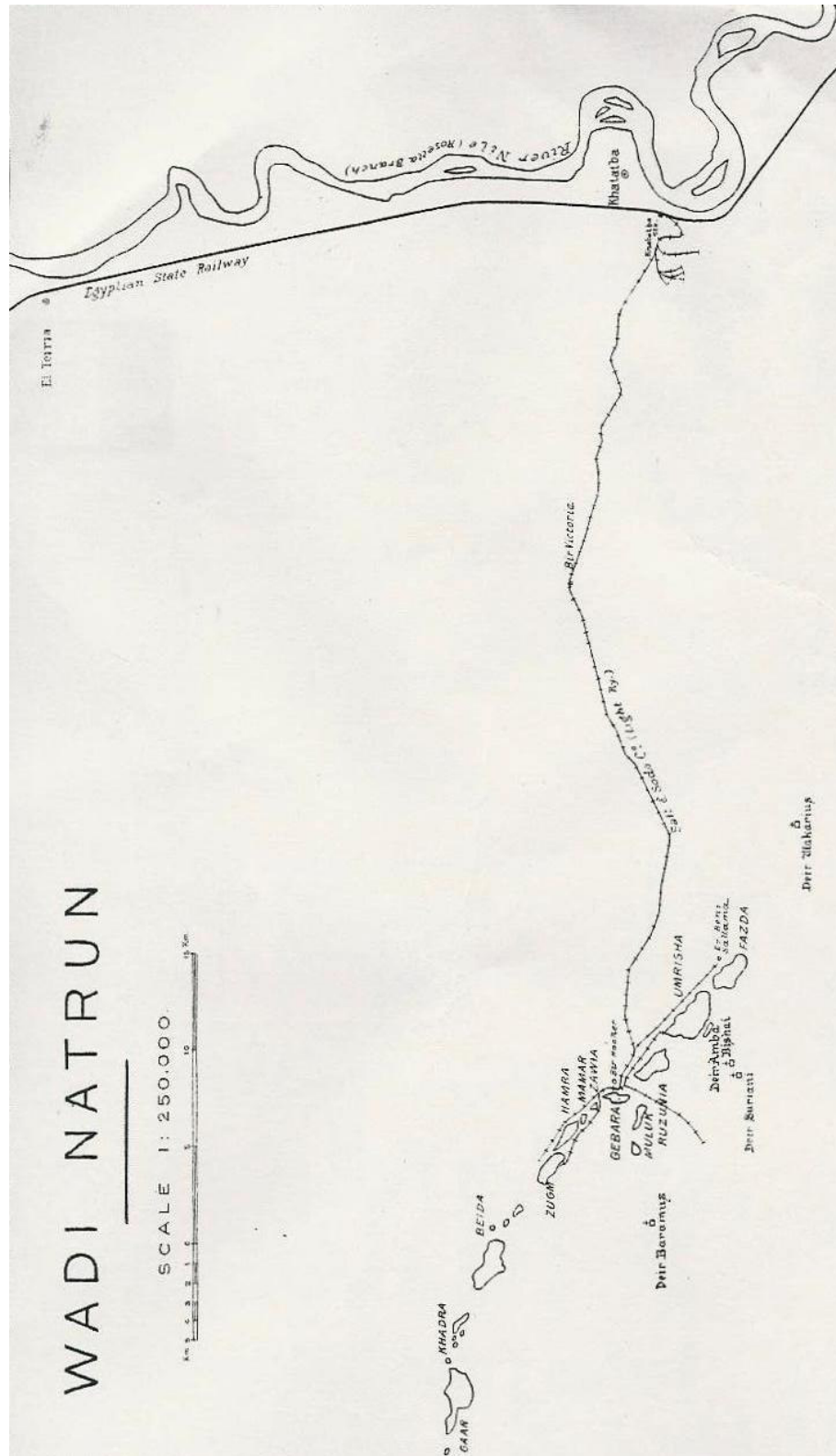


Figure 72: Lucas' map of the Wadi Natrun (Lucas 1912)

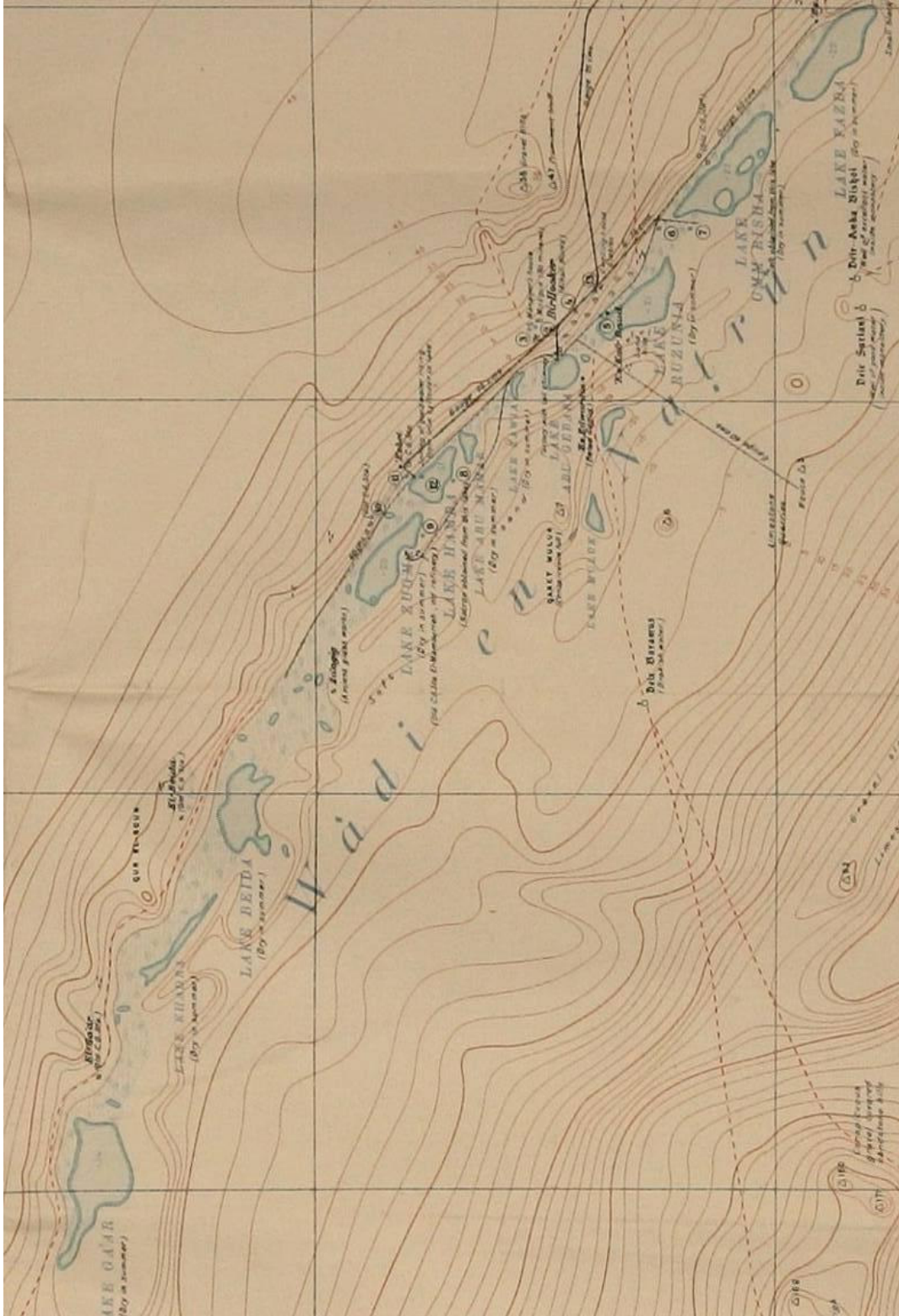


Figure 73: The Wadi Natrun as drawn in a military map of the First World War (Liddle 1915)

6.3 Analytical Work

6.3.1 Introduction

The overall aim of this project was to develop an understanding of the use and procurement of minerals in medicine and in medically associated industries. From an analysis of the medical papyri it was determined that sodium salts, salt and natrun were the most commonly used minerals. Their use was also found in other industries such as purification and mummification. An analysis of historical records shows that the Wadi Natrun was an extensive resource for sodium salts - most notably natrun - this clear link between the Wadi Natrun and Egyptian industry mean that an accurate mineralogical analysis of the systems helps give a better understanding of its 4000 year industrial history. Therefore the analytical work expressed here covers a number of areas. Firstly, an identification of the mineralogy of the deposits is important as this will enable us to develop a better understanding of the formation process present within the system and allows for the chemical heritage of the lakes to be traced, as can be seen in Table 18. Secondly, the formation process of these minerals needs to be understood as this can be allied with the stratigraphy of the lakes - which can be identified through a macroscopic analysis of the mineralogical samples gathered. These stratified minerals have been commented on since the early 19th century and analysis conducted by Berthollet (1800). Once the formation of the system is understood and modelled then a comprehension of what the ancients called “natron” can be established.

These twin objectives of identifying the mineralogy of the deposits found in the Wadi Natrun and the formation of such deposits are accomplished in two ways. The mineralogical analysis was conducted using X-Ray Diffraction (XRD), whilst the formation processes present within the Wadi Natrun were analysed using geochemical modelling.

The lakes are oriented North-West to South-East (Figure 60). The results expressed in this document will follow this pattern by starting with Lake Gaar and going through to Lake Fazda. The lakes are in order of Gaar, Khadra, Beida, Zugm, Hamra, Ruzunia, Umrisha and Fazda.

6.3.2 Fieldwork

Fieldwork was conducted in two stages, the first being a sample collecting expedition in 2004 which was followed in 2006 by a second fieldwork expedition. This purpose of the latter expedition was to observe the system as a whole, identify lake location and to observe exploitation of the system (Figure 61, Figure 62, Figure 63, Figure 64 and Figure 65). Both sets of fieldwork were conducted at the beginning of September when the lakes would be at their lowest point for water content.

Samples were collected from the surface and cores were taken to better understand the stratigraphy of the lake. From a cursory examination of the cores it was evident that there was a clear stratigraphy with mineral deposition occurring intermittently between mud layers which contained organic matter. The top mineral layer of these cores was generally between 10 and 20cm thick.

6.3.3 Methodology

The analytical work conducted on the mineralogy and formation processes of the Wadi Natrun involved two key analytical tools, XRD and geochemical modelling in the form of Geochemist Workbench. These techniques are described in detail in Chapter 2.

6.3.4 Results

The results are displayed here by lake rather than by the different techniques used, to give a clearer perspective on the formation and the mineralogy of the lakes.

Lake Gaar

Lake Gaar was subjected to analysis through Geochemist Workbench and the ion concentrations were based on Shortland et al. (2006a, 526). Geochemist Workbench predicted (Table 22, Figure 74, Figure 75, Figure 76 and Figure 77) that the most common mineral to be deposited would be halite, with the addition of burkeite and trona at temperatures above 25°C and 60°C respectively.

Table 22: Table Showing Results of the Modelling for Lake Gaar at 10; 25; 60 and 100°C

Temperature (°C)	Major Phase Present	Additional Phases	Order of Precipitation	Notes
10	Halite	Mirabilite	Mirabilite; Halite	n/a
25	Halite	Trona; Burkeite	Halite; Trona; Burkeite	n/a
60	Halite	Trona; Burkeite	Halite; Trona; Burkeite	n/a
100	Halite	Trona; Burkeite	Trona; Halite; Burkeite	n/a

No mineralogical samples from Lake Gaar were analysed during the course of this study however, some analysis was conducted by Shortland et al. (2006a, 525).

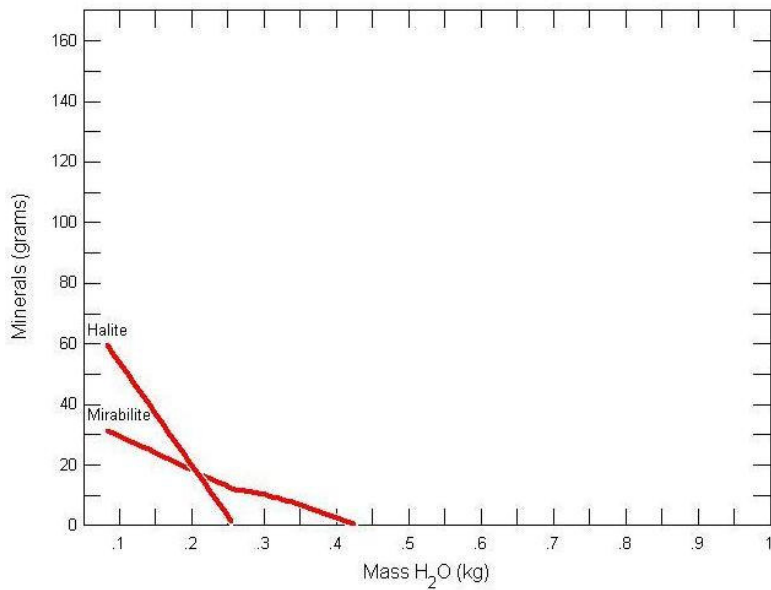


Figure 74: Results from geochemical modelling for Lake Gaar, modelled at 10°C and taken to dryness. The results show the formation of two minerals, halite and mirabilite, with halite being the predominate mineral formed.

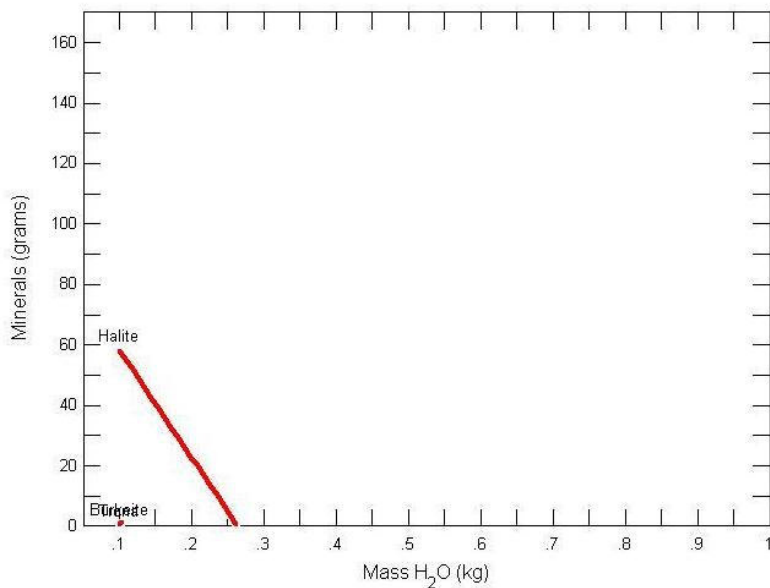


Figure 75: Results from geochemical modelling of Lake Gaar at 25°C, and taken to dryness. The results show the formation of three minerals, burkeite, trona and halite. Halite is the predominate mineral formed.

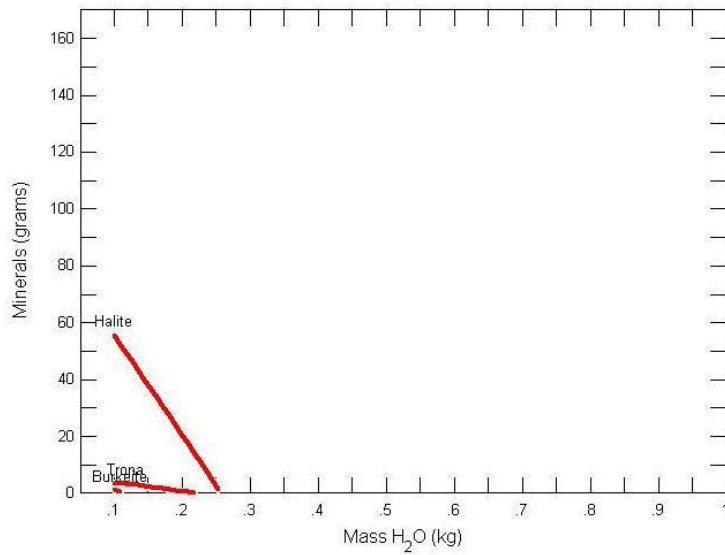


Figure 76: Results from geochemical modelling of Lake Gaar modelled at 60°C. The results show the formation of three minerals, burkeite, trona and halite, with halite being the predominate mineral formed.

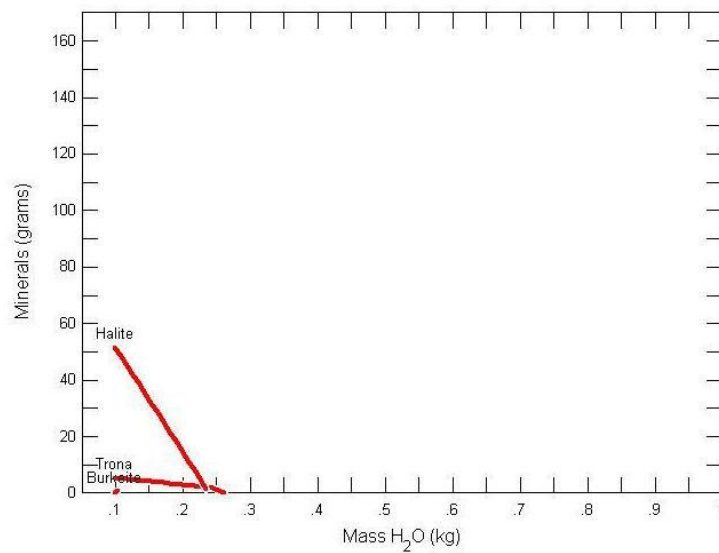


Figure 77: Results from geochemical modelling of Lake Gaar modelled at 100°C and the body of water taken to dryness. The results show that halite is the predominate mineral formed, and in addition to this trona and burkeite were also formed.

Lake Khadra

Lake Khadra is always full of water and as such does not have a mineralogical deposit of which to speak. The X-Ray Diffraction of a sample gathered from the side of the lake (Table 23) showed that there was a high concentration of quartz (sand) and the only other phase found was of halite.

Table 23: Table showing the mineralogical phases from samples gathered from Lake Khadra

Sample Number	Location of sample	Layers	Description	Major Mineralogical Phase	% (weight)	Minor Mineralogical Phase	% (weight)
WN21	n/a	None	Compressed sand coloured crystals	Quartz	89.38	Halite	10.62

Lake Beida

Deposits from Lake Beida were analysed using XRD and the chemistry of this lake was assessed using Geochemist Workbench. The analysis conducted by XRD showed that Lake Beida had a high concentration of sodium chloride and sodium sulphate groups (Table 24). WN18 was determined before analysis to be highly stratified (Figure 78, Figure 79 and Figure 80) with strong halite crystal structures on the uppermost layer of the sample (Figure 79).

The ion chemistry of Lake Beida was determined by Shortland et al. (2006a, 526) and this was used to model the formation processes of the lake. The major phase to be predicted in forming was that of halite, with additional phases in the form of mirabilite, burkeite and trona (Table 25 and Figure 81, Figure 82, Figure 83 and Figure 84).

Table 24: Table showing the mineralogical phases present from samples taken from Lake Beida

Sample #	Location of Sample	Layers	Description	Major Phase	% (weight)	Minor Phase	% (weight)	RWP
WN14	NE edge	None	White crystals	Halite	61.1	Thenardite	31.2	13.649
						Quartz	7.7	
WN16	NE 18m from edge	a	Base layer - soil coloured	Thenardite	72.2	Halite	11.7	24.395
						Quartz	8.6	
						Sodium Sulphate	7.5	
		b	White crystals	Halite	58.4	Thenardite	37.6	17.289
						Quartz	4	
WN17	NE 10m from edge	None	Large compressed white crystals	Halite	65	Thenardite	23.9	15.053
						Quartz	11.1	
WN18	Centre	a	Thin sandy coloured base layer	Halite	100			16.276
		b	Densely packed large white crystals	Halite	100			16.531
		c	Off white/pinkish layer of small closely packed crystals	Thenardite	84.8	Halite	15.2	15.22
		d	Top layer - strong cubic crystal structure - pink	Halite	87.3	Thenardite	12.7	19.472
		e	White loose powder covering back side of sample	Halite	90.1	Thenardite	9.9	14.784
WN19	NE 10m from edge	None	Easily powderable compressed white crystals	Halite	82.7	Thenardite	17.3	16.336

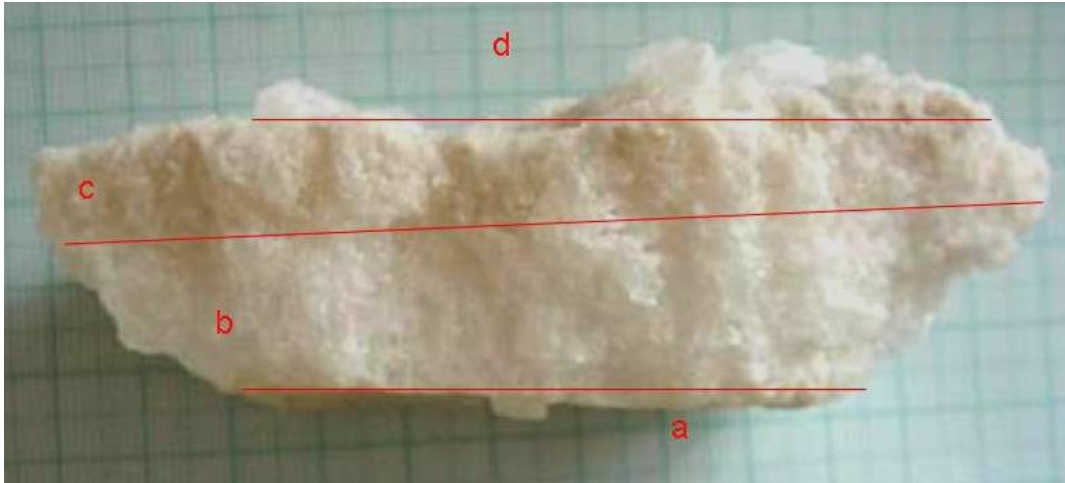


Figure 78: Photo showing the four layers present in sample WN18



Figure 79: Photo showing the halite crystals deposited on top of sample WN18

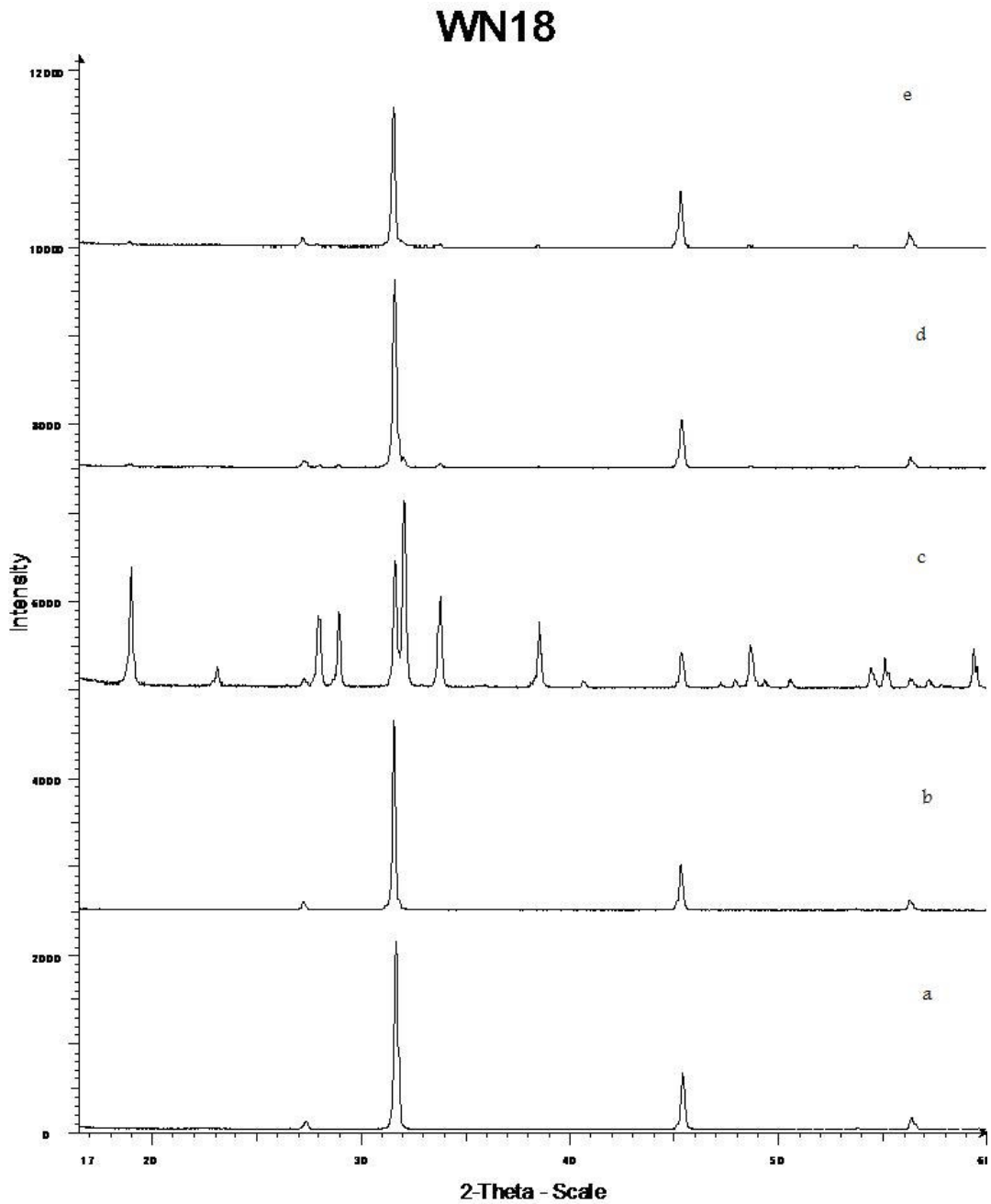


Figure 80: Image showing the XRD results for the layered sample # WN18, the base (a) is found at the bottom of the image, whilst the top (d) is found near the top of the image.

Table 25: Table showing results of the modelling for Lake Beida at 10; 25; 60 and 100°C

Temperature (°C)	Major Phase Present	Additional Phases	Order of Precipitation	Notes
10	Halite	Mirabilite	Halite; Mirabilite	n/a
25	Halite	Burkeite	Halite; Burkeite	n/a
60	Halite	Burkeite; Trona	Halite; Trona; Burkeite	n/a
100	Halite	Trona; Burkeite	Halite; Burkeite; Trona	n/a

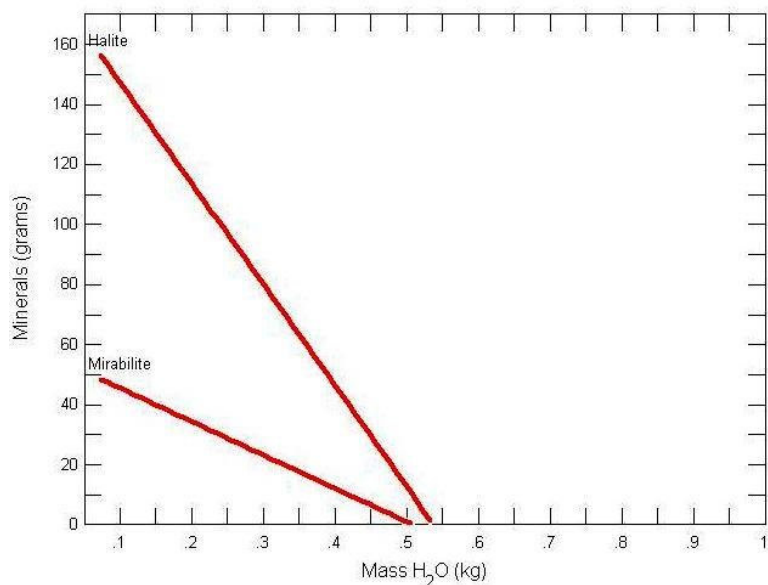


Figure 81: Results from geochemical modelling of Lake Beida, modelled at 10°C and to dryness. The results show that two minerals are formed, mirabilite and halite, with halite being the predominate mineral to be formed.

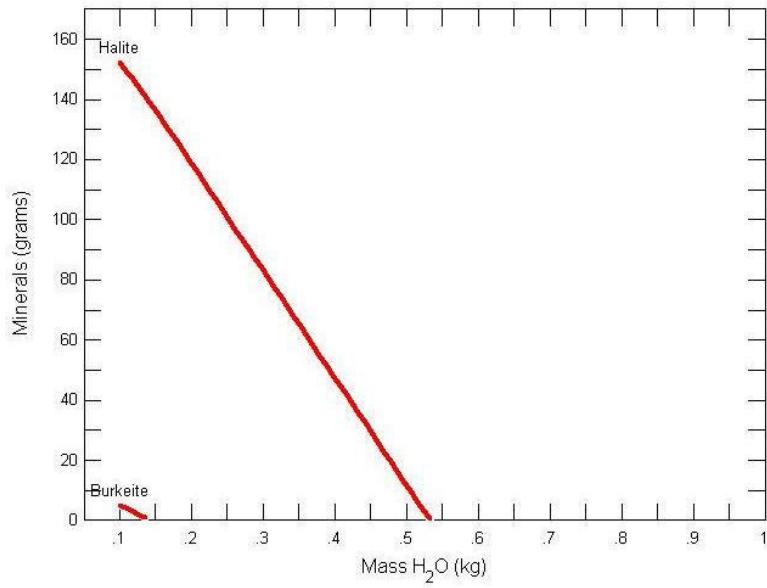


Figure 82: Results from geochemical modelling of Lake Beida at 25°C and to dryness. With two minerals being formed, burkeite and halite, with the latter being the predominate mineral.

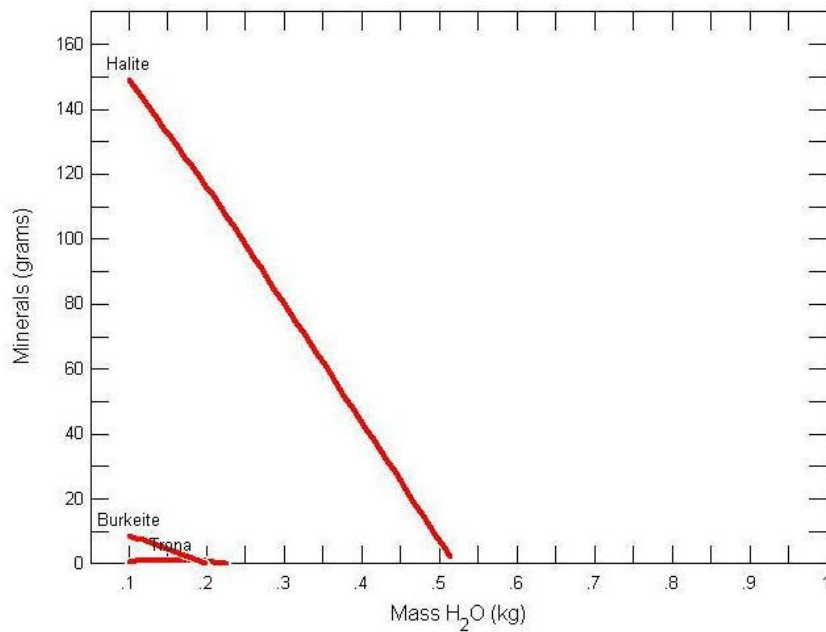


Figure 83: Results from geochemical modelling of Lake Beida at 60°C and to dryness. Three minerals are formed, halite (predominate), burkeite and trona.

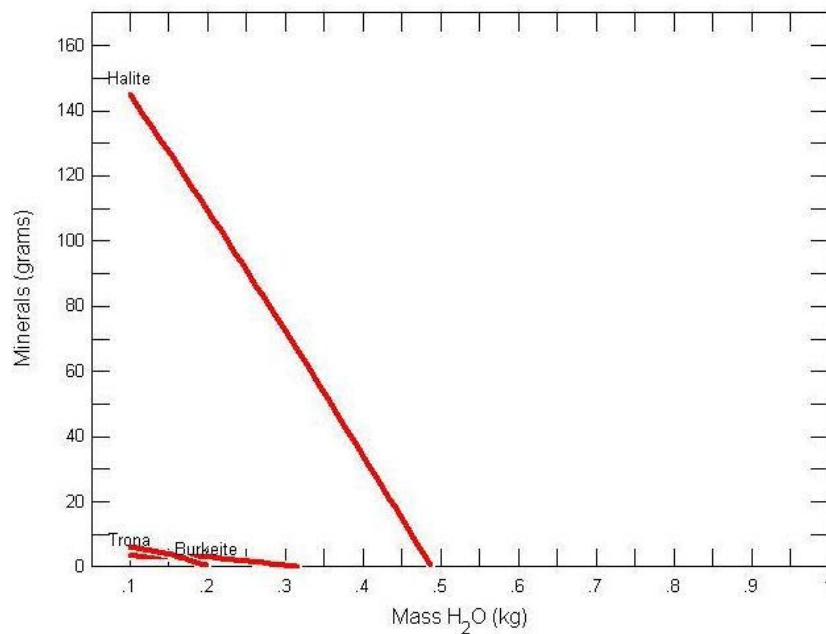


Figure 84: Results from geochemical modelling of Lake Beida at 100°C and to dryness. Three minerals are formed, halite (predominate), burkeite and trona.

Lake Zugm

The results of XRD analysis of Lake Zugm specimens (Table 26) show that the lake is highly chloride rich with significant traces of burkeite in samples WN9 and WN12 (>25%), as well as the high level of burkeite present in WN10 (>60%). No carbonate other than burkeite was detected.

Table 26: Table showing the mineralogical phases for samples from Lake Zugm

Sample Number	Area sample gathered from	Layer	Description	Major Mineralogical Phase	% (weight)	Minor Mineralogical Phase	% (weight)	RWP
WN9	NE	None	Pink crystals	Halite	73.5	Burkeite	26.5	13.383
WN10	NE	a	Cornflake crystal - dark red colour	Burkeite	85.5	Quartz	14.5	17.56
		b	Cornflake crystal - light pink colour	Halite	50.7	Burkeite	49.3	13.423
WN11	NE	a	Loosely packed white cornflake crystals	Burkeite	69.6	Halite	30.4	10.251
		b	Compressed white cornflake crystals	Halite	100			12.027
		c	Compressed white crystals	Halite	100			10.427
WN12	NE	None	White crystals	Halite	61.35	Burkeite	38.65	11.822
WN36a	SW	None	Large white crystals	Halite	100			14.397
WN36b	SW	None	Compacted white crystals	Halite	100			10.864
WN36c	SW	None	Pink crystals	Halite	100			17.159

Two of the specimens were found to be stratified, and the decision taken over the location of each layer was determined by a change in colour or crystal structure (Figure 85 and Figure 87), these samples were analysed separately (Table 26, Figure 86 and Figure 88) and the results show a difference in the chemistry between some of the layers although not all.



Figure 85: Photo showing the two distinct colour differences between two layers a and b in sample WN10

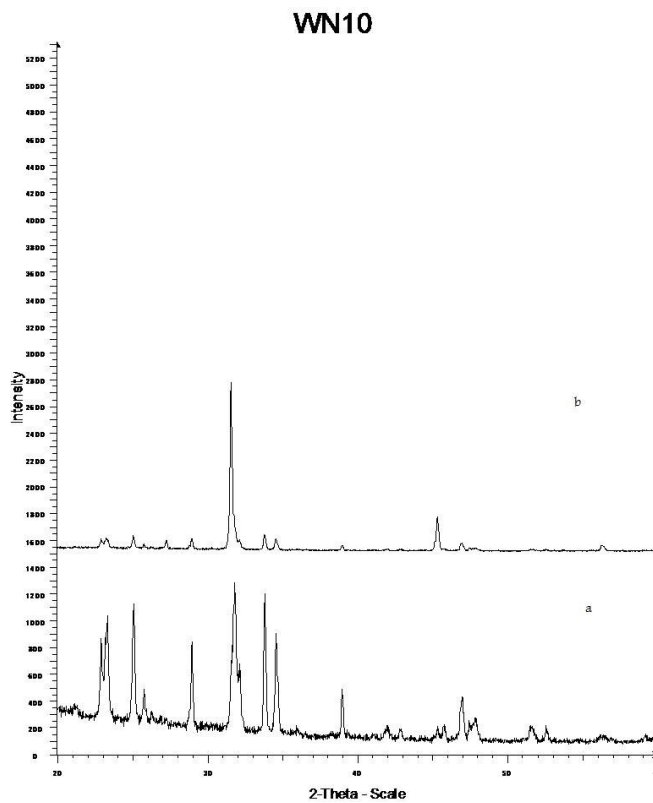


Figure 86: XRD results for sample WN10. Showing the difference between the results of the two layers.



Figure 87: Photo showing the three layers present in WN11

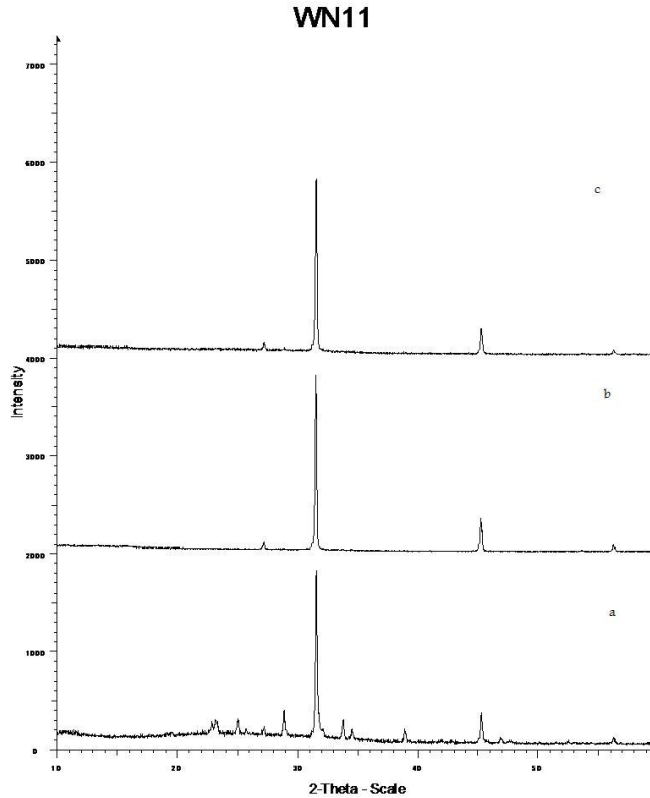


Figure 88: XRD results for sample WN11. It shows the difference between the three layers, a (base of image), b and c (top of image)

Lake Hamra

Lake Hamra was analysed using both XRD and Geochemist Workbench. The results of the XRD analysis (Table 27) show that there is a high predominance of halite within the lake but also quantities of the sulphate minerals thenardite and burkeite.

The ion chemistry of Lake Hamra had already been ascertained (2006a, 526) and these figures were run through Geochemist Workbench in order to get an idea of what minerals were precipitating when and how much was produced. The results (Table 28, Figure 89, Figure 90, Figure 91 and Figure 92) show a

chloride rich system producing halite as the dominate species with the presence of additional minerals in the form of trona, burkeite and mirabilite. The modelling of Lake Hamra chemical system at 10°C also suggests that there was some form of redissolution occurring whereby mirabilite was redissolved into the system very close to the end of the run.

Table 27: Table showing the mineralogical phases from Lake Hamra samples

Sample #	Location	Layer	Description	Major Phase	% (weight)	Minor Phase	% (weight)	RWP
WN1	NE	a	Compressed pink crystals	Halite	100			18.57
		b	White crystals	Burkeite	74.5	Halite	20	16.353
						Thenardite	5.5	
WN2	NW	None	Compressed sandy coloured crystals	Thenardite	85.25	Halite	7.31	9.597
						Quartz	7.44	
WN3	SW	None	Easily powderable pink compressed crystals	Halite	100			13.848
WN4	SW	None	Powdery white crystals	Halite	100			11.918
WN5	SW	a	Compressed white crystals	Halite	100			13.168
		b	Compressed pink crystals	Halite	100			14.568
		c	Loosely packed pink crystals	Halite	77.13	Burkeite	22.87	18.71
WN6	SW	None	Compressed small white crystals	Halite	100			16.047
WN8	SW	None	Compressed white crystals	Halite	100			13.575
WN33	SW	None	White cornflakes	Burkeite	81.9	Halite	15.15	16.144
						Thenardite	2.96	
WN34	SW	None	White crystals	Burkeite	86.01	Halite	13.99	13.557
WN35	SW	a	Pink compressed crystals	Burkeite	82.23	Halite	17.77	13.529
		b	White crystals	Halite	54.23	Burkeite	33.5	13.92

Table 28: Table showing results of the modelling for Lake Hamra at 10; 25; 60 and 100°C

Temperature (°C)	Major Phase Present	Additional Phases	Order of Precipitation	Notes
10	Halite	Mirabilite; Trona; Burkeite	Mirabilite; Trona; Halite; Burkeite	Some evidence for redissolution
25	Halite	Burkeite; Trona	Trona; Burkeite; Halite	n/a
60	Halite	Burkeite; Trona	Trona; Burkeite; Halite	n/a
100	Halite	Burkeite; Trona; Natron	Trona; Burkeite; Halite; Natron	n/a

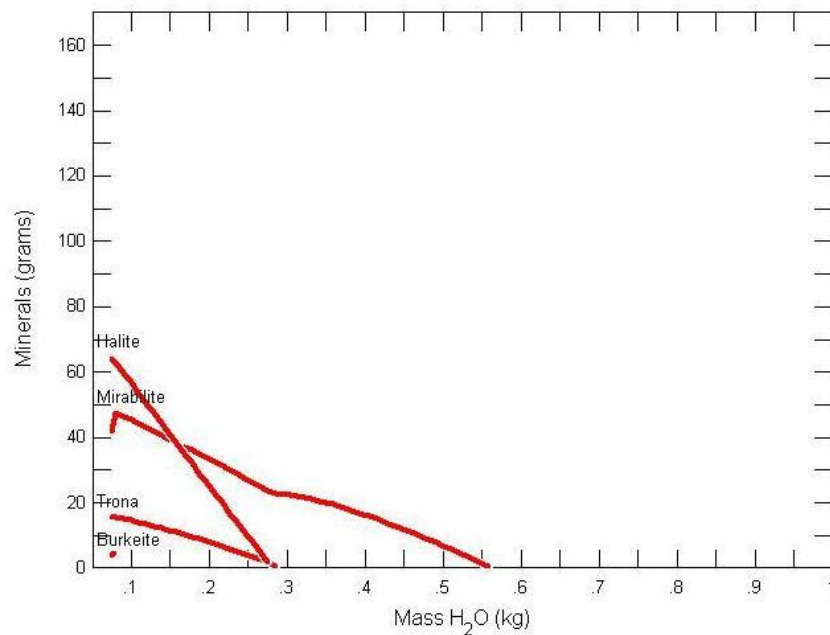


Figure 89: Results from geochemical modelling of Lake Hamra, modelled at 10°C and to dryness. Four minerals were formed, halite (predominate), mirabilite, trona and burkeite.

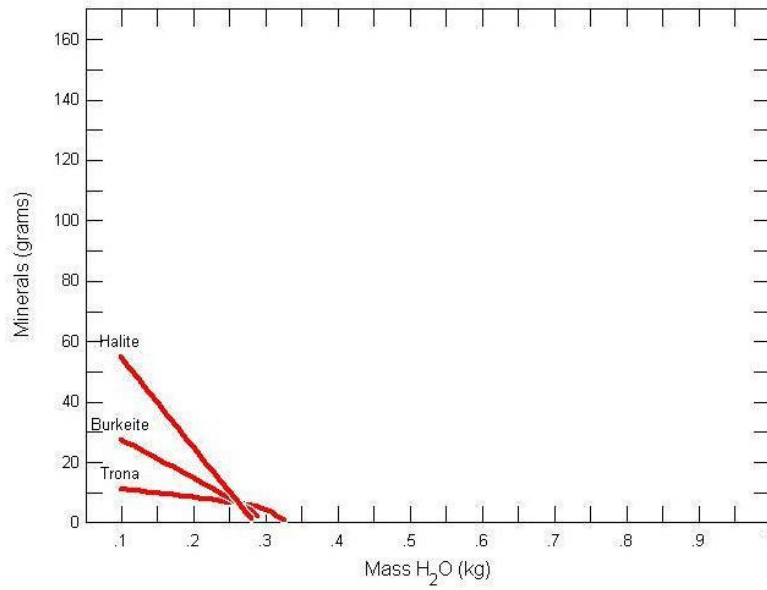


Figure 90: Results from geochemical modelling of Lake Hamra, modelled at 25°C and to dryness. Three minerals are formed, halite (predominate), burkeite and trona.

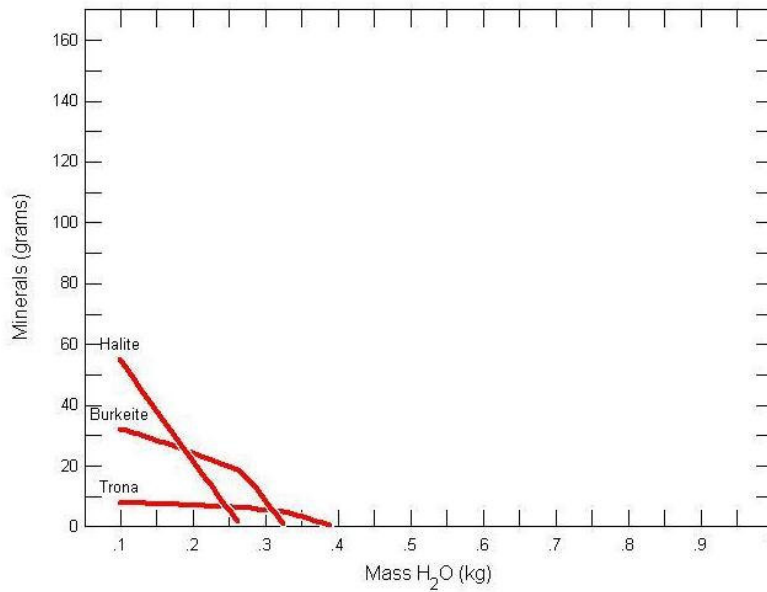


Figure 91: Results from geochemical modelling of Lake Hamra, modelled at 60°C and to dryness. Three minerals are formed, halite (predominate), burkeite and trona.

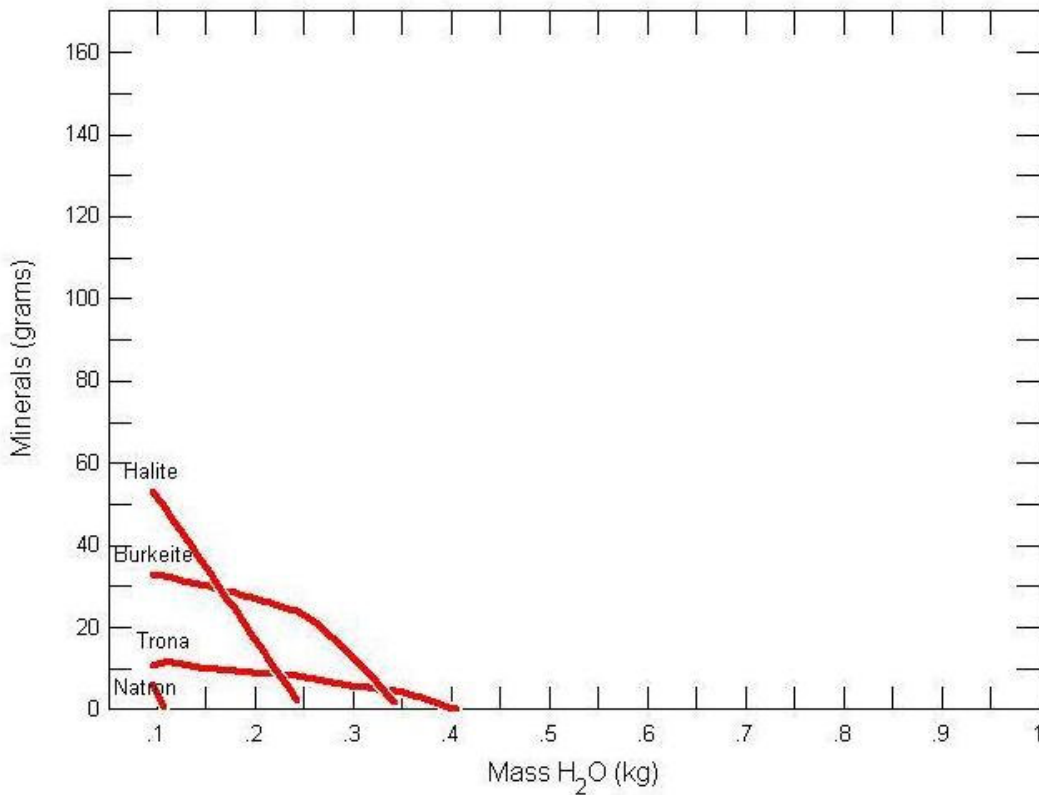


Figure 92: Results from geochemical modelling of Lake Hamra, modelled at 100°C and to dryness. Four minerals are formed, halite (predominate), burkeite, natron and trona.

Lake Ruzunia

Lake Ruzunia was analysed using Geochemist Workbench only and the results (Table 29, Figure 94, Figure 93, Figure 95 and Figure 96) show that halite is predicted to be the predominant mineral formed. Indeed with the system at 25°C halite is the only mineral formed, whereas at 10°C mirabilite is formed and above 60°C, trona is also present.

Table 29: Table showing results of the modelling for Lake Ruzunia at 10; 25; 60 and 100°C

Temperature (C)	Major Phase Present	Additional Phases	Order of Precipitation	Notes
10	Halite	Mirabilite	Halite; Mirabilite	n/a
25	Halite	n/a	Halite	n/a
60	Halite	Trona	Halite; Trona	n/a
100	Halite	Trona	Halite; Trona	n/a

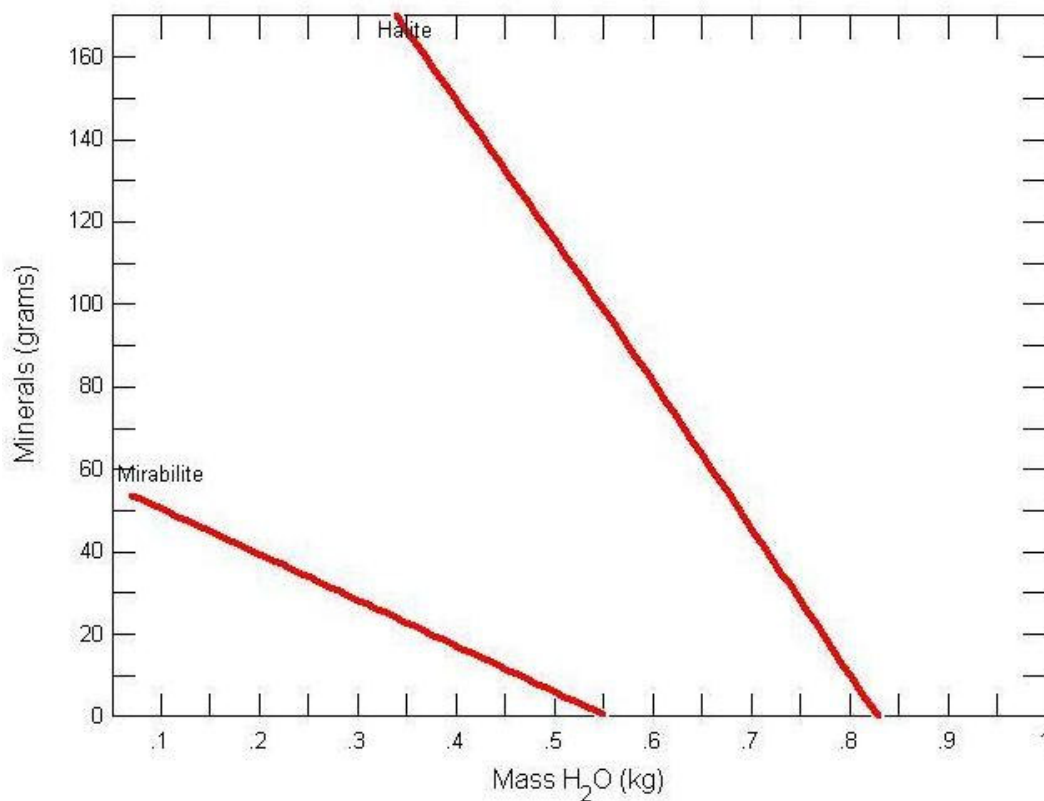


Figure 93: Results from geochemical modelling of Lake Ruzunia at 10°C and to dryness. Results show that two minerals, halite (predominate) and mirabilite were formed.

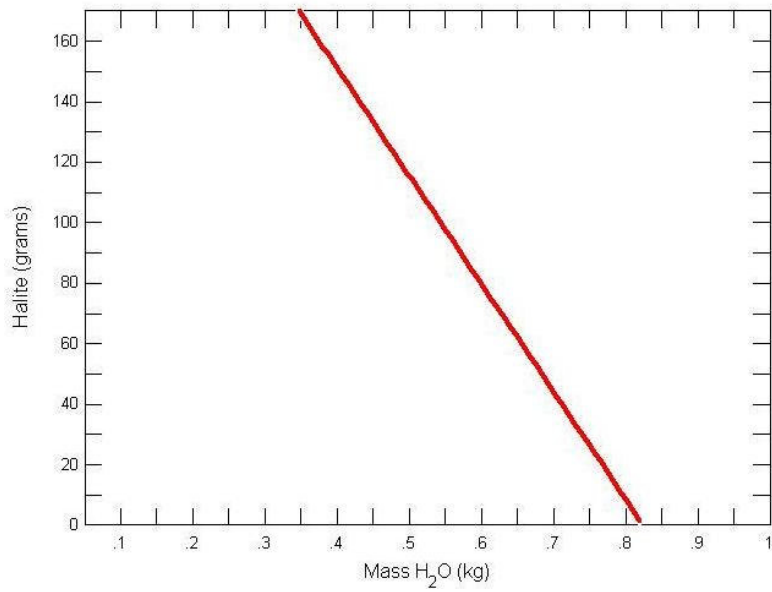


Figure 94: Results from geochemical modelling of Lake Ruzunia at 25°C and to dryness. There is only one mineral formed and that is halite.

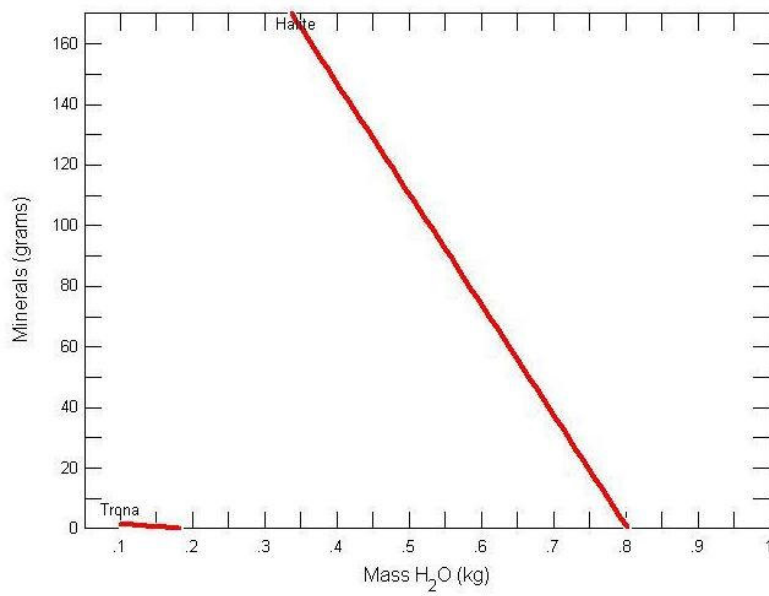


Figure 95: Results from geochemical modelling of Lake Ruzunia at 60°C and to dryness. There are two minerals formed, halite (predominate) and trona.

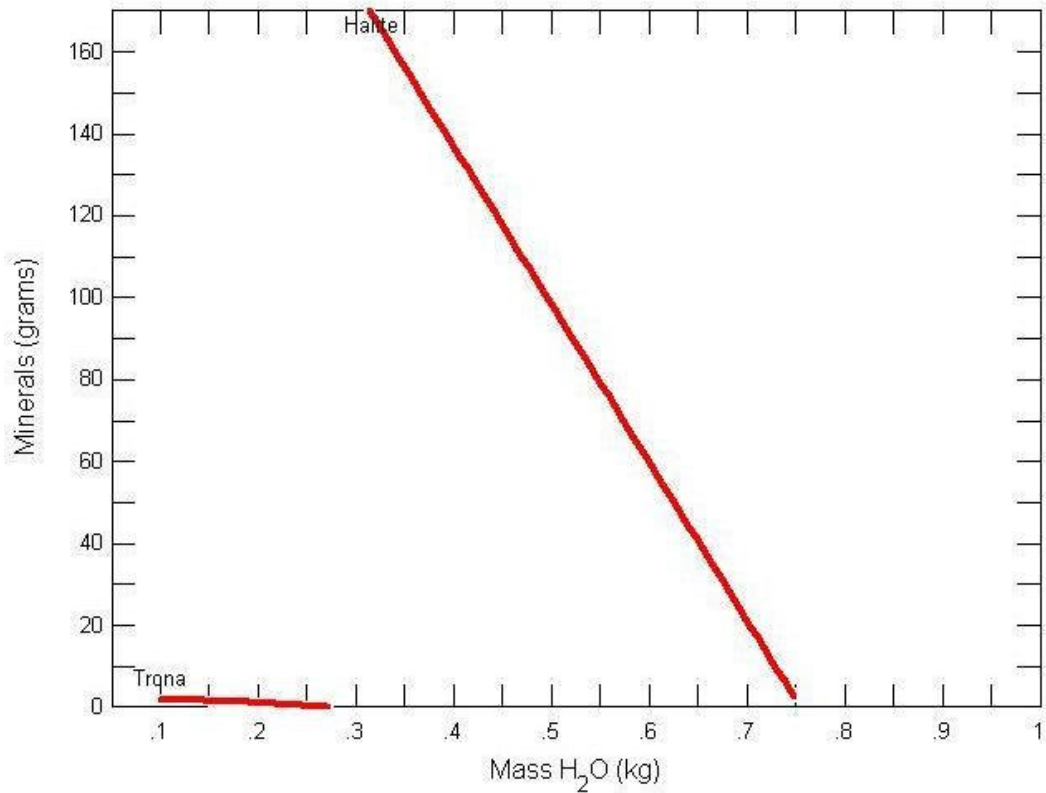


Figure 96: Results from geochemical modelling of Lake Ruzunia at 100°C and to dryness. There are two minerals formed, halite (predominate) and trona.

Lake Umrisha

The results of the Geochemist modelling (Table 30, Figure 97, Figure 98, Figure 99 and Figure 100) show that the lake is chloride rich with halite being the only mineral formed above 60°C, although there is a presence of sulphate ions as mirabilite is formed below 60°C.

Table 30: Table showing results of the modelling for Lake Umrisha at 10; 25; 60 and 100°C

Temperature (°C)	Major Phase Present	Additional Phases	Order of Precipitation	Notes
10	Halite	Mirabilite	Mirabilite; Halite	n/a
25	Halite	Mirabilite	Halite; Mirabilite	n/a
60	Halite	n/a	Halite	n/a
100	Halite	n/a	Halite	n/a

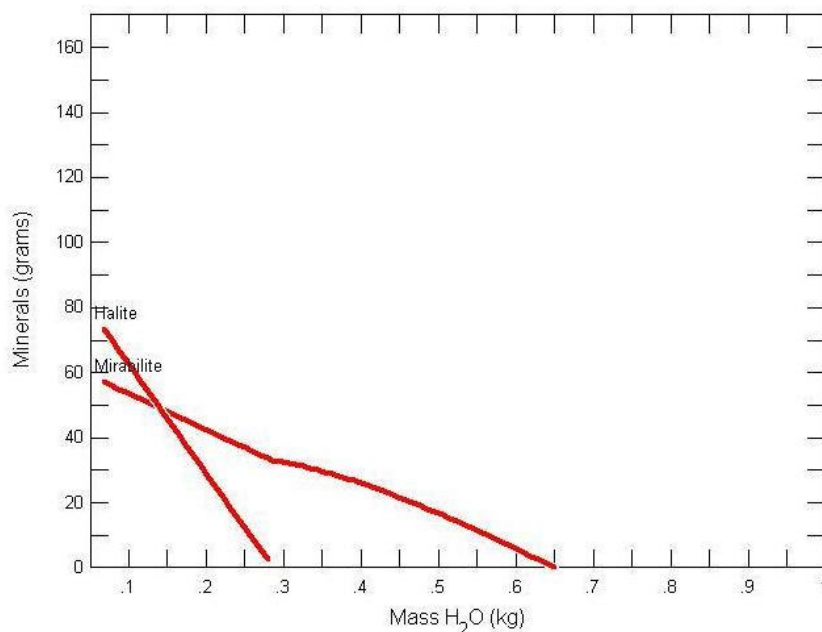


Figure 97: Results from geochemical modelling of Lake Umrisha at 10°C. The results show the formation of two minerals, halite (predominate) and mirabilite.

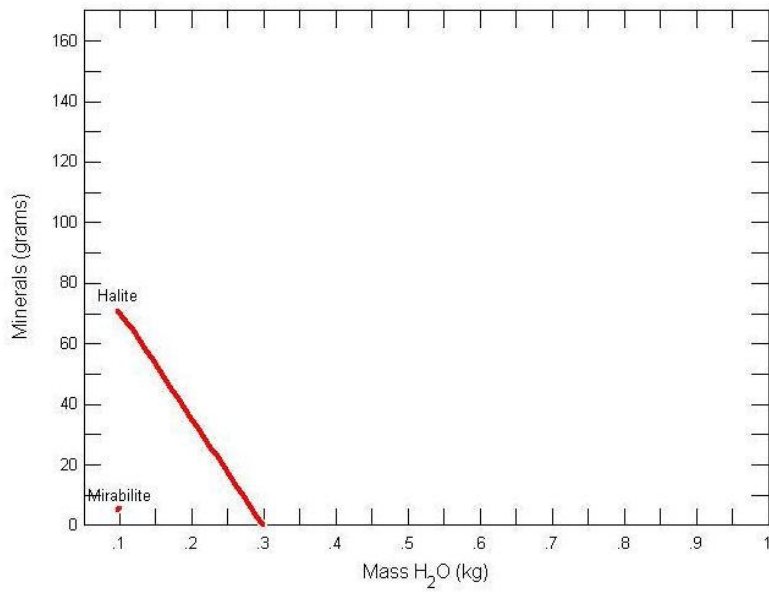


Figure 98: Results from geochemical modelling of Lake Umrisha at 25°C. The results show the formation of two minerals, halite (predominate) and mirabilite.

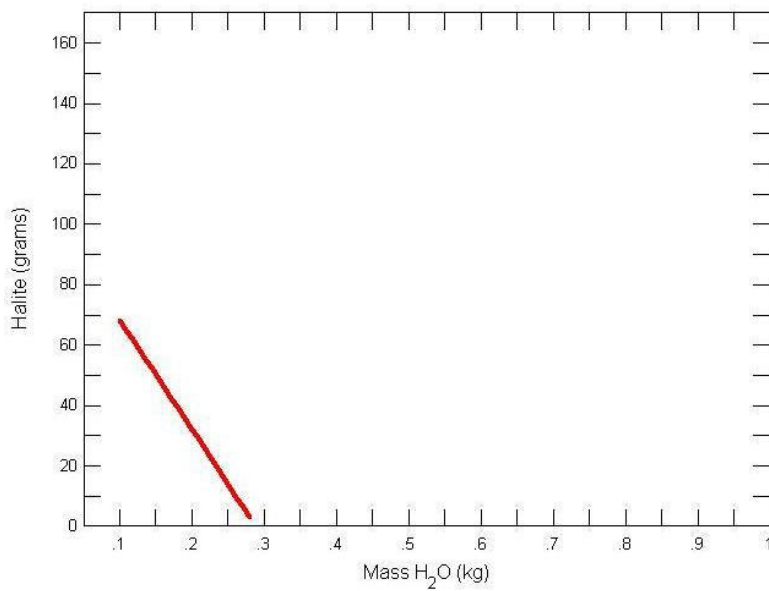


Figure 99: Results from geochemical modelling of Lake Umrisha at 60°C and to dryness. Results show that the only mineral to be formed is that of halite.

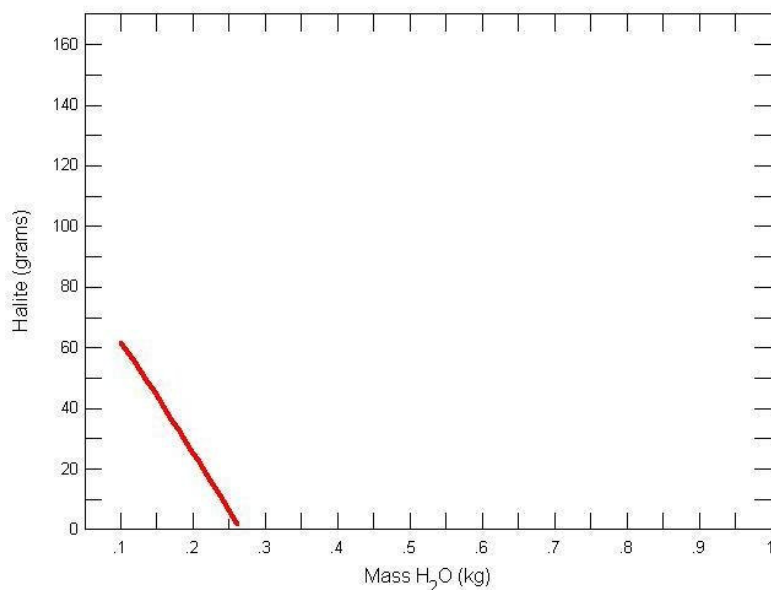


Figure 100: Results from geochemical modelling of Lake Umrisha at 100°C and to dryness. Results show that the only mineral to be formed is that of halite.

Lake Fazda

Lake Fazda's chemistry was subject to analysis by both XRD and Geochemist Workbench. Eleven mineralogical specimens were taken (Table 31) from Lake Fazda and two of these were found to be layered (WN30c (Figure 101, Figure 102, Figure 103 and Figure 104) and WN30d (Figure 105 and Figure 106)). Two specimens (WN23 and WN24) were gathered from piles of deposit that were stored on the side of the lake.

In one core sample Lake Fazda there were four mineral layers interspersed between three mud layers in the first meter. It is assumed that this stratigraphy continued into the lake bed in a similar pattern. It was not possible to date these layers, but it is clear that in the past the system was left to recuperate during which time mud layers were generated, which has already been discussed in 6.2.4.

The results of the mineralogical analysis (Table 31) show that burkeite and halite are found in abundance within the deposit. Two specimens from the lake (WN24 and WN30a) were also found to contain the sodium carbonate mineral, trona.



Figure 101: Photo showing the base layer (a) from specimen WN30c

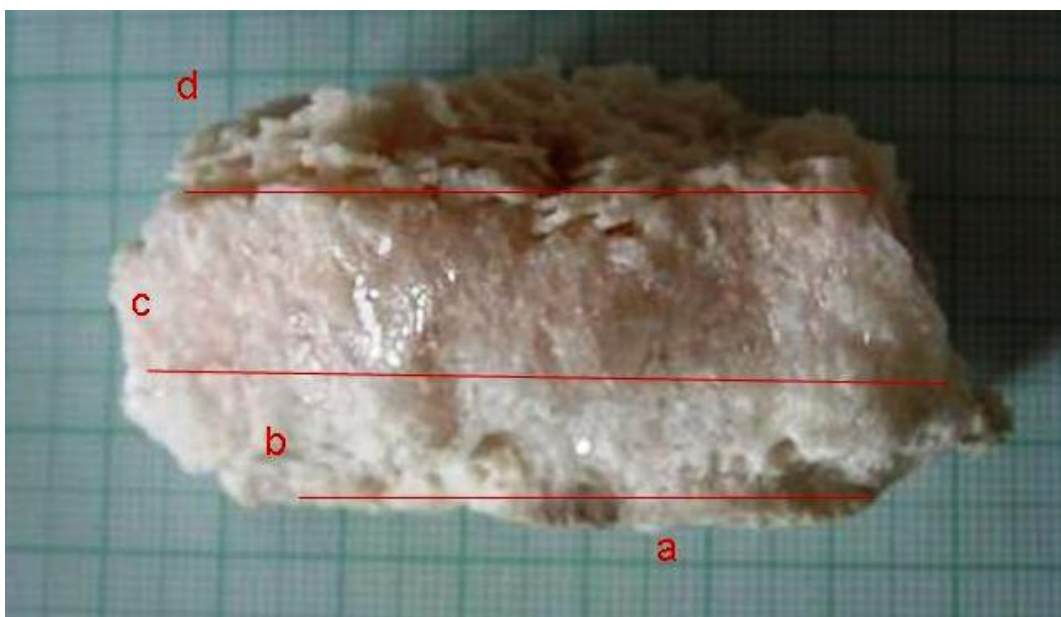


Figure 102: Photo showing all the layers of WN30c

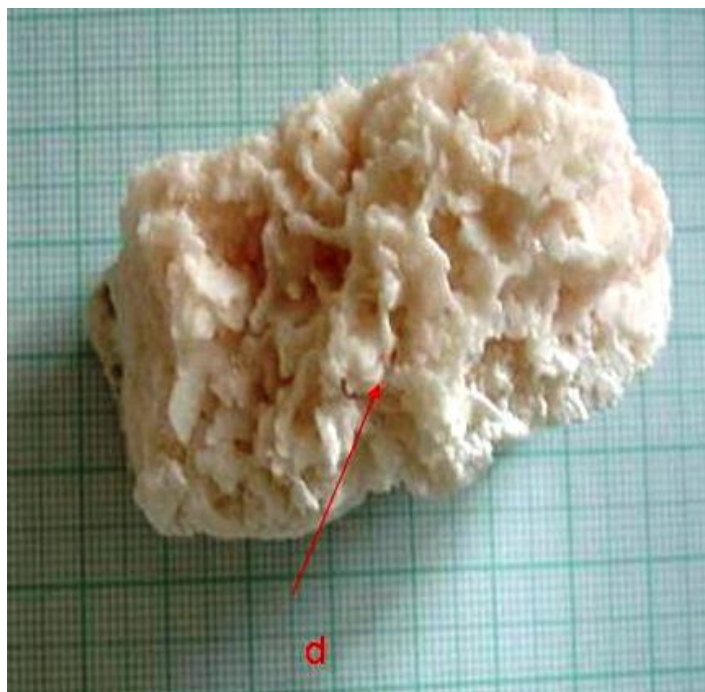


Figure 103: Photo showing layer d from WN30c, note the clear and strong "cornflake" crystal shape

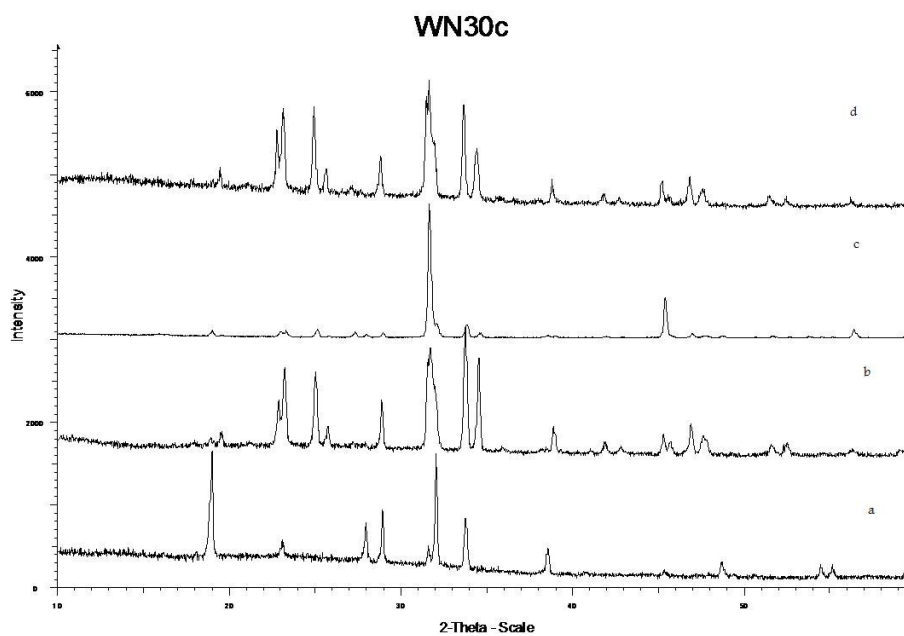


Figure 104: XRD results of the four layers of sample WN30c. It shows clearly the distinct mineralogical differences between the layers.

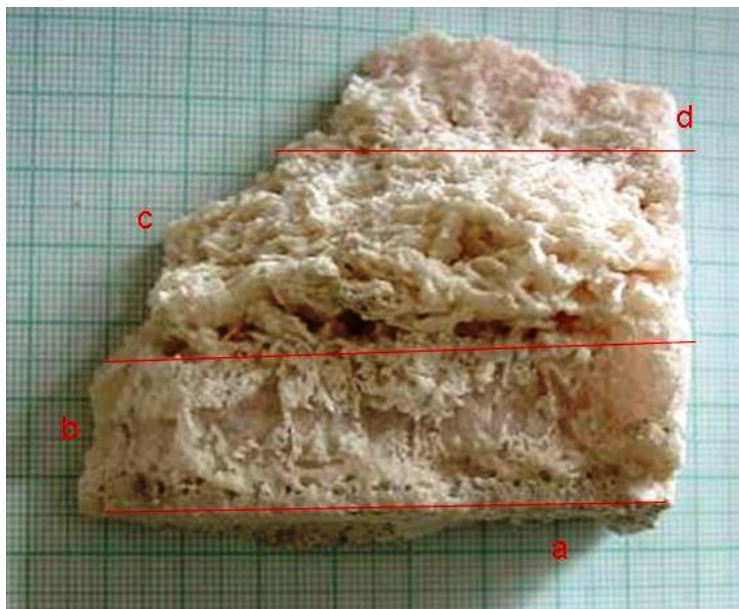


Figure 105: Photo showing the four layers of WN30d

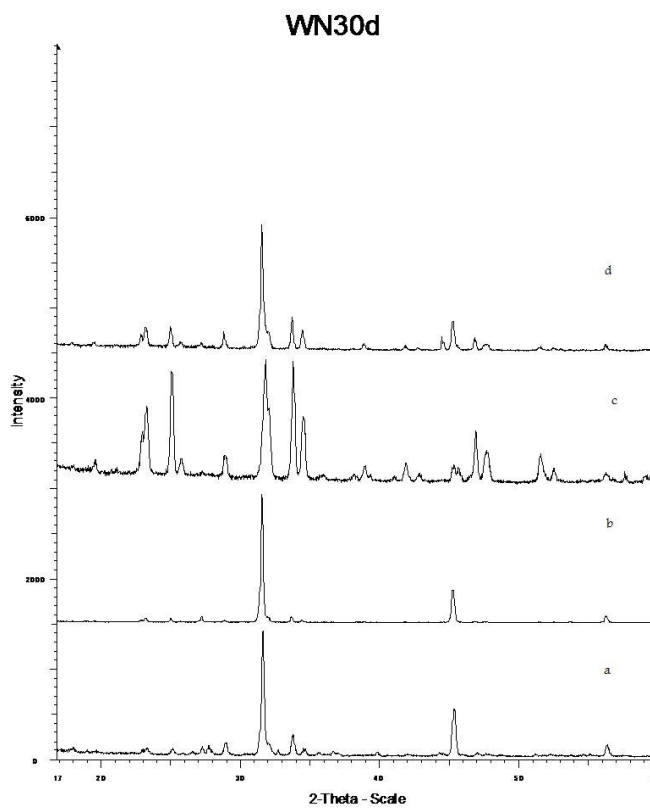


Figure 106: XRD results of the four layers from sample WN30d. A (base layer) is found at the bottom of the image, with d (top layer) is found at the top of the image.

Table 31: Table showing the mineralogical phases of Lake Fazda

#	Sample area	Layer	Description	Major Phase	% (weight)	Minor Phase	% (weight)	RWP
WN 23	Pile	None	Sheets of compacted pink crystals	Burkeite	75.37	Halite	17.47	10.229
						Quartz	7.16	
WN 24	Pile	None	Sheets of compacted pink crystals	Trona	44.1	Burkeite	31.7	10.84
						Thenardite	13.5	
						Quartz	4.5	
						Halite	2.8	
WN 26	75m from edge	None	Pink sheets	Burkeite	55.8	Halite	24.4	10.205
						Quartz	15.9	
						Thenardite	3.9	
WN 27	Zoom	None	Compressed white "cornflake" crystals	Burkeite	53.9	Halite	43.1	12.761
						Quartz	3	
WN 28	200m from edge	None	Compressed white "cornflake" crystals	Burkeite	82.1	Halite	17.9	11.812
WN 29	Near shore	None	White crystals	Burkeite	81.7	Halite	18.3	14.689
WN 30a	W edge 200m	None	Large pink crystals	Trona	79.75	Burkeite	19.1	17.142
WN 30b	W edge 200m	None	Pink flaky "cornflake" crystals	Burkeite	95.5	Halite	4.5	24.625
WN 30c	W edge 200m	a	Base rock compacted	Thenardite	76.2	Quartz	23.8	12.994
		b	closely packed white "cornflakes"	Burkeite	78.2	Thenardite	16.9	18.578
						Halite	4.9	
		c	Compacted pink crystal	Halite	43	Thenardite	29.2	15.476
						Burkeite	27.8	
						d	Large scale pink crystals loosely packed	Burkeite
							8.4	
WN 30d	W edge 200m	a	Compacted base rock	Halite	45.8	Burkeite	42.5	18.911
						Sodium Sulphate	11.7	
		b	Compacted pink crystal	Halite	69.9	Burkeite	27.8	13.423
						Quartz	2.3	
		c	Closely packed white "cornflake"	Burkeite	96.35	Halite	3.65	13.939
		d	Compacted pink crystal	Burkeite	75.9	Halite	24.1	14.622
WN 30e	W edge 200m	None	Pink "cornflake" crystals	Halite	80.4	Burkeite	19.6	19.012

As Lake Fazda was identified as being an important resource for the use of natrun from at least the Roman period (6.2) the decision was taken to geochemically model the lake system at temperatures between 0°C and 100°C at increments of 5°C. Although this range of temperatures is extreme it was felt that this was necessary to accurately predict and discuss the formation chemistry of the lake.

The results of the modelling (Table 32, Figure 107, Figure 108, Figure 109, Figure 110, Figure 111, Figure 112, Figure 113, Figure 114, Figure 115, Figure 116, Figure 117 and Figure 118) show the high presence of the sodium carbonate mineral, natron, after 40°C. The modelling predicts that the chemical system in Lake Fazda should be able to precipitate trona, natron, burkeite and halite. The model also shows that redissolution of the minerals mirabilite, trona and natron would occur. Mirabilite was redissolved into the system at 10°C; trona was redissolved in the system at 85°C, 90°C, 95°C and 100°C (Appendix B), whilst natron was reabsorbed by the system at 90°C and 95°C but was reprecipitated into the same system once it had reached another saturation point.

Table 32: Table showing results of the modelling for Lake Fazda at 10; 25; 60 and 100°C

Temperature (°C)	Major Phase Present	Additional Phases	Order of Precipitation	Notes
10	Halite	Trona; Burkeite; Mirabilite	Trona; Halite; Burkeite	Redissolution of mirabilite occurs
25	Halite	Natron; Burkeite	Trona; Burkeite; Halite; Natron	n/a
60	Natron	Halite; Burkeite; Trona	Trona; Halite; Natron; Burkeite;	n/a
100	Natron	Halite; Trona; Burkeite	Trona; Halite; Natron; Burkeite;	n/a

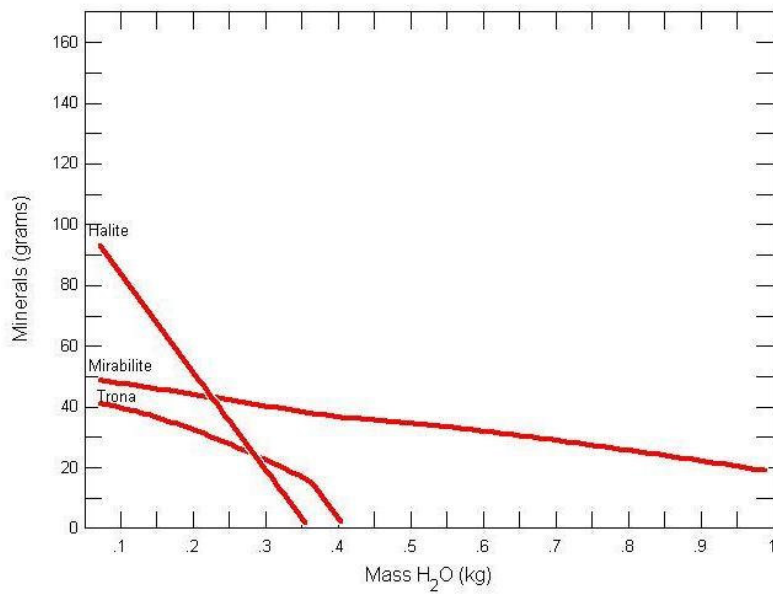


Figure 107: Results from geochemical modelling of Lake Fazda at 0°C and to dryness. The results show the formation of three minerals, halite (predominate), mirabilite and trona.

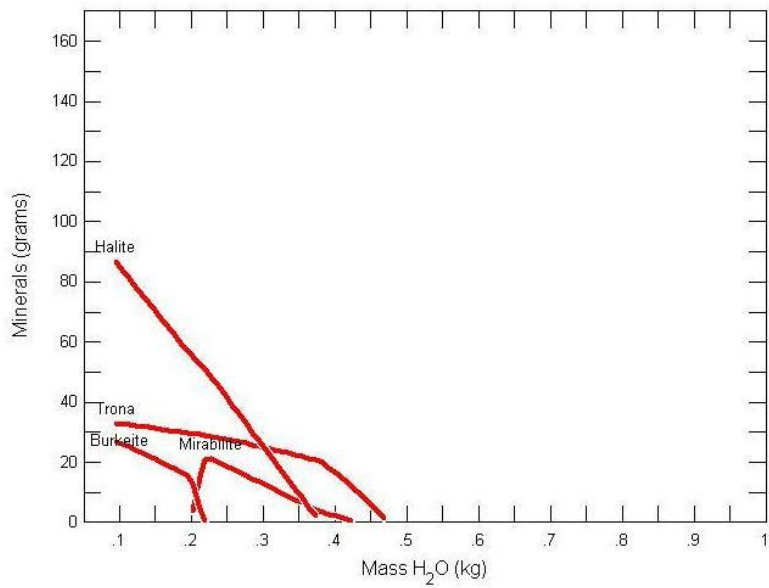


Figure 108: Results from geochemical modelling of Lake Fazda at 10°C and to dryness. The results show the formation of four minerals, halite (predominate), mirabilite, trona and burkeite.

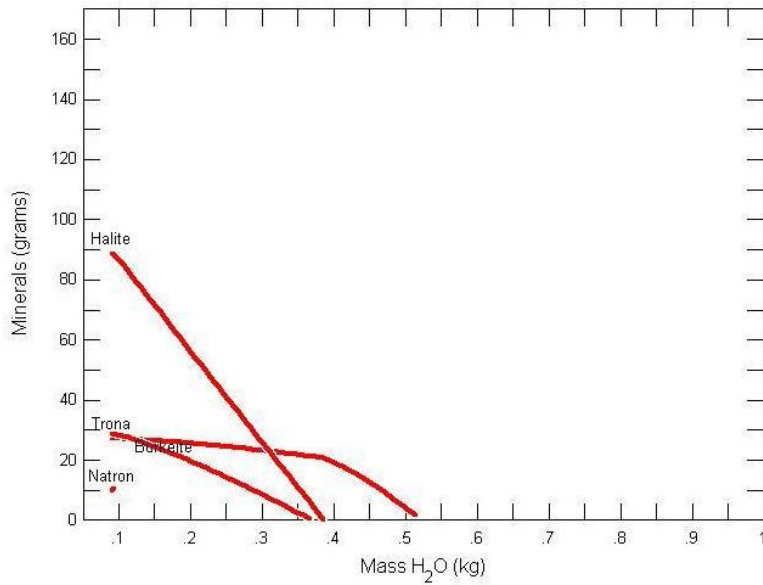


Figure 109: Results from geochemical modelling of Lake Fazda at 20°C and to dryness. The results show the formation of four minerals, halite (predominate), natron, trona and burkeite.

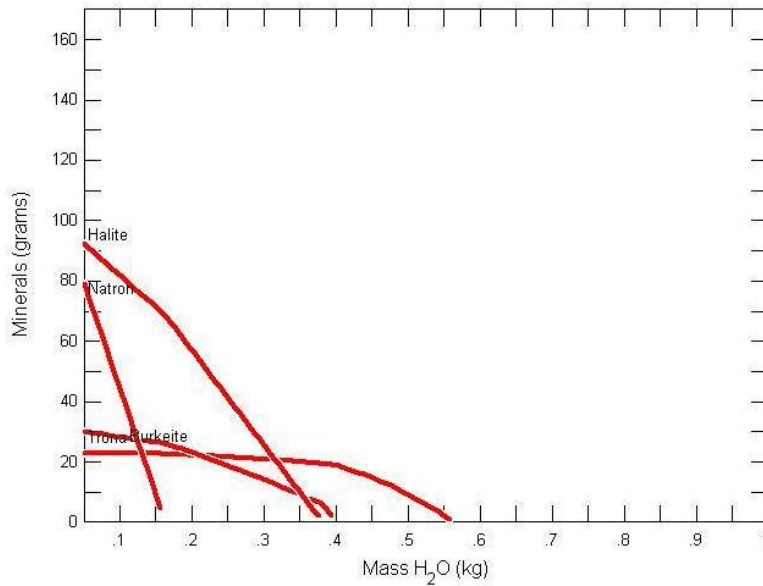


Figure 110: Results from geochemical modelling of Lake Fazda at 30°C and to dryness. The results show the formation of four minerals, halite (predominate), natron, trona and burkeite.

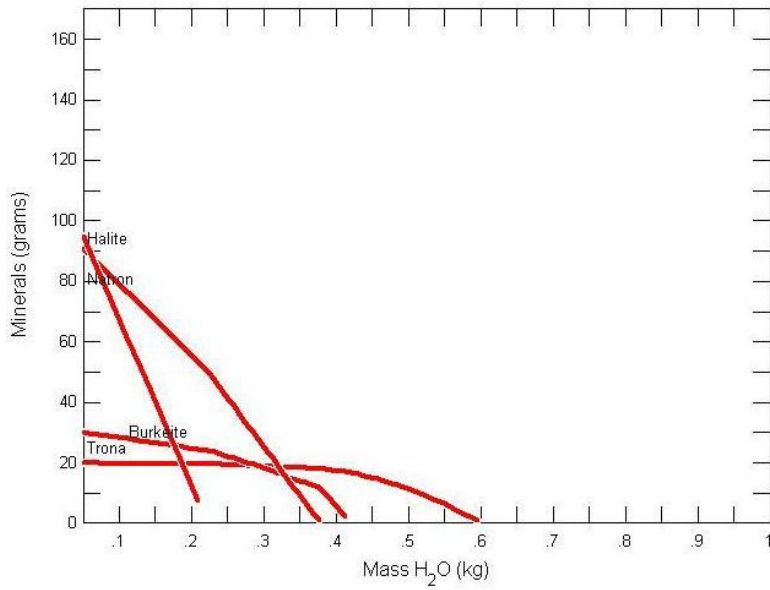


Figure 111: Results from geochemical modelling of Lake Fazda at 40°C and to dryness. The results show the formation of four minerals, halite (predominate), natron, trona and burkeite.

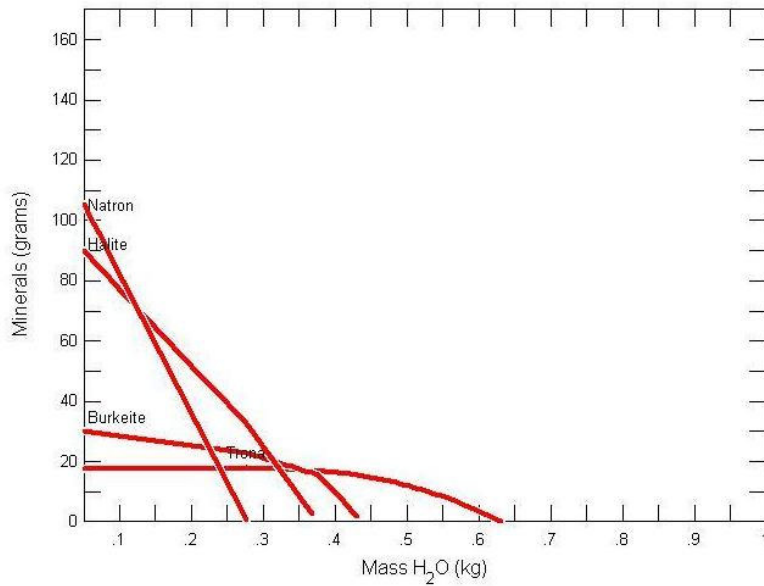


Figure 112: Results from geochemical modelling of Lake Fazda at 50°C and to dryness. The results show the formation of four minerals, natron (predominate), halite, trona and burkeite.

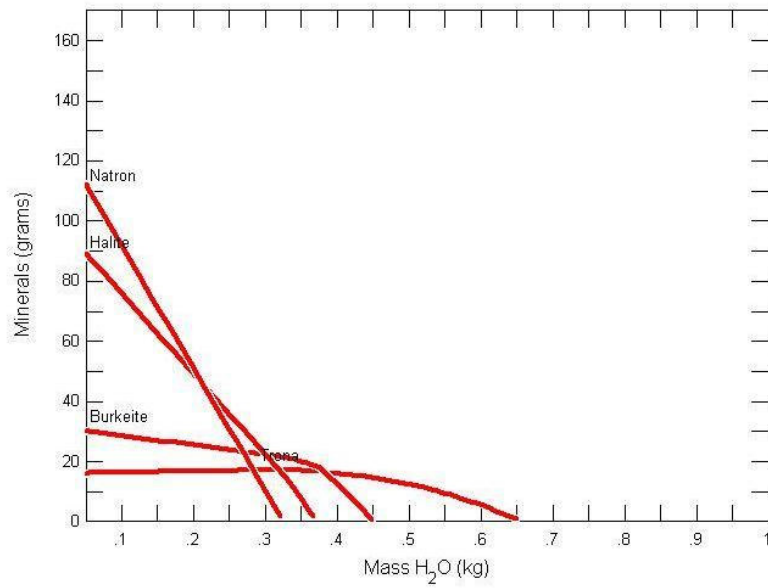


Figure 113: Results from geochemical modelling of Lake Fazda at 60°C and to dryness. The results show the formation of four minerals, natron (predominate), halite, trona and burkeite.

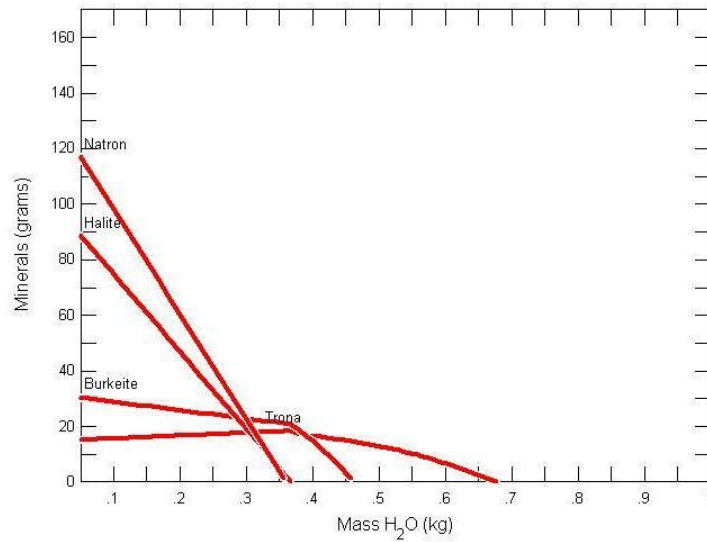


Figure 114: Results from geochemical modelling of Lake Fazda at 70°C and to dryness. The results show the formation of four minerals, natron (predominate), halite, trona and burkeite. An interesting feature is the redissolution of trona into the system.

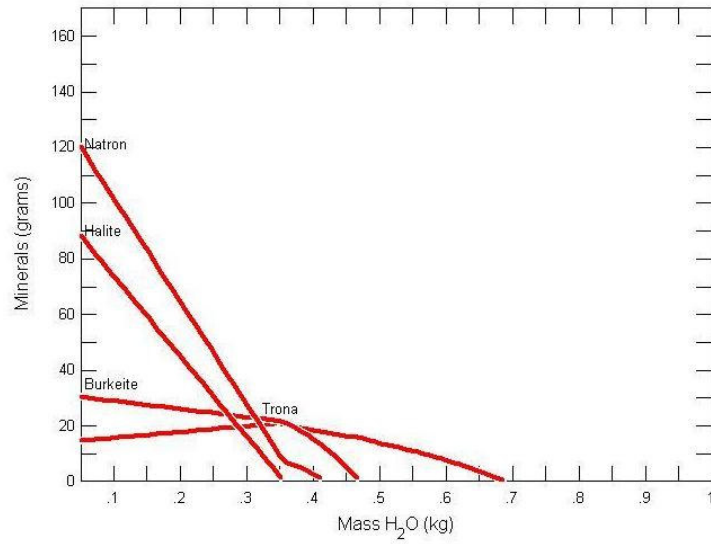


Figure 115: Results from geochemical modelling of Lake Fazda at 80°C and to dryness. The results show the formation of four minerals, natron (predominate), halite, trona and burkeite. An interesting feature is the redissolution of trona into the system.

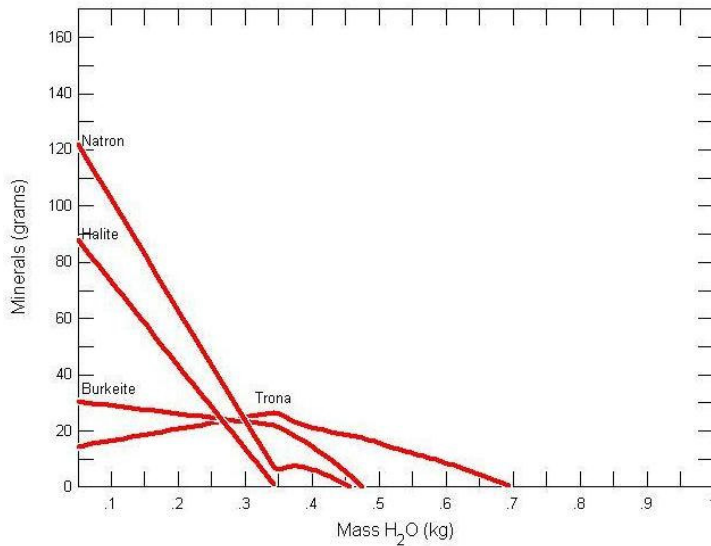


Figure 116: Results from geochemical modelling of Lake Fazda at 90°C and to dryness. The results show the formation of four minerals, natron (predominate), halite, trona and burkeite. An interesting feature is the redissolution of trona into the system, and the syndepositional recycling of natron.

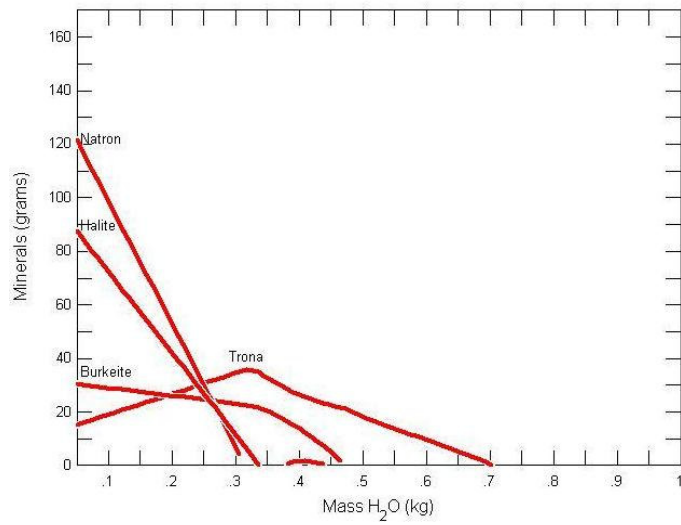


Figure 117: Results from geochemical modelling of Lake Fazda at 100°C and to dryness. The results show the formation of four minerals, natron (predominate), halite, trona and burkeite. An interesting feature is the redissolution of trona into the system.

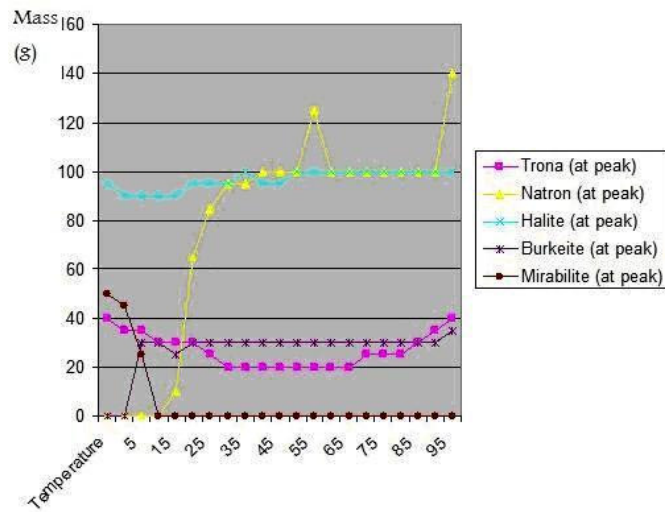


Figure 118: Graph showing the amount of mineral predicted to be produced at its peak from 1l of solution from Lake Fazda using Geochemist Workbench. The axis along the bottom shows temperature from 0°C to 100°C, whilst the y axis shows mass in g

6.3.5 Experimental Summary

Lake Gaar

Lake Gaar was only assessed by Geochemist Workbench. Shortland et al. (2006a, 525) have however analysed some mineral deposits and found them to contain four different minerals, halite, quartz, thenardite and trona. Thenardite and halite were by far the more abundant minerals and were found in all three samples, whilst quartz was only found in two in minor traces and trona only in the one sample as a minor phase. Two of the four minerals determined by XRD analysis were predicted by the geochemical modelling. The presence of quartz in two of the samples is explained by the fact that they were taken from the shore of the lake (Shortland et al. 2006a, 525). The model however, failed to predict the presence of thenardite, preferring to predict the precipitation of the mineral burkeite. Geochemical modelling does not take into consideration external factors on the system such as a reduction in the water table, biological communities or extraction of the mineral deposit, and as such these factors could impact the chemical balance of the system.

Lake Khadra

Unfortunately due to the nature of the lake there is little that can be determined from a mineralogical study except that quartz and halite are found along the shore of the lake.

Lake Beida

There is a discrepancy between the mineralogy present within Lake Beida and the geochemical modelling predictions. From the mineralogy it can be determined that there is little viable carbonate present - otherwise burkeite would have been formed at some level rather than the pure sulphate mineral thenardite being formed. This is not predicted in the system as the geochemical

modelling suggests that both burkeite and trona would be formed, albeit not in large concentrations. The Lake Beida system is notably chloride rich with halite the most abundant mineral as detected in mineralogical samples from the lake, and as predicted by geochemical modelling.

The stratified sample WN18 (Figure 78 and Figure 79) shows that there were four periods of deposition and the large size of the crystals on the top layer of WN18 (Figure 79) suggests that this layer was formed during a period of slow precipitation, probably a result of the shallowness of the lake at the time. In the same specimen it can be seen that layer c, the thenardite layer, precipitated at a faster rate than the other layers, perhaps suggesting that it precipitated at a high temperature where it was supersaturated in the solution.

Lake Zugm

The chemistry of the lake waters in Lake Zugm show that the system is chloride rich, with most samples taken from the lake being pure halite. Burkeite is also formed which suggests that carbonate and sulphate are present within the system, albeit in far lower concentrations than the chloride anions.

Again stratified specimens were identified (WN10 (Figure 85) and WN11 (Figure 87), however from the results (Table 26) it can be seen that, while there are differences between some of the layers, layers WN11b and c are identical in composition. This demonstrates that although the crystals and layers may appear different that it does not necessarily follow that there is a change in the mineralogical nature of the sample. Indeed the difference between these two layers shows different conditions in the lakes at the time of precipitation rather than a difference in the chemical composition in the lake waters. The contrast between sample WN10a and WN10b was based on the colours of the sample. The intense red colour is likely the result of an increase in the presence of cyanobacteria, and this may explain why more burkeite was present in the redder layer, although a contrasting theory is that this layer was nearer the

surface and as the water in the lake reduced halite precipitated around the mineral deposit, depositing halite on the burkeite structure.

Lake Hamra

The XRD results show that Lake Hamra is both chloride and sulphate rich. As had been anticipated from the results of previous research into the lake there was no carbonate detected other than in the form of the mineral burkeite. The system itself was a heavy halite precipitator, with what appears to be a highly dominate thenardite system detected in the north-west portion of the lake. The modelling did not predict this presence of thenardite. This might be explained by the fact that the water sample taken to be analysed was not taken from the north-west portion of the lake.

Lake Ruzunia

The system present within Lake Ruzunia was chloride rich with trona precipitated alongside halite. The geochemical models show that the anions carbonate and sulphate are both present but in minimal concentrations.

Lake Umrisha

The high predominance of halite predicted in the Lake Umrisha system fits in well with what appears to be the overall system of the wadi.

Lake Fazda

Lake Fazda is an important lake within the overall lake system. Near the lake lies a ruined glass factory of Roman date and it is a lake which is still exploited by hand rather than by machine. The fact that the deposits from this lake are

known to have been used in the manufacture of glass means it can be assumed that Lake Fazda produces a significant concentration of carbonate.

From the mineralogical samples taken from Lake Fazda two (WN24 and WN30a) showed the presence of a carbonate mineral in the form of trona. This is interesting in a number of respects, as although not highly abundant it shows that the chemistry of the lake can support the formation of a carbonate mineral, which supporting the theory that carbonate was gathered from the lakes in order to manufacture glass in the Roman factory. The fact that trona is formed in Lake Fazda is also notable as it suggests that the system is more carbonate rich than the other lakes within the wadi. This could also explain why Lake Fazda produces the most burkeite, with burkeite being the most abundant mineral formed within the lake.

Some samples also showed that minerals were not always fully redissolved during the “wet” season. One good example of this is the base of WN30d (layer a (Figure 105) suggests that this layer was formed in a different season to the additional three layers.

Natron is predicted to be the most predominant mineral found within the lake and this adds weight to the argument for the location of the glass factory nearby. The fact that the chemistry is clearly there to support a natron system is important and it raises a number of questions. It is believed that the reason natron is not identified within samples is due to the biological nature of the lake. It could also be that the working of the lake causes irreparable damage to the natron deposit by causing an element of redissolution and reprecipitation in another form, perhaps trona or even burkeite. The fact that natron is predicted at all by the geochemical model also gives a better understanding as to how natron is formed as earlier discussions on the material have stated that natron cannot form in water temperatures above 35°C (Bryant 1903; Eugster 1966).

The purpose of the analysis into the lakes and their deposits was to understand the mineralogy of the deposits and to understand how these minerals formed. When the lakes are assessed together it is clear that the Wadi Natrun system is generally chloride rich with significant portions of sulphate anions and there is little carbonate present. This contrasts with earlier analyses of the lakes and seems to suggest that the system is becoming an increasingly sulphate rich system with diminishing quantities of carbonate. The XRD analysis coupled with the geochemical modelling show that halite is the dominant mineral and is followed by burkeite. Although this is not the first time that the burkeite has been mentioned in relation to the wadi, this is one of the first documents to name it as a major phase in the lake formation.

In other aspects the fieldwork demonstrated that there was a significant stratigraphy through the lake beds showing a mud-mineral-mud pattern. This fits with earlier discussions where Andreossi (1800) states that once mud was discovered the lake was left to recuperate for a period of four to six years. Although the layers could not be dated, there is clearly a significant history in these strata and if dating were possible it could show a history of exploitation and recuperation. The fieldwork also showed continued exploitation of the area by both hand and machine. The XRD analysis of the piles along the shore of Lake Fazda are a testament to the fact that carbonate rich minerals such as trona and burkeite are still in demand and this continues the history of exploitation of carbonate rich minerals from the wadi that goes back for at least 4000 years.

The specimens showing stratification enable a better understanding of mineral deposition with halite, as predicted, being the last mineral to be precipitated whilst burkeite amongst the first. Information about the rate of precipitation and possible water levels of the lake can also be gathered which gives further information as to how the minerals are formed and deposited. This

mineralogical analysis has also allowed for theories surrounding the exploitation of the lakes to be confirmed, the most important of which is the identification of Lake Fazda as a carbonate rich system and able to produce carbonate minerals in the form of trona. Indeed it is the only lake of this nature in the wadi system and this explains the presence of the Roman glass factory and why the lake continues to be important to this day. In contrast Lake Beida was identified as being sulphate rich and more abundant in thenardite than the other lakes; confirming its use as a thenardite deposit as discussed in 6.1.5.

While the geochemical modelling has generally fitted in with the pattern of the wadi as a whole and has often been confirmed by the mineralogy present in the samples for particular lakes, the software does not take into account external factors such as extraction or the presence of microbial communities. Three lakes were shown to have different mineralogies to those predicted by the model. All are related to carbonate chemistry; with burkeite predicted in Lake Gaar, burkeite and trona in Lake Beida and natron in Lake Fazda. These minerals were not detected through chemical analysis and it is clear that there is an external factor present within these lakes that makes the carbonate unviable in terms of mineral formation. It is believed that this is primarily due to the microbial communities that live in these lakes.

From both the XRD analysis and the geochemical modelling it is possible to establish that the system within the Wadi Natrun is of a Na-Cl-SO₄-CO₃ nature and that it fits the formation products of this system well. The data gathered has also shown that the lakes should be able to form carbonate minerals in quantity and as has been proved from the chemistry of Lake Fazda – which may in turn have implications for the way in which the lakes and their exploitation will need to be managed. It is true that the Wadi Natrun is indeed a possible source for the sodium carbonate minerals utilised in medicine, purification, mummification

and other industries, and, as was indicated in the Eloquent Peasant, (6.2.1) a useful source of salt.

6.4 Discussion

In this section the results of three lakes are discussed in depth. Unfortunately from historical studies there are no definitive analyses for individual lakes and so it is only possible to generalise here about the Wadi Natrun's mineralogical make-up based on the literary sources.

In all it can be concluded that some form of carbonate was present within the Wadi Natrun for it to have been used as both bleach and in the manufacture of glass, and this was true from ancient times until pre-19th Century. The decline in use detected by Shortland et al. in 2006 may be a reaction against the rapidly increasing presence of other salts within this carbonate system, thereby making it unviable for glass manufacture. One of the most interesting notes is Berthollet's comment on small islands of natron present within the lakes, as has already been discussed, the expedition in 2006 saw islands of what was determined to be burkeite. It could be that the lakes described by Berthollet was also burkeite and that their unsophisticated techniques were unable to identify high concentrations of sulphate, or it could be that burkeite and sodium carbonate have similar formation patterns. The fact that Berthollet could have been describing burkeite islands, is important for archaeologists and archaeomineralogists alike, and the implication if an accurate analysis had been conducted would have been huge as it would have suggested that the "ancients" had exploited this resource for its carbonate content. Although Berthollet and Andreossi mention that no processing was conducted to make the samples purer this also corresponds with an almost fifty year absence of exploitation (Berthollet 1800; Andreossi 1800), and it is not to say that the exploiters prior to the 19th Century were unable to process the mineral burkeite to get a stable version of carbonate.

The division of two lakes into more appears to be a man made feature rather than a natural one, as has been described by a number of visitors to the area the lakes are clearly distinguished into sections where certain minerals precipitate. These sections are then believed to have been contained independently to ensure a purer form of mineral, as was discussed by both Berthollet and Andreossi the locals had previously dammed some of the lakes. This damming if continued over a number of decades, coupled with relentless exploitation for almost 4000 years would have indeed changed the number of lakes present within the wadi today.

6.5 Conclusion

The results here differ to previous studies due to the quantification of the minerals, thereby leading to the understanding that burkeite and halite are by far the prevailing minerals that are found in the Wadi Natrun. Other interesting features such as the discovery that Lake Fazda is chemically able to support the formation of natron, suggesting that there is an alternative reason, such as biological processes that mean that the prevalent mineral formed is burkeite.

The results have been discussed in depth previously and are discussed again in Chapter 7, however it is necessary here to divert slightly and to comment on the implications that this work has on archaeology. The presence of burkeite and halite as the dominate minerals within the lakes has major implications for their use predominately in the glass industry (as has already been discussed the use of natron was probably more symbolic in both medicine, mummification and purification), however this was not the case in terms of glass manufacture where carbonate is needed to act as a flux. The high portion of sulphates present in the burkeite, would mean that there would need to be a number of stages prior to the attempt at glass manufacture to ensure that the amount of sulphate was reduced and that the carbonate would be able to act in the required manner (as discussed in Chapter 3). The fact however that the chemistry of the Fazda lakes was able to support the production of natron and the presence of a number of glass working factories could suggest a non-sedentary working environment, whereby glass production was moved along the lakes depending on the formation products of those lakes, and like Andreossi discussed in order for the lakes to recuperate. Natron could have indeed been forming in the lakes prior to the early 20th century when mass extraction and a huge population increase started to change the environmental system, allowing for the increase in the microbial community which overrides the chemical nature of these lakes. This would explain why the chemical analysis conducted prior to 1950 is so different to that identified today, but would also explain the presence of the glass factories in the area.

Chapter 7: Discussion and Conclusion

7.1 Discussion

This project examined the use of minerals in ancient Egyptian medicine, from source and procurement through to eventual use in medicine and medically associated industries. This aim was addressed through case studies investigating both the role and procurement of selected minerals in the medical and medically associated industries of ancient Egypt. This body of work contributes to our knowledge in two disciplines; archaeomineralogy and medical history - and is the first to systematically address the way in which minerals were used in an ancient medical tradition.

The minerals selected for research as part of the case studies were chosen on the basis of which were the most commonly used – this was assessed by using the prescription database. This showed that salt and natron were respectively the most and third most common minerals used in Egyptian medicine. These minerals are intrinsically linked by their use, their mineralogical formation and the fact that they are both sodium compounds. The case studies therefore investigated the formation of salt and natron, the location of their deposits, their exploitation and procurement, their use and finally their eventual disposal.

This chapter brings together the results of the extensive literature review, the experimental work and the analysis of geological, ethnopharmacological and archaeological samples. The results show the importance of salt and natron in everyday Egyptian life and identified the Wadi Natrun as a key site for sodium salt exploitation. It also gives a geographical history of the Wadi Natrun over the last 4000 years and a more detailed chemical history of the deposits over the last 200 years. The work is an addition to both archaeomineralogy and medical

history and breaks new ground in our understanding of the use of these minerals.

7.1.1 Importance of salt and natron

This project focuses on the function of salt and natron in medical and medically associated industries; namely medicine, purification and mummification. These industries do not encompass the full extent to which the minerals salt and natron were used, as they also played a part in additional ancillary industries including food preparation and glass manufacture.

7.1.1.1 Medicine

The prescription database showed that there were 17 medical texts from ancient Egypt that contained a reference to minerals. In all there were 98 different minerals identified which can be split into 29 different mineral groups - of these salt and natron were found to be among the most commonly used. The research also illustrated that minerals were used in a rational manner with only 11 medical paragraphs out of 522 (Table 5) being deemed to be a spell in nature. This project was also the first to identify the 20 different forms of administration used in relation to mineral formulations.

Salt was identified as being the most common medicinal mineral with 175 mentions and with the identification of seven different types. Of the seven different types of salt the most common were northern salt and sea salt. Animal bites and stings were the most frequently occurring problems for which salt used, and it was most common for the formulations including salt to be applied to the exterior of the body. This leads to the presumption that salt was therefore used for its active astringent quality rather than for its ability to act as a flavourer.

From the medical texts there are references to five different types of natron and in total the natron group is represented 92 times making it the third most common mineral. The usage of natron was similar in content to salt with 83% of administration methods being externally applied and its primary use also being in the treatment of animal bites and stings. One of the most commonly cited uses for natron has been as a contraceptive, however this was identified as being potentially erroneous and new research may instead lead to the identification of natron as a procreation aid.

The medical texts also helped to identify potential sources for said minerals. Of the seven different types of salt, there are five which contain a reference to a location; northern salt, sea salt, eastern salt, salt from the Delta and salt from the oasis. Although they do not detail the exact location they can at least help infer potential sources. Natron is also described in terms of location with reference to both a northern natron and a natron from the oasis. There is also a reference to a red natron which could in turn relate to the formation process of the specific source of this material. These pieces of information are invaluable to archaeomineralogists and Egyptologists alike in giving an insight into both trade and the sources of the minerals.

The solubility of both salt and natron inevitably mean they are rarely found in the archaeological record, hence the only direct evidence available regarding their use and potential chemical nature comes from literature. It is surprising that the medical texts have not previously been used in a detailed way to assess their use.

Hearst 154 was identified as a good candidate for prescription replication since it contained information regarding the problem to be treated, the ingredients necessary and the applicable dosage. The formulation was meant to act as an anti-wrinkle cream and would therefore need to act as a moisture retainer. The results showed that the formulation indeed worked in the manner to which it

was designed and acted as a moisture retainer due to the barrier created by the inclusion of honey.

The analysis of the prescription database has also allowed for a comprehensive study to be conducted into the transfer of medical knowledge. It has been reported for example that many medicines are handed down from generation to generation through a culture in the form of “folk” medicine, a prime example being Chinese medicine. One factor of Chinese medicine is that it appears to have remained remarkably unchanged throughout their history and is a direct link to the medicine from the past. Studies have discussed this accuracy of this transmission of medicinal knowledge previously but have often lacked the ability to look at these on a systematic basis. The prescription database allows for a systematic comparison between contemporary ethnographic data and the Egyptian medical paragraphs. This can help us both gauge the reliability of the passing and the development of such knowledge over time but could also be of use when looking at how such medicine has spread in geographical terms and between cultures. Ethnographic records regarding the use of sodium compounds in medicine in Egypt and Sudan were examined and this led to the analysis of four medicinal minerals bought in a Khartoum market on behalf of the British Museum. Part of the purpose of this analysis was to help identify the language and terminology around minerals - a language commonly used between Egypt and the Sudan - as has frequently been the cause of confusion and debate between scholars trying to identify the minerals. The two words which were primarily examined are sha'ab and atrun, these words have variously been believed to have referred to a number of different minerals. The analysis showed that the mineral referred to as atrun was trona and that sha'ab was pure alum.

7.1.1.2 Associated industries

As well as medicine salt and natron were used in purification and mummification. These two industries were intrinsically linked and were similar in the way in which natron and salt were used.

Purification was important in everyday and in religious life. More is known about the latter as there are a number of documentary accounts surviving which are concerned with the rituals needed to enter temples and the means by which offerings to the temples could be made. Salt was used primarily in rituals borne out of the Ancient Near East rather than in regular Egyptian ceremonies, whilst natron was used in the purification industry primarily due to its astringent nature. Natron is frequently mentioned in documents pertaining to both purification and mummification and is full of symbolism even in terms of language. One of the clearest examples of this is the term for menstruation which is formed from the stem word *ḥsmn* and literally means to purify with natron (*ir ḥsmn*). This is probably derived from the purification rituals related to the reacceptance of the woman back into the community at the end of her monthly cycle. In addition natron is mentioned in a number of key purification formulae including the Pyramid Texts and the Opening of the Mouth Ceremony. These formulae were deeply religious and a number were usually followed to the letter. For example Pyramid Text 592, which mentions a chest of natron, was replicated within Tutankhamen's tomb and a chest containing almost pure sodium carbonate was found. Iconographic evidence also shows the way in which natron was used in purification and scenes from tombs and temples show the presence of natron balls both as a masticatory and to be added to libation water (Figure 27). This use of natron is still found in ethnographic analysis of traditional Bedouin and Sudanese communities. Another key use of natron in purification and hygiene is in the laundry industry where it was a key ingredient in order to both cleanse and bleach linen. Most of the evidence is based from documentary accounts although there are a few images found in tombs. Physical evidence from linen found in tomb complexes has also shown the presence of both salt and natron.

Mummification is an industry commonly identified with natron and evidence from earlier studies, specifically Sandison (1963; 1969) and Lucas (1908a; 1908b; 1908c; 1910; 1911; 1912; 1932b), has shown that both natron and salt were used in this industry – which corresponds with the surviving documentary evidence. The industry has two main principles, the ceremonial side which includes the Opening of the Mouth ceremony, and also the purification of the deceased to allow them to enter the afterlife pure and with the potential to eat and breathe. Experiments regarding mummification were conducted and the results showed that sodium chloride and sodium carbonate were effective desiccants. The experiment also served to prove that these minerals, when introduced into a solution, were able to preserve a life-like state, which would be more desirable for both the family and for the embalmers who would find the pliable state of the deceased easier to control than the brittle remains which were found when using carbonate as a desiccant. The analysis of the content of the “embalming” jar from the Bolton Museum was consistent with other studies in that the jar was found to contain what would be considered as mainly impurities of natron, namely sodium chlorides and sulphates. The title of the “embalming jar” is however believed to be an erroneous description with it being more akin to a libation vessel in shape than either a natron or embalming pot.

7.1.2 Sources of salt and natron

As has been explored in this project there are a number of sites of potential salt and natron exploitation, some of these sites are known only from “modern sources”, such as Barnugi, whilst others have references made to them dating from at least the Middle Kingdom (2040-1640 BC), for instance the Wadi Natrun.

There are a number of different types of evidence to identify the sources for both salt and natron. Firstly there are the clues given in the medical texts. Salt was known to be exploited from the north, the east, the sea, the oasis and the Delta. These descriptions do not in themselves name specific geographical

locations, however it is possible to use modern accounts of natron and salt sources and coupled with an understanding of how these minerals form, possible to identify potential sources. For example it is thought that northern salt came from a location in the vicinity of the Wadi Natrun, salt from the east was rock salt traded from Sinai, sea salt came from along the coast of the Mediterranean, salt from the oasis could refer to a local unknown deposit, or larger deposits such as the Siwa Oasis or the Wadi Natrun. Salt from the Delta probably refers to several small local deposits in this vicinity. Natron is similar in description to salt, with two types of natron mentioning general areas of exploitation. Northern natron probably refers to natron gathered from the Wadi Natrun, whilst natron from the oasis could refer to a small local deposit or to a site such as El Kab.

There are modern references to natron sources at Kharga, Barnugi and Hottara, however there are no pre-modern references to these deposits or to their use. This lack of pre-modern evidence suggests that these sites were not exploited to any great extent, if at all, in the period in which we are interested, although they could still be one of the sites for substances such as oasis natron. One source which has been disproved is the reference made by Pliny to the extraction of natron from Nile water, using a similar technology to that seen in the salt pans along the Mediterranean.

Using historical accounts and archaeological evidence the Wadi Natrun was identified as being a major source of both salt and natron in ancient Egypt. Alongside the exploitation occurring in the Wadi Natrun there were a number of minor sites such those which as can be found in El Kab, the Siwa Oasis and the Sudan.

El Kab is known to have contained a significant natron deposit in the vicinity of a temple that was still present up until the 1920s. It is believed that the natron deposits were used as a sacred lake to purify the objects and people who were to enter. El Kab is an interesting case study as from satellite imagery it is

possible to identify that there is no natron deposit present in this area anymore, which suggests that in the last 80 years the chemistry and geography of the area has changed dramatically.

The Oasis of Siwa is known as an extensive source of salt with four lakes in the area. From the medical texts a salt known as Ammoniac salt was identified which could be a reference to salt from this location, whilst 'salt from the oasis' is also a possible allusion to salt from this area. References to the area around Siwa date to as early as the 6th Dynasty and there is evidence for trade from this area with the King of Persia, for whom the salt was to be used in special religious ceremonies.

Natron was also imported into Egypt and it is known that Sudan was a major source for imported natron, with references to "incense mixed by the Nubians" being found in a number of religious texts. More recent accounts also show that even during the height of exploitation from the Wadi Natrun in the early 20th Century Sudanese natron was still being imported.

7.1.3 History of the Wadi Natrun

As already stated the major source identified for the trade of natron and salt in ancient Egypt was the Wadi Natrun. A 4000 year history of this area can be ascertained including the patterns of trade and geography of the area for this period and also a detailed chemical history of the lakes for the last 200 years.

The earliest reference to the Wadi Natrun dates from the Middle Kingdom (2040-1640 BC) text the "Eloquent Peasant". The "Eloquent Peasant" describes the trade of a number of items from this area in return for corn from Egypt. Evidence from the "Eloquent Peasant" and archaeological remains from the area implies that the Wadi Natrun was not part of Egypt and that it instead acted as a vassal state under the control of a vizier. The ancient name for the Wadi Natrun was *štp.t* which is literally translated as being the "salt field". *štp.t* has

been found in a wide-ranging array of documents, including religious literature and funerary stela although few of these detail traded items from the area. However ceremony 6th of the Opening of the Mouth ceremony refers to the use of natron coming from this area.

Classical references can be found in the work of Strabo and Pliny, and it is believed that Herodotus' account of natron from the oases of the Libyan Desert may also refer to this area. Both Strabo and Pliny mention the presence of two lakes in the area of the Wadi Natrun, with Pliny developing the idea further with a description of the red colour of the lakes. The lakes are known to have been exploited on a large scale in the Roman period for sodium carbonate due to the identification of a number of Roman glass factories surrounding the lakes.

The time between the 5th and 19th century is a dry period in terms of literature on the Wadi Natrun. Despite this the evidence suggests that natron was still being exploited and traded with the internal (Cairo) and external (Alexandria) markets. In the 15th century around 1,360 tonnes were exploited each year for which the return was around 70,000 gold coins. The earliest known chemical analysis of minerals from the Wadi Natrun deposit was published in 1685, though woefully inaccurate it shows how important these deposits were and again the red colour of the deposit was mentioned.

More intensive exploitation of the lakes was conducted from the 19th century onwards, and it is from this time that detailed chemical analysis began to be conducted on the deposits. This chemical history shows that the lakes are dominated by halite with thenardite as a minor product and, prior to the 1970s, the presence of sodium carbonate products with the identification of natron and trona.

The geographical history of the lakes shows figures given for the number of lakes ranging from one to 16. The presence of one lake is only mentioned by Sicard in the 18th century and is probably a reflection of the fact that he visited

the area in winter and that from the monastery at which he is staying he would only have been able to see one. Two lakes have been mentioned since Pliny and Strabo visited the area in the 1st Century AD, and have been depicted in maps of the area until the end of the 18th Century AD. Starting with the more reliable accounts dating from the 19th Century onwards, Andreossi mentioned the presence of six lakes, although the workers of the lake state that there should be seven. This number increases within 40 years to 16 and in the early 20th century the lake numbers seems fairly stable with 11 or 12 being mentioned. All visitors to the area comment on how the lakes were exploited in the height of summer, with Andreossi going further in his account by stipulating that the lakes were left to recuperate once the mineral deposit had been extracted. Exploitation has clearly had an impact on the lakes with evidence of at least one dam. It is believed that these dams were placed in order to separate the different types of minerals for easier exploitation.

7.1.4 Wadi Natrun analytical work

The analysis of the historical records shows that the Wadi Natrun was an extensive resource for sodium salts. There is a clearly defined link between sodium salts and Egyptian industries, and more specifically between sodium salts mentioned in a number of different Egyptian industries and the Wadi Natrun. Consequently an accurate mineralogical analysis of the system helped build a better foundation for the understanding of the Wadi Natrun's 4000 year industrial heritage.

This aspect of the project investigated the mineralogical formation process of eight lakes in the Wadi Natrun, Lake Gaar, Khadra, Beida, Zugm, Hamra, Ruzunia, Umrisha and Fazda. This was accomplished in two ways through XRD analysis of mineralogical samples and through geochemical modelling. Once the formation of the system is understood and modelled then a comprehension of what the ancient called natron can be undertaken.

Overall the results of the mineralogical samples and geochemical modelling found that the system present within the wadi is a chloride and sulphate rich one, leading to the understanding that the system present within the Wadi Natrun is a Na-Cl-SO₄-CO₃ one, with halite and burkeite being the main minerals formed. This is the first document to suggest that the presence of burkeite is a major phase in mineralogical formations in the lakes of the Wadi Natrun.

The formation of these lakes from what is believed to be the presence of two in the area to the 16 which has been documented in the past has been previously touched upon within this project. There are a number of areas through which these formations have occurred. The first is in relation to the season to which the visitor came to the area. In winter the lakes are submerged and a number of smaller “pools” are joined together to form a bigger water mass. In summer these lakes precipitate at different rates and show their presence as dry lake beds. Secondly there is the impact of man whereby the lakes have been artificially separated and this technique was documented in the 19th Century. It is believed that this technique was begun in the Medieval period and continued until the mid-19th Century, whereby the lakes were fully developed and exploited for their differing resources. The damming process is believed to have been conducted on observations rather than a detailed chemical understanding of the minerals found in the lakes. There are two clear lakes which were formed due to their mineralogical components, Fazda and Beida. Fazda being a major producer of carbonate minerals, and Beida a major sulphate deposit. Others could have been chosen due to identified minerals, ie. halite crystals, or through colour changes such as the presence of a deep red colour in such lakes as Hamra.

The mineralogical samples on a macroscopic level are also able to give information regarding the formation processes. For example WN18d (Figure 78 and Figure 79) shows that the halite crystals were formed through a process of

slow precipitation in shallow water. The mineralogical samples also clearly show the stratified formation processes present within the lakes.

Geochemical modelling is consistent with the mineralogy of the lakes which suggests that halite is a dominant mineral formed. However the geochemical modelling doesn't take into account the external factors of extraction or the presence of microbial community. Consequently there are three lakes which show different mineralogies to those predicted by the modelling. These lakes are Gaar (which is predicted to form burkeite although there is no burkeite present in mineralogical samples analysed), Beida (where burkeite and trona were predicted, whilst thenardite was a major mineralogical phase present in the lake) and Fazda (where natron was predicted but the only carbonate identified was trona). It is notable that these three lakes were expected to precipitate carbonate minerals when in actuality sulphate minerals were precipitated, although in the case of Lake Fazda trona was precipitated. It can therefore be assumed that these minerals were not formed due to external factors, and this is probably due to the large increase in sulphate anions from the breakdown of organic matter in the lakes and the inability for complete sulphate reduction. This shows that the lakes' system is dynamic and demonstrates how difficult it is to model a real system.

The lake with which this research was primarily concerned is Lake Fazda, this is due to the presence of a Roman glass factory in the vicinity which suggests that Lake Fazda was exploited for its carbonate minerals. There is also additional archaeological evidence for its importance in the form of a temple overlooking the deposit. The lake is still exploited today, and this work is still conducted by hand, and accurate monitoring of this activity, could give a better understanding as to the impact this hand extraction would have on the system as a whole.

The lake itself occupies the most southerly position and has been depicted on maps since 1800. Indeed it is the only lake to have retained its position and shape in cartography of the area for the last 200 years, and since the name of

the lake was first mentioned in the mid-19th Century, to have its name connected with the same lake. This is important in a number of respects. We know for example that this lake was exploited from at least the Roman period for its carbonate deposit, and indeed in Andreossi's account was illegally exploited for its carbonate deposit in 1800. To this day carbonate material is removed from the lake in order to be sold to soap manufacturers across Egypt. This shows continuity in exploitation and in mineral deposition. The fact that the lake has retained its name, location and shape since the beginning of the 19th Century is also an important indicator as to just how important this lake was in regards to the economy of the area, and was clearly the most important lake to the locals, in order for them to have been able to identify it so clearly.

From both geochemical modelling and XRD analysis of mineralogical samples it is clear to see that there is a clear anion chemistry present within the lake that should allow for the precipitation of carbonate minerals such as natron or trona. Lake Fazda is the largest producer of the double carbonate-sulphate salt burkeite and it is believed that due to external factors this lake produces the burkeite mineral in preference to the carbonate.

Core samples from Lake Fazda were also taken and these showed that there is a period of recuperation whereby soil replaces mineral precipitation for an undisclosed time period. This fits with the documentary evidence we have regarding allowing the lakes to recuperate. If it were possible to date these sediments then it could show a complete history of exploitation and recuperation.

The presence of at least three Roman glass factories along the shore of the Wadi Natrun shows that it must have been a significant deposit of sodium carbonate at this time. It is believed that the three factories were located strategically so that the glass manufacture could be moved once recuperation within the lakes was necessary ie. when they hit soil. This would have given the

Roman glass makers a constant supply of a good quality product enabling them to manufacture glass on a large scale with a good quality product at the end.

It is therefore true to say that the Wadi Natrun is a possible source of sodium carbonate which was utilised in medicine, purification and mummification as well as other industries. The Wadi Natrun would have also been a useful source for salt, as confirmed by salt being listed as a commodity in the “Eloquent Peasant”.

7.2 Conclusion

The use of salt and natron covers the everyday life of all forms of Egyptian society from the secular to the religious through the King and state itself. Few other minerals can express such a pervasive position in the Egyptian world whilst also being a necessity in the life of most Egyptians.

There are two overriding groups of people who require the use of both salt and natron. These minerals were in demand both to the religious community and also to the private individual.

Salt and natron are needed in religious ceremonies primarily as a means of purification in four main ceremonies, the temple foundation ceremony, everyday ceremonies performed in the temple (including the purification of the priests), the purification of temple visitors and the purification of offerings made both to the temple, and those objects made as funerary offerings. There is sufficient evidence for these uses in terms of temple documents, ranging from accounts, documented religious procedures such as the Opening of the Mouth ceremony and criminal proceedings. There is also limited archaeological evidence that shows the necessity of these religious procedures in the form of Tutankhamen's natron chest which was found to fulfil Pyramid Spell 592. This evidence coupled with acknowledged criminal proceedings against a priest who did not fulfil his purification rites by drinking natron water for a period of seven days, show how closely religious formulae were followed. It is this evidence that shows that not only did natron and salt have an acknowledged spiritual purpose in Egyptian religion, but a practical one, indeed a one that was followed to the letter.

There is a secondary religious function of both salt and natron, and this is in the form of the embalming industry whereby salt and natron performed two services. Firstly it allowed for the administration of the specific purification rituals needed in order for the deceased to be reborn in the afterlife, as discussed in the Book of the Dead and the Opening of the Mouth Ceremony. Their

secondary function was more practical and allowed for the desiccation of the corpse and thereby helped form the “mummy” as we today know it. The primary evidence for their use in this aspect has come from the mummies themselves as well as analysis of embalming caches and proposed embalming refuse pots. These have shown high concentrations of sodium salts, primarily in the form of sodium chloride although sodium carbonate minerals have also been found. Again archaeological evidence supports documentary evidence in which embalming procedures are discussed. In relation to mummification rites and practices however there is little documentary or iconographic evidence, however Herodotus and the Apis Embalming Ritual mention the use of both these substances, and it is these documents that form the basis for many modern day studies on the ancient Egyptian embalming tradition.

In terms of secular use there are three categories, there is the use of natron and salt in the medical tradition, in palaces and in the use by private individuals. Salt has already been identified as being the most commonly used mineral in Egypt's medical tradition, and was predominately used as an astringent. Natron's use in medicine followed very similar lines, but was only the third most common mineral to be used, following ochre. This use of sodium salts in medicine permeates from the lowest Egyptian subject through to the King himself. However medicine is not the only industry in which these minerals were used throughout the Egyptian strata.

Common to religious practice natron and salt were used in purification matters, such as after an illness or as a means to be reaccepted as a functionable person in Egyptian society. There is sufficient evidence in the way that Egyptian words for both purification and natron are similarly constructed to prove this connection, and indeed the term for menstruation *ir ḥsmn* means to be purified with natron. Suggesting not only that a woman on her menstrual cycle was not classed as a ritually clean person and could therefore have been ostracized by society, but also that natron was used as a means of purifying oneself after a period of “uncleanliness”.

Laundry, personal hygiene and food preparation are other uses of these minerals which would have been used by the Crown and the population alike. The evidence for these uses can be found not only in the language, but in iconography and archaeological evidence. Archaeological evidence for these minerals is rare, but both salt and natron have been found in freshly laundered clothes found in tombs, and also in terms of "blocks". These bricks of natron and salt have been documented in archaeological evidence from houses in the working men's town of Deir el-Medina. Bricks as a unit of measurement for salt and natron have also been mentioned in documentary accounts ranging from temple accounts to household inventories. Consequently this rare archaeological evidence is probably a rare example of this measurement and is not a subsequent reprecipitation of the mineral in the archaeological environment.

Both religious and secular communities required a supply of in this material and one of the many concerns surrounding the use of these minerals is how exactly they were obtained, both in terms of sites of exploitation but also in terms of availability in the market. Again there are two aspects of this supply, how did the religious community and the secular community acquire the natron and salt needed for their day to day existence? Are these two governed by the same market forces, or were they obtained under completely separate circumstances.

Religious communities are believed to have gathered their material in two ways. Firstly there is the evidence in the form of temple accounts from which it can be seen these minerals were generously donated by the king on an annual basis. Indeed one temple record shows the donation of 44,000 bricks of natron and an additional 44,000 bricks of salt in one year of temple accounts. Secondly there is the location of "sacred" pools, these can either be in the form of natural salt or natron deposits such as at el Kab or Siwa or manufactured "sacred" pools. These sacred pools are discussed in the literature as being places for visitors to temples to purify both themselves and their offerings before entering the holy space.

In terms of secular uses, there is less evidence for the way in which this material was obtained but there is the potential for private supply where natron and salt can be purchased from specific markets. There is some basic documentary evidence primarily in relation to the use of salt and natron in laundry (the Zenon Papyri and O. DeM 314) where it is shown that these minerals were given to the workers of Deir el Medina as part of a state provided service. In addition to this it is believed that salt and natron were also given to individual households in the village as part of their monthly ration package.

There are a number of sites of potential exploitation; evidence shows that both salt and natron could be gathered from internal and external to Egypt's borders. Externally, for example natron is known to have formed a tribute paid to the country by Syria. Internally there are a number of large and small scale sites. Most notable of which are the Wadi Natrun and el Kab in terms of natron, and the Oasis of Siwa in relation to salt. Evidence from these sites as potential deposits comes in the form of both ancient documentary accounts and archaeological evidence. However there is in addition to this direct evidence the indirect evidence derived from accounts of the Medieval period through to the early 20th Century which showed that there was some form of exploitation for these minerals from these areas which shows the potential for these sites.

Once the minerals were exploited they were transported into trading ports (Alexandria and Cairo in later periods) to be sold, at, occasionally, super-inflated costs. It is clear that from the Medieval period onwards this transport was conducted using camels. Camels are only known to have inhabited Egypt in vast numbers since the late Greco-Roman period and prior to this, donkeys would have been used as the main work animal. There is a lot of documentary evidence regarding the ability of camels to transport large quantities of natron from the Wadi Natrun area, however there is no such evidence for the ability of the donkey. Using modern day standards a donkey has the ability to carry 50kg of load comfortably (sourced from the Brooke Trust). This is a calculation based on the work conducted by Animal Rights charities, whereby the load would be

limited under concern for the animal's health. This load is obviously a great deal smaller to the loads that would have been expected even 25 years ago. This ability of the donkey therefore does not counter the evidence for vast exploitation and the donkey was of immense use getting the material from source to table.

There are four pieces of evidence regarding who was conducting the mining of the minerals, especially in relation to the Wadi Natrun. Firstly there is the direct documentary evidence of exploitation from the Wadi Natrun as described in the Eloquent Peasant. This story suggests that the people doing the exploitation were non-Egyptian and non-sedentary, but were trading this material in return for corn. Archaeological evidence in the form of a 12th Dynasty fortress and a temple of indeterminate date suggest that the Wadi Natrun was treated much like other "non-sedentary" quarries. Whereby specific exploitation groups were sent to these areas in order to extract the necessary deposits at specific times and in specific years. This is further supported with the fact that so far there has been no archaeological evidence that suggests that there was an established Egyptian town or indeed a sedentary community in the vicinity. From documentary accounts covering the last 400 years there has been no clear sedentary community of exploiters and these accounts exemplify the non-sedentary nature of the work. This aspect is probably due to the fact that the work involved in exploiting the lakes is based in the summer, "between seed and harvest time", and there was therefore no need for a sedentary community in order to extract the desired quantities. Besides the modern understanding of how the lake system works, documentary accounts from Pliny to Sicard, Andreossi and Wilkinson show that it was clearly the summer in which the minerals were exploited. This time coincided not only with the hottest time of the year and therefore the drying of the lakes, but with the time of a surplus population, where the farming communities running along the Nile were not needed for their agriculture and could therefore work in quarrying and mining expedition, such as those that were sent to the wadi. Although the sites were exploited in the summer, it did not necessarily follow that they were exploited

every summer. Indeed the work produced by Andreossi and Berthollet on the lakes suggest that there was a period of recuperation required in order to obtain the best quality product. This period of recuperation occurred once soil had been struck in the lake bed, and could last between four and six years. There is no reason why this could not have occurred in even ancient times, and there are at least two lakes known in the area from Pliny's time and this could show a predating tradition whereby one lake would be exploited whilst the other recoups. This required period of recuperation could also explain the comment made by Pliny that one was not producing good quality natron.

In contrast to this large scale exploitation we should not forget the smaller scale lakes found near temples. These deposits were presumably not exploited in the same way but were used daily in order to purify the priests as well as the temple visitors and offerings, and it was the water within these deposits which were required rather than the solid material gathered elsewhere.

The lakes were clearly exploited by hand, and a modern day example can be seen currently at Fazda where ancient methods are still used. Today there are a series of lakes that lie in the wadi, and this number has changed in documentary accounts from two to 16. From accounts of the early 19th century, we know that this number of lakes was controlled by their exploiters through a series of dams. There is no reason to why this activity did not take place in earlier times. This damming would lead to the ability to control the deposit formed as well as the quality of the deposit. It would also allow for the recuperation of lakes once the last layer of deposits was removed. Besides this pattern of exploitation it is believed that once extracted the substance would be stored along the lake side, both in order to remove water so that it is lighter to transport, but also to achieve a quicker transport turn around, as it would take even in later times at least three days to arrive at a trading point for this substance, from which it was shipped to either Alexandria or Cairo.

This exploitation both in the form of extraction and in the form of lake damming would lead to a change in the chemical nature of the lakes as well as to the mineralogical volume to be produced by the lakes. As already stated the lakes were well maintained and allowed for the mineral deposits to recuperate over a certain number of years and consequently the quality of the product could be maintained. It is believed that this idea of recuperation led to the establishment of a number of glass factories in the vicinity. Allowing for the factory staff to move between factories in order to be closer to the lakes being exploited and therefore the mineral deposit, rather than incur the issues of transporting the natron to the factory. This would not only cut down on unnecessary inefficiency in transportation and therefore glass manufacture, but would also have been a reliable means for maintaining their source of flux.

The natural system of the Wadi Natrun is a delicate one and when carefully husbanded it still produces the desired minerals in desired quantities, however if over exploited it can have disastrous consequences. There is a good comparison to be made between the lakes of Fazda and Gaar, between the old and the modern ways of exploitation. In addition to this the water level of the system is currently being damaged through the Egyptian's governmental policy of desert irrigation to move people out of over populated areas such as Cairo into the areas which used to be desert. The water table is also damaged by the increased demand placed on the system by the large town which now lies along the lake banks. The chemical constituents of this water are also changed by the new burden of pollution from both the nearby factory and the town, and this in turn changes the chemical nature of the lakes and the mineralogy of the system. Without allowing the system to recoup and by damaging the inflowing water the lakes are being irreversibly damaged, potentially damaging the mineralogical nature of the system in the short term making it unprofitable and unstable in its nature. In the long term the lakes and subsequent eco-system could be lost forever, such as can be seen at el Kab.

Although salt and natron are a necessary product both today and in the past, it is in the last 50 years that man has forgotten the lessons and traditions of the past and the delicacy of nature and in so doing have begun the decline of one of the greatest sodium salt deposits available. It is hoped that in the future that there were will be a change of policy both by government and industry that will allow these important natural reserves to recuperate.

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Index to Appendices

Due to the size of the thesis itself it has been decided that the large prescription databases should be placed onto a CD, which allows the additional benefit of the reader to search through the data themselves. There are two appendices found here.

Appendix A: Summary

Appendix A contains the XRD and TOPAS data which is not otherwise expressed in the document. These include:

British Museum Samples

Bolton Museum Samples

Lake Khadra

Lake Beida

Lake Zugm

Lake Hamra

Lake Fazda

Appendix B: Summary

Appendix B contains the remaining Geochemist Workbench results produced when examining the mineralogy of Lake Fazda.

Appendix C: Summary

Appendix C can be found on the CD and is the collection of prescription databases created and used for the research conducted in this project.

Appendix A

Contained within this appendix are the XRD and TOPAS results which have not been expressed within the document thus far.

British Museum Samples

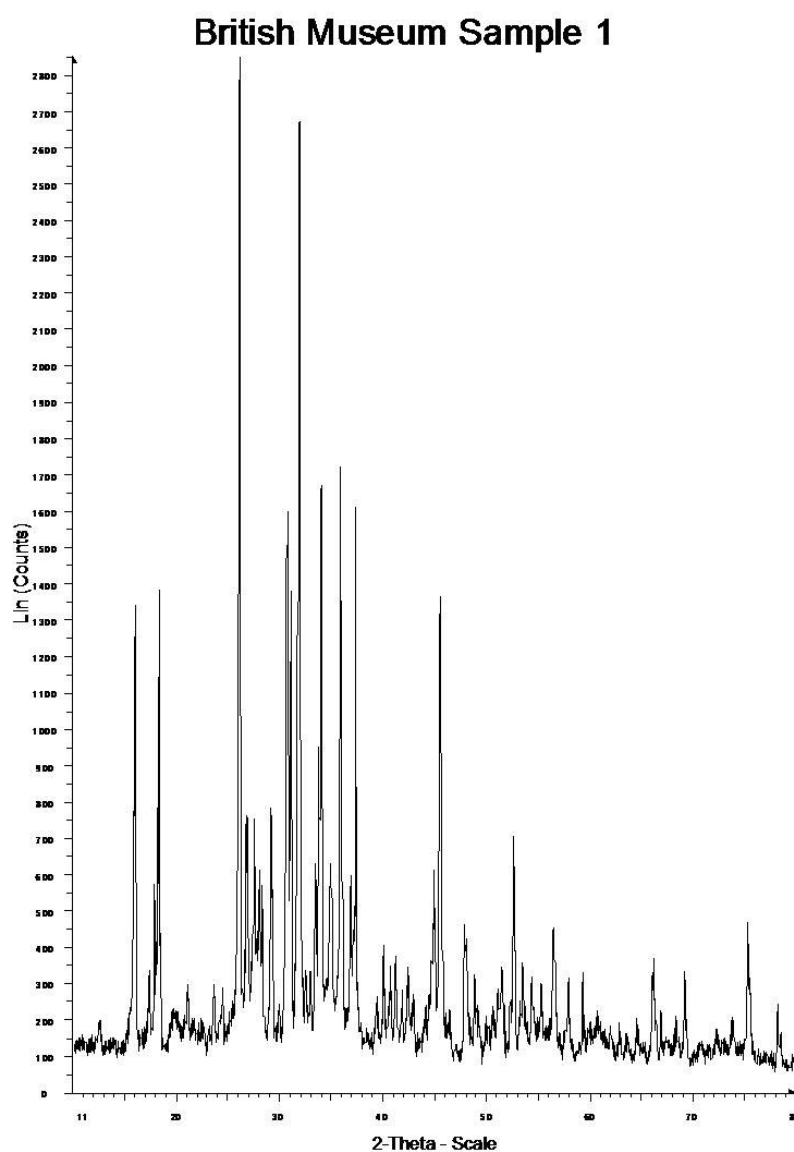


Figure 119: XRD Results for British Museum Sample 1

British Museum Sample 2

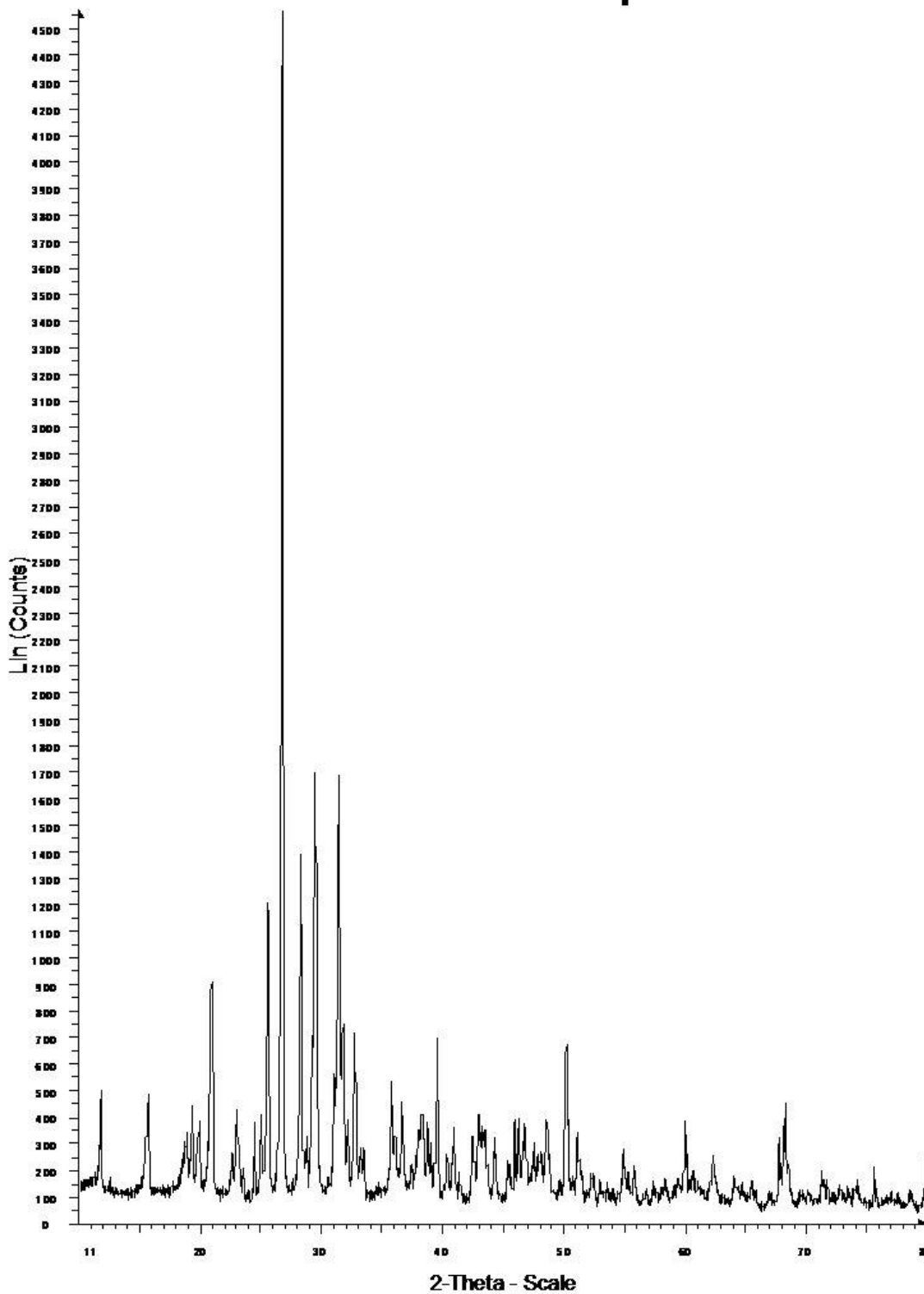


Figure 120: XRD results of British Museum Sample 2

British Museum Sample 3

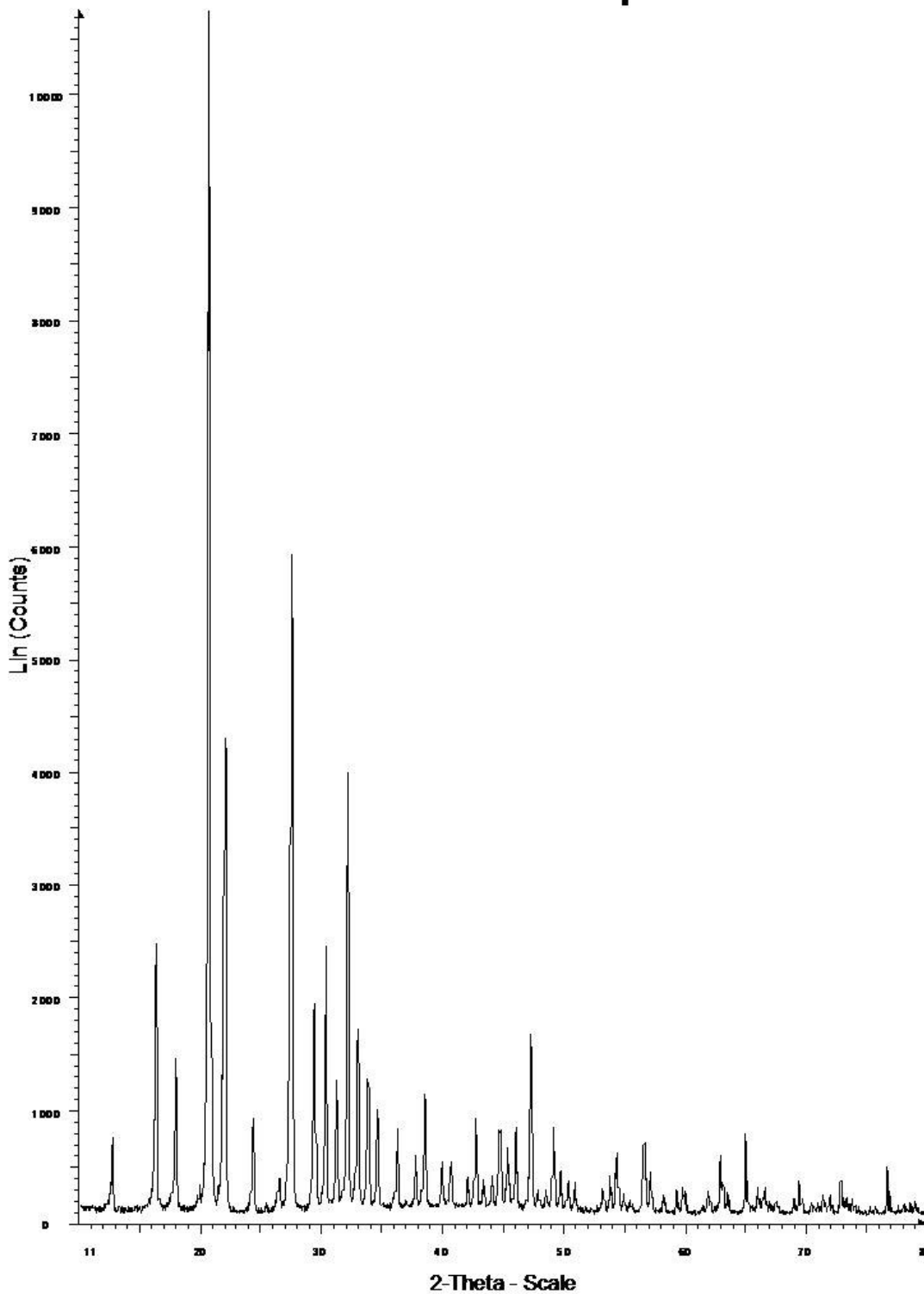


Figure 121: XRD results of British Museum Sample 3

British Museum Sample 4

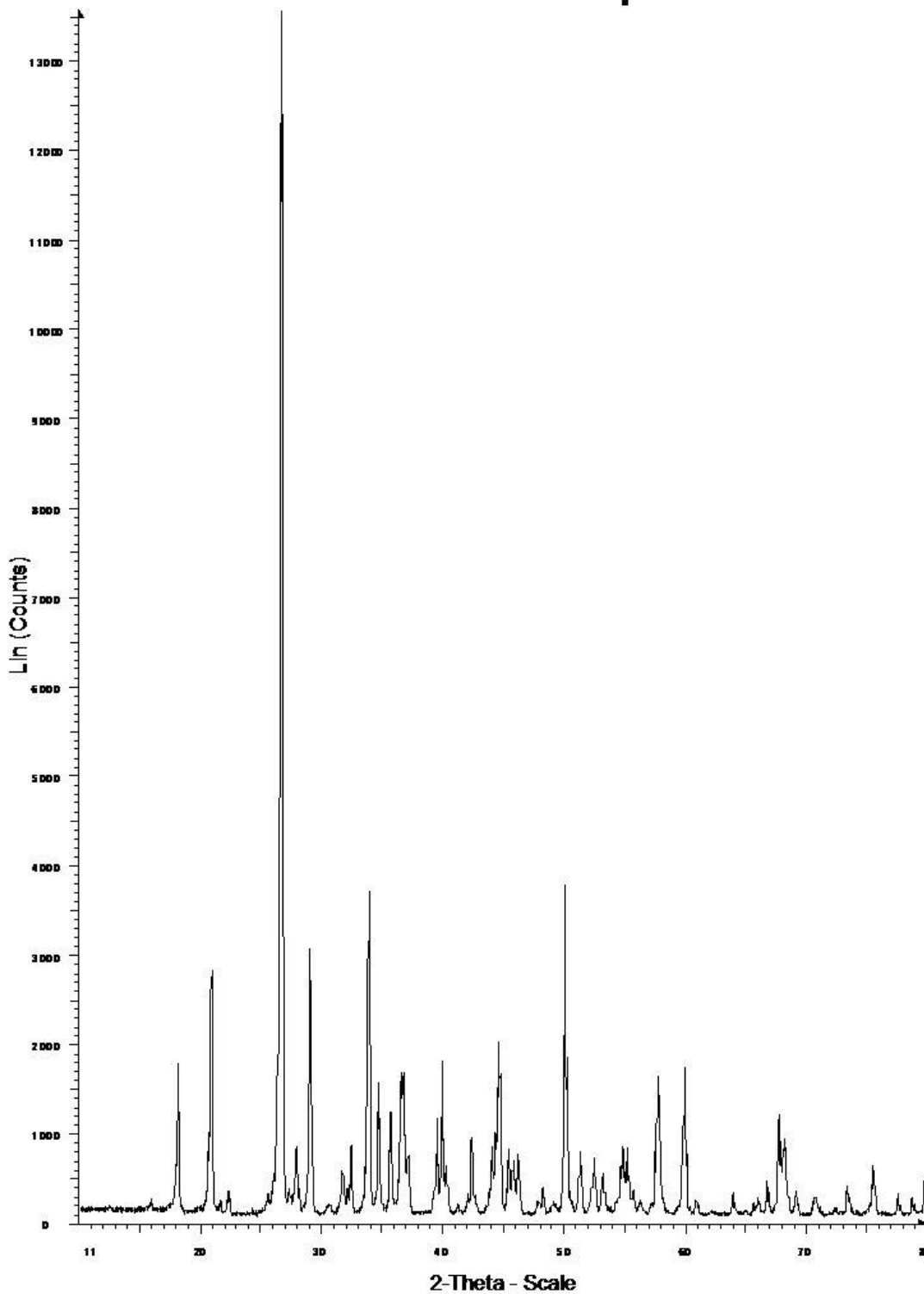


Figure 122: XRD Results of British Museum Sample 4

Bolton Museum Embalming Pot

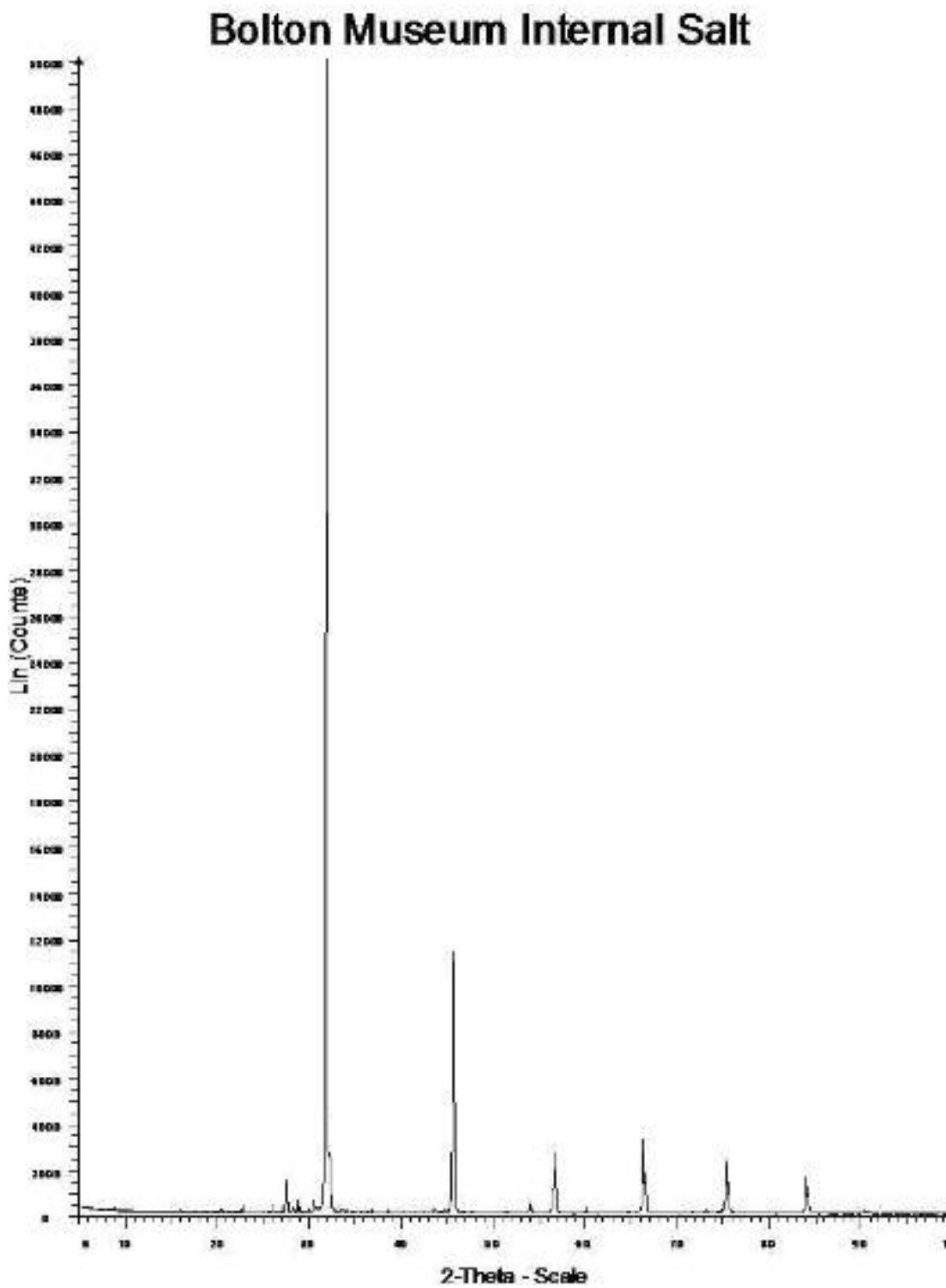


Figure 123: XRD results of the internal salt sample taken from the Bolton Museum Embalming Pot

Bolton Salt

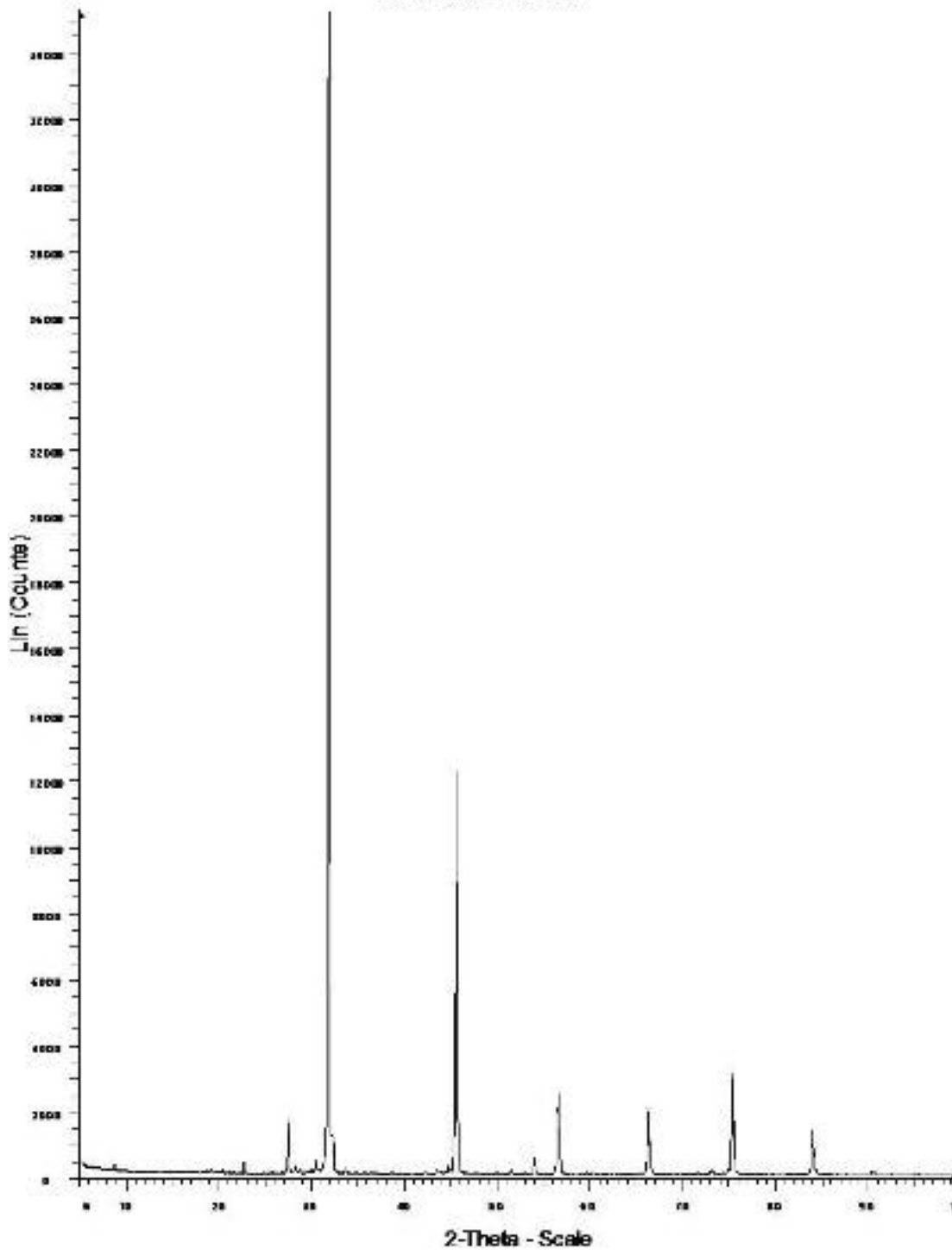


Figure 124: XRD results for the external salt sample taken from the Bolton Museum Embalming Pot

Lake Khadra

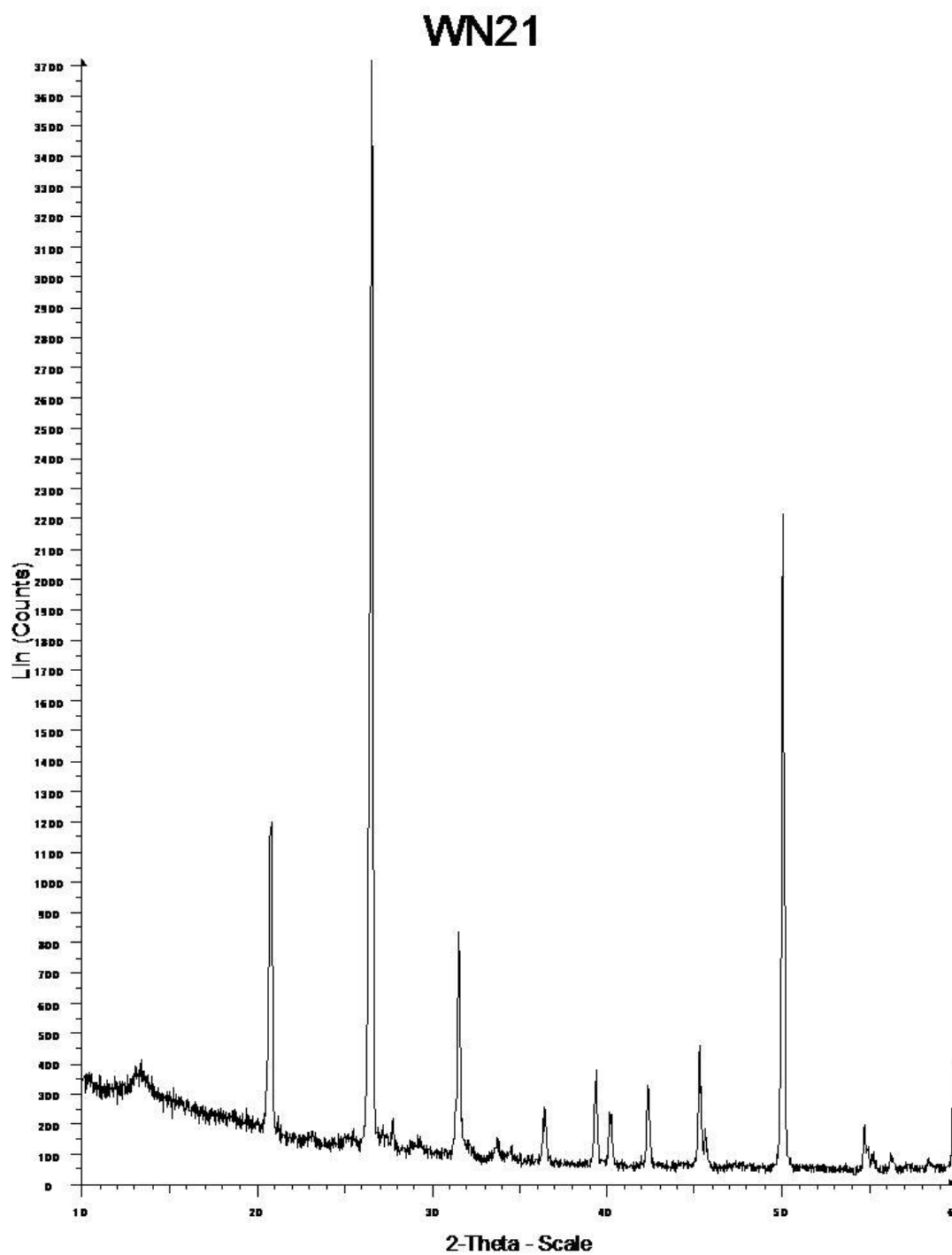


Figure 125: XRD results for sample WN21

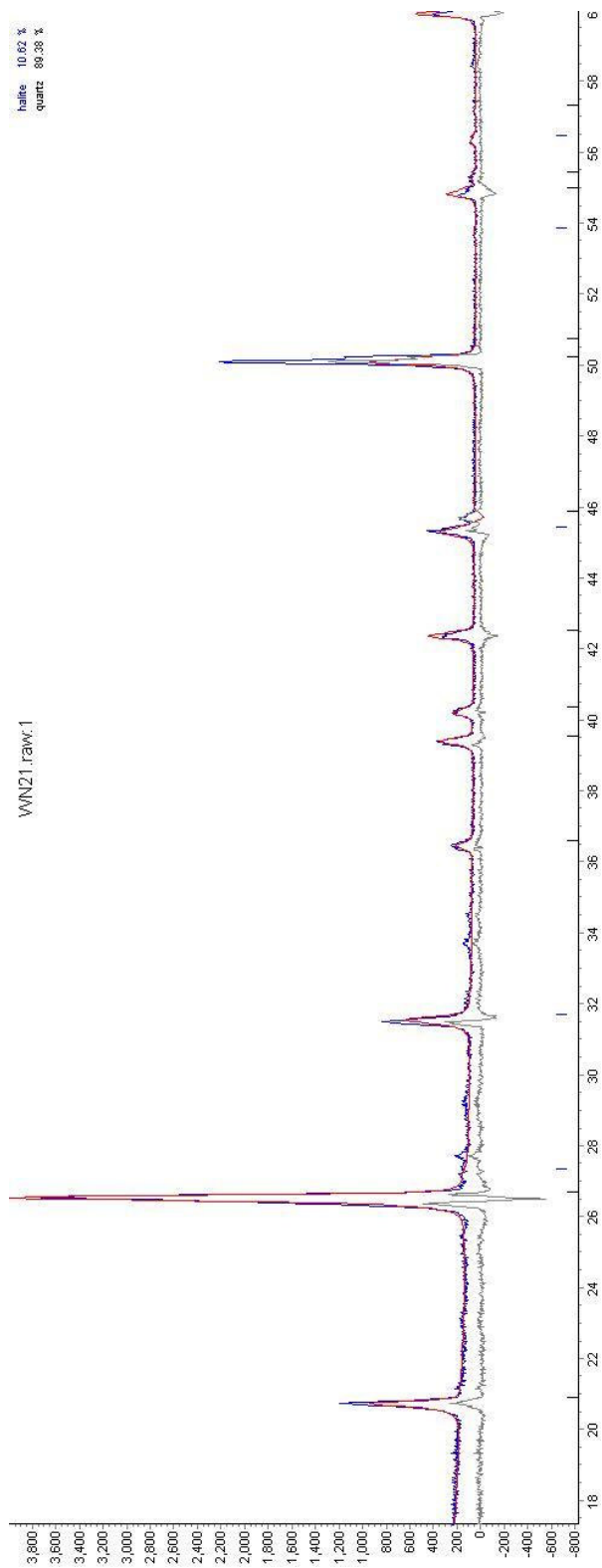


Figure 126: TOPAS results for WN21

Lake Beida

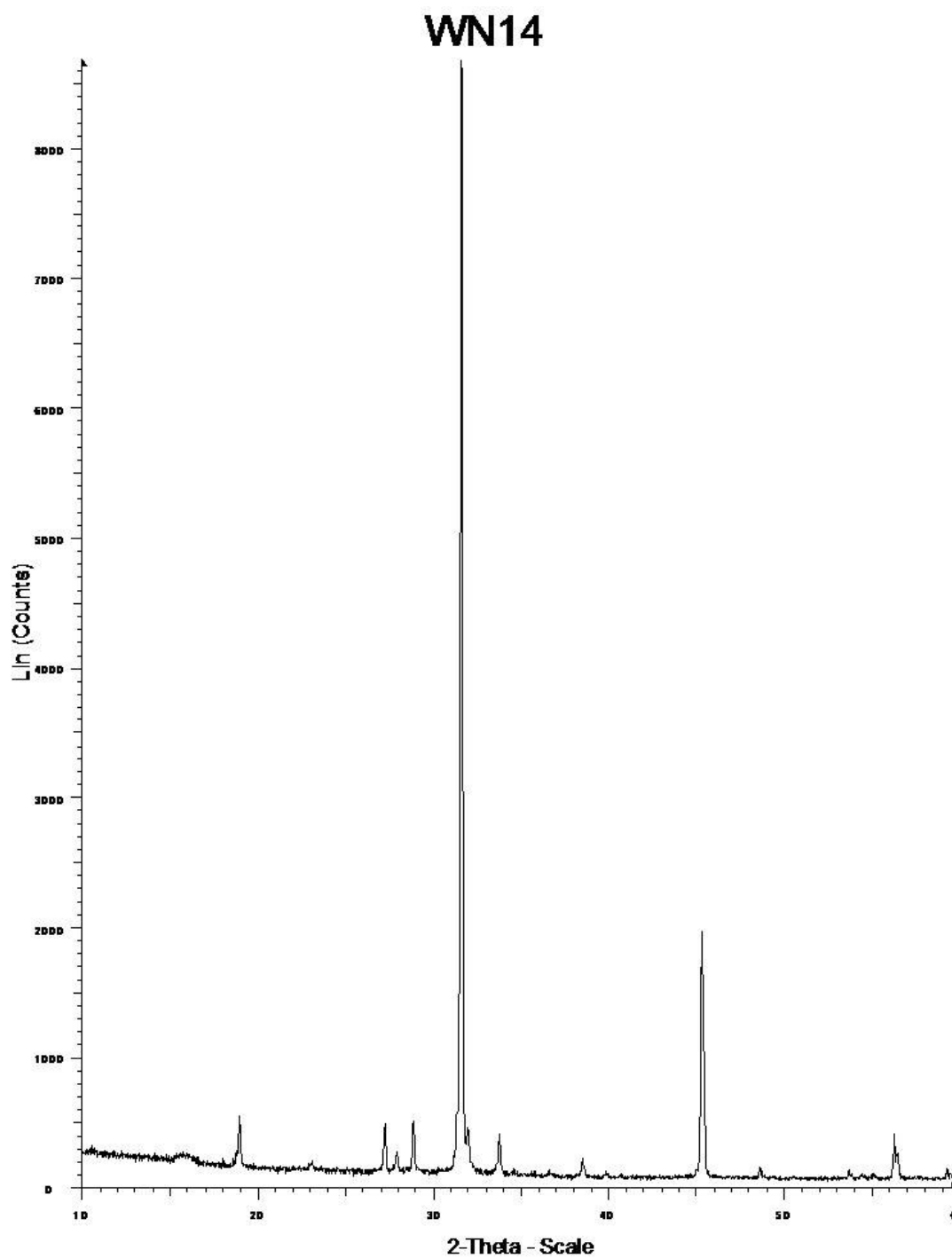


Figure 127: XRD results for WN14

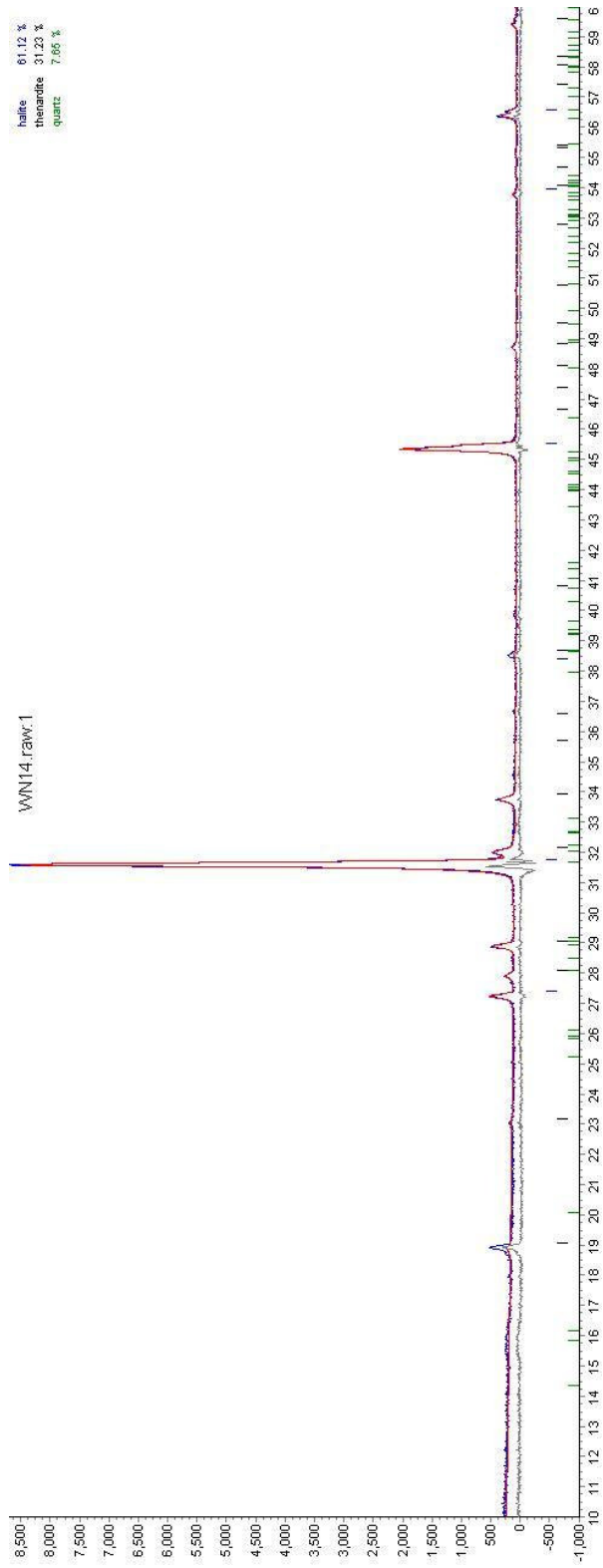


Figure 128: TOPAS results for WN14

WN16

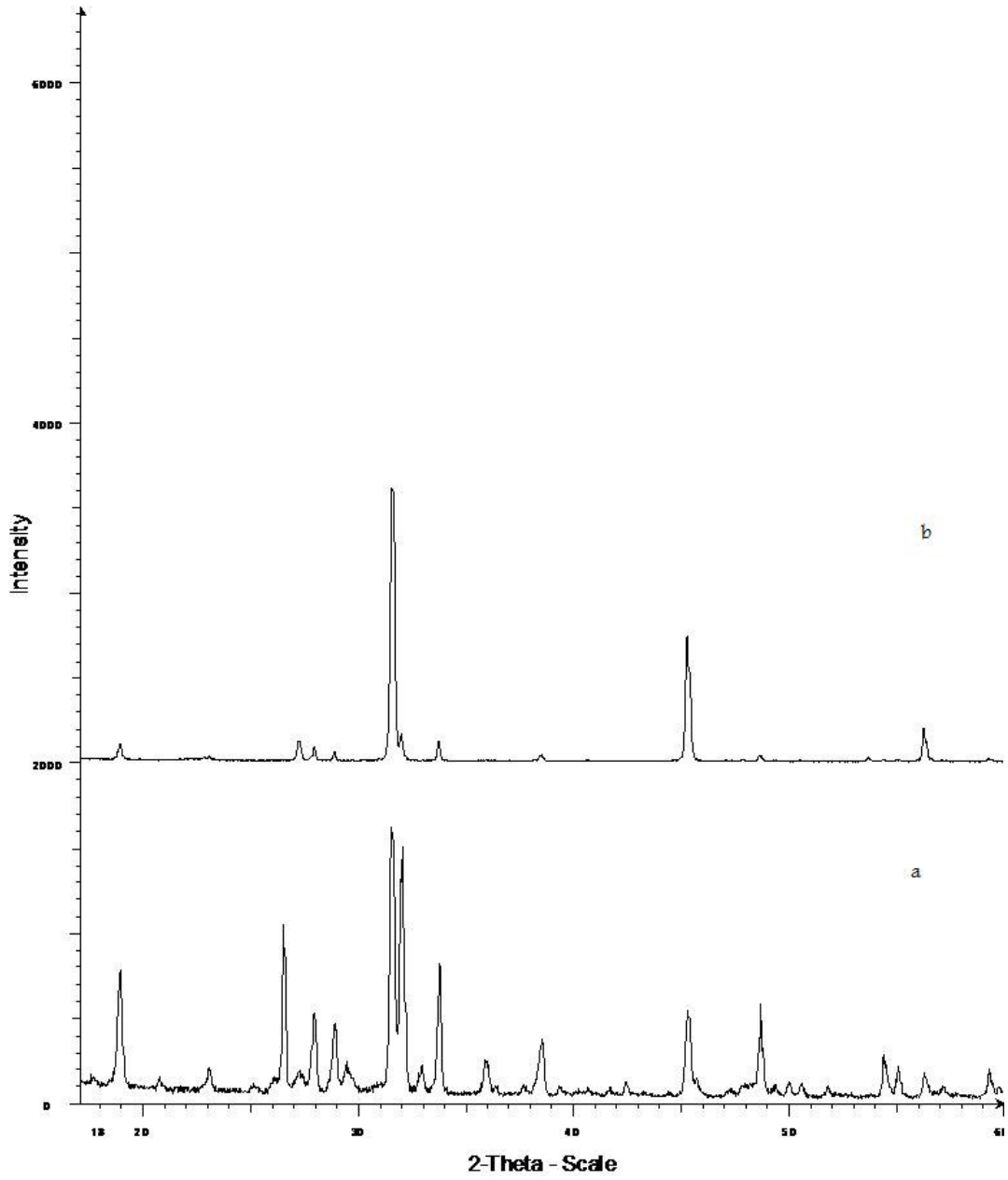


Figure 129: XRD results for sample WN16

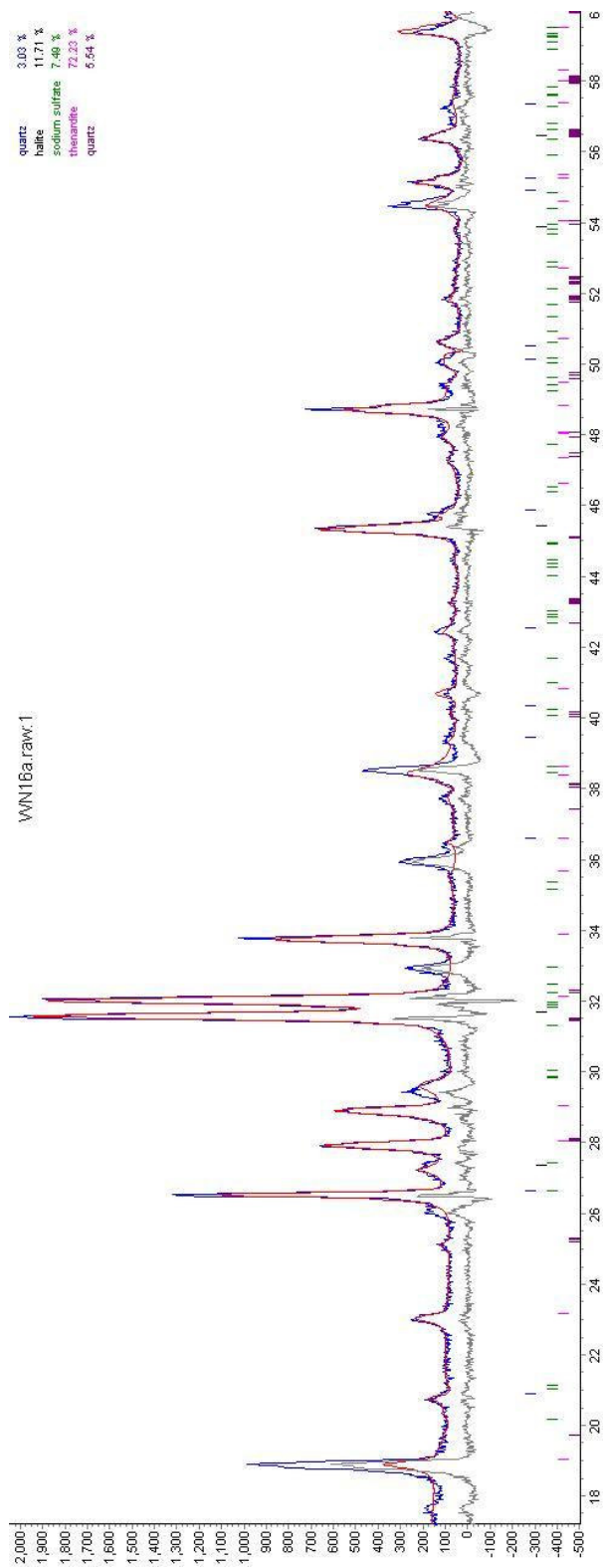


Figure 130: TOPAS results for sample 16a

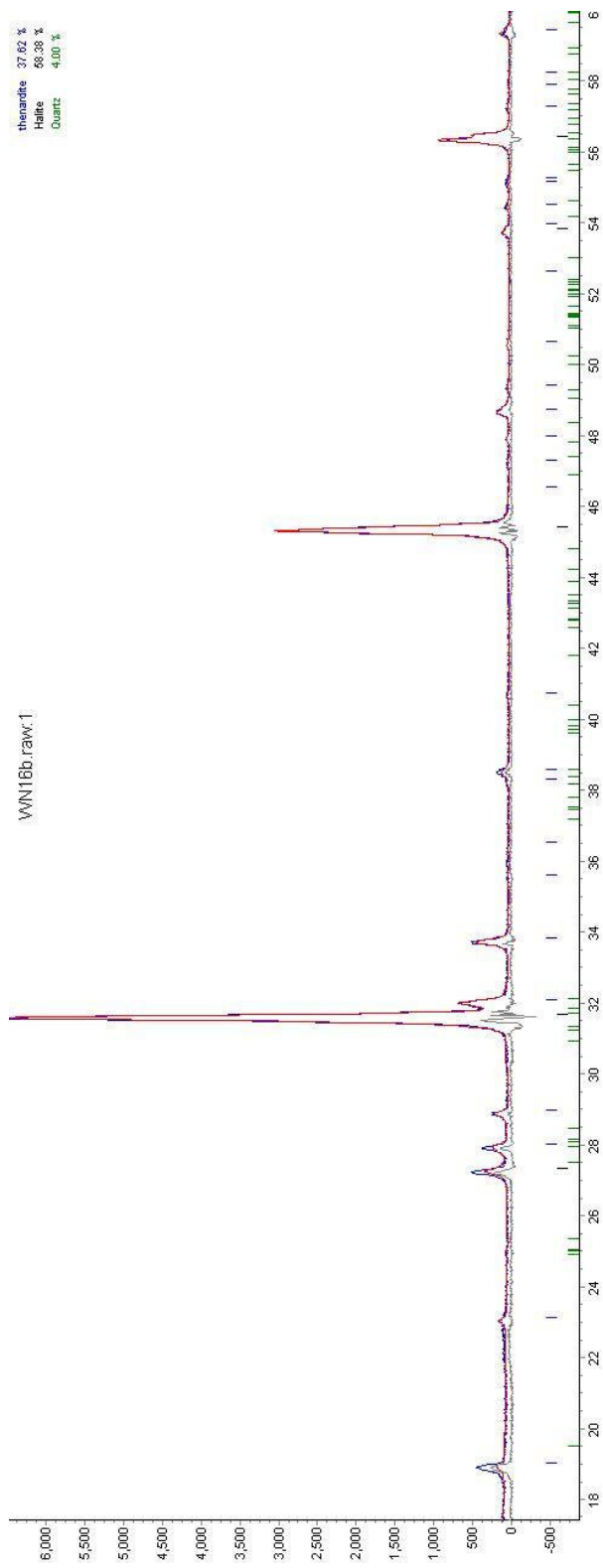


Figure 131: TOPAS results for WN16b

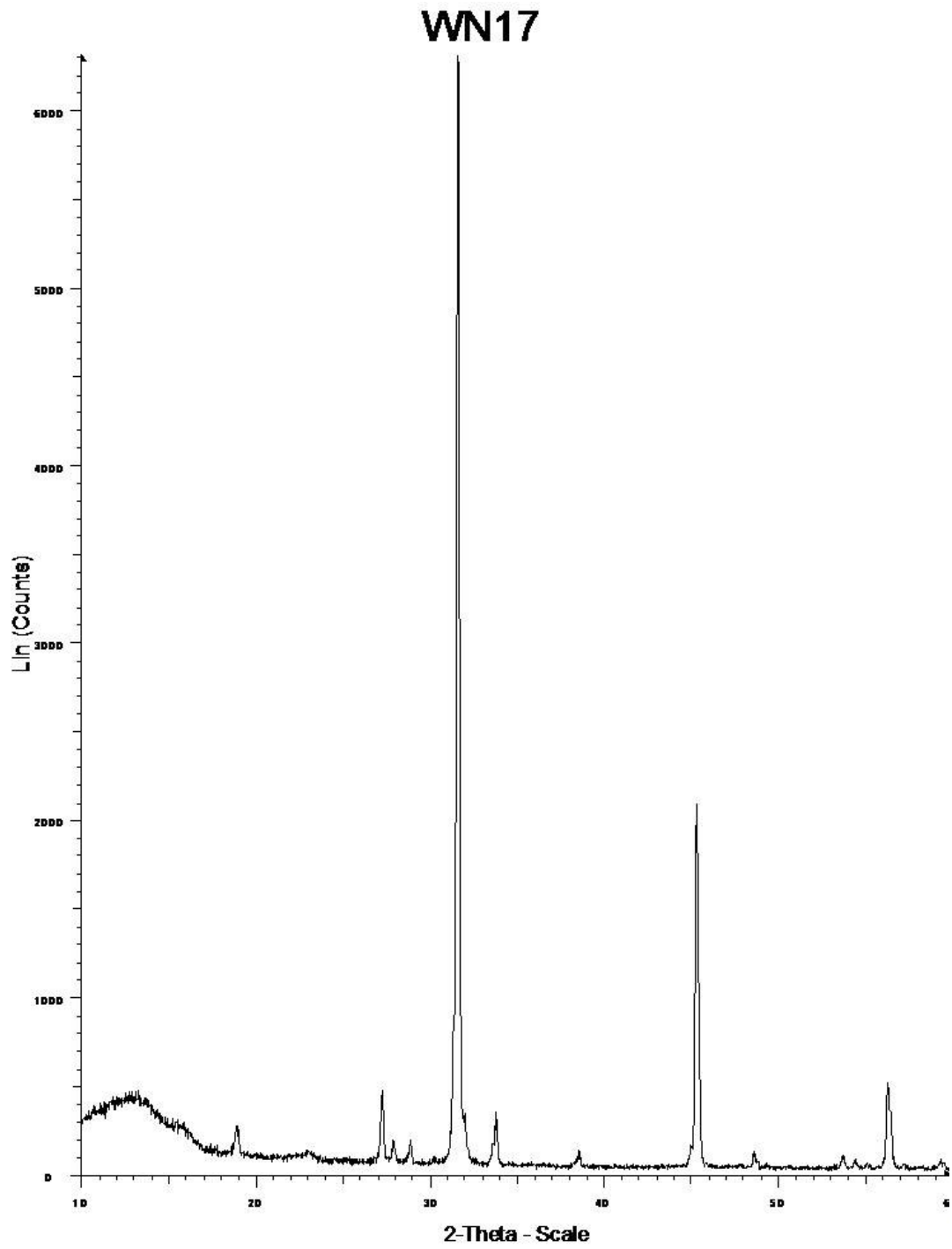


Figure 132: XRD results for WN17

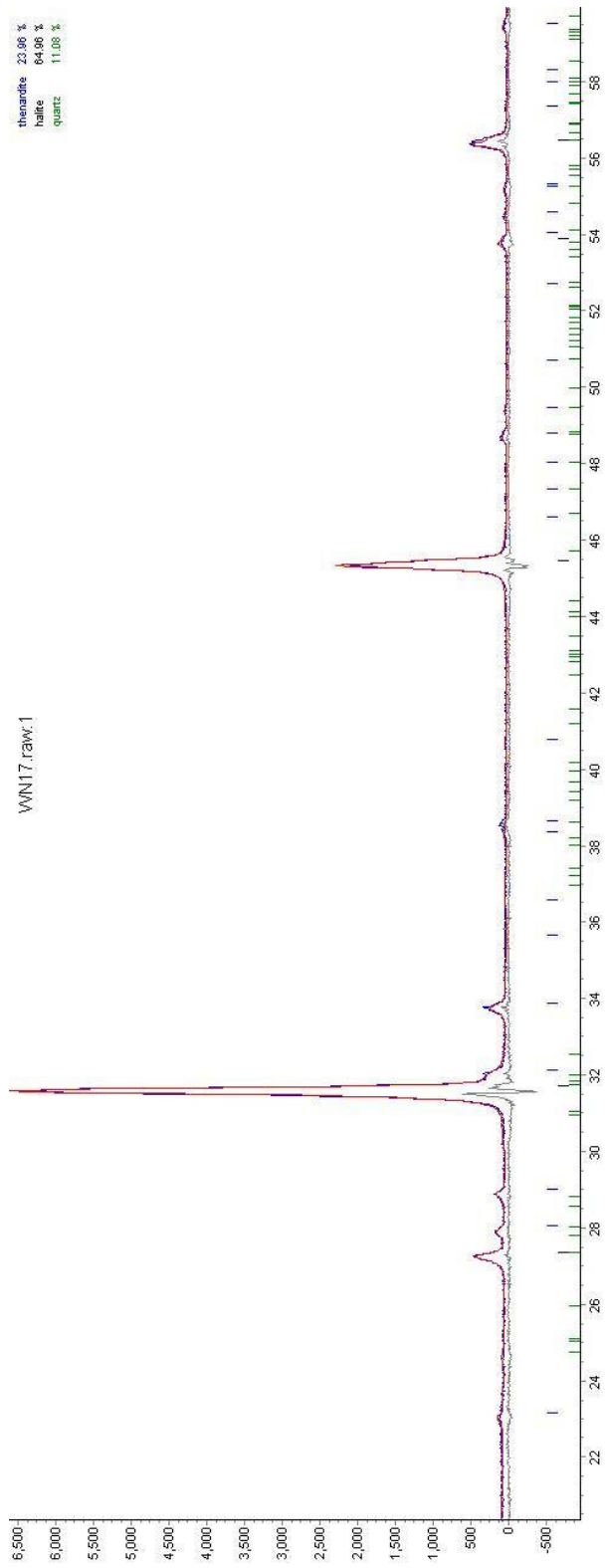


Figure 133: TOPAS results for WN17

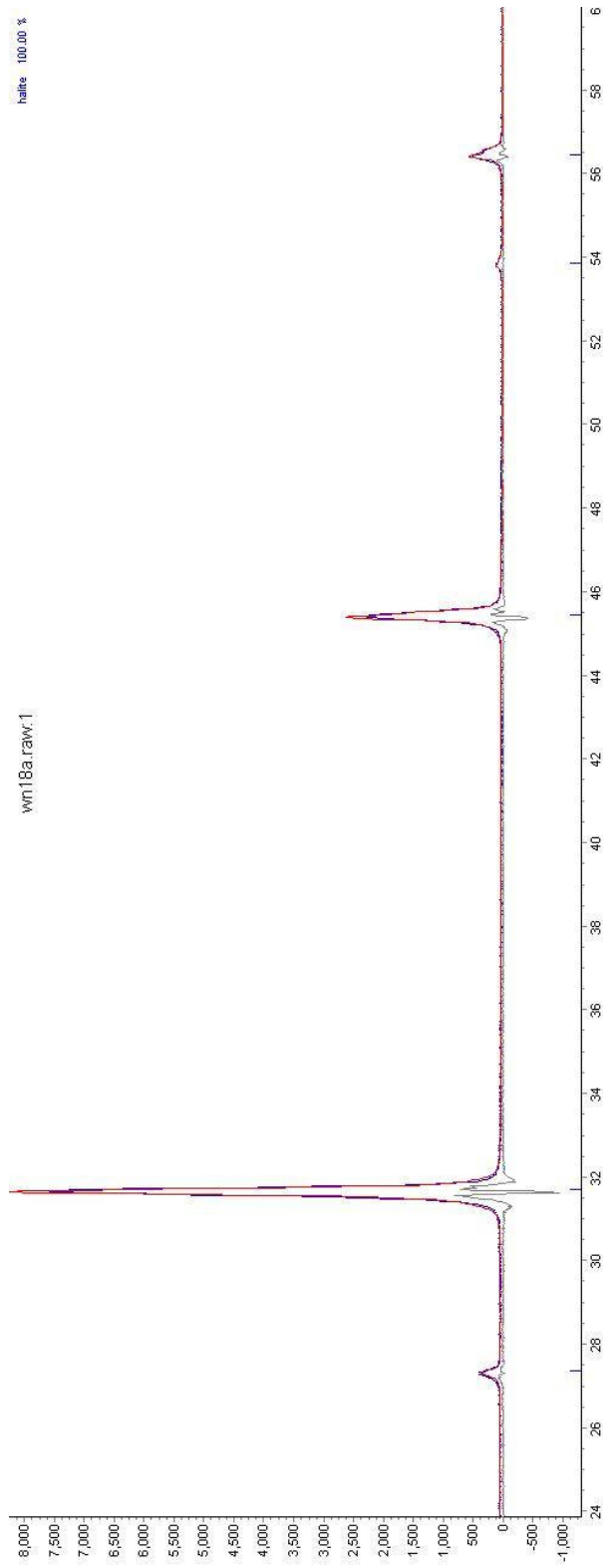


Figure 134: TOPAS result for WN18a

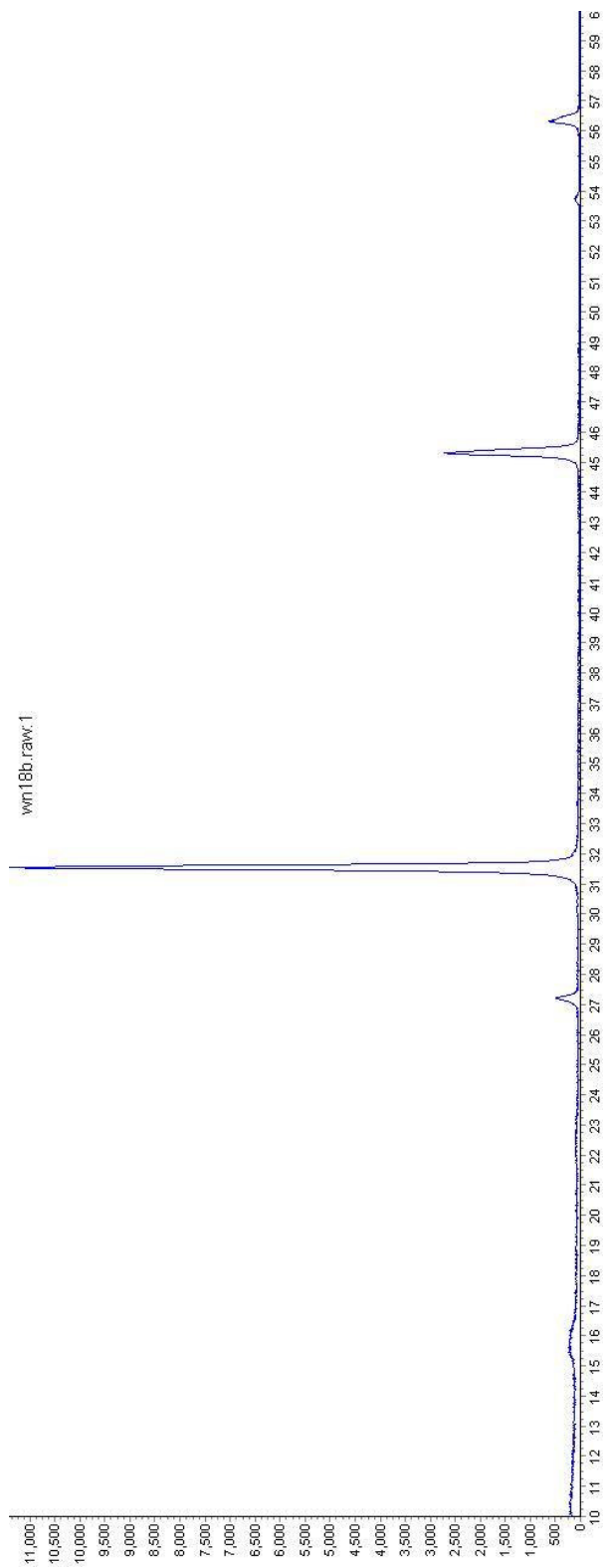


Figure 135: TOPAS result for WN18b

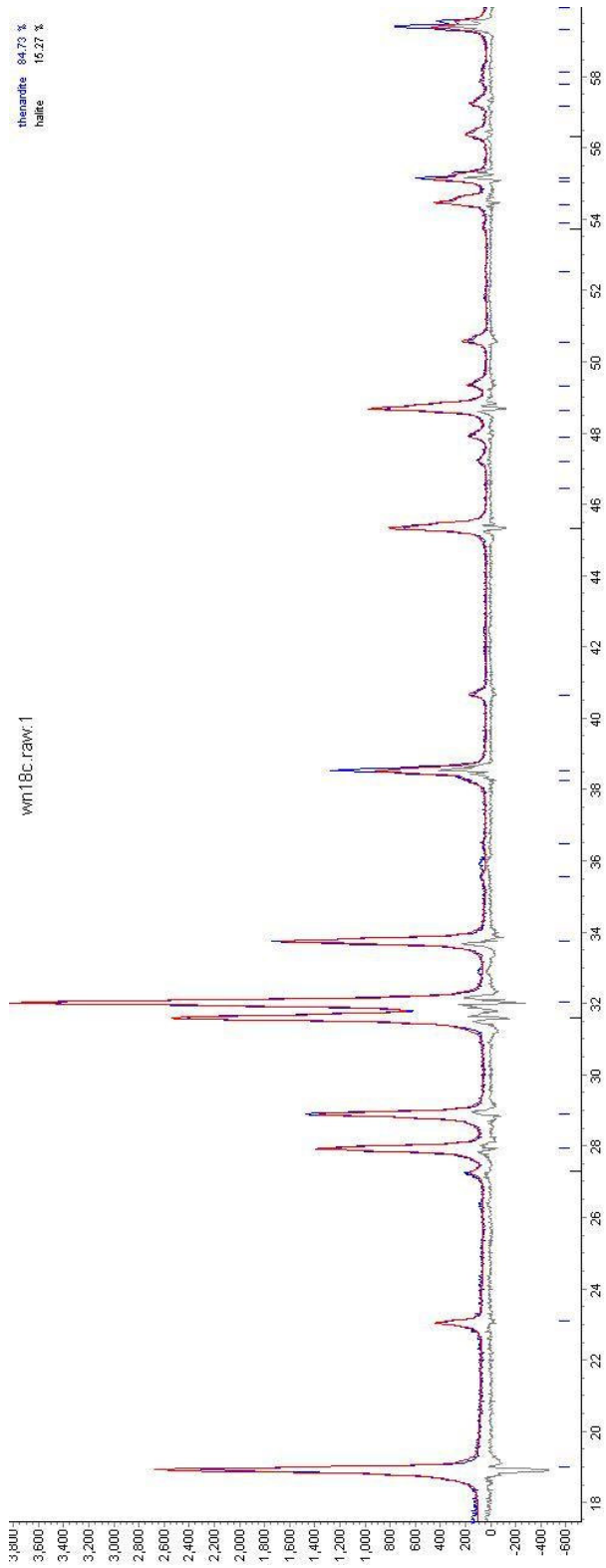


Figure 136: TOPAS result for WN18c

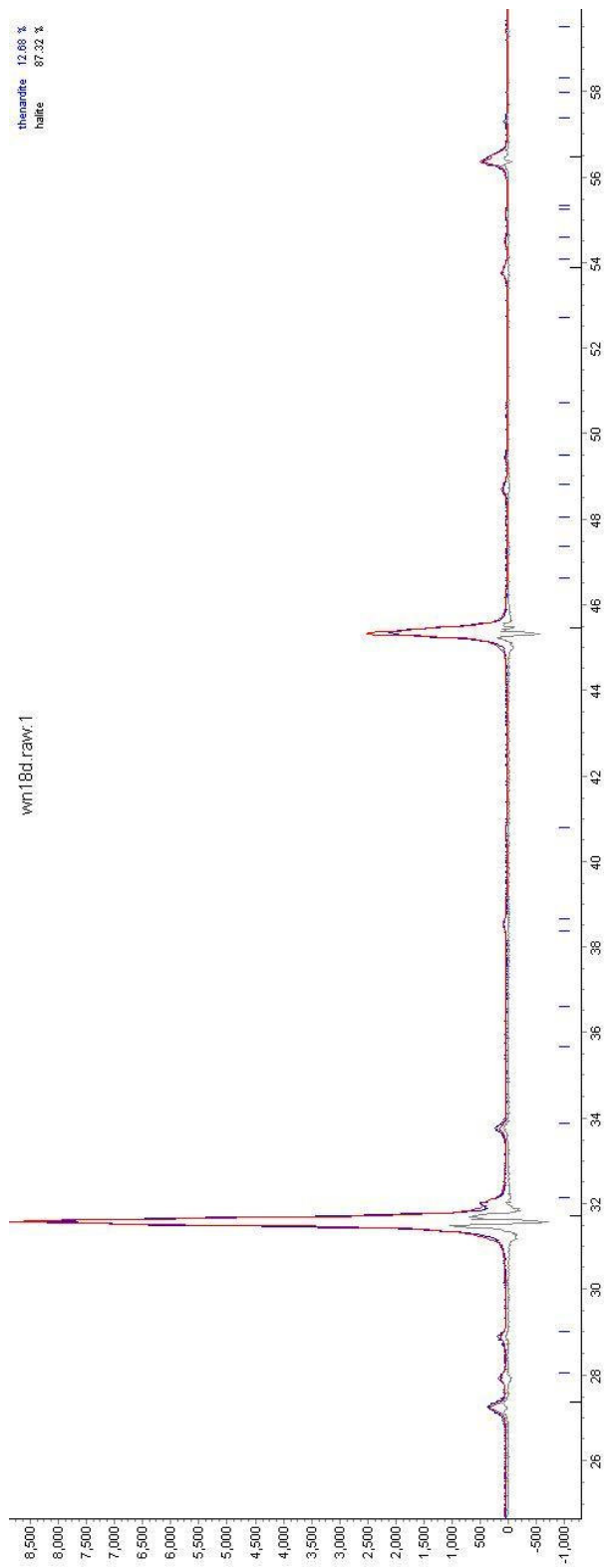


Figure 137: TOPAS result for WN18d

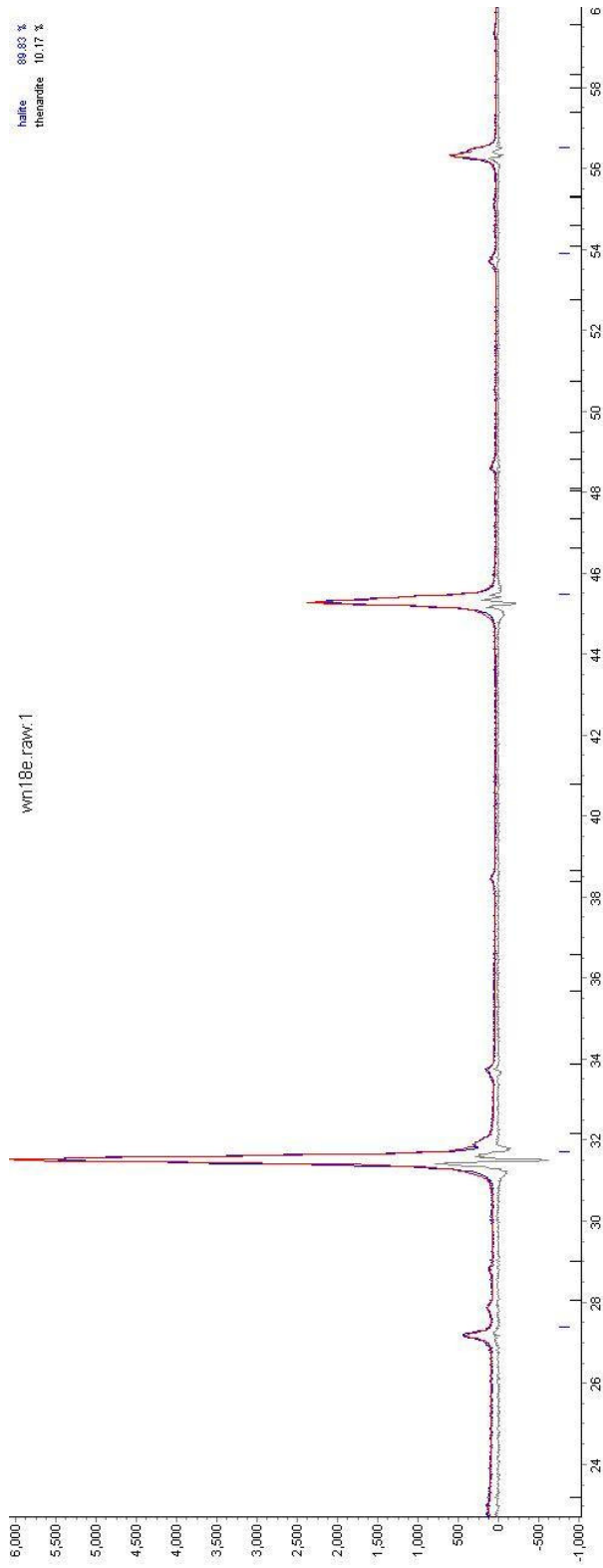


Figure 138: TOPAS result for WN18e

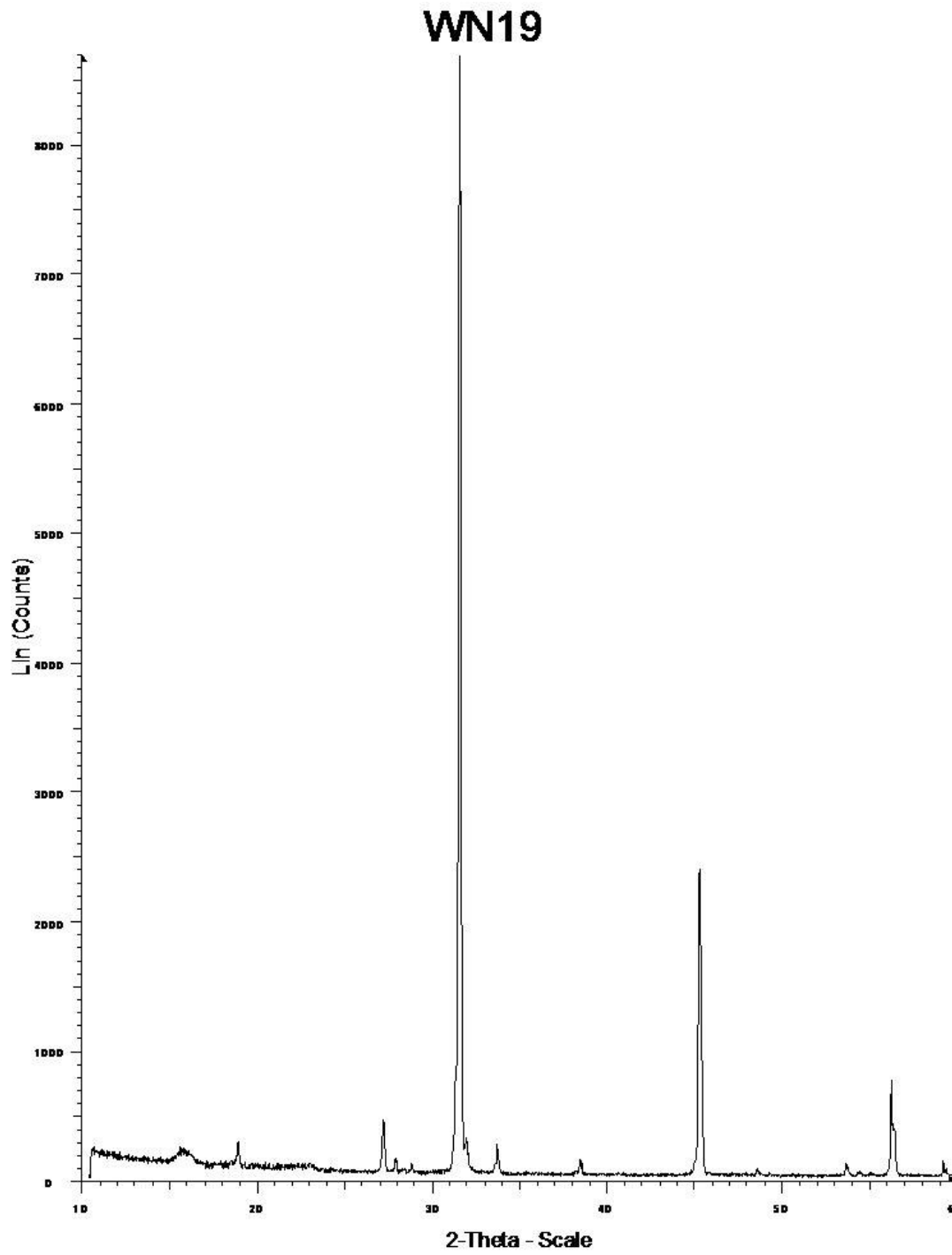


Figure 139: XRD result for sample WN19

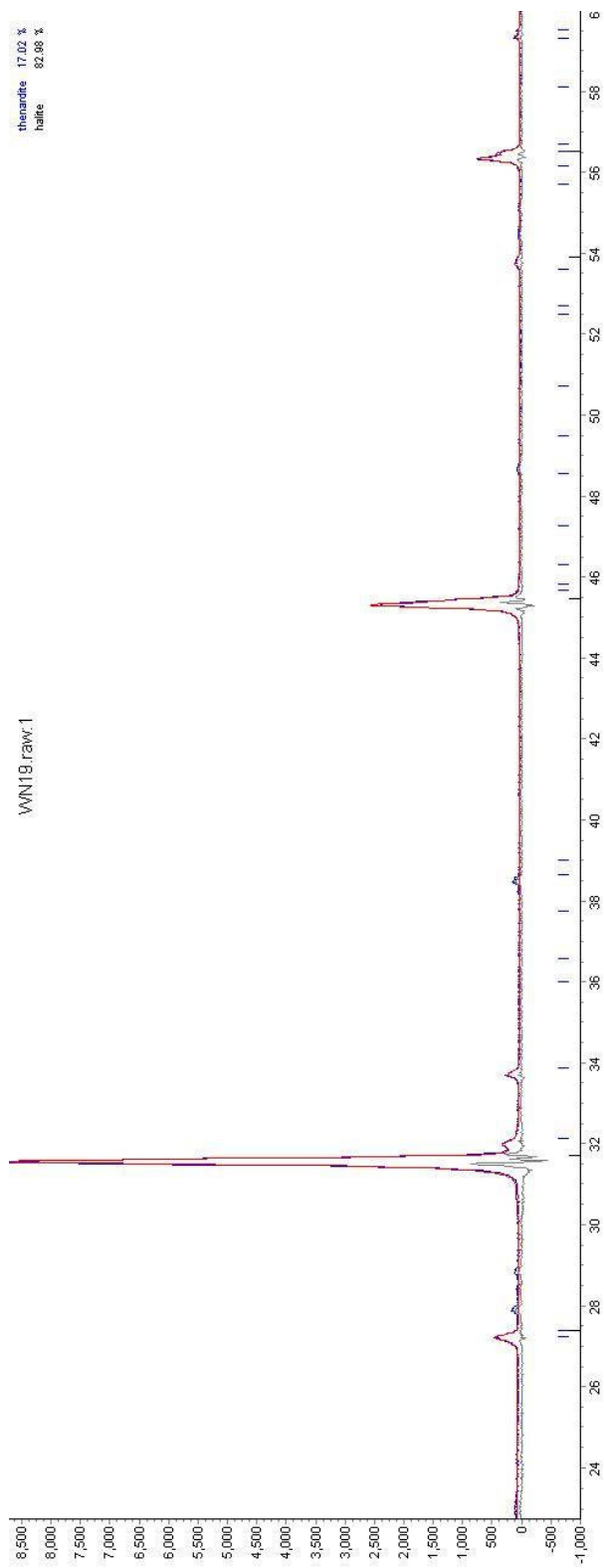


Figure 140: TOPAS result for WN19

Lake Zugm

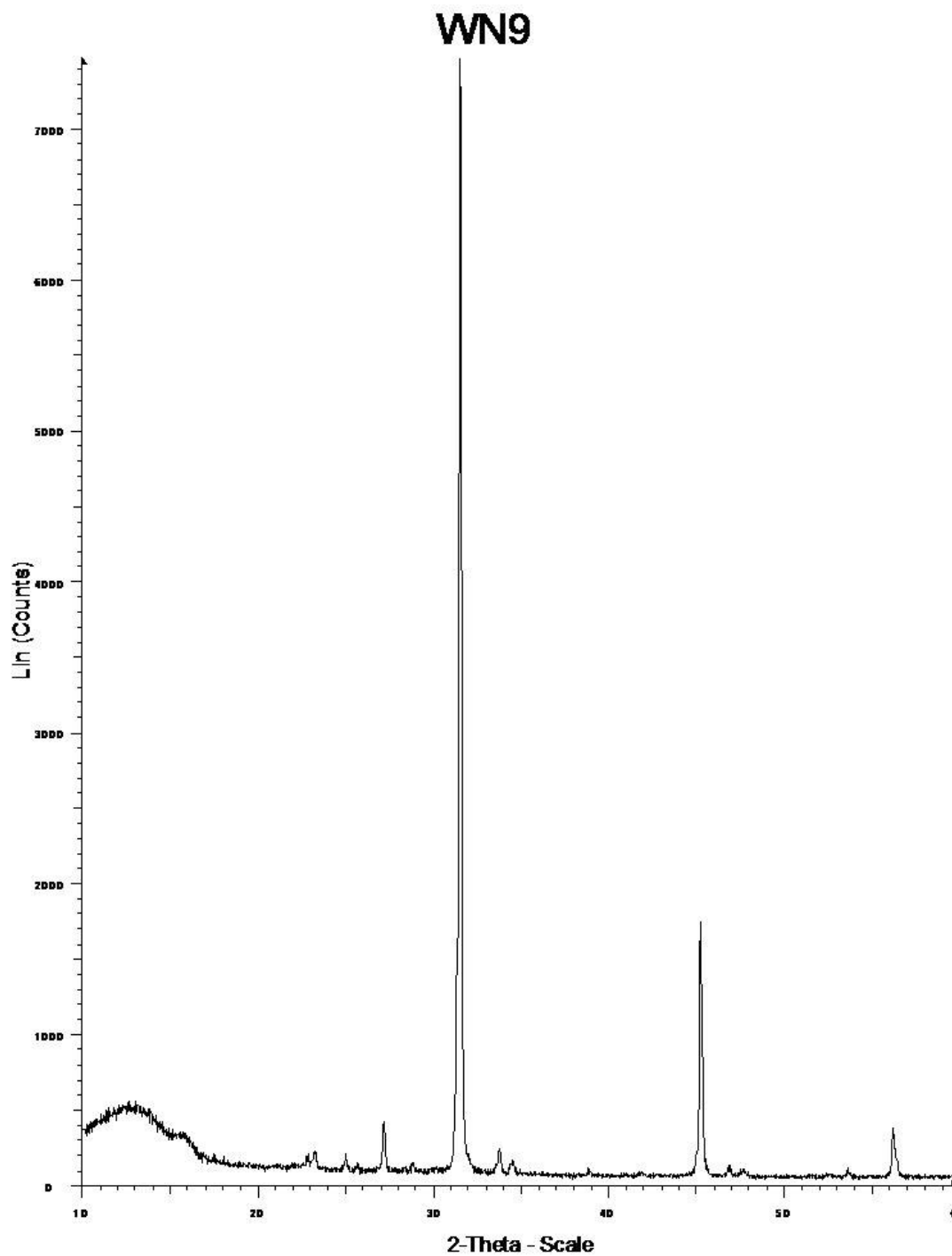


Figure 141: XRD result for WN9

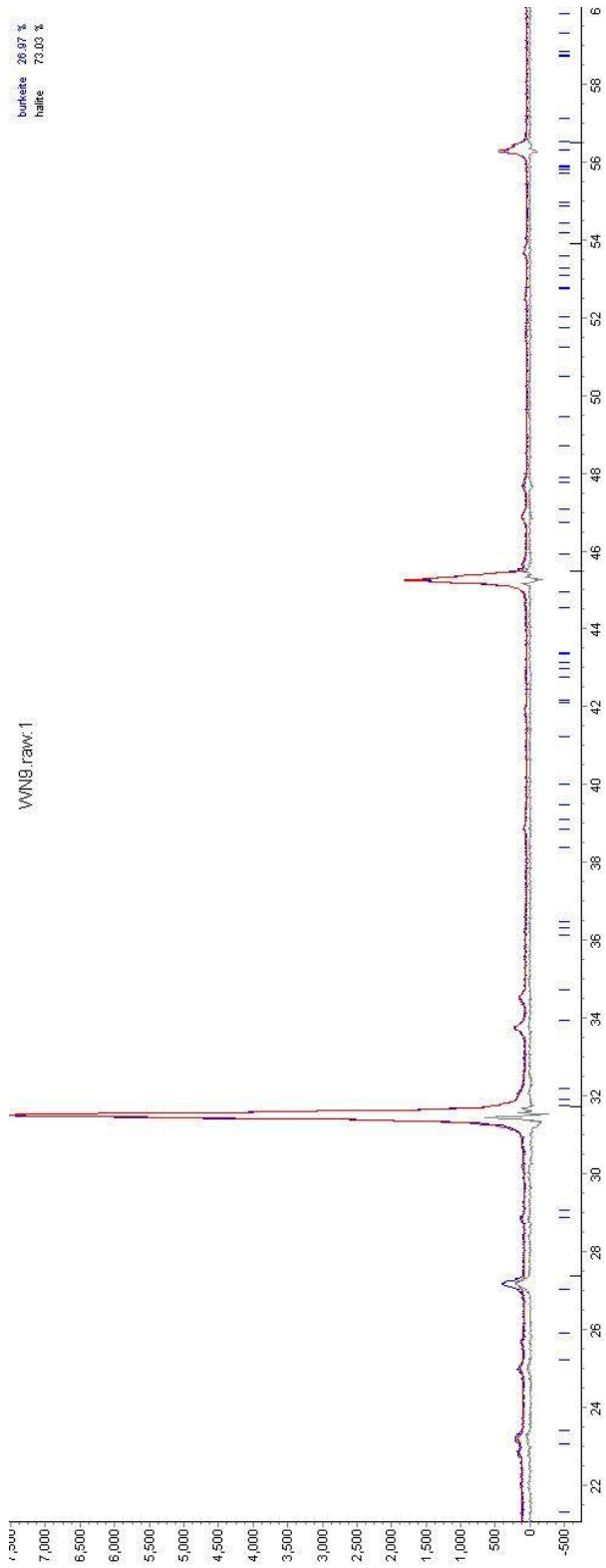


Figure 142: TOPAS result for WN9

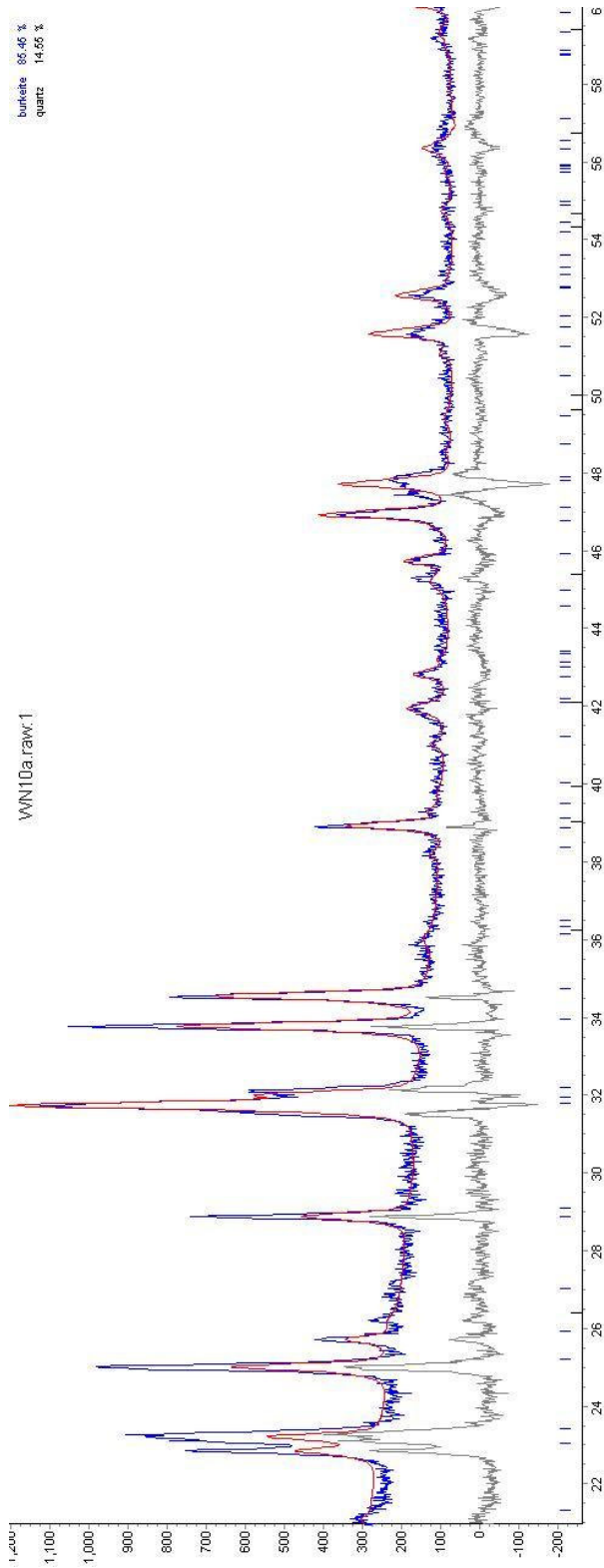


Figure 143: TOPAS for WN10a

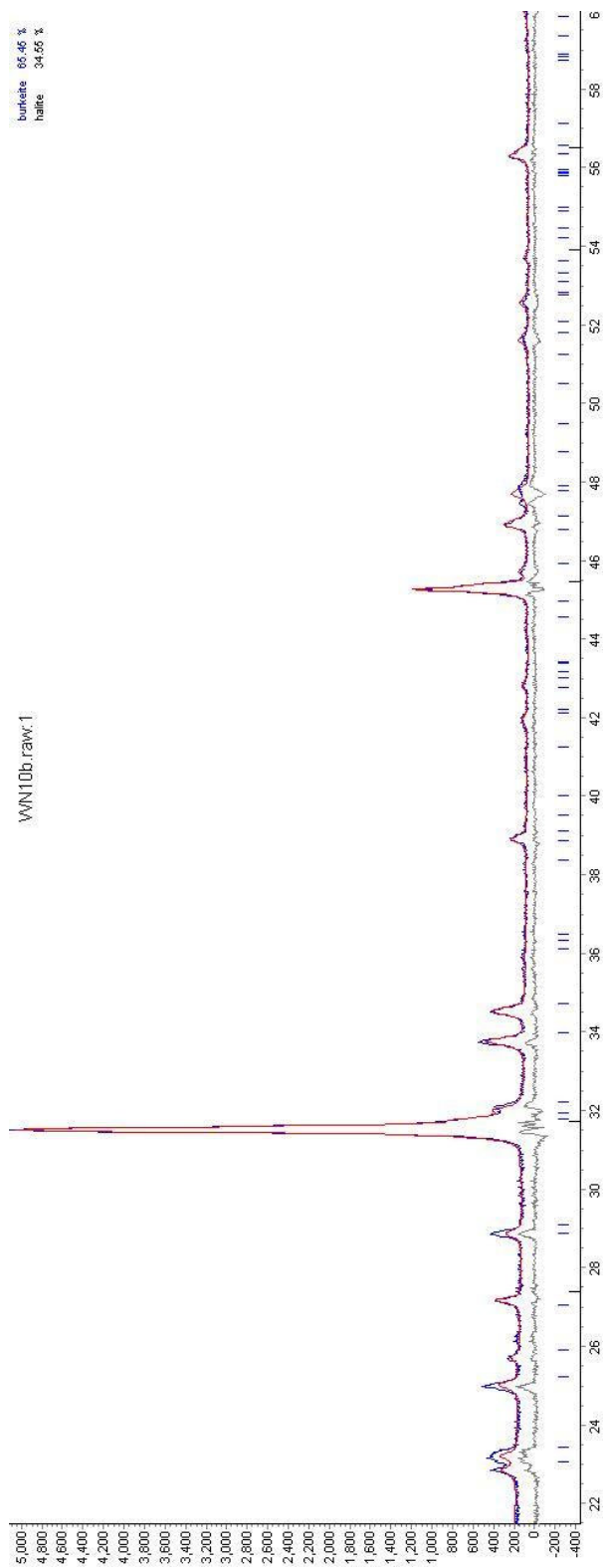


Figure 144: TOPAS result for WN10b

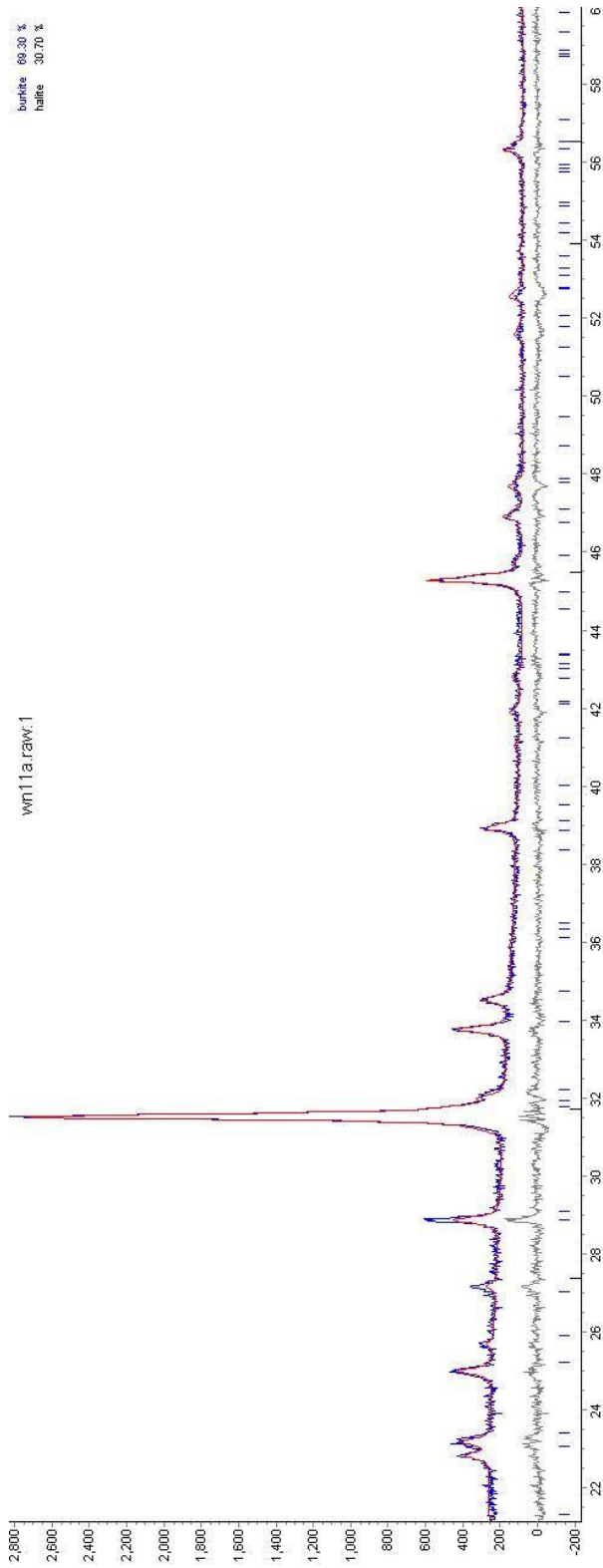


Figure 145: TOPAS results for WN11a

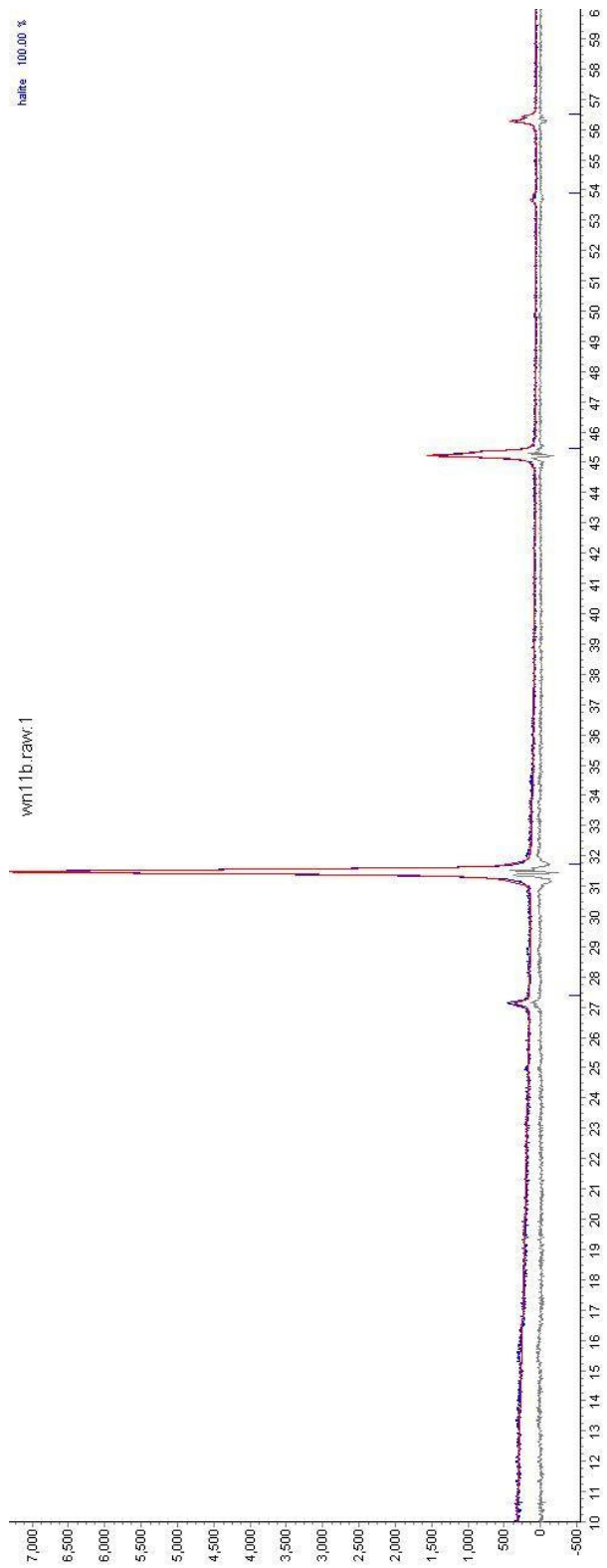


Figure 146: TOPAS results for WN11b

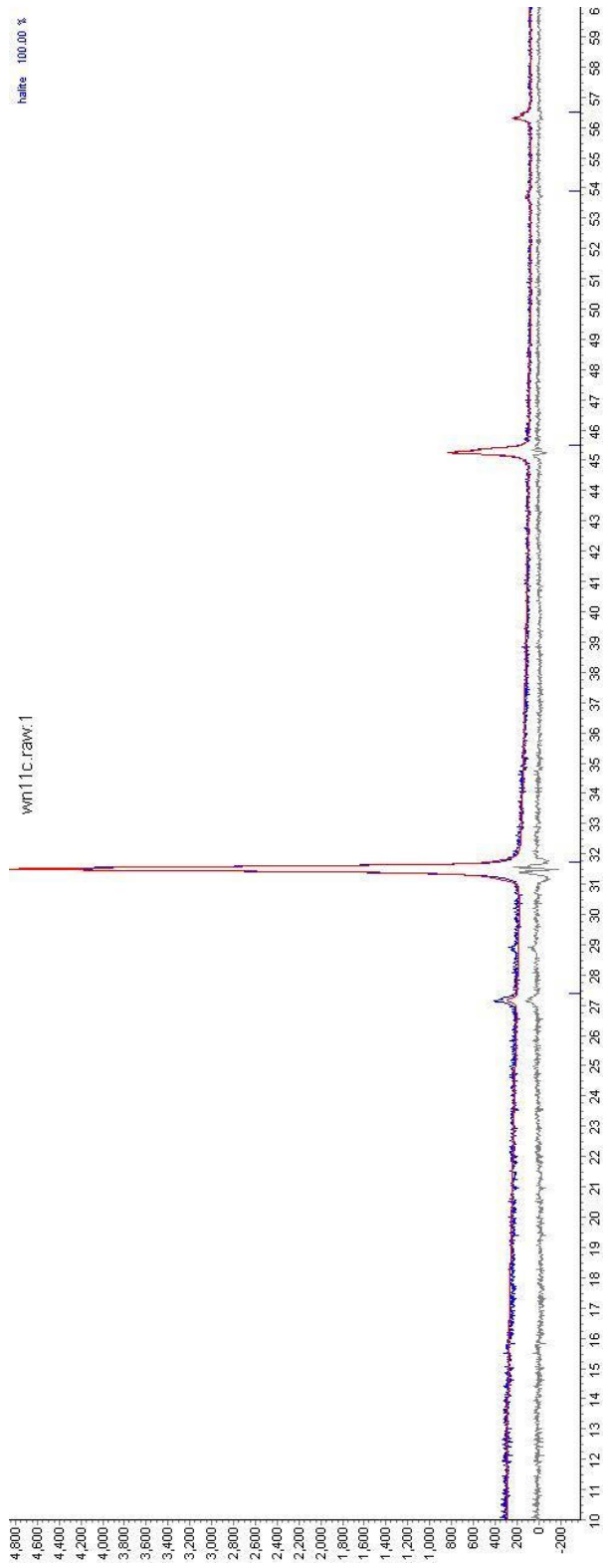


Figure 147: TOPAS result for WN11c

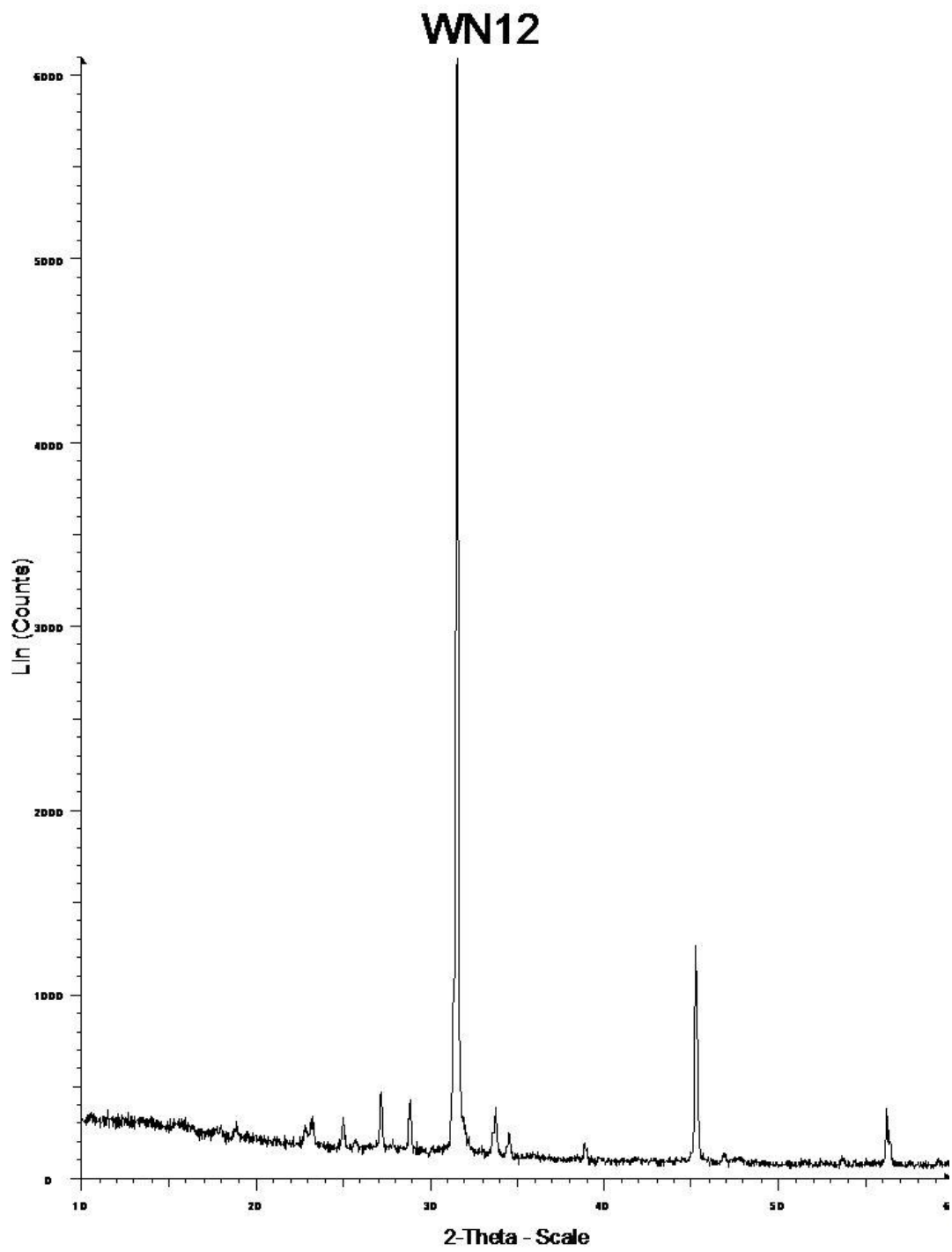


Figure 148: XRD result for WN12

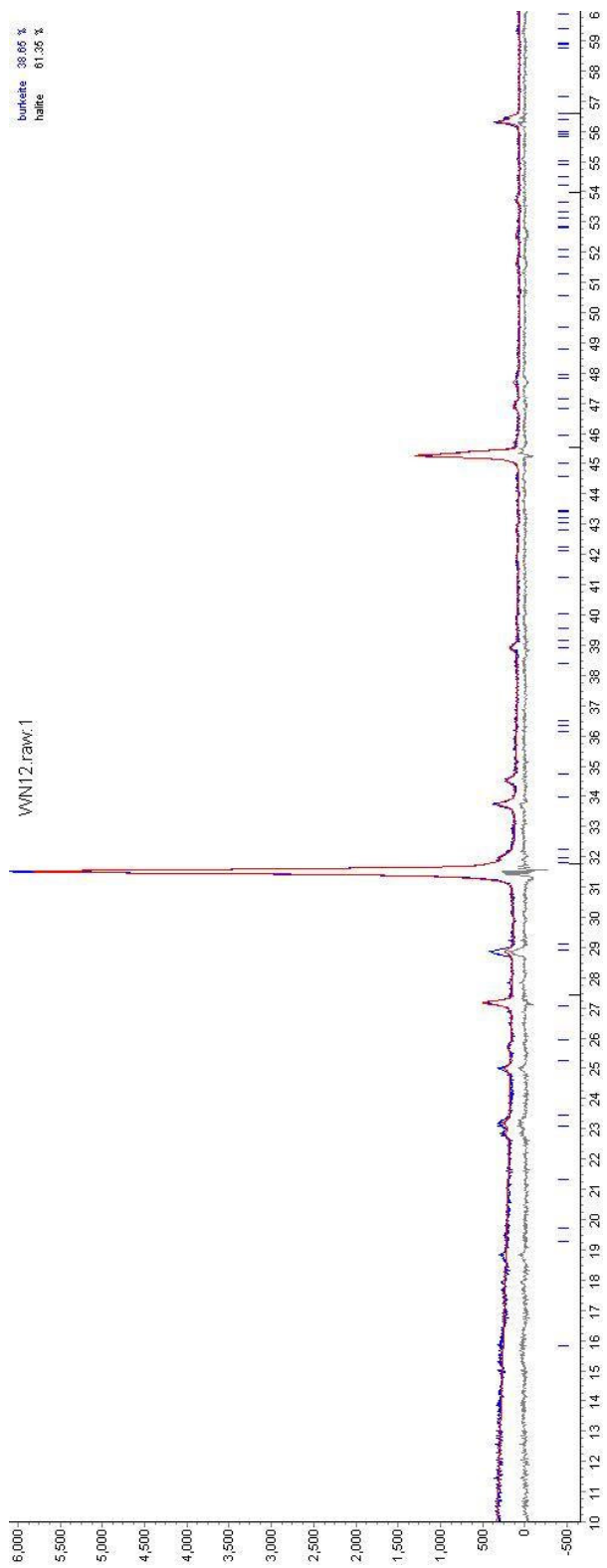


Figure 149: TOPAS for WN12

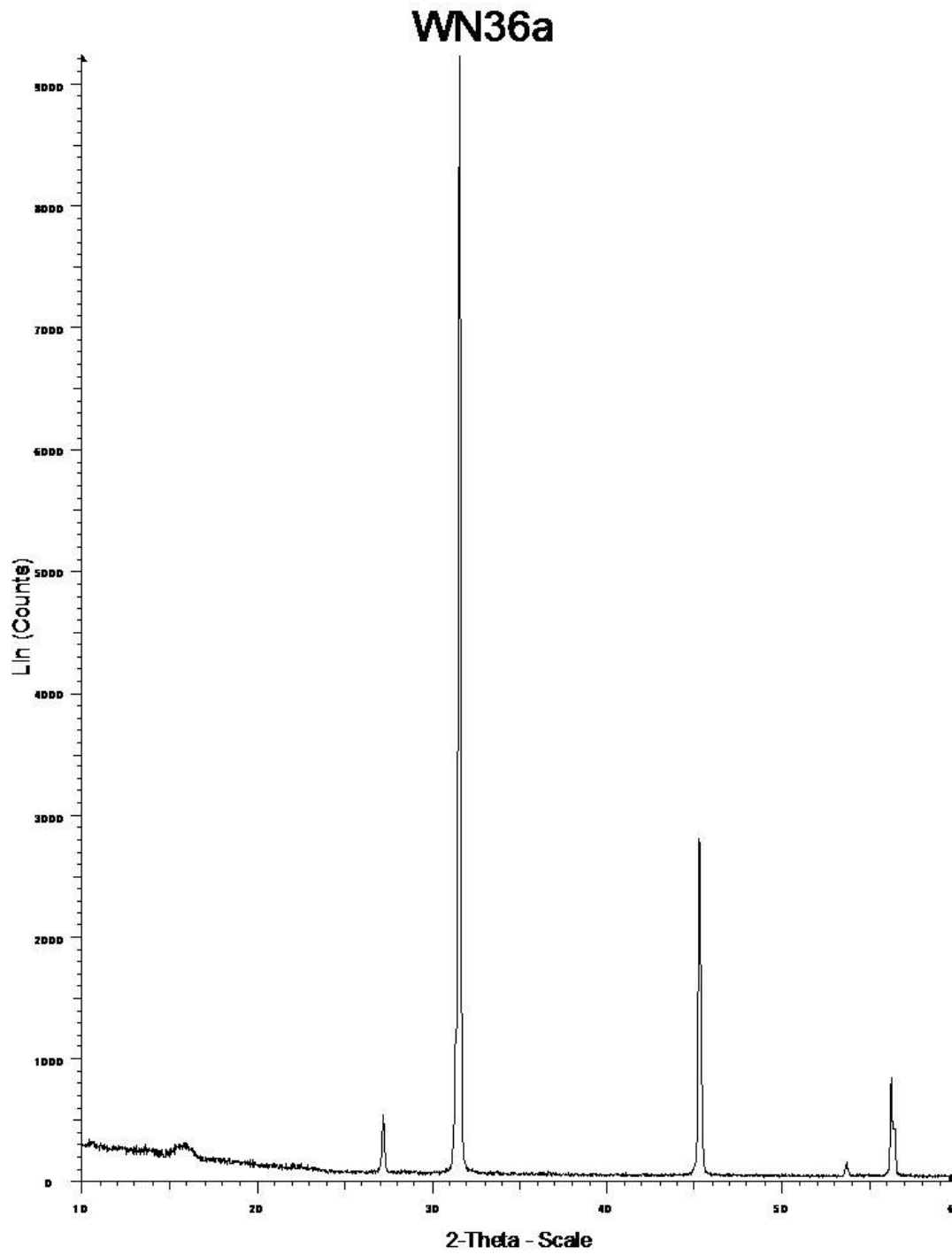


Figure 150: XRD results from WN36a

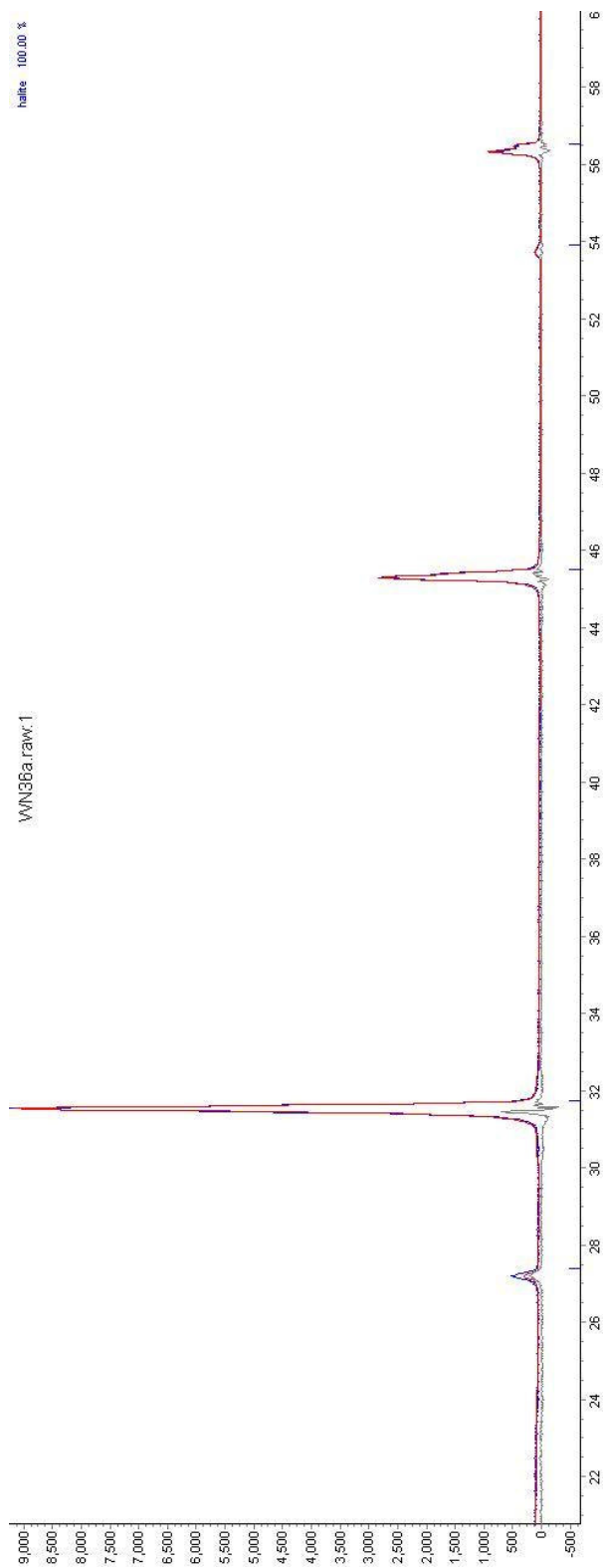


Figure 151: TOPAS result for WN36a

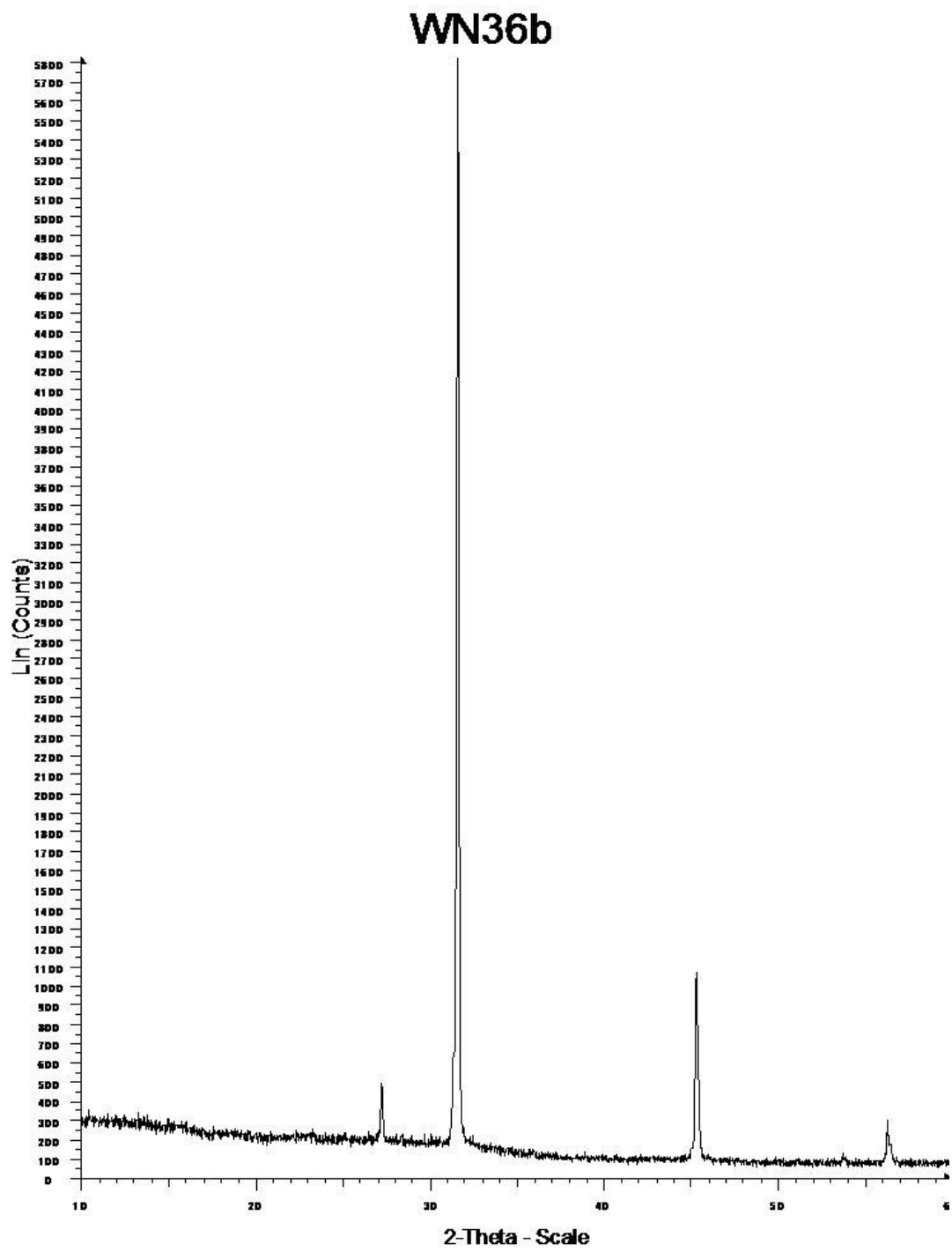


Figure 152: XRD result for WN36b

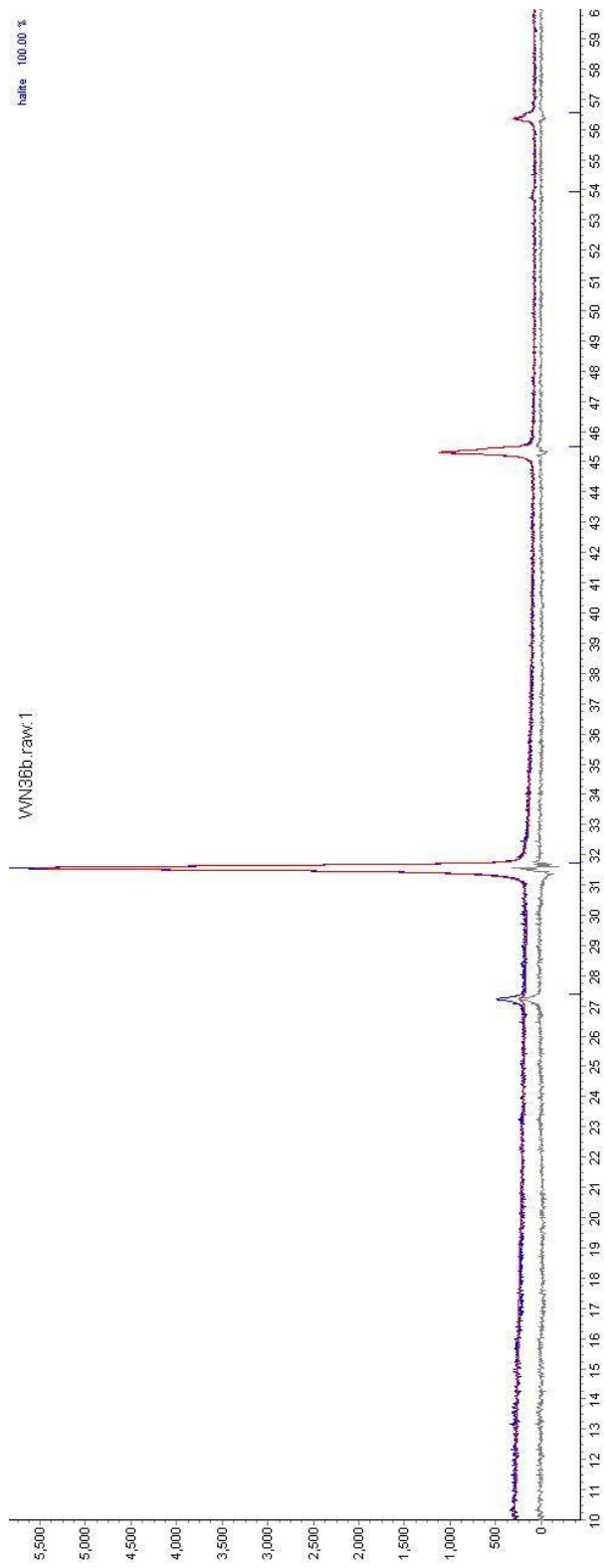


Figure 153: TOPAS result for WN36b

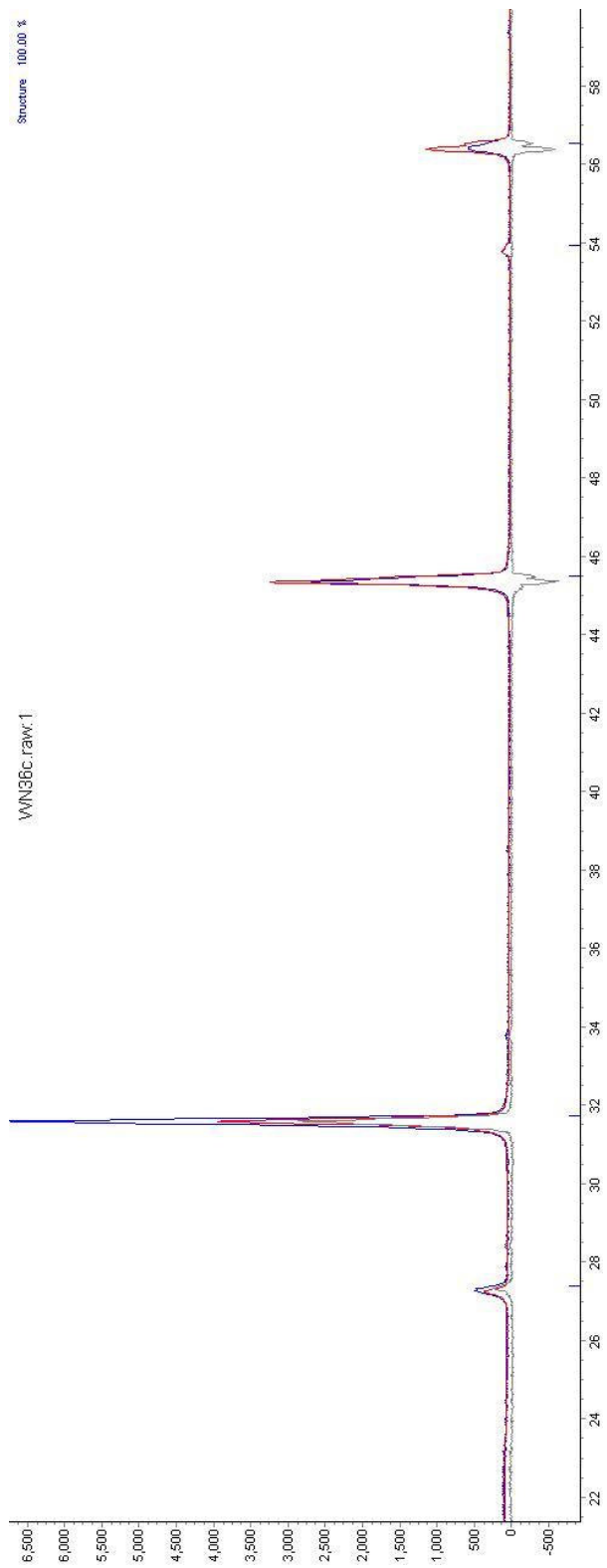


Figure 154: TOPAS result for WN36c

Lake Hamra

WN1

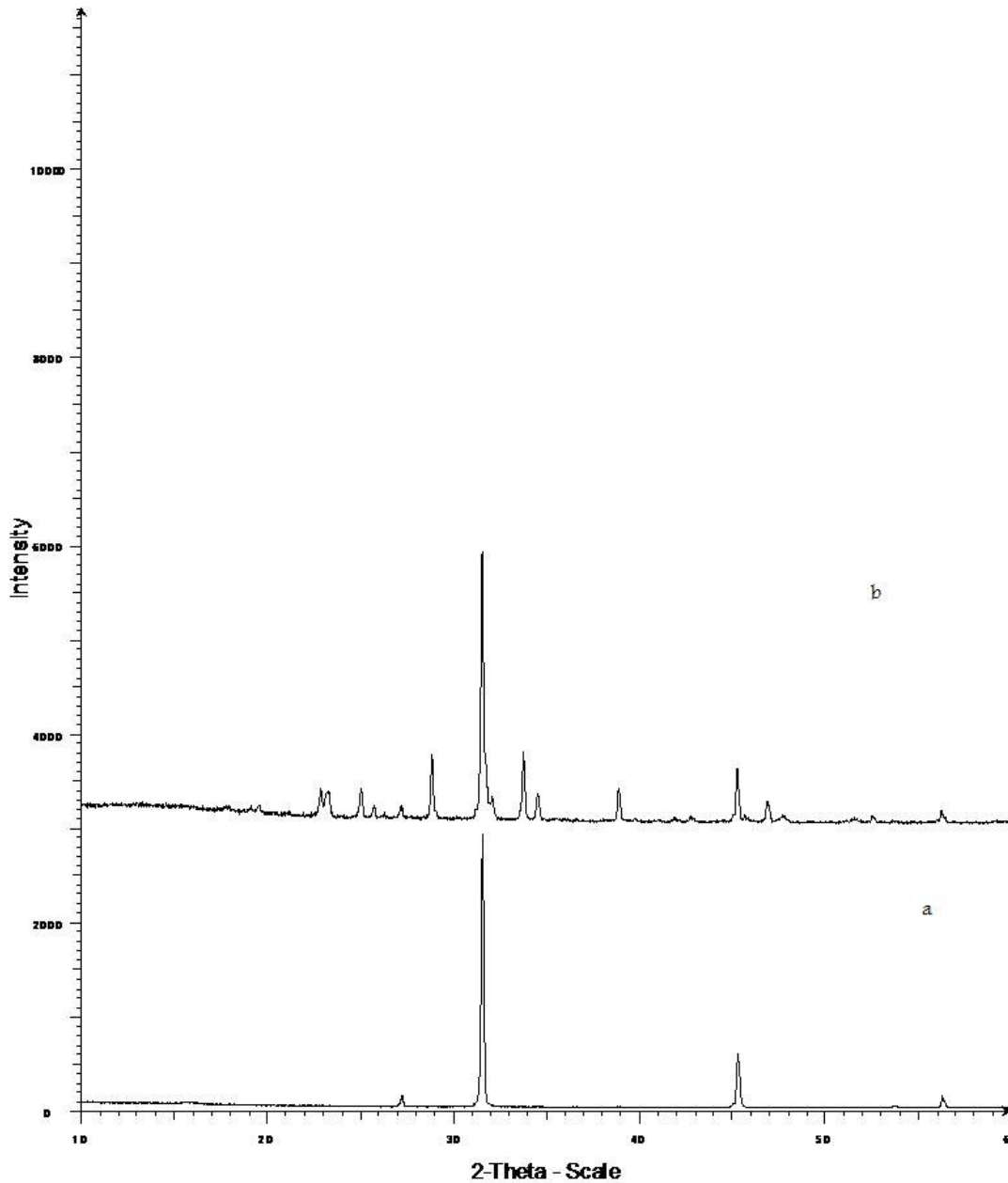


Figure 155: XRD results from WN1

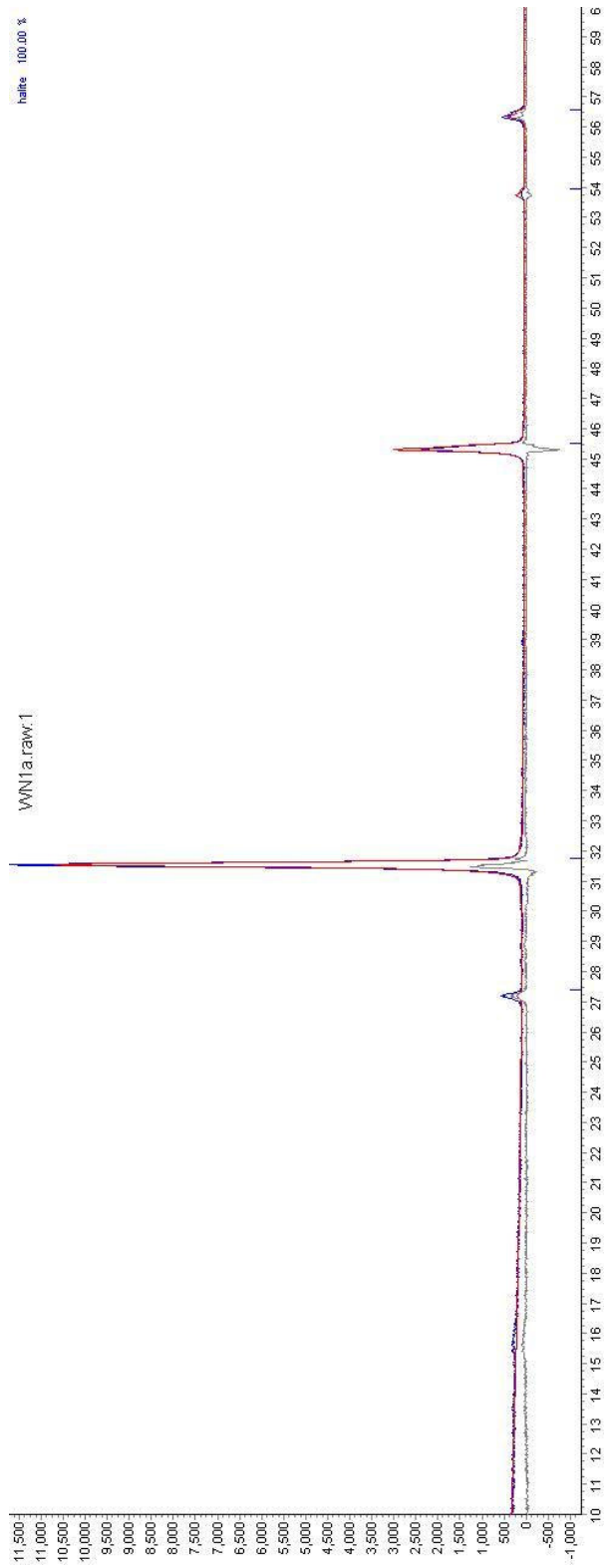


Figure 156: TOPAS result for WN1a

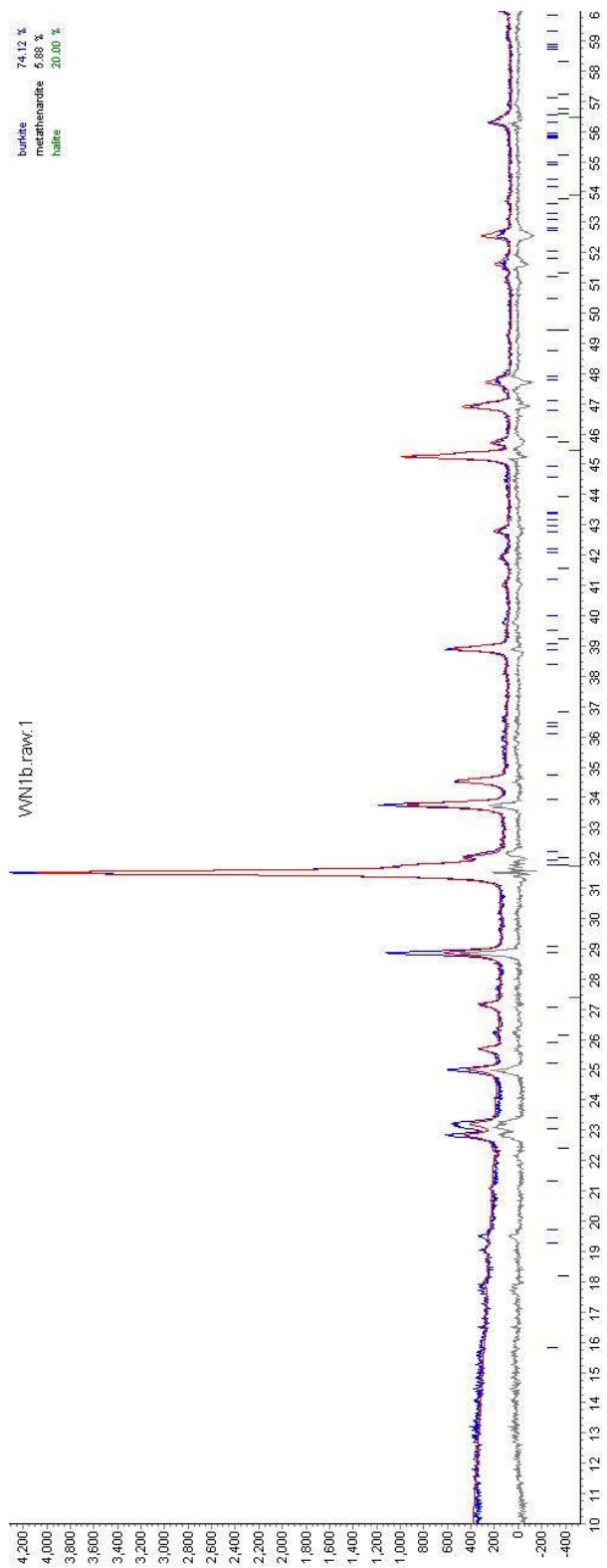


Figure 157: TOPAS result for WN1b

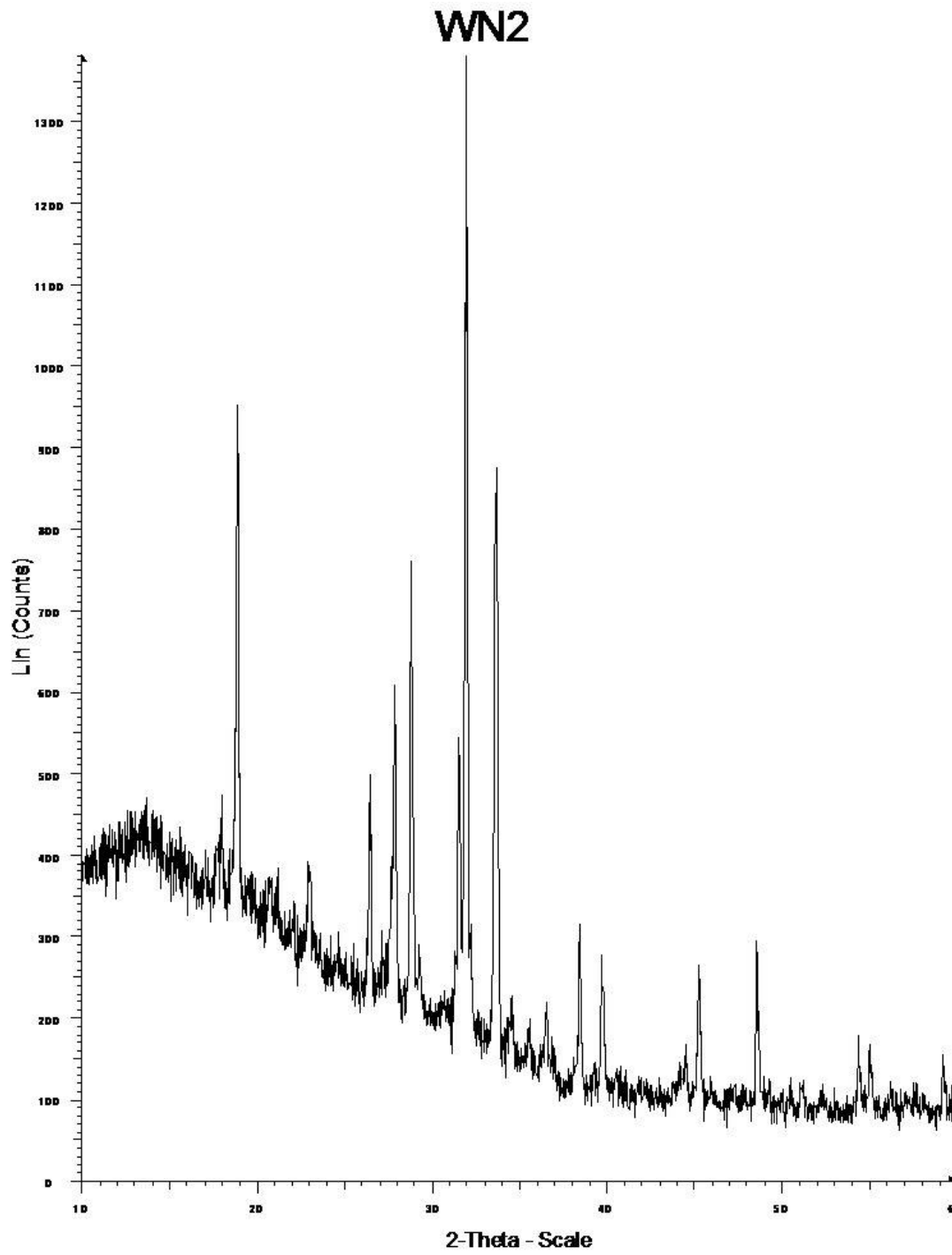


Figure 158: XRD results for WN₂

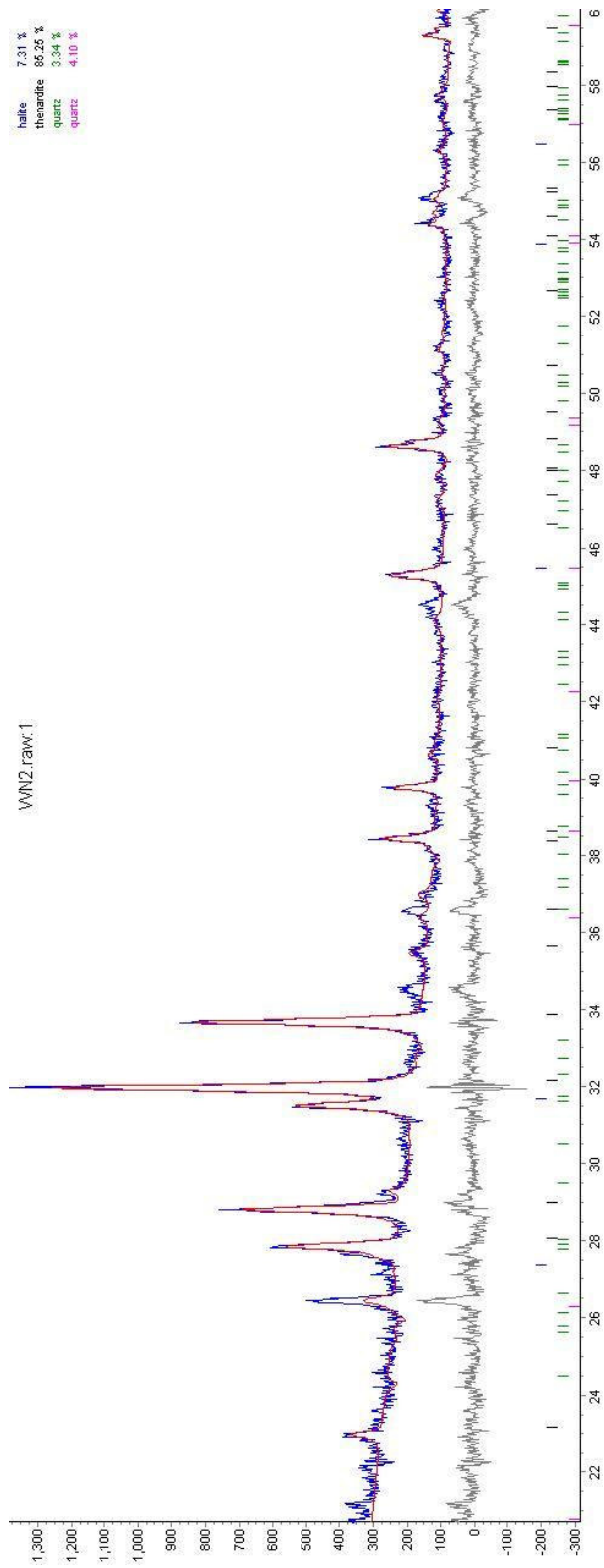


Figure 159: TOPAS result for WN2

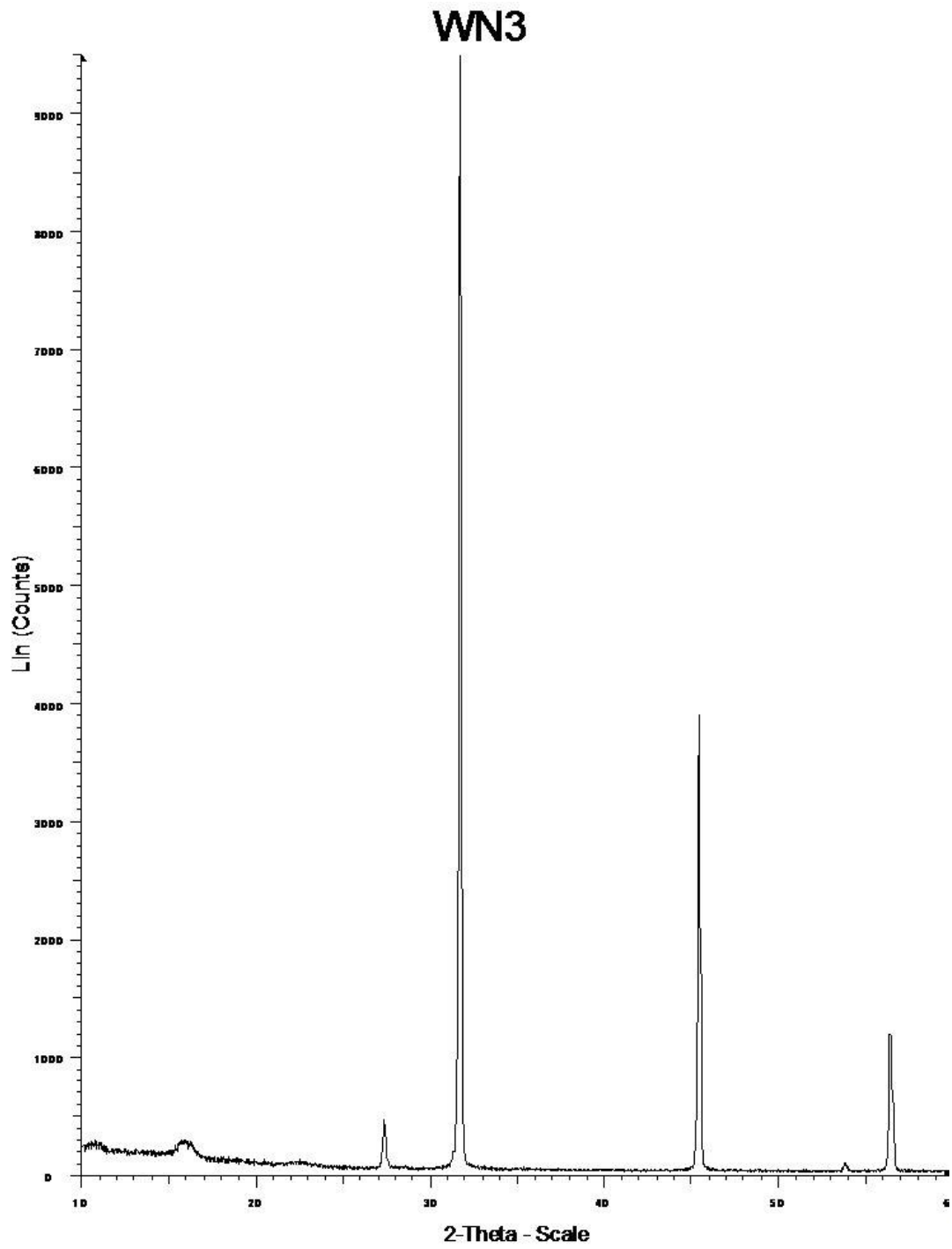


Figure 160: XRD result from WN3

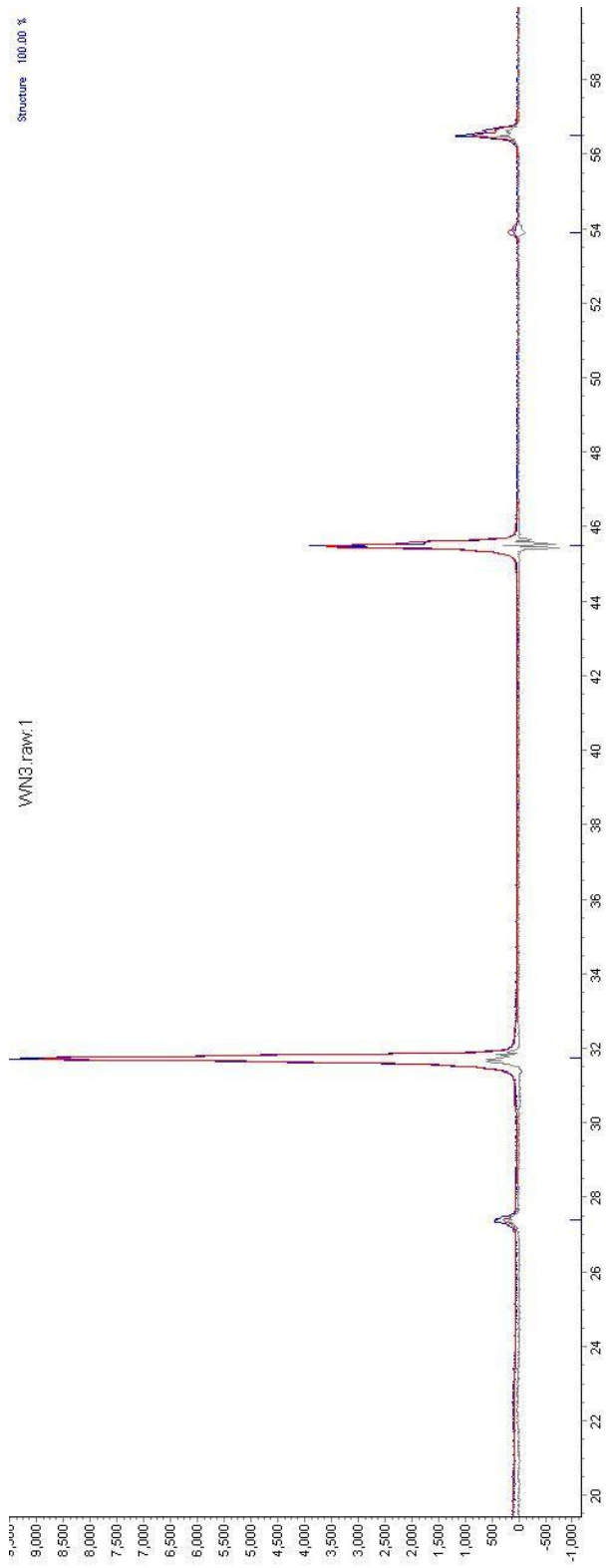


Figure 161: TOPAS result for WN3

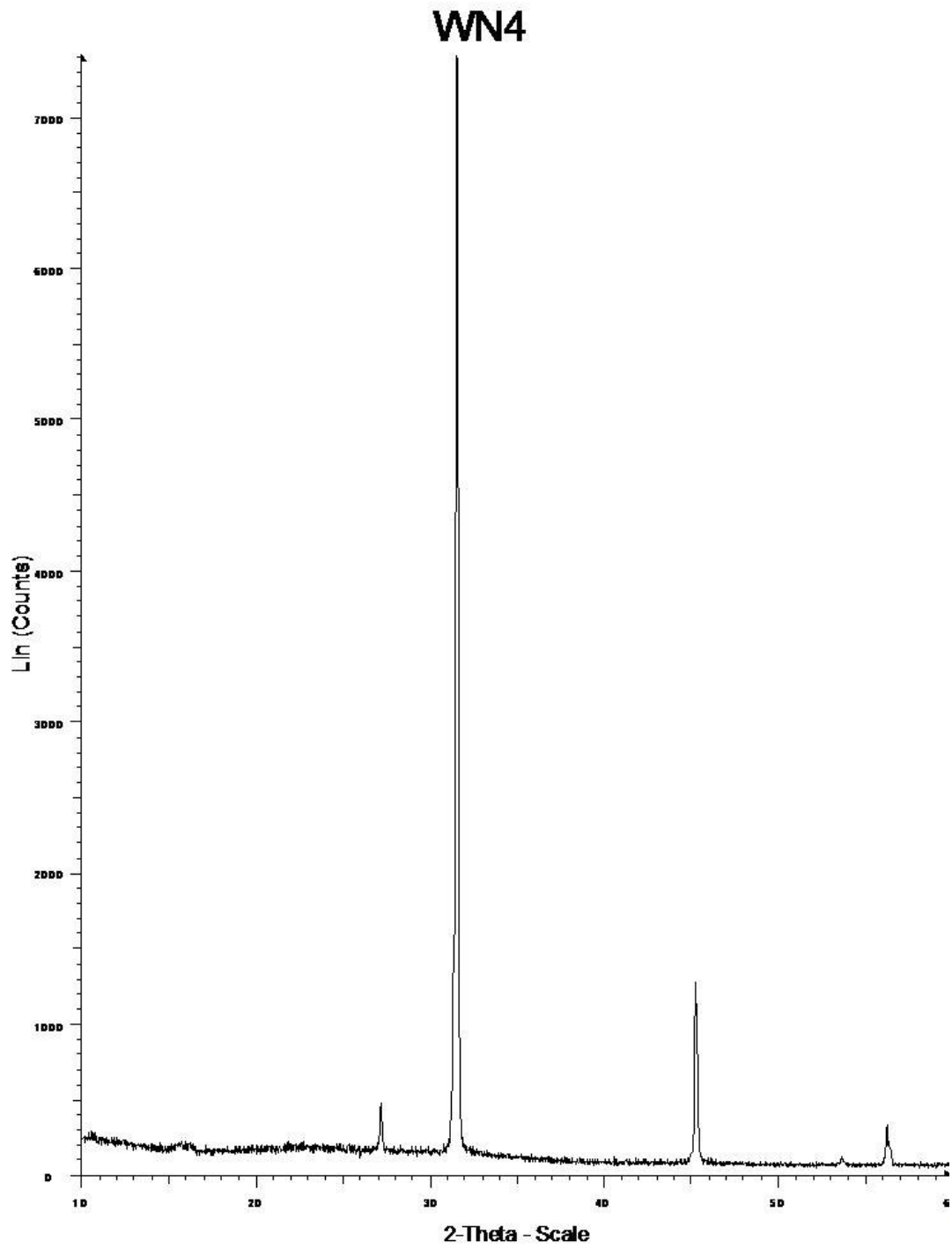


Figure 162: XRD result for WN4

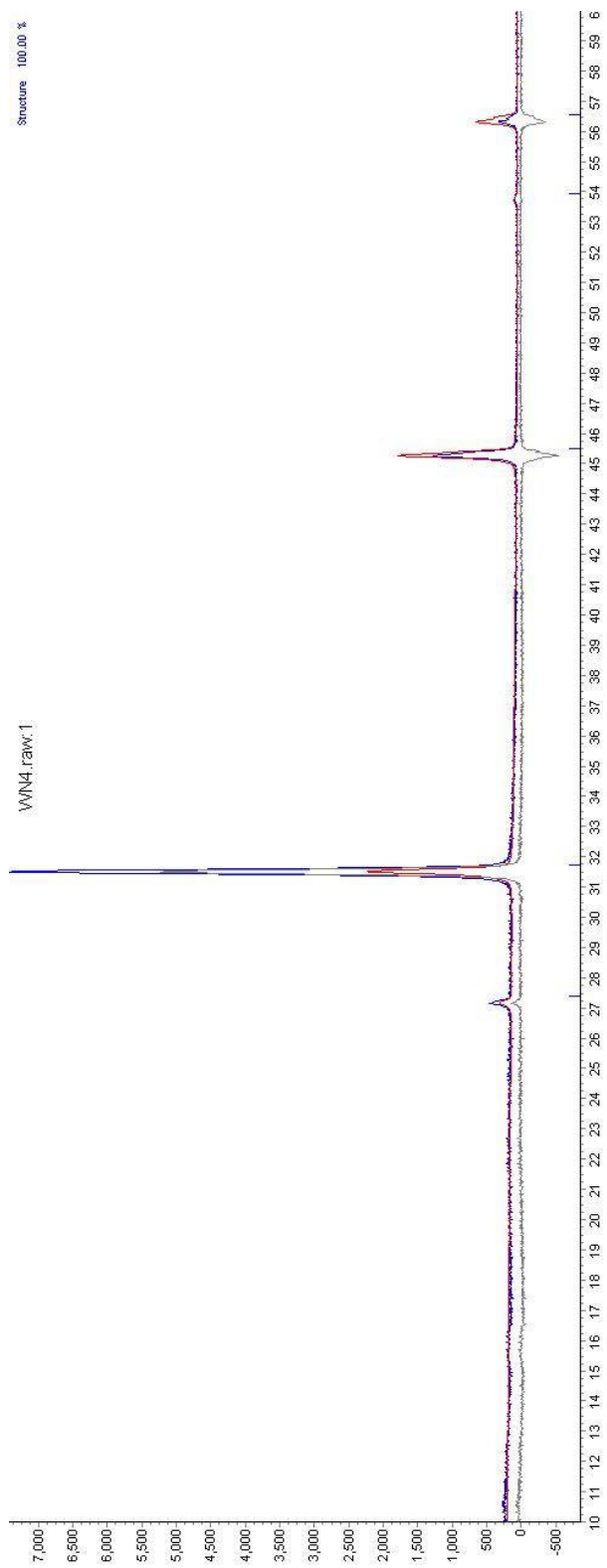


Figure 163: TOPAS result for WN4

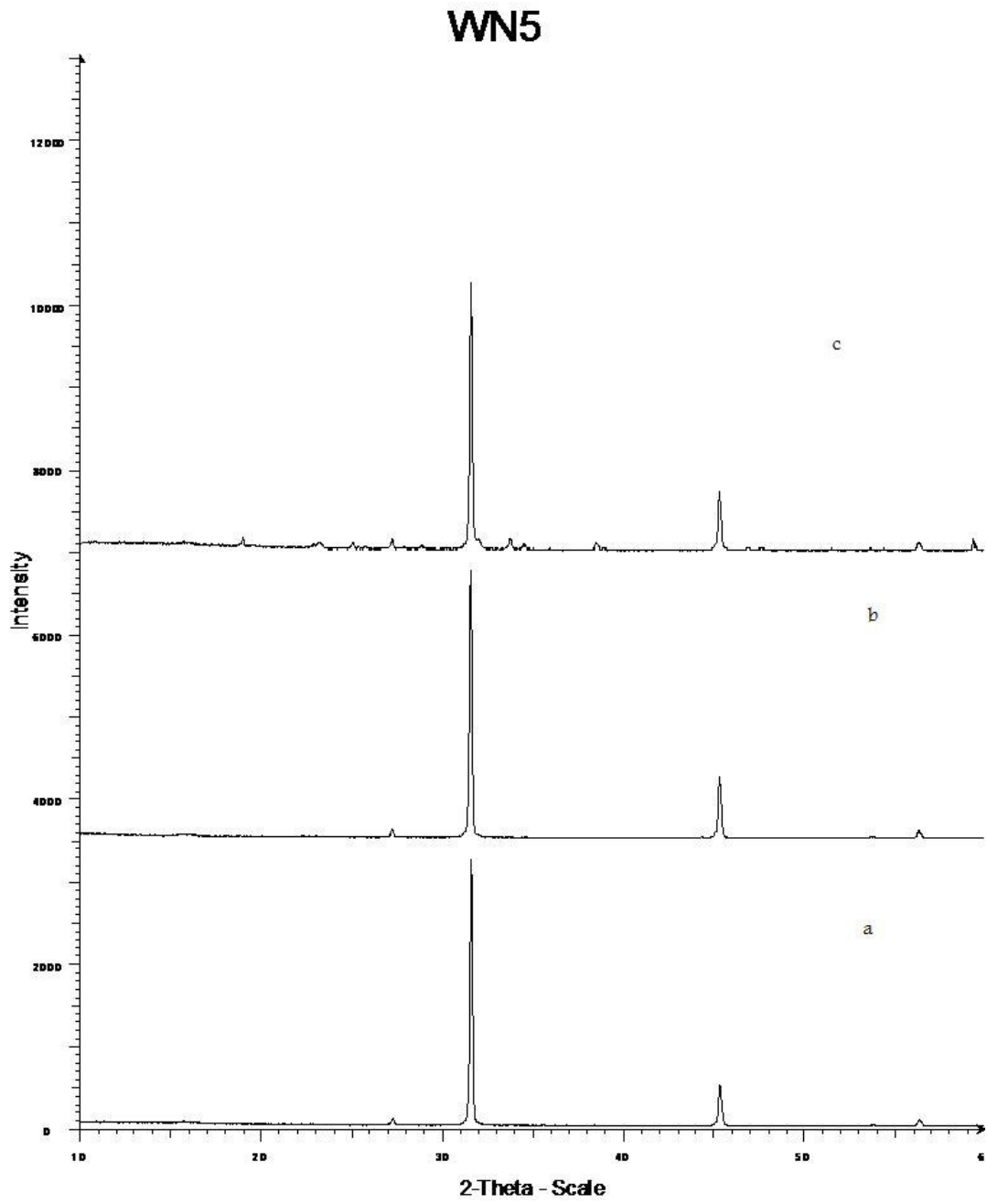


Figure 164: XRD result for WN5

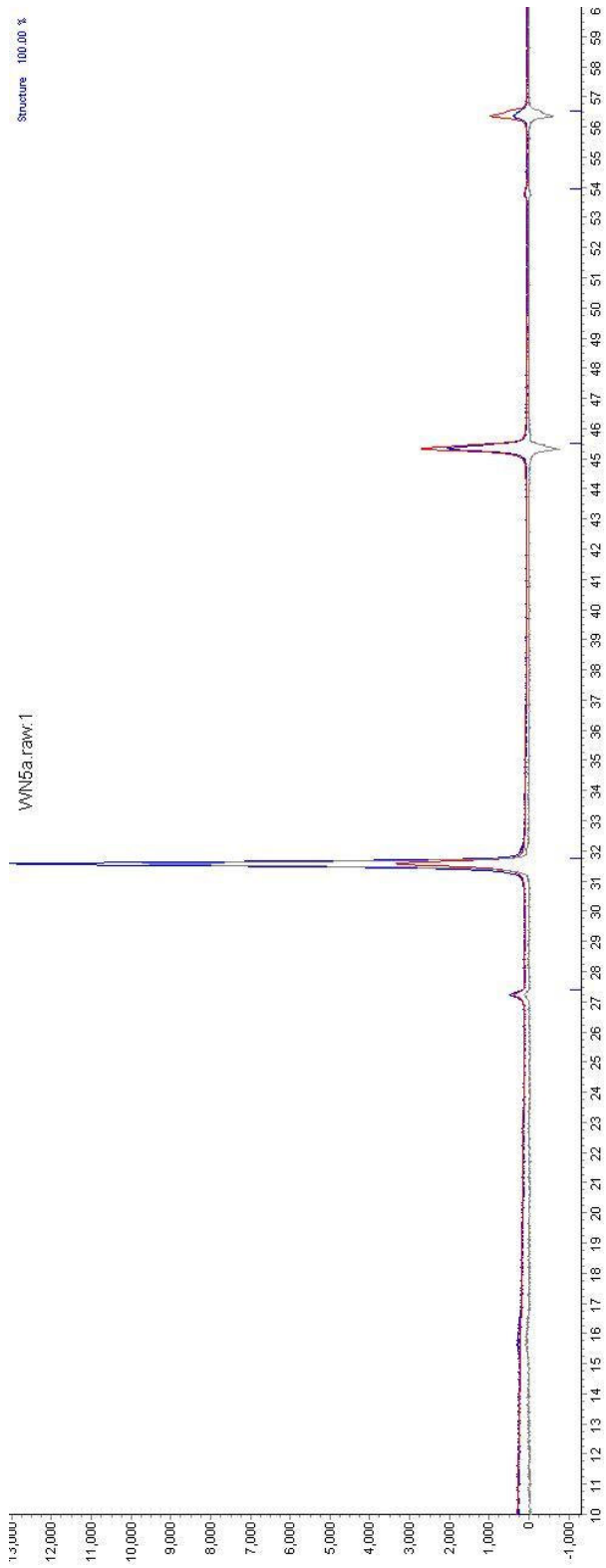


Figure 165: TOPAS result for WN5a

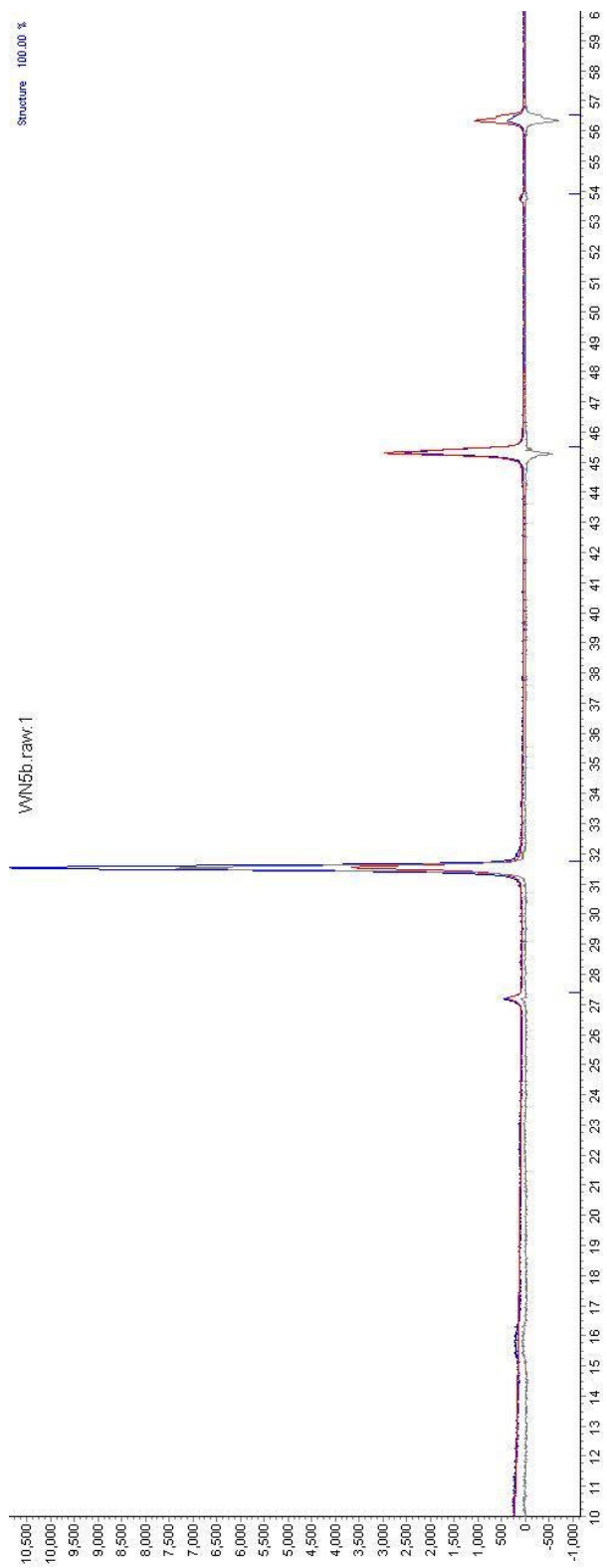


Figure 166: TOPAS result for WN5b

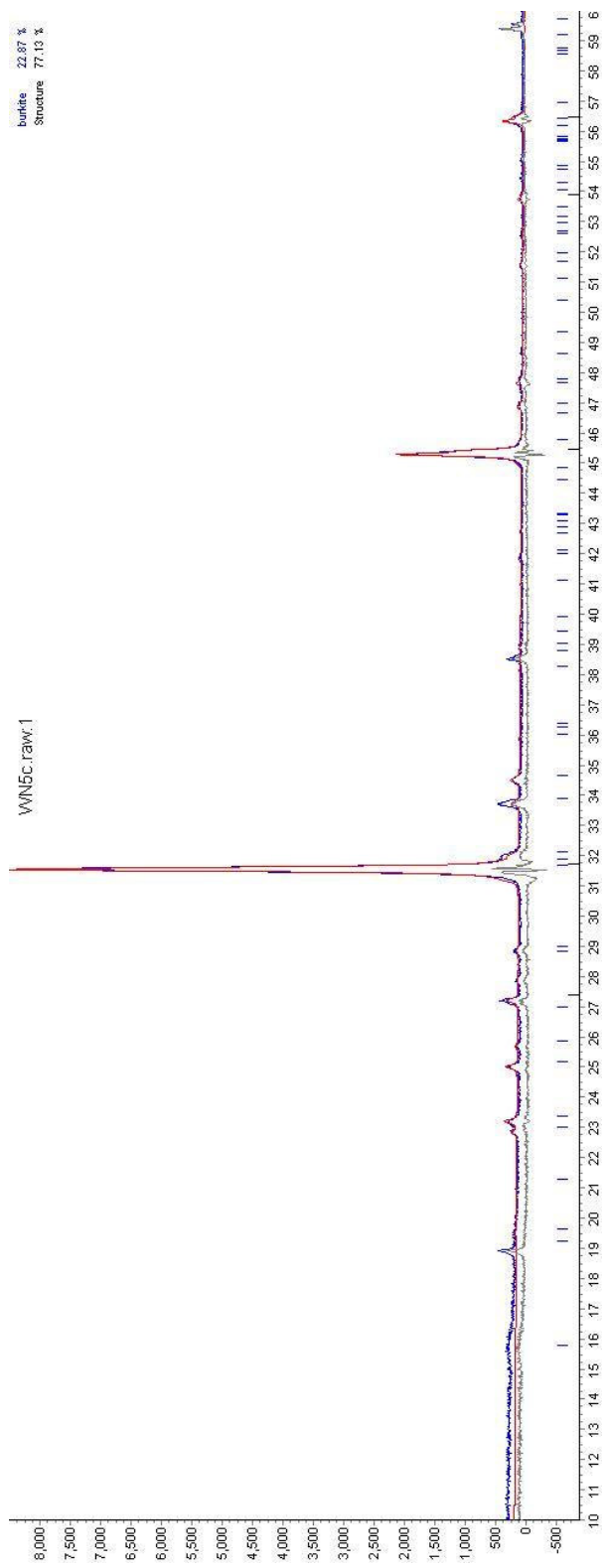


Figure 167: TOPAS result for WN5c

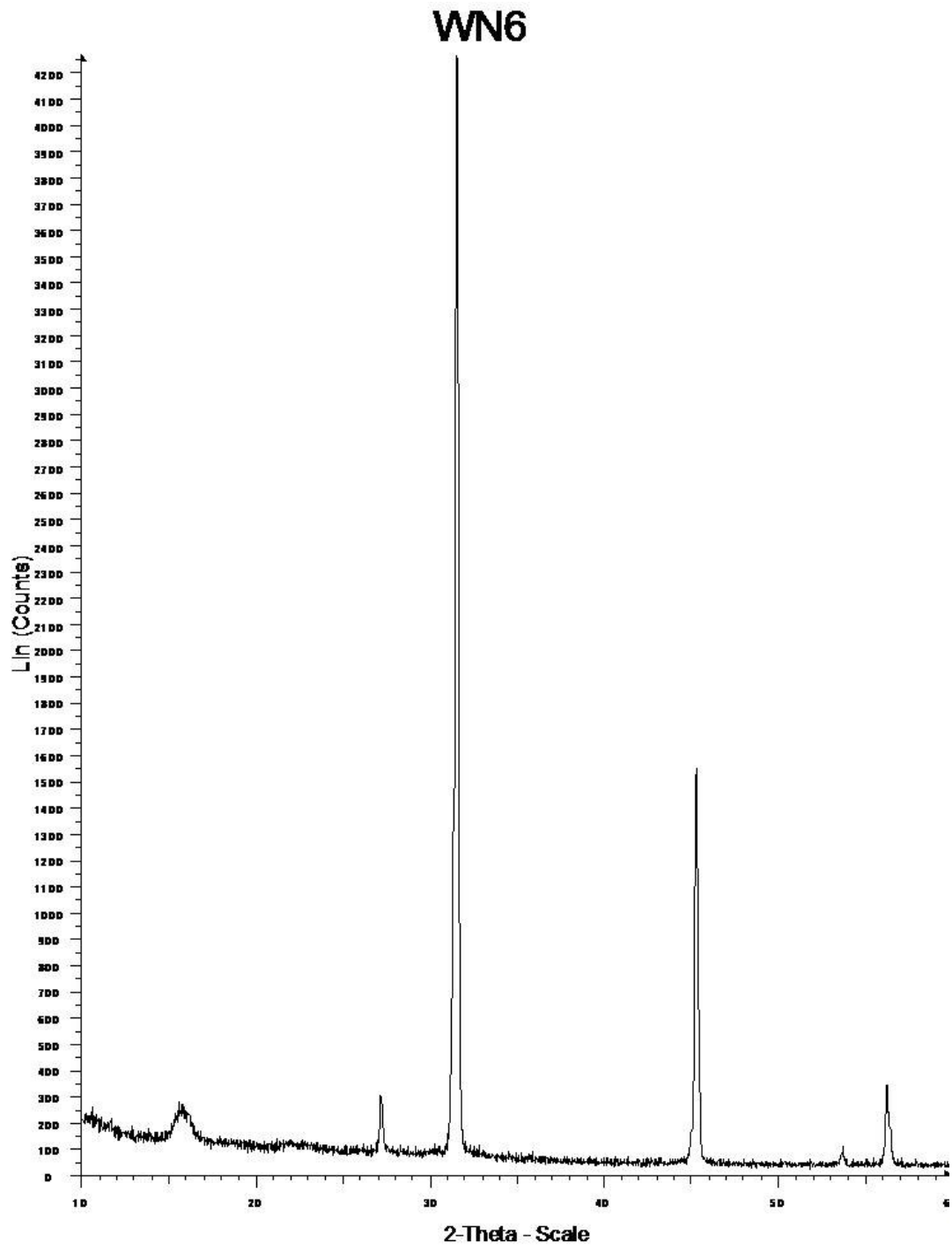


Figure 168: XRD result for WN6

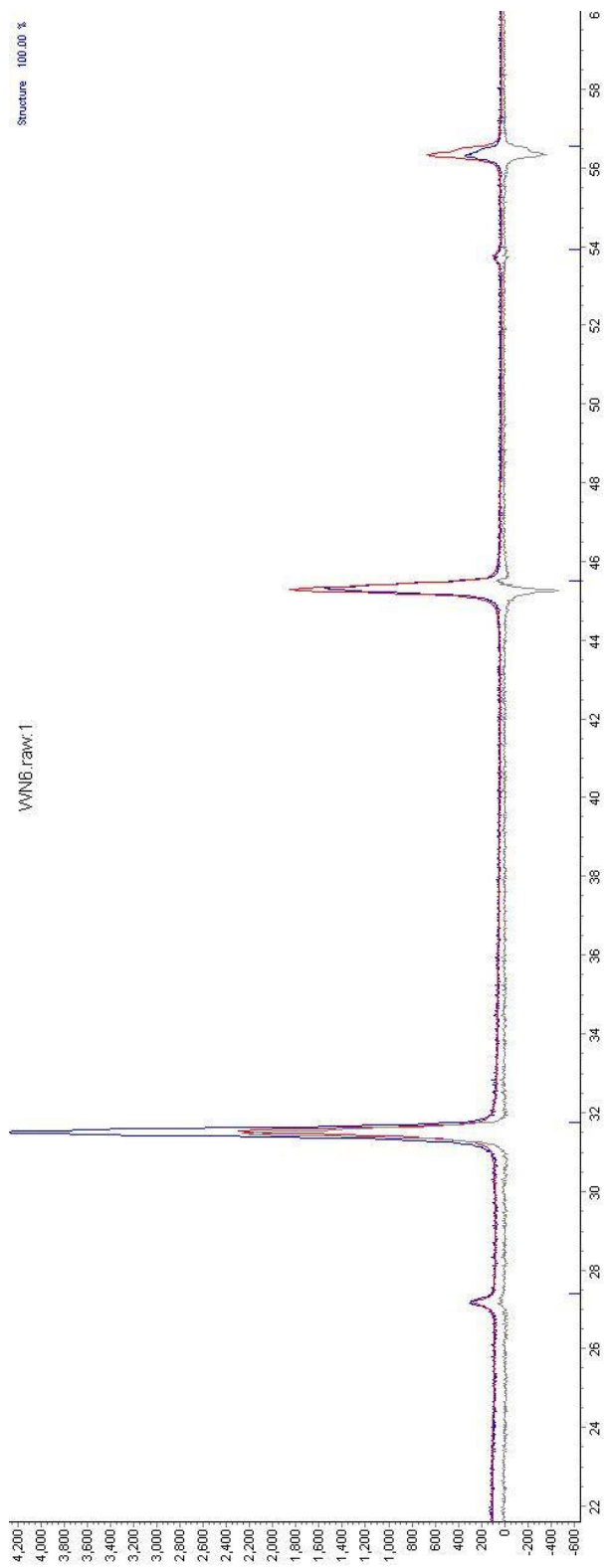


Figure 169: TOPAS result for WN6

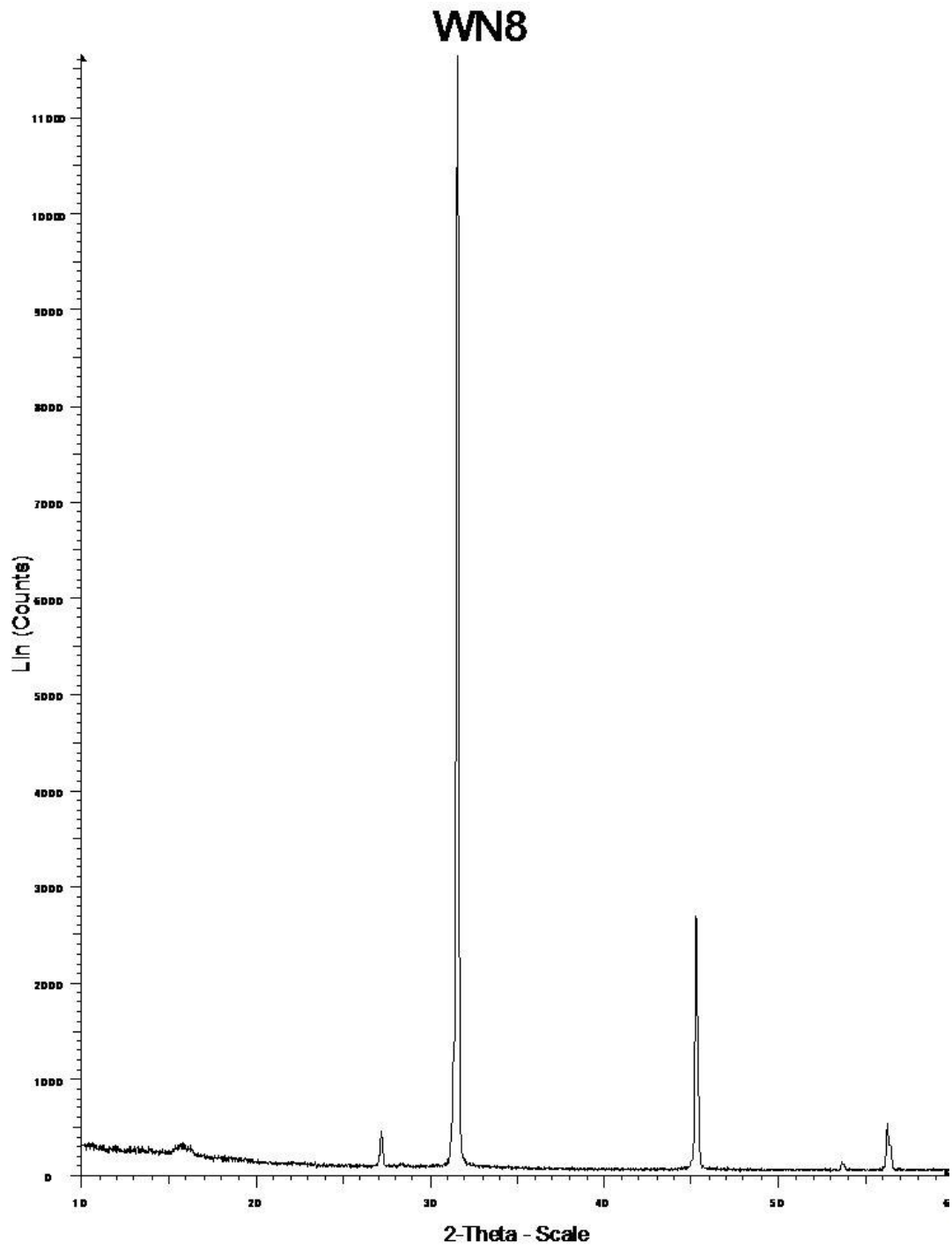


Figure 170: XRD result for WN8

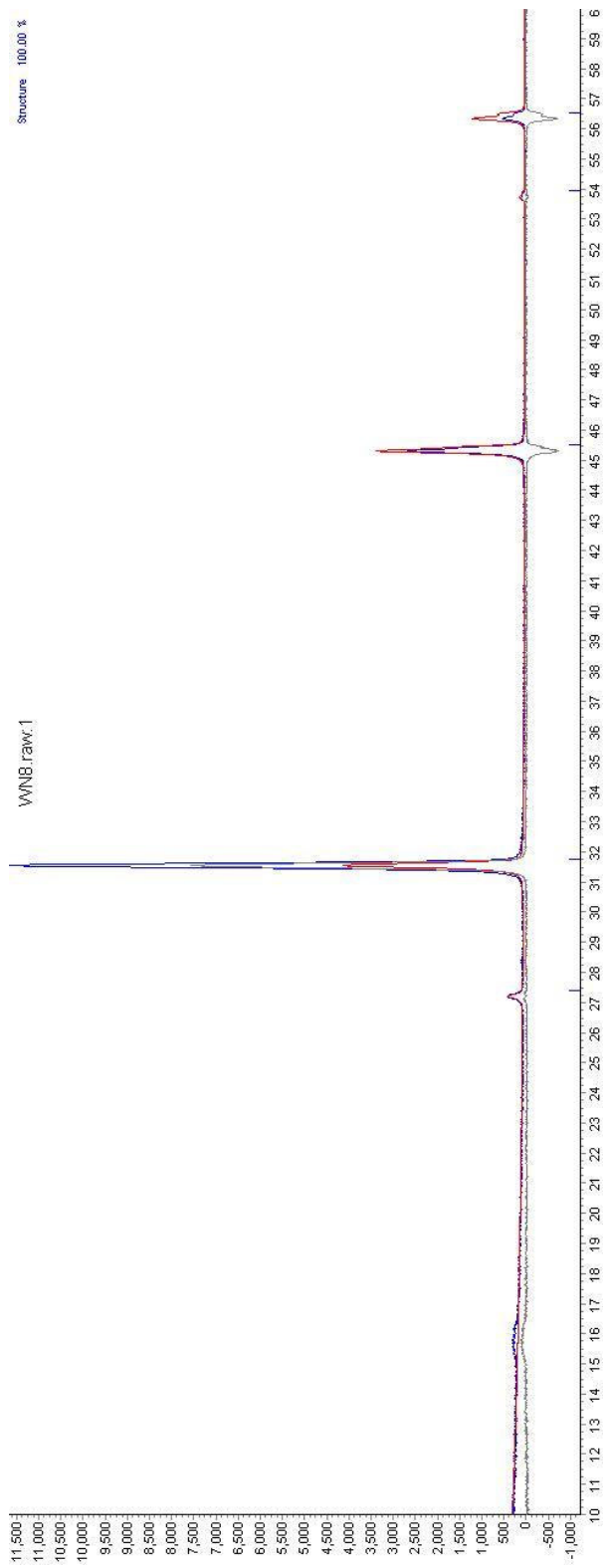


Figure 171: TOPAS result for WN18

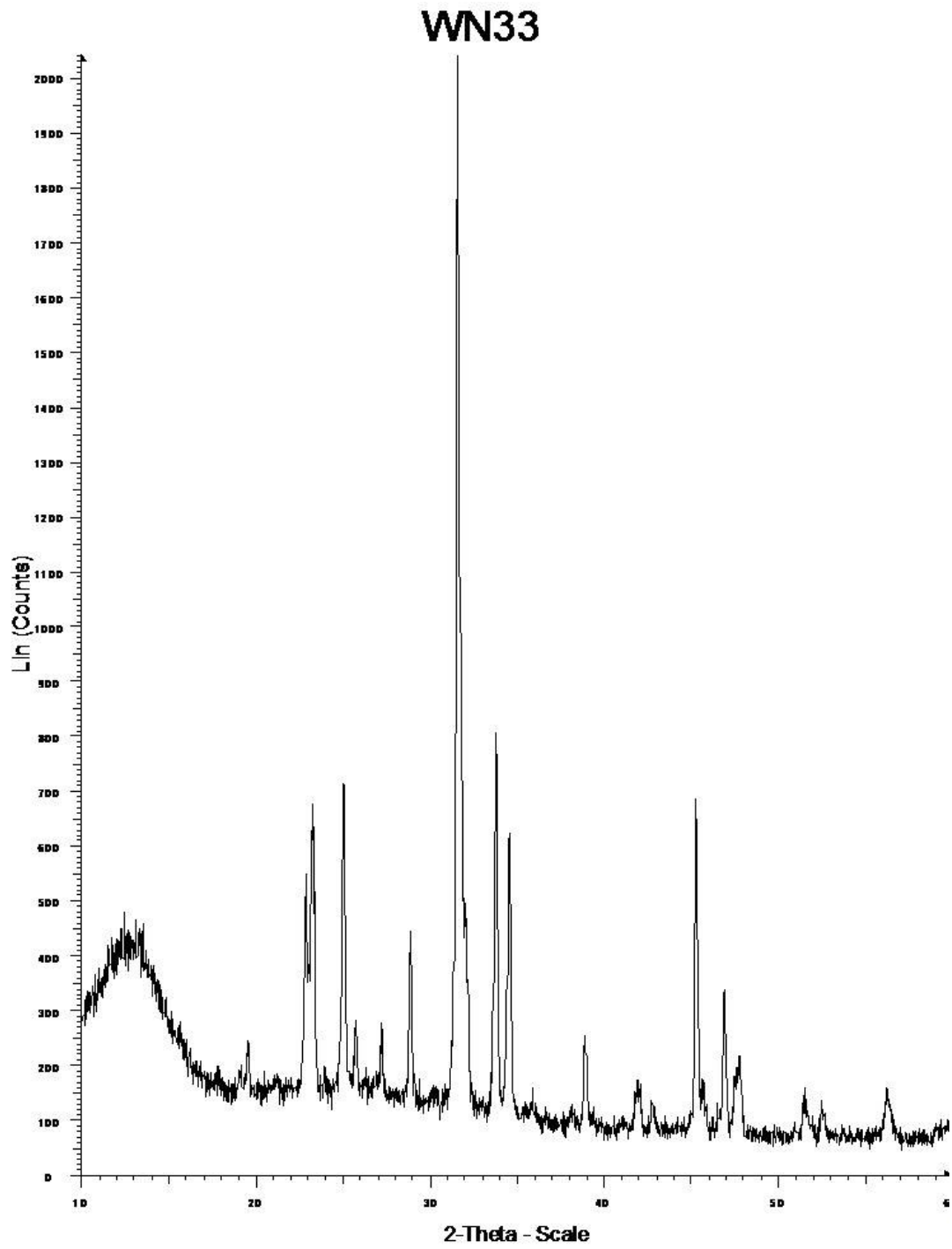


Figure 172: XRD result for WN33

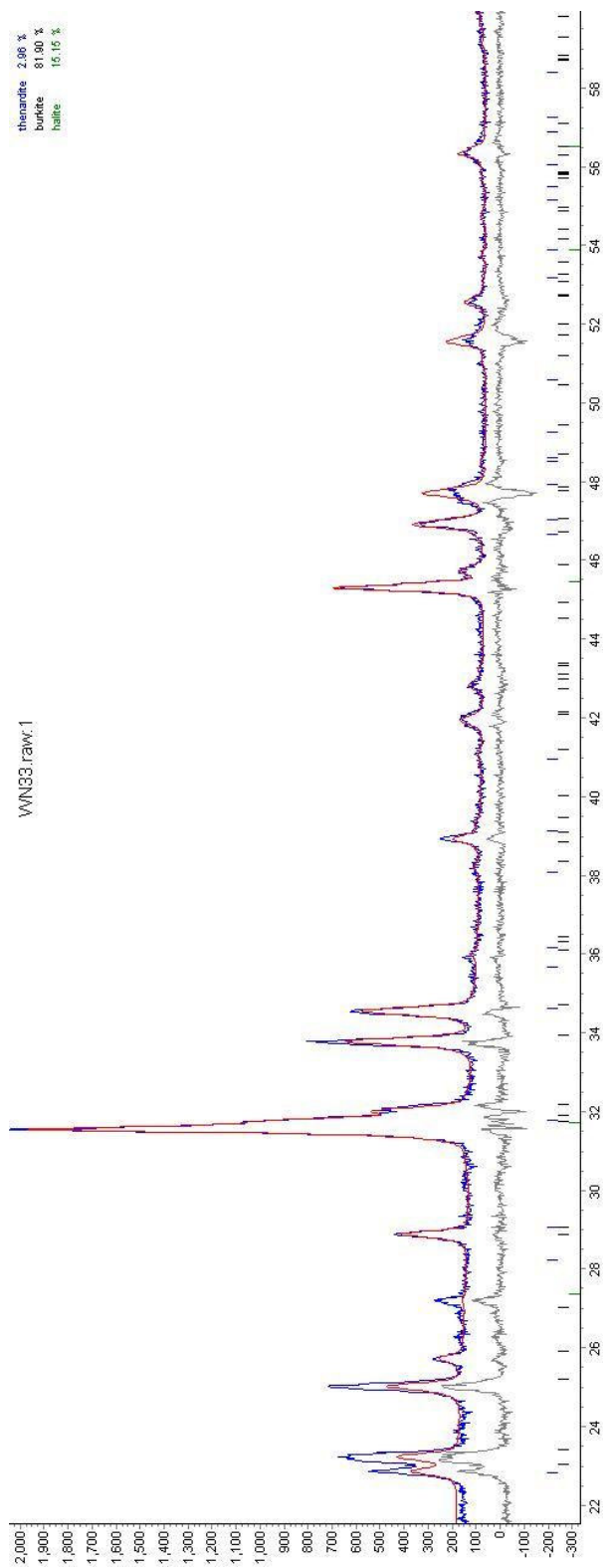


Figure 173: TOPAS result for WN33

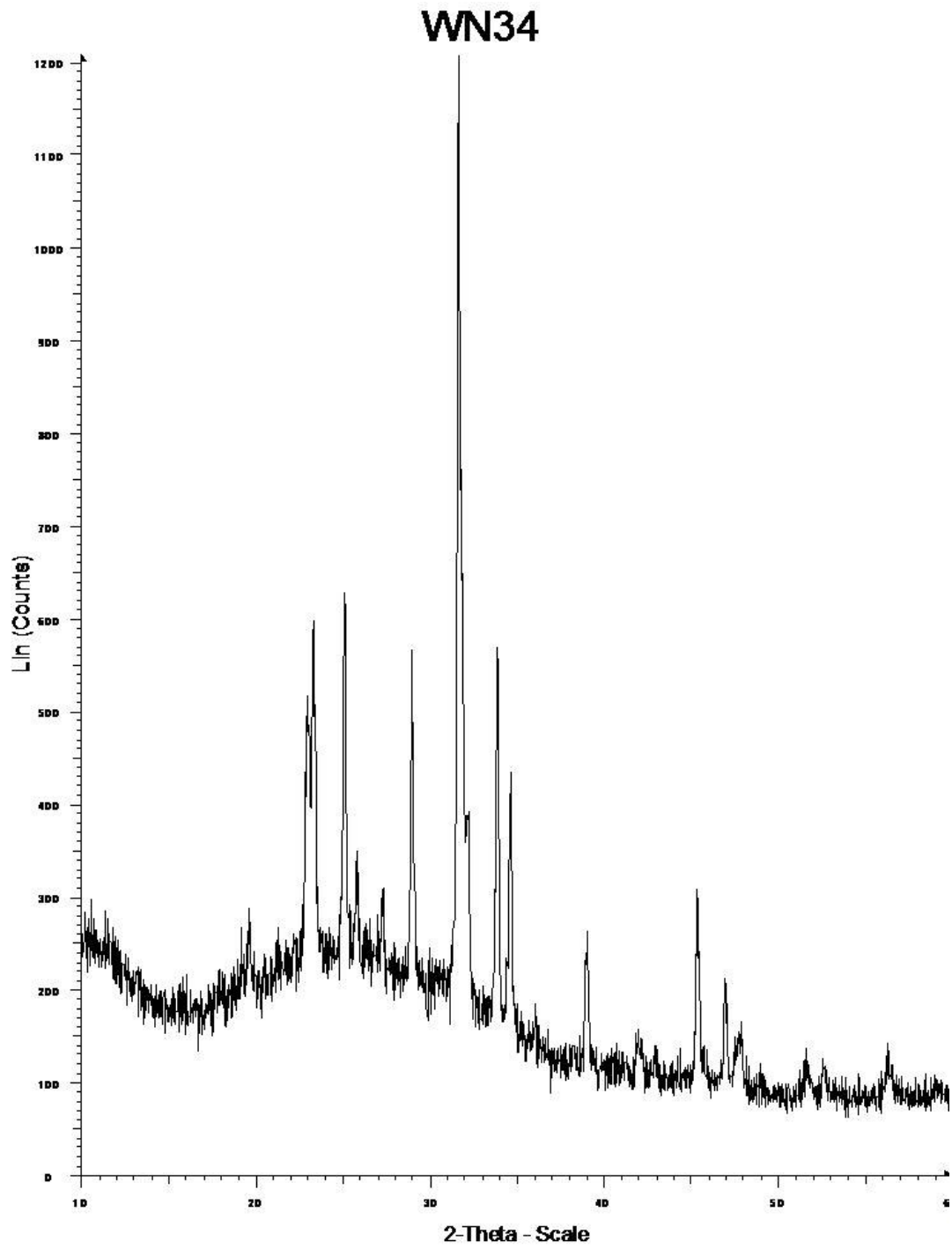


Figure 174: XRD result for WN34

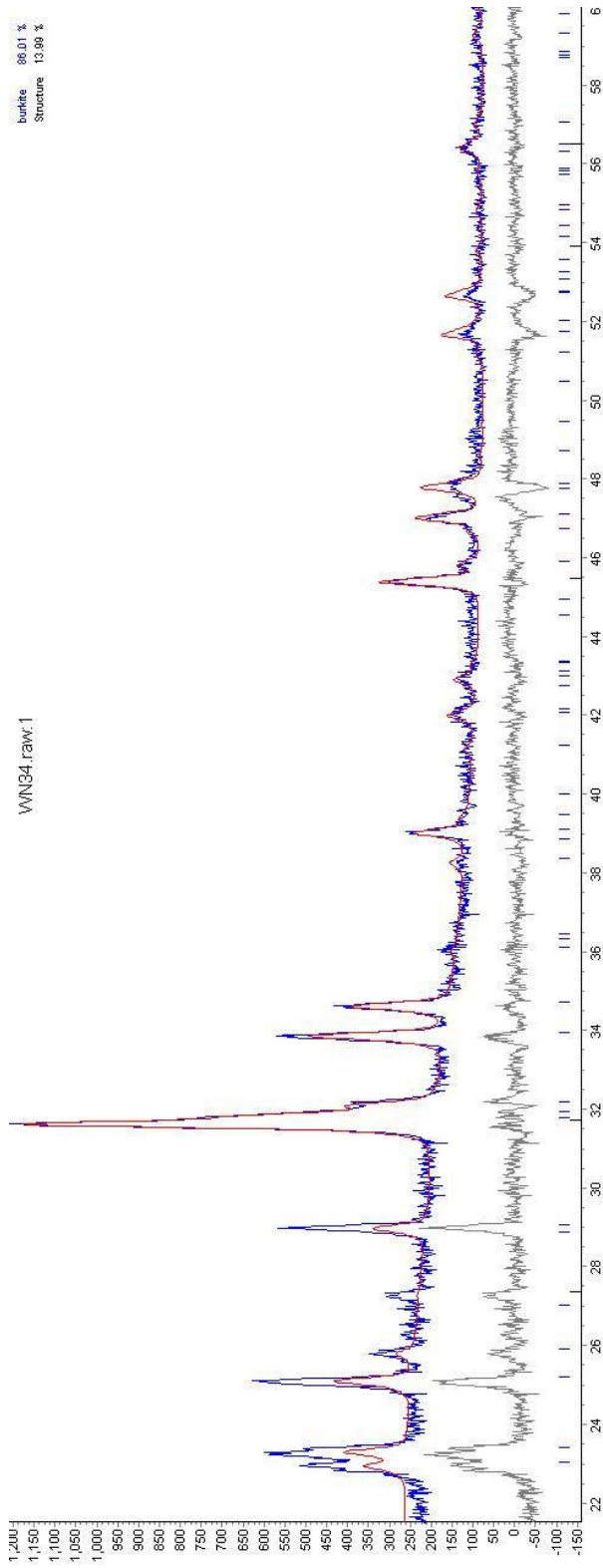


Figure 175: TOPAS result for WN34

WN35

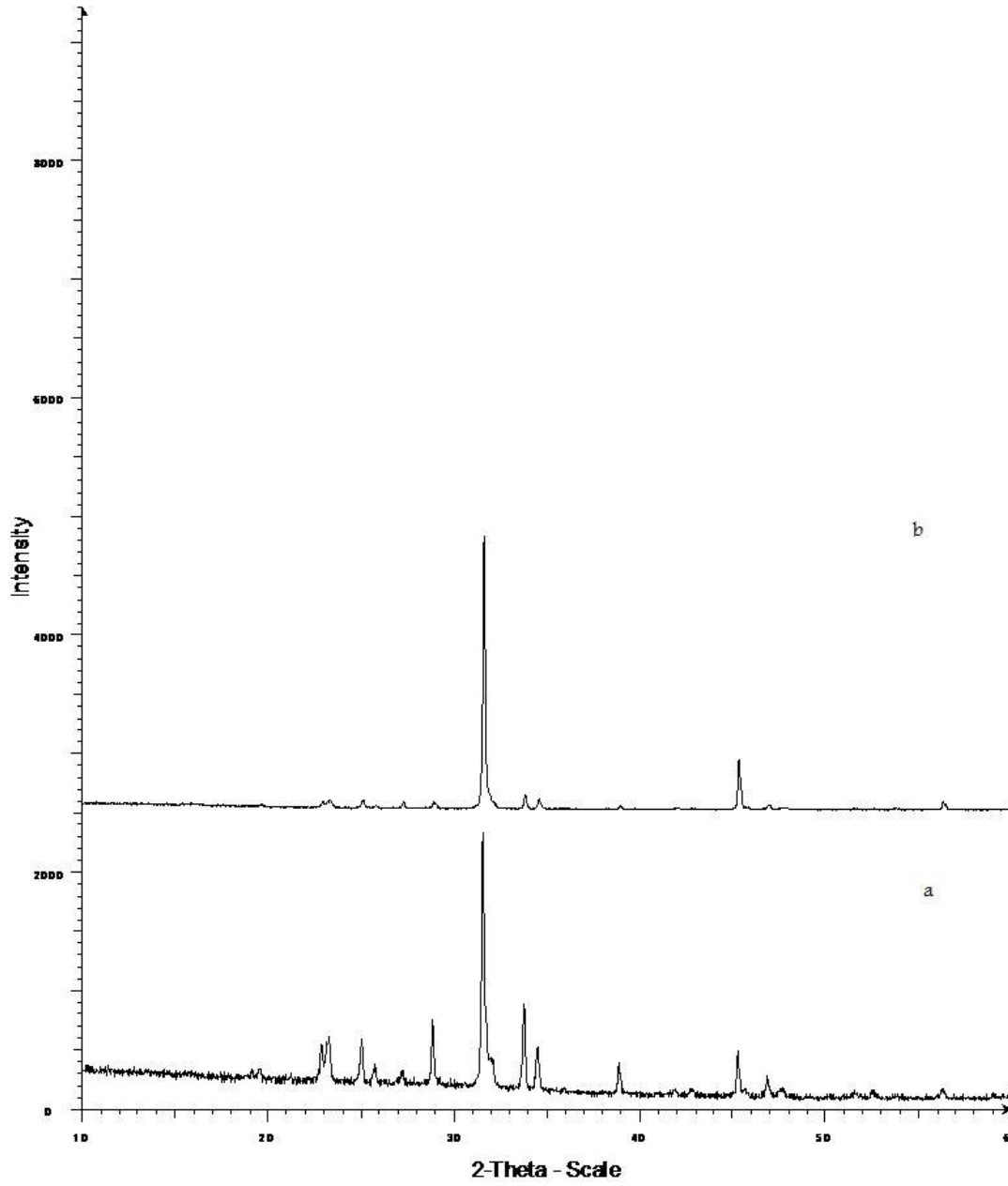


Figure 176: XRD result for WN35

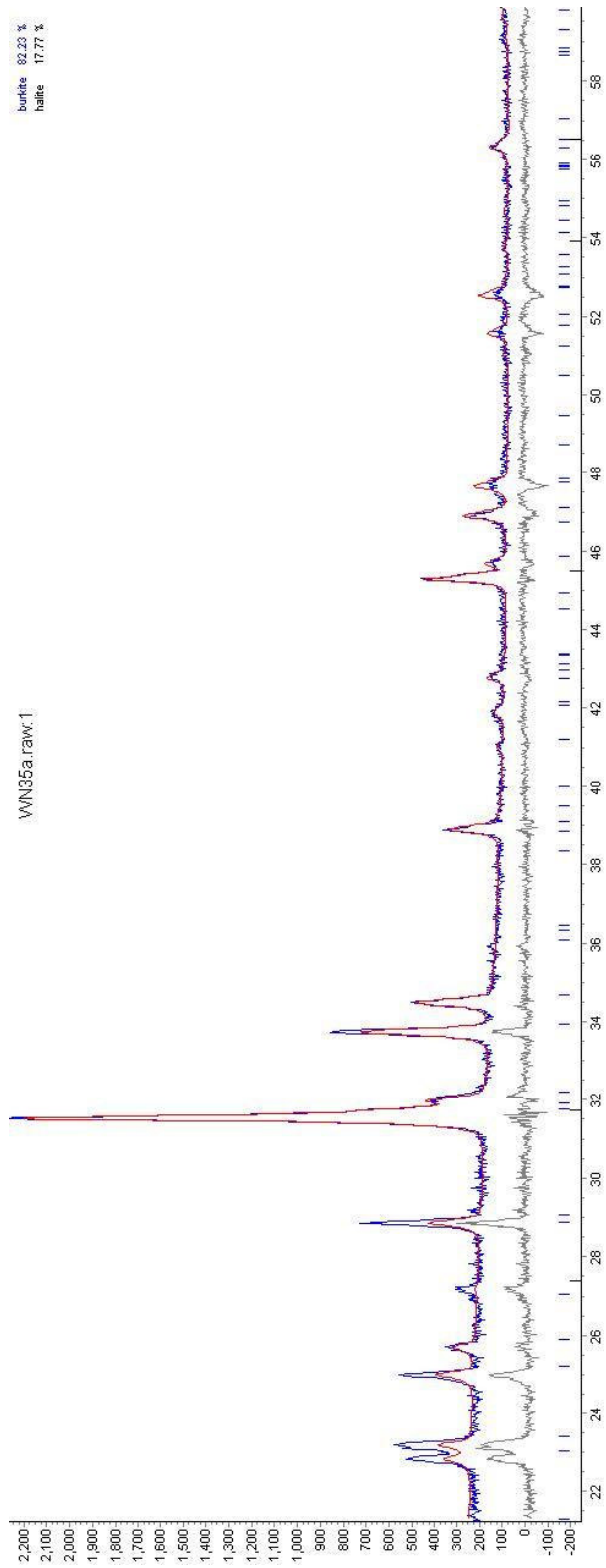


Figure 177: TOPAS result for WN35a

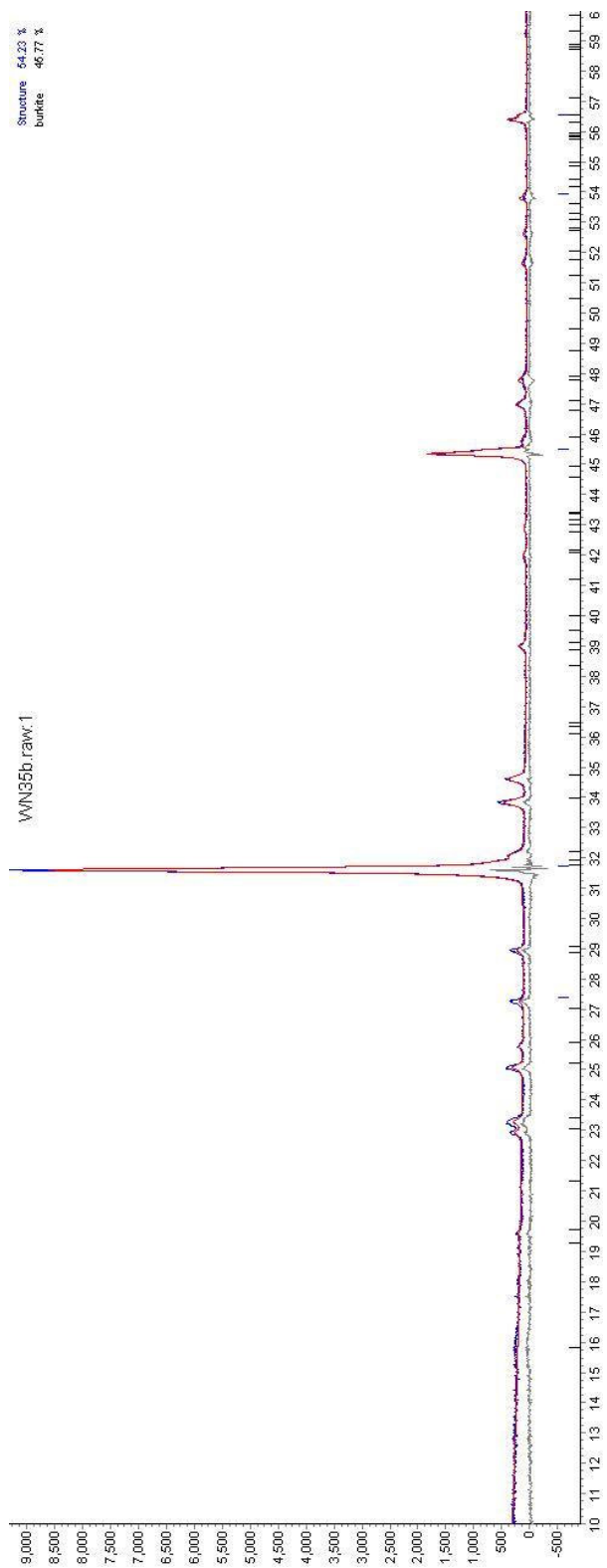


Figure 178: TOPAS result for WN35b

Lake Fazda

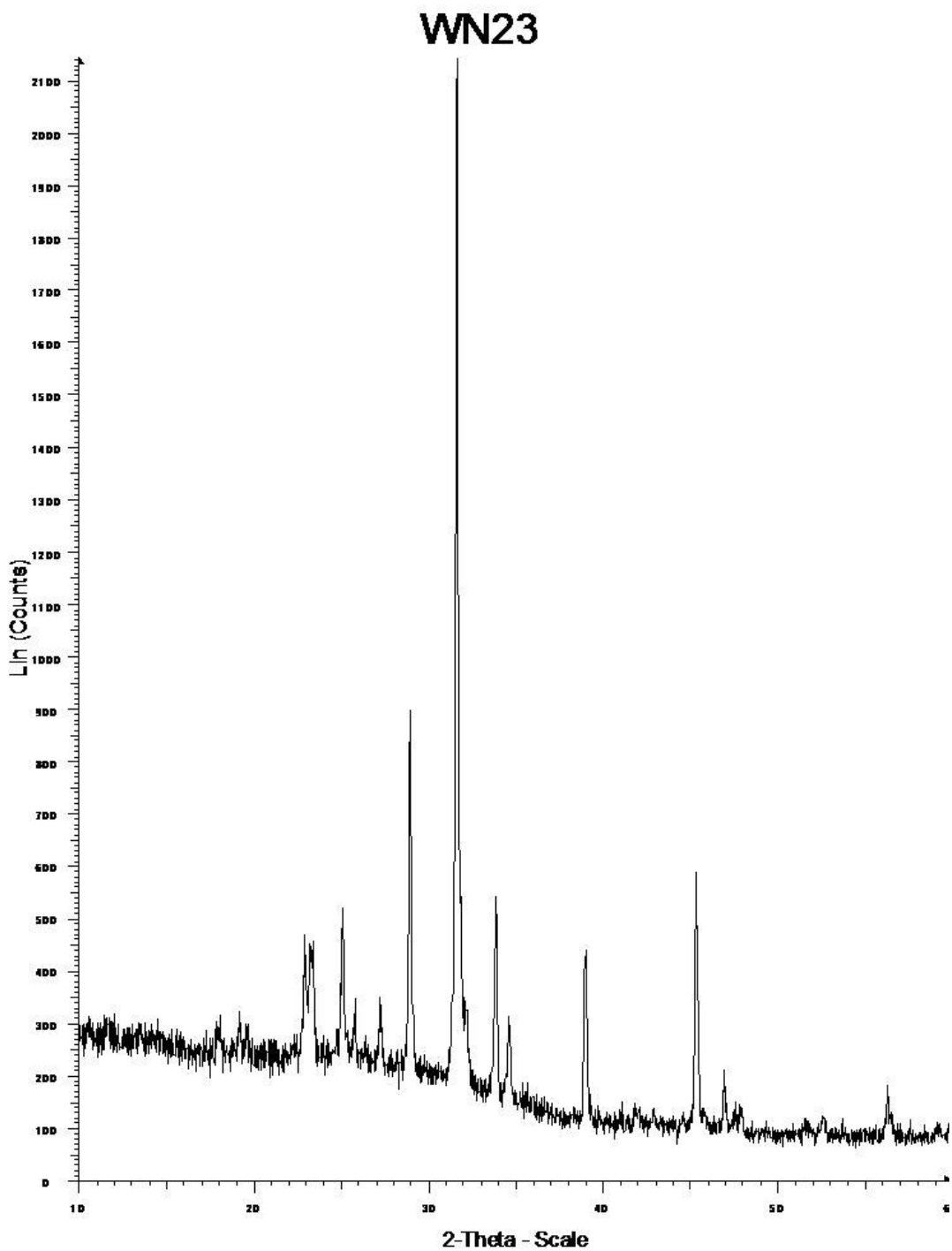


Figure 179: XRD result for WN23

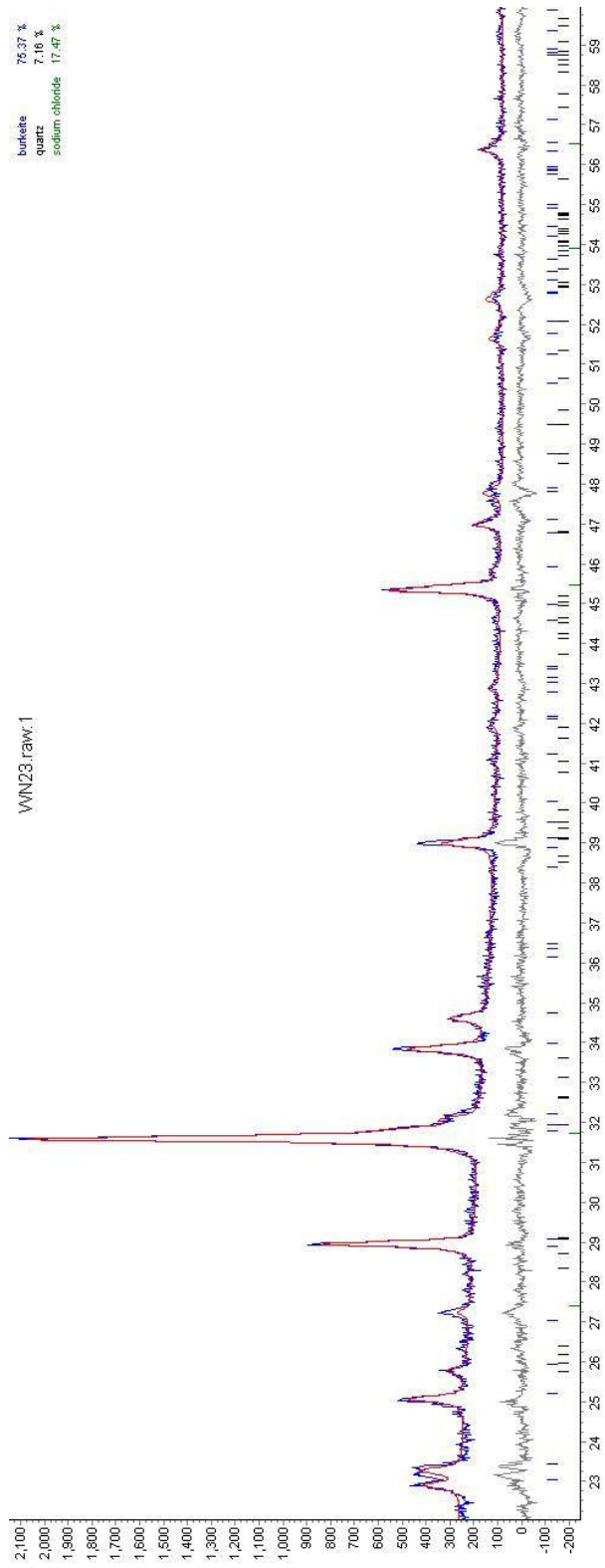


Figure 180: TOPAS result for WN23

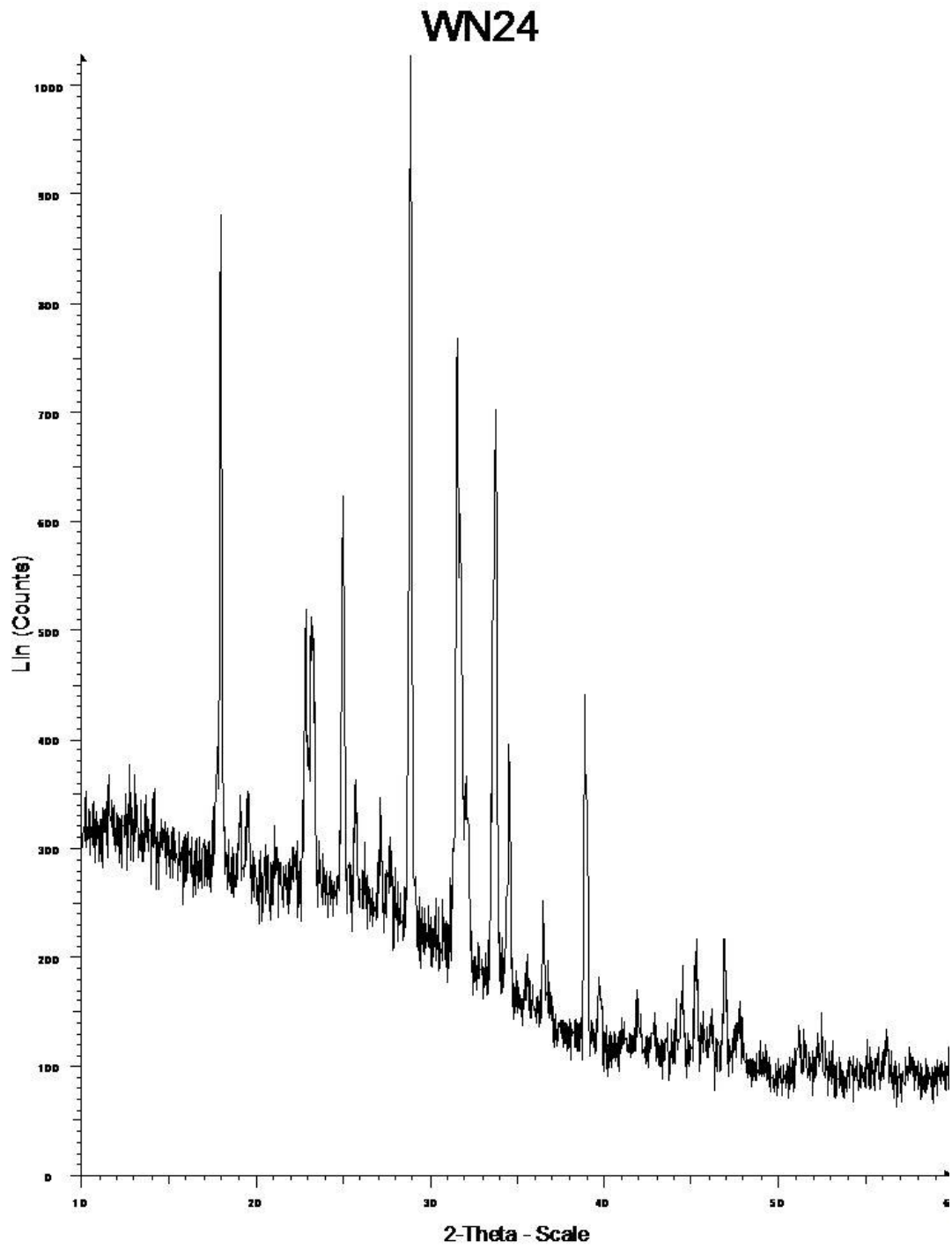


Figure 181: XRD result for WN24

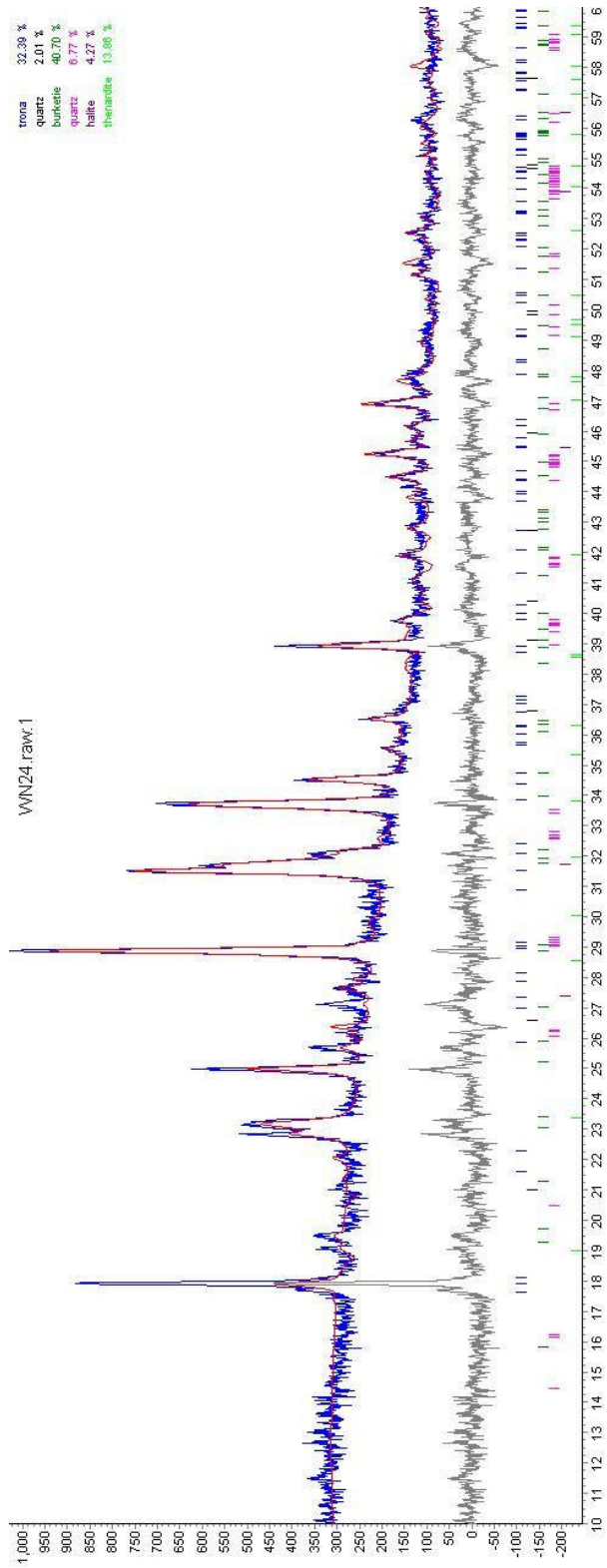


Figure 182: TOPAS result for WN24

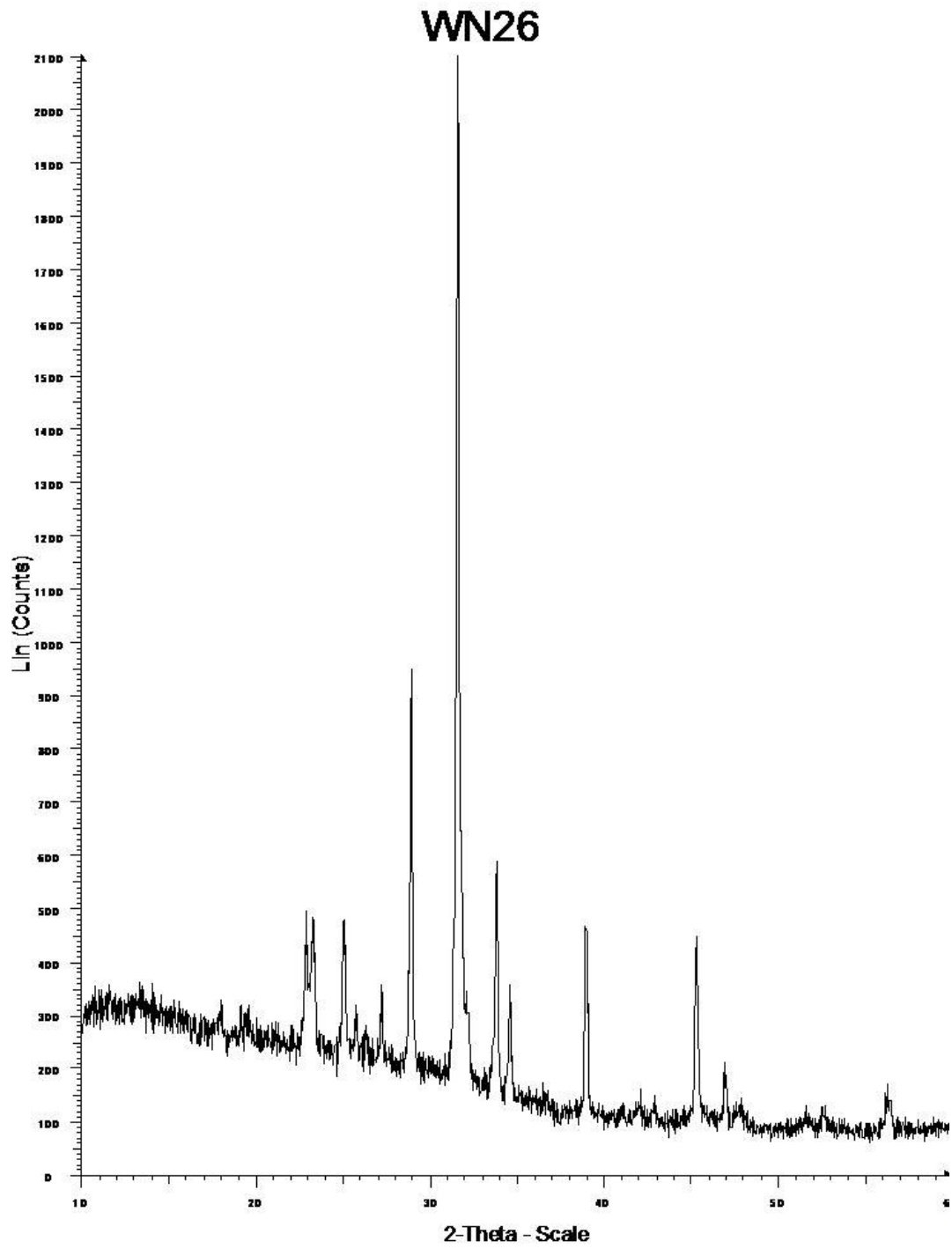


Figure 183: XRD result for WN26

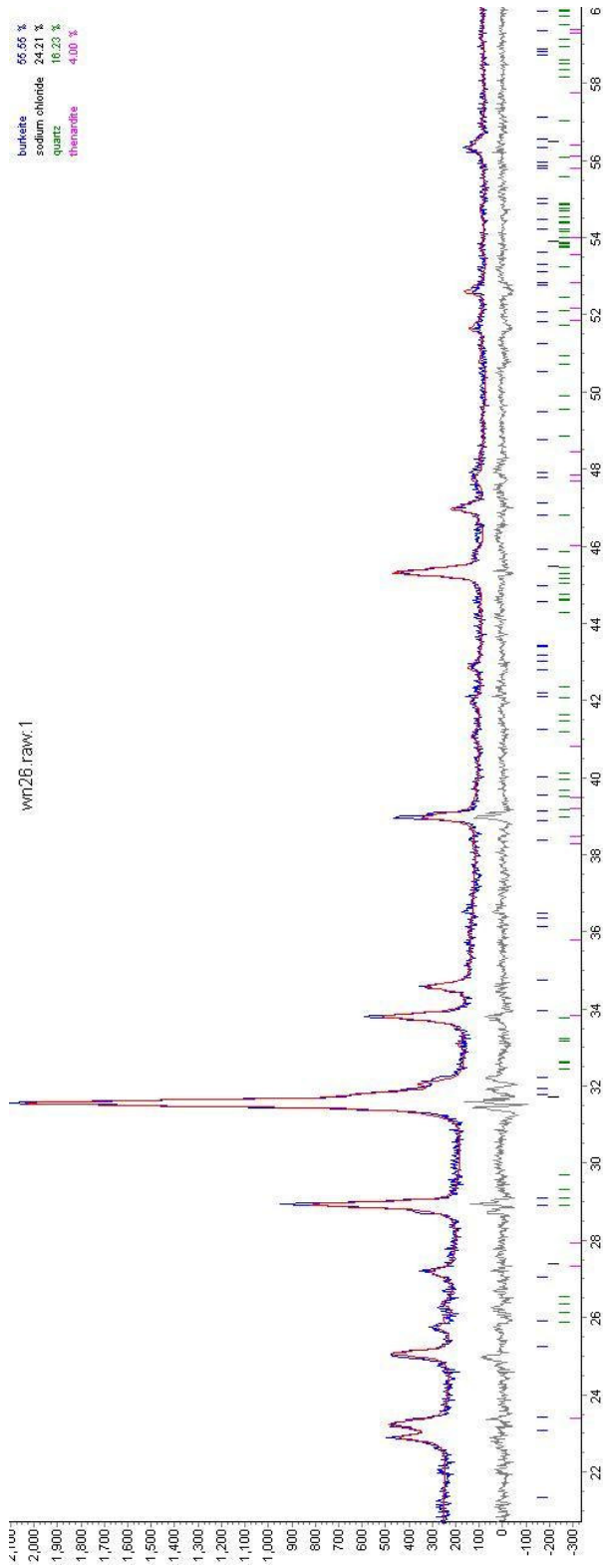


Figure 184: TOPAS result for WN26

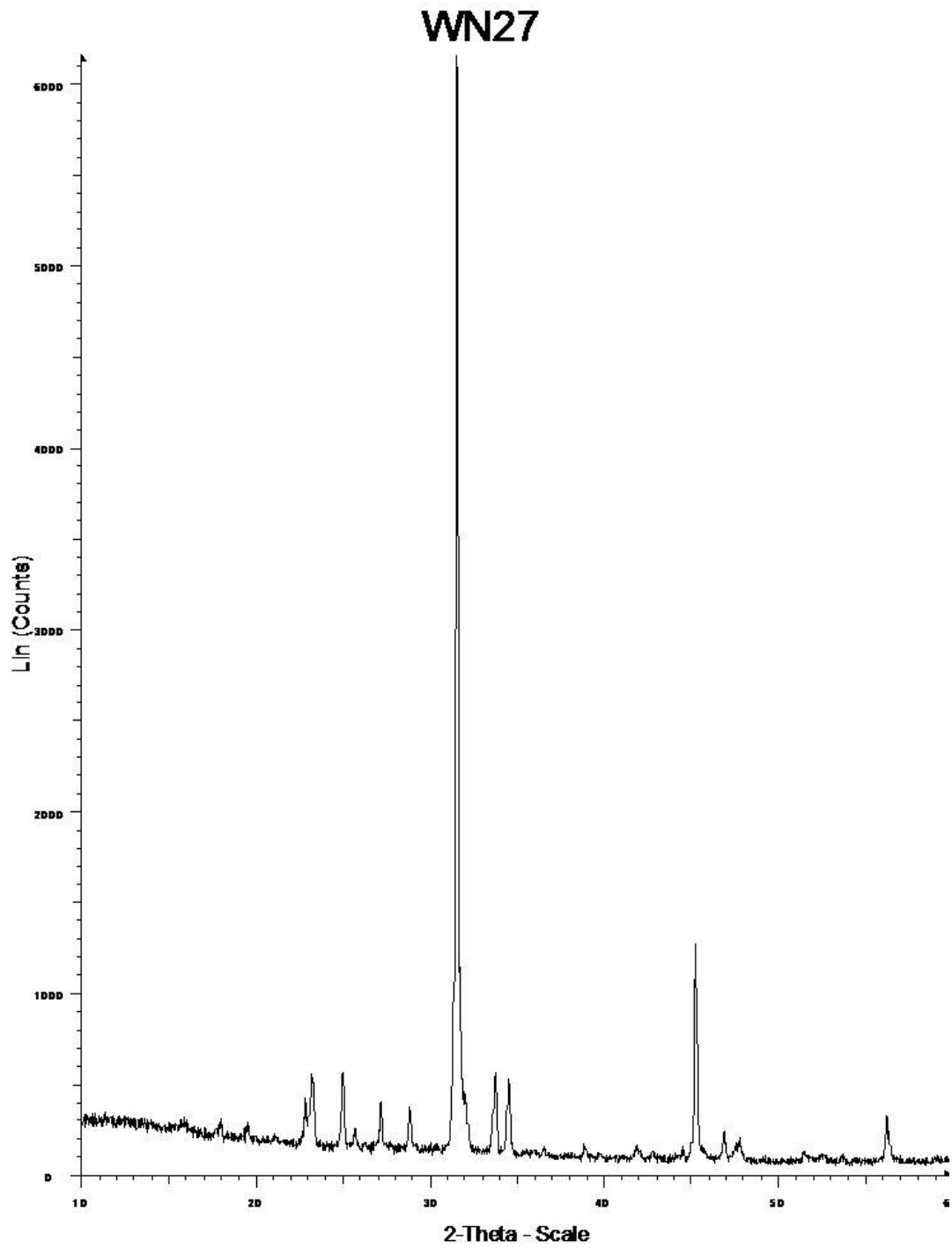


Figure 185: XRD result for WN27

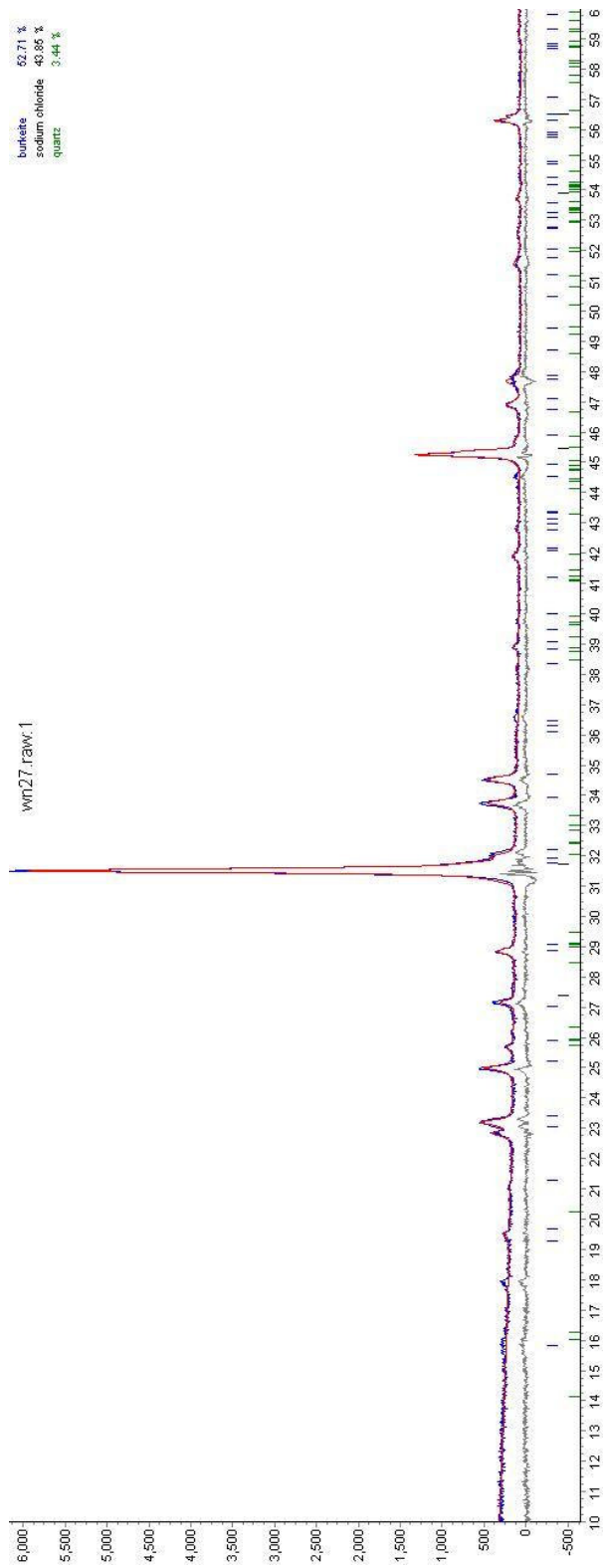


Figure 186: TOPAS results for WN27

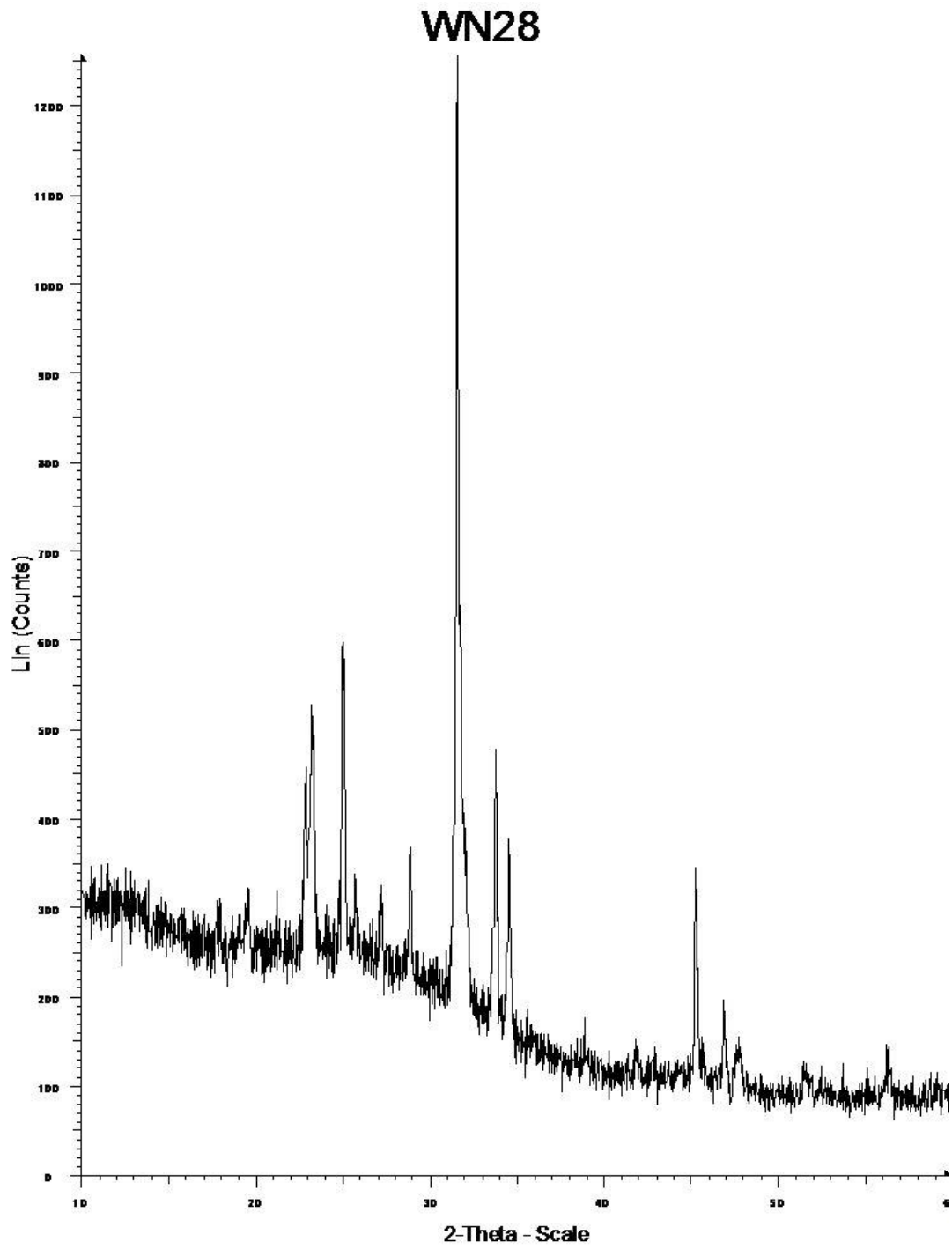


Figure 187: XRD result for WN28

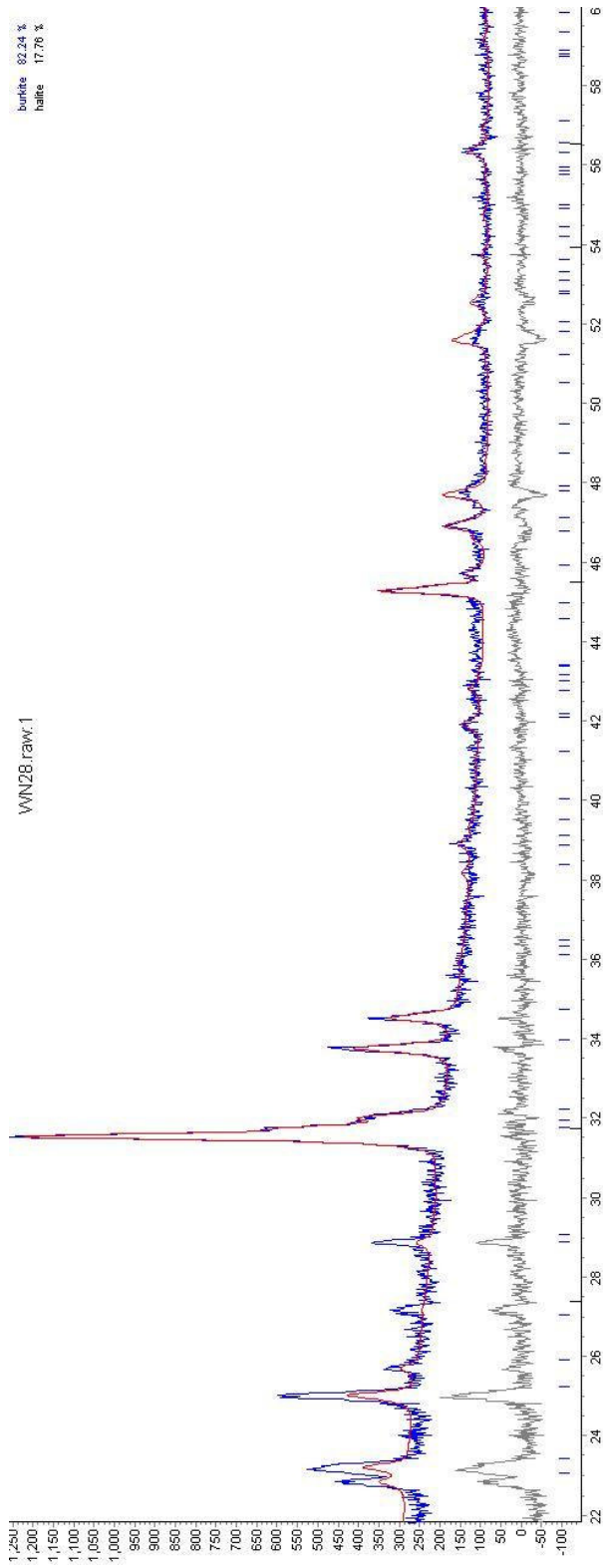


Figure 188: TOPAS result for WN28

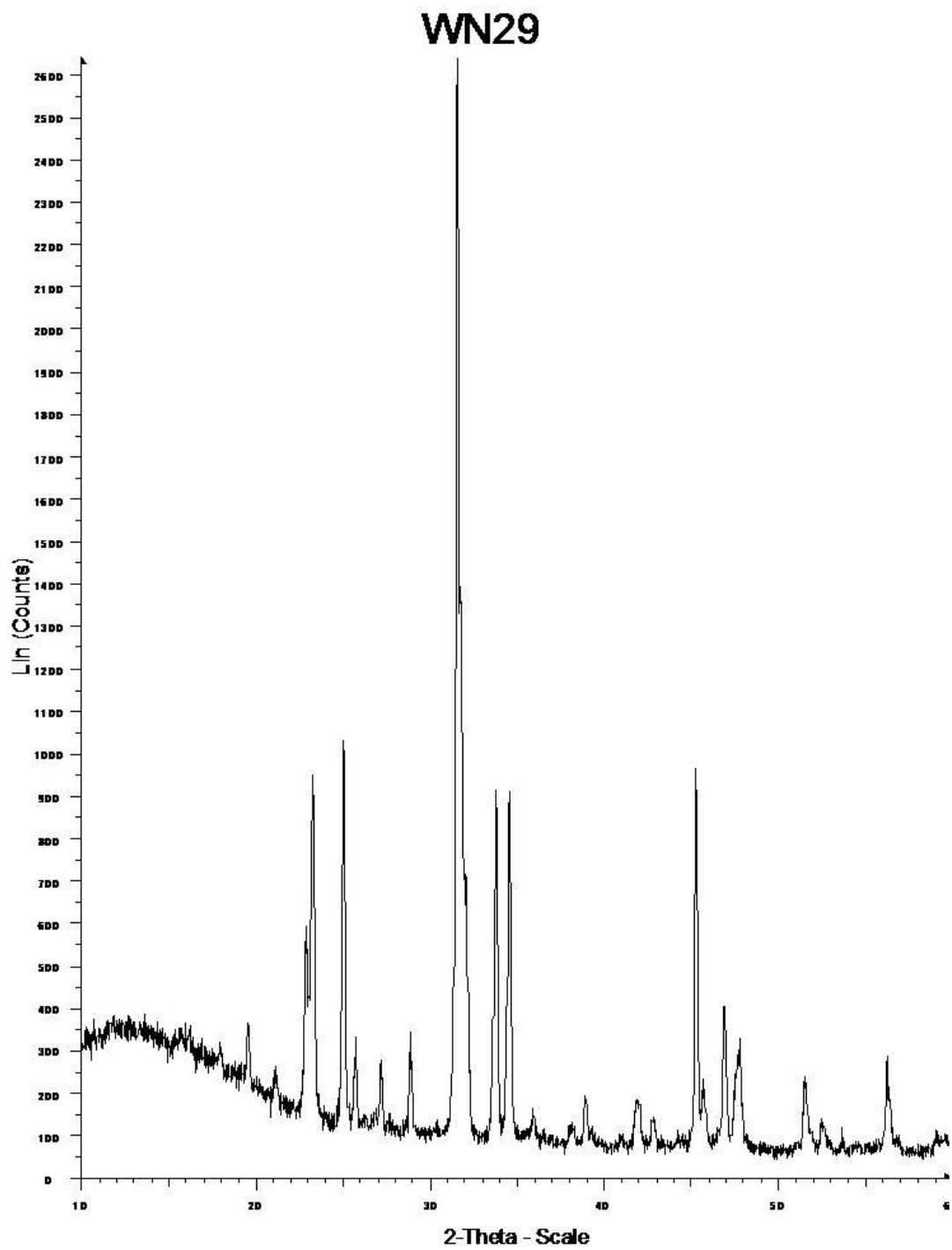


Figure 189: XRD result for WN29

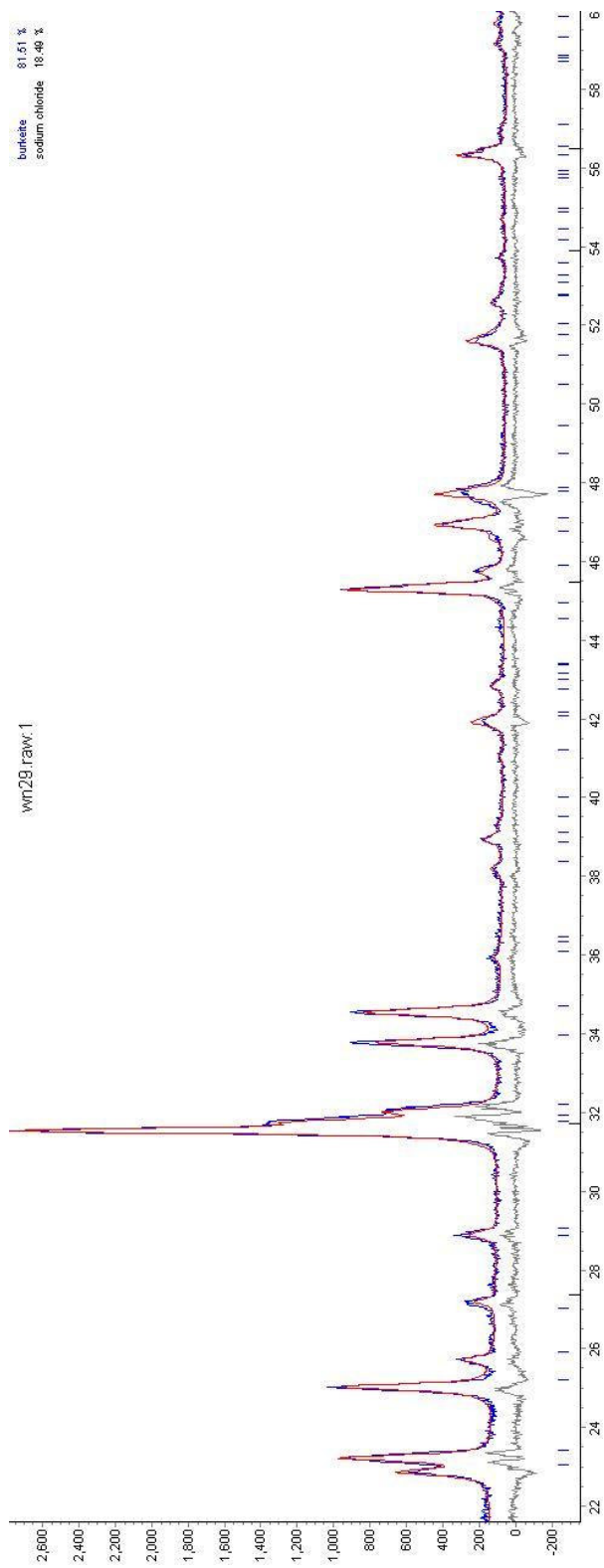


Figure 190: TOPAS result for WN29

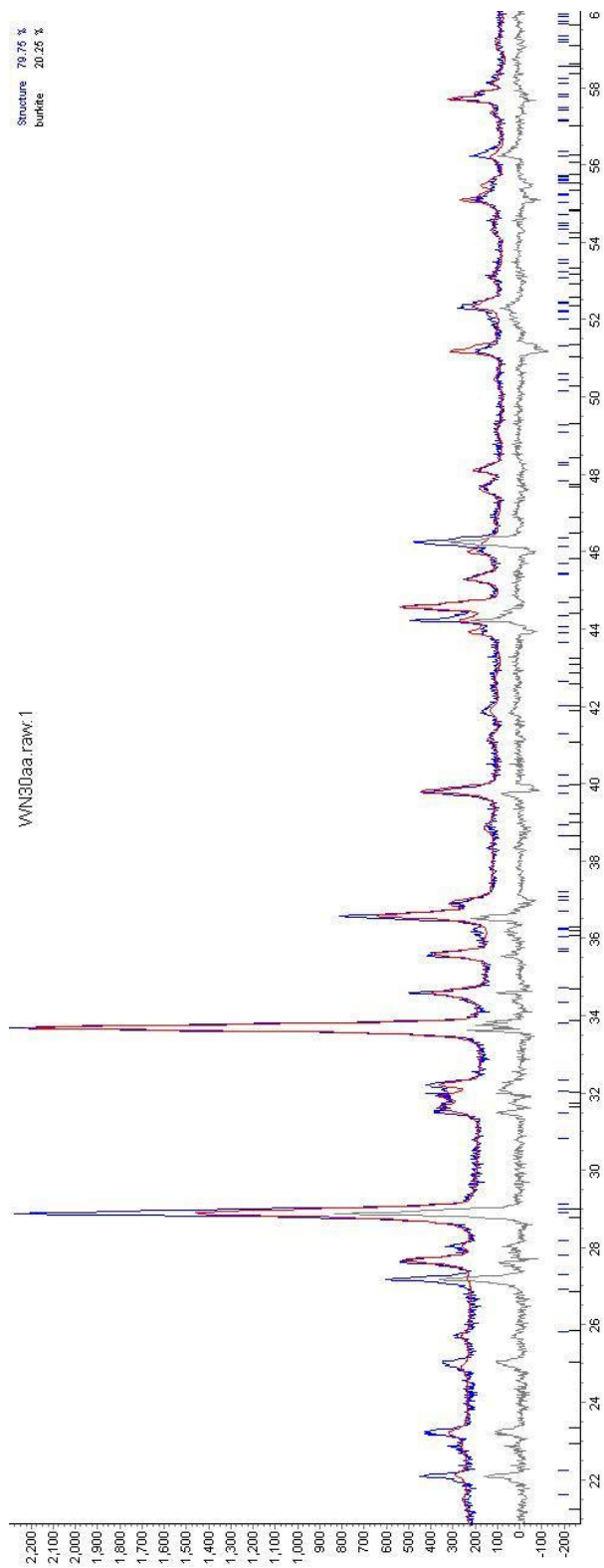


Figure 191: TOPAS result for WN30a

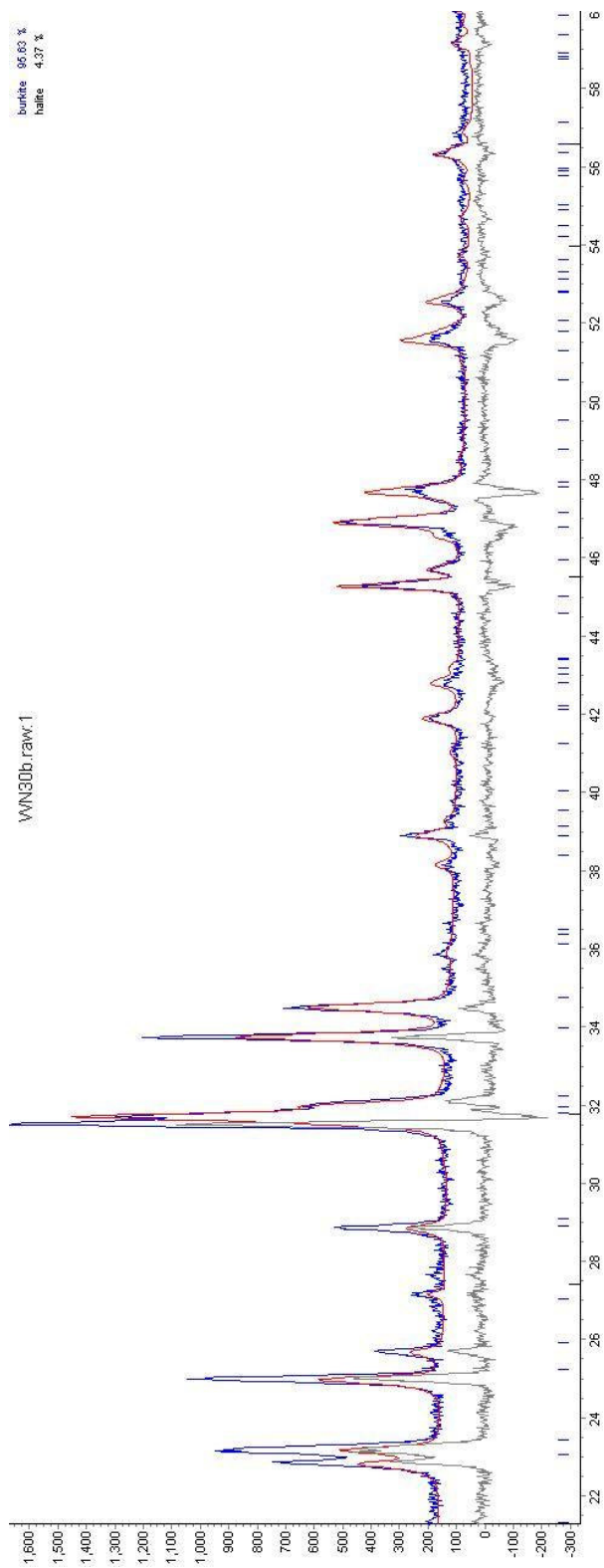


Figure 192: TOPAS result for WN30b

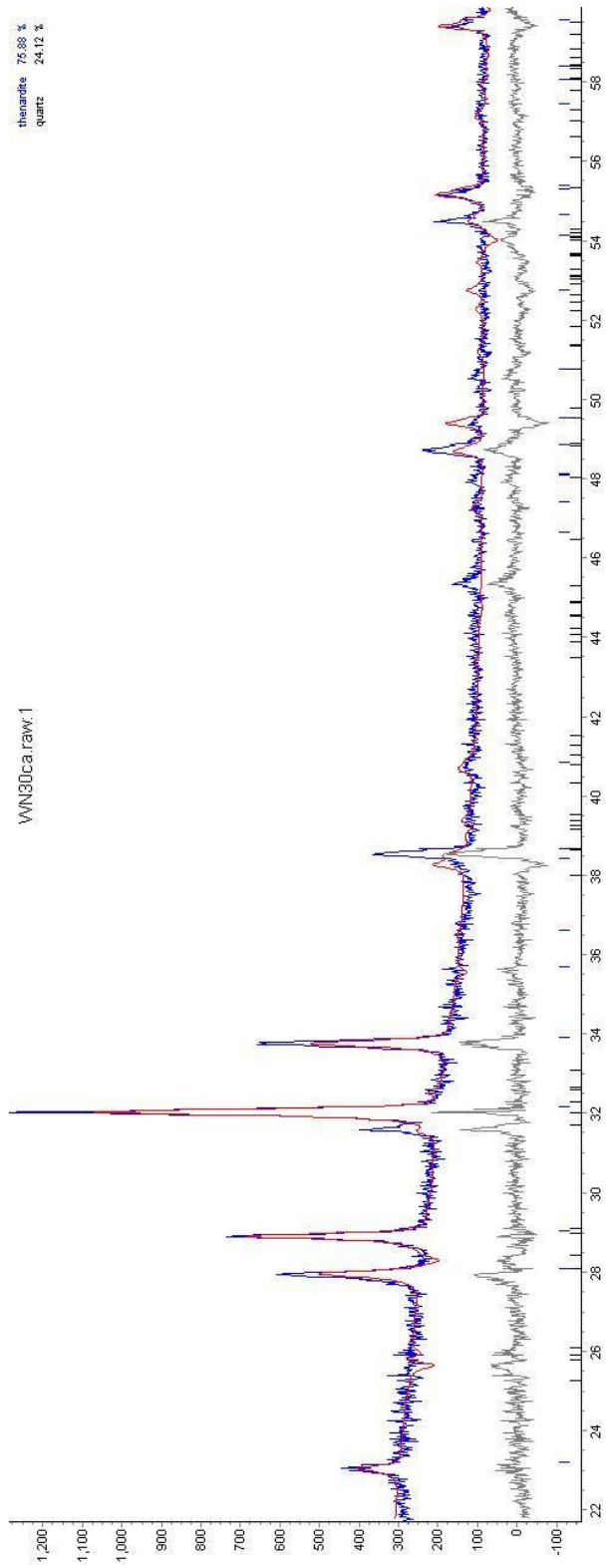


Figure 193: TOPAS result for WN30ca

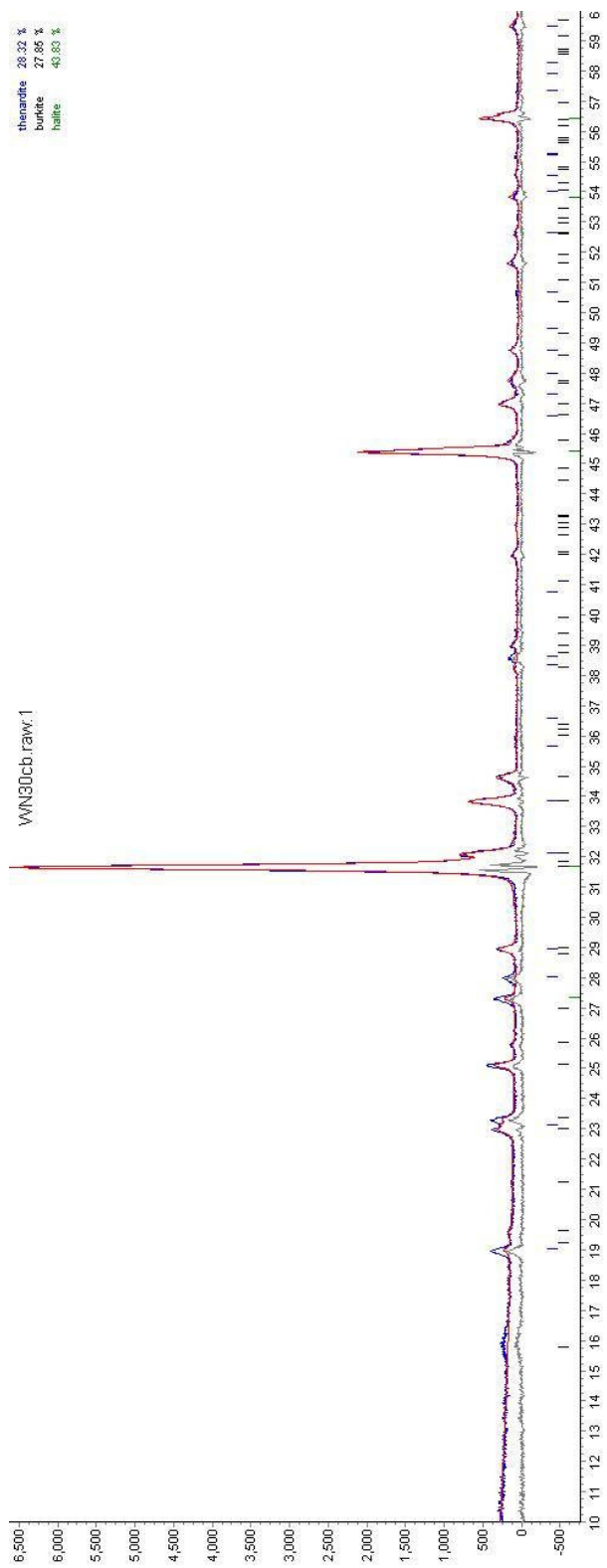


Figure 194: TOPAS result for WN30cb

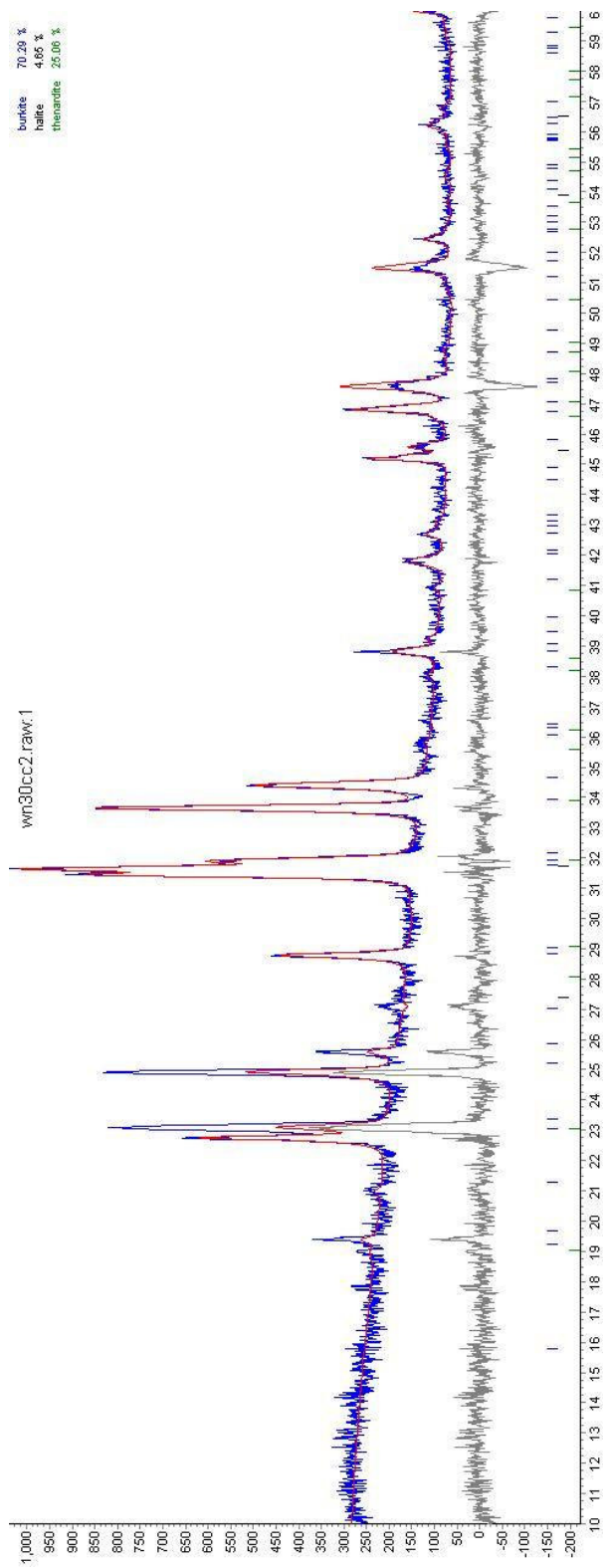


Figure 195: TOPAS result for WN30cc

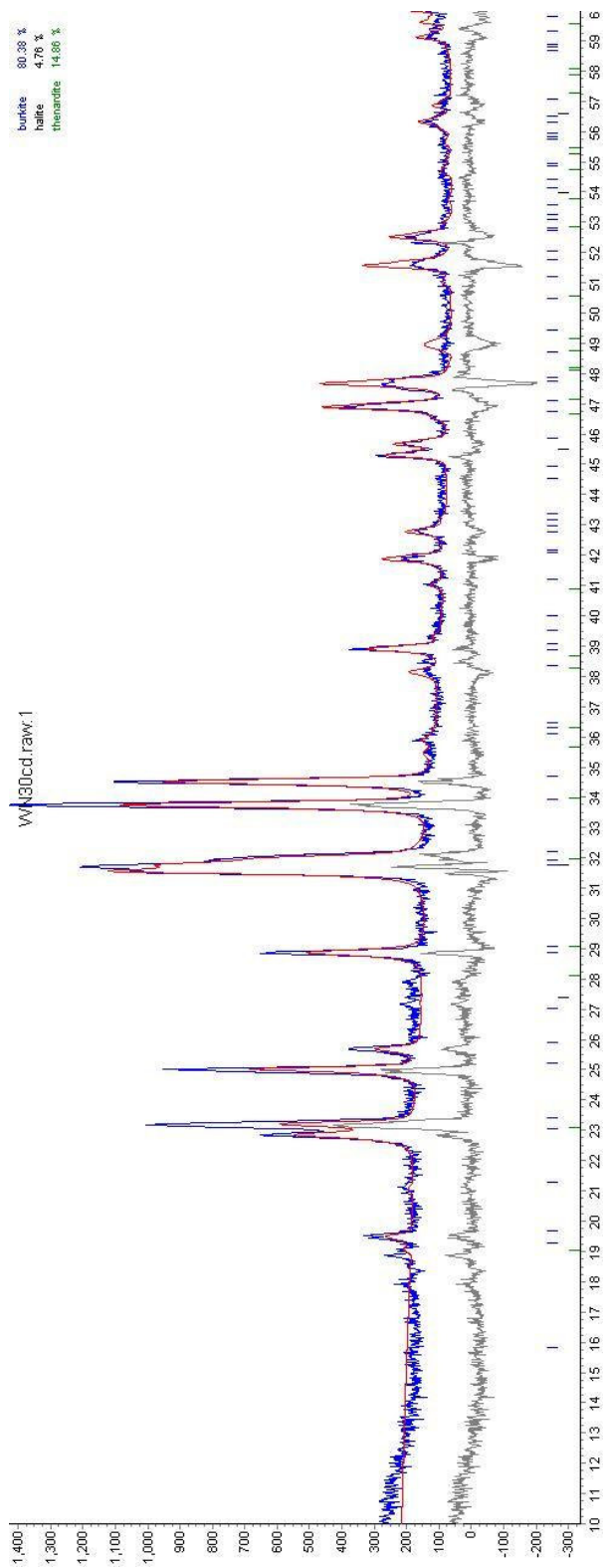


Figure 196: TOPAS result for WN30cd

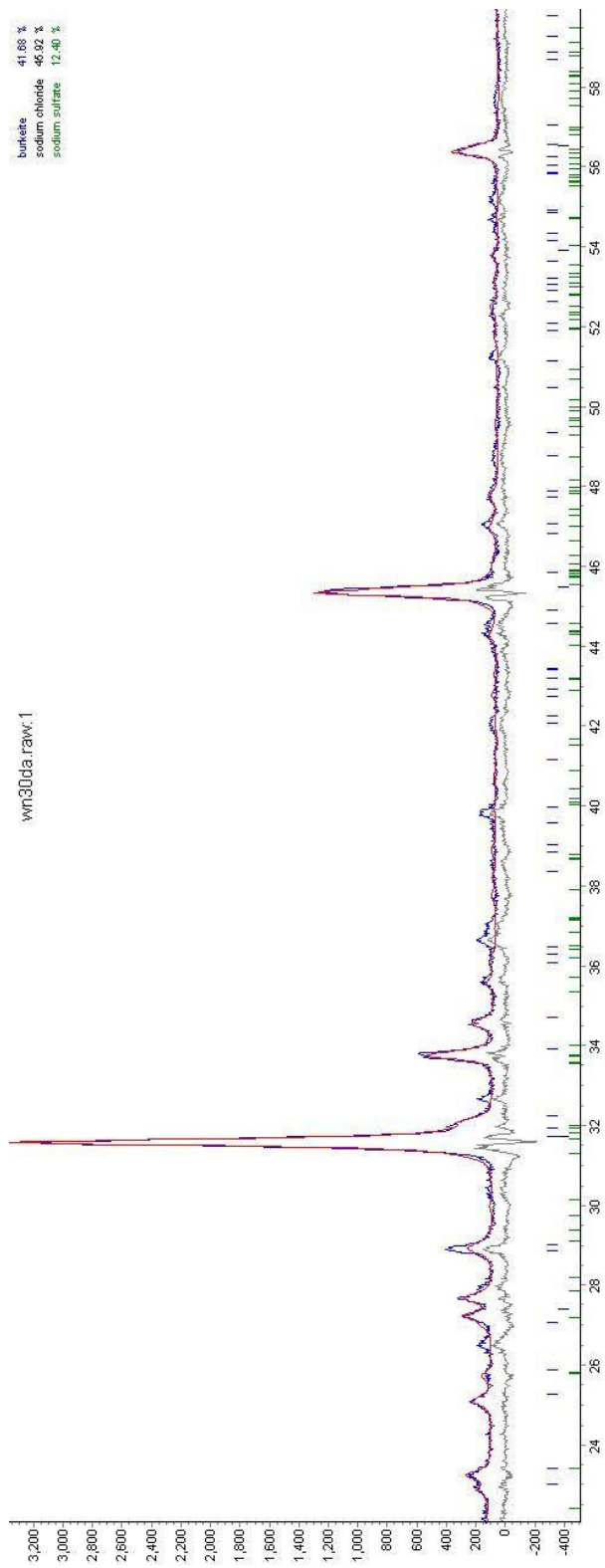


Figure 197: TOPAS result for WN30da

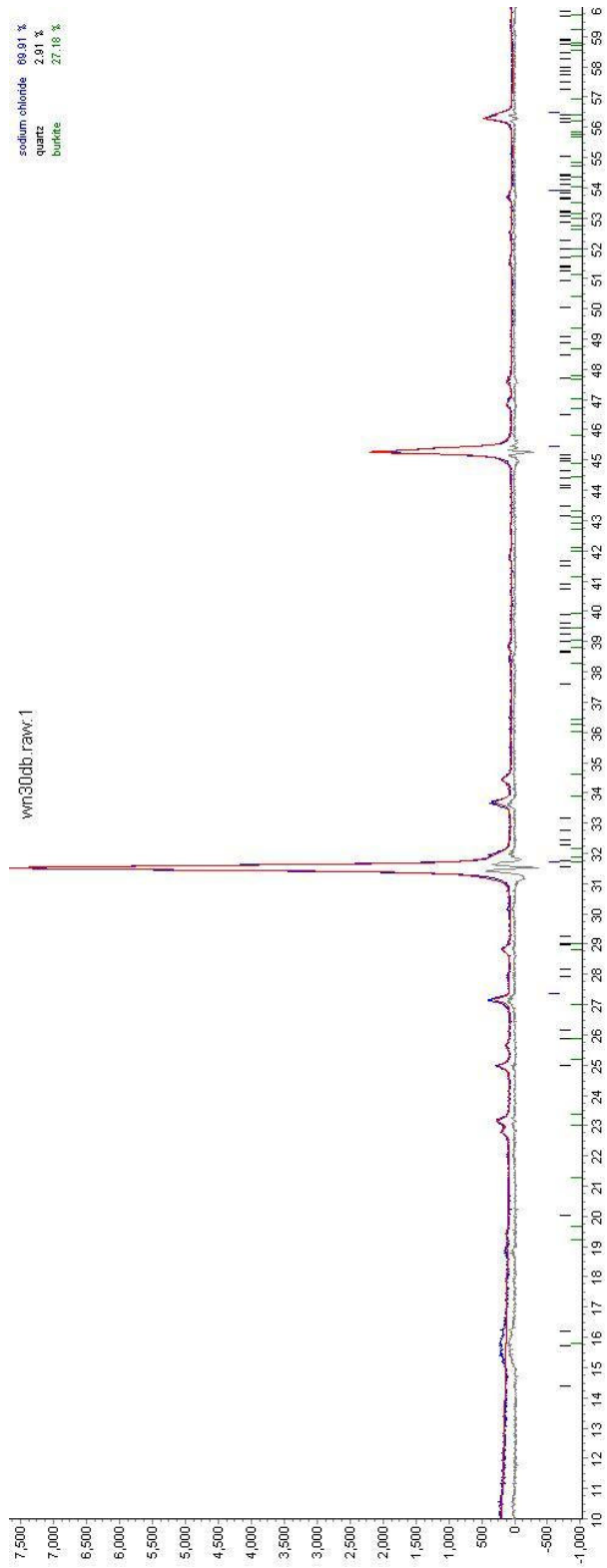


Figure 198: TOPAS result for WN30dc

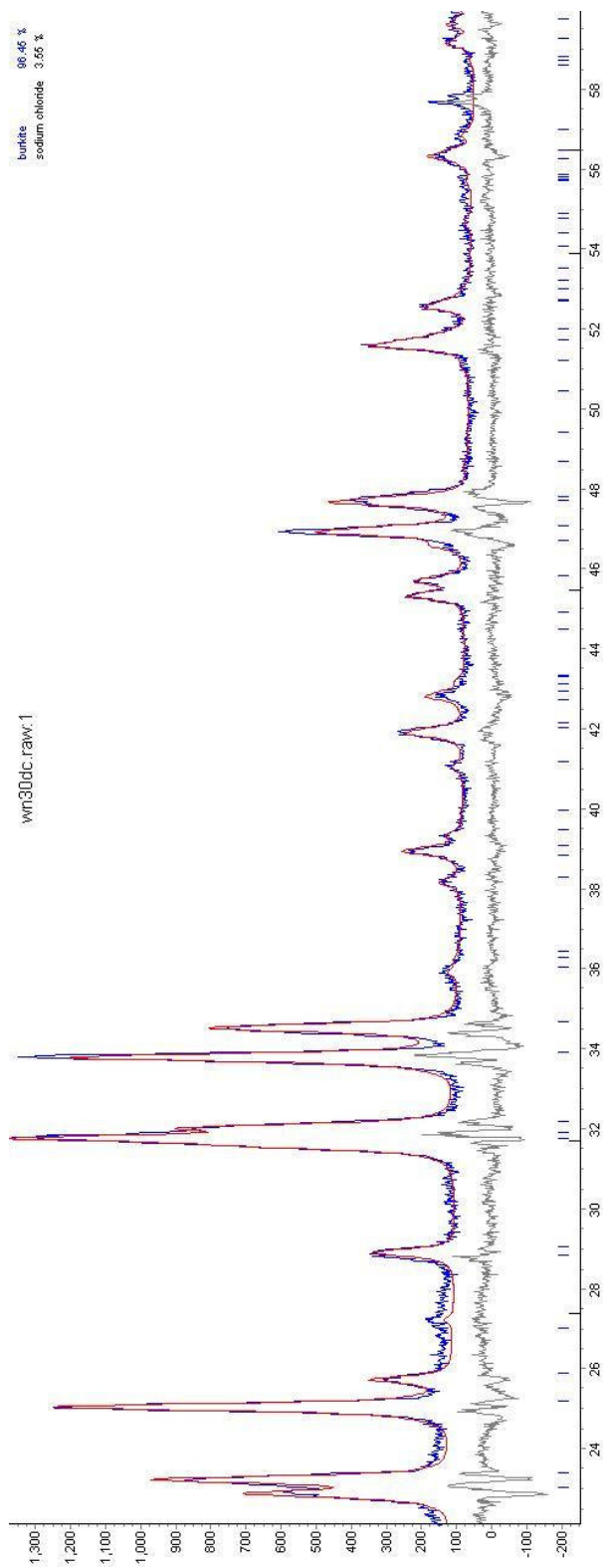


Figure 199: TOPAS result for WN30dc

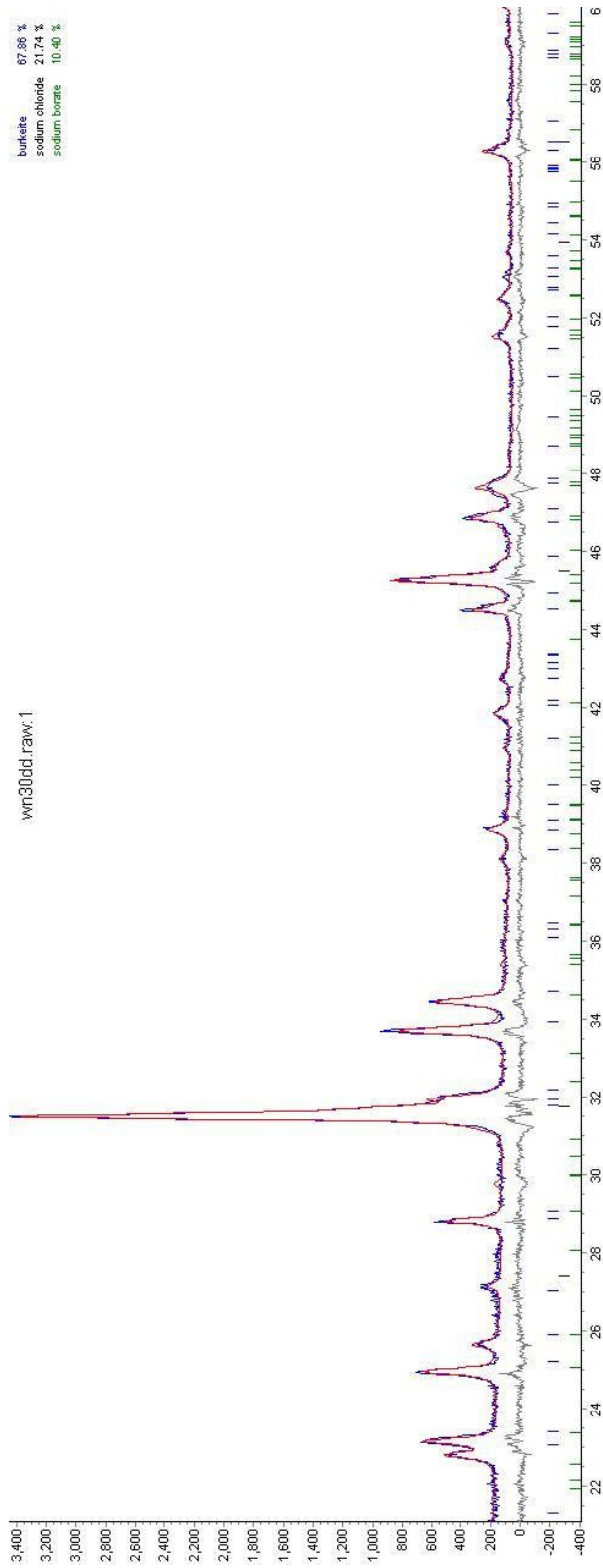


Figure 200: TOPAS result for WN30dd

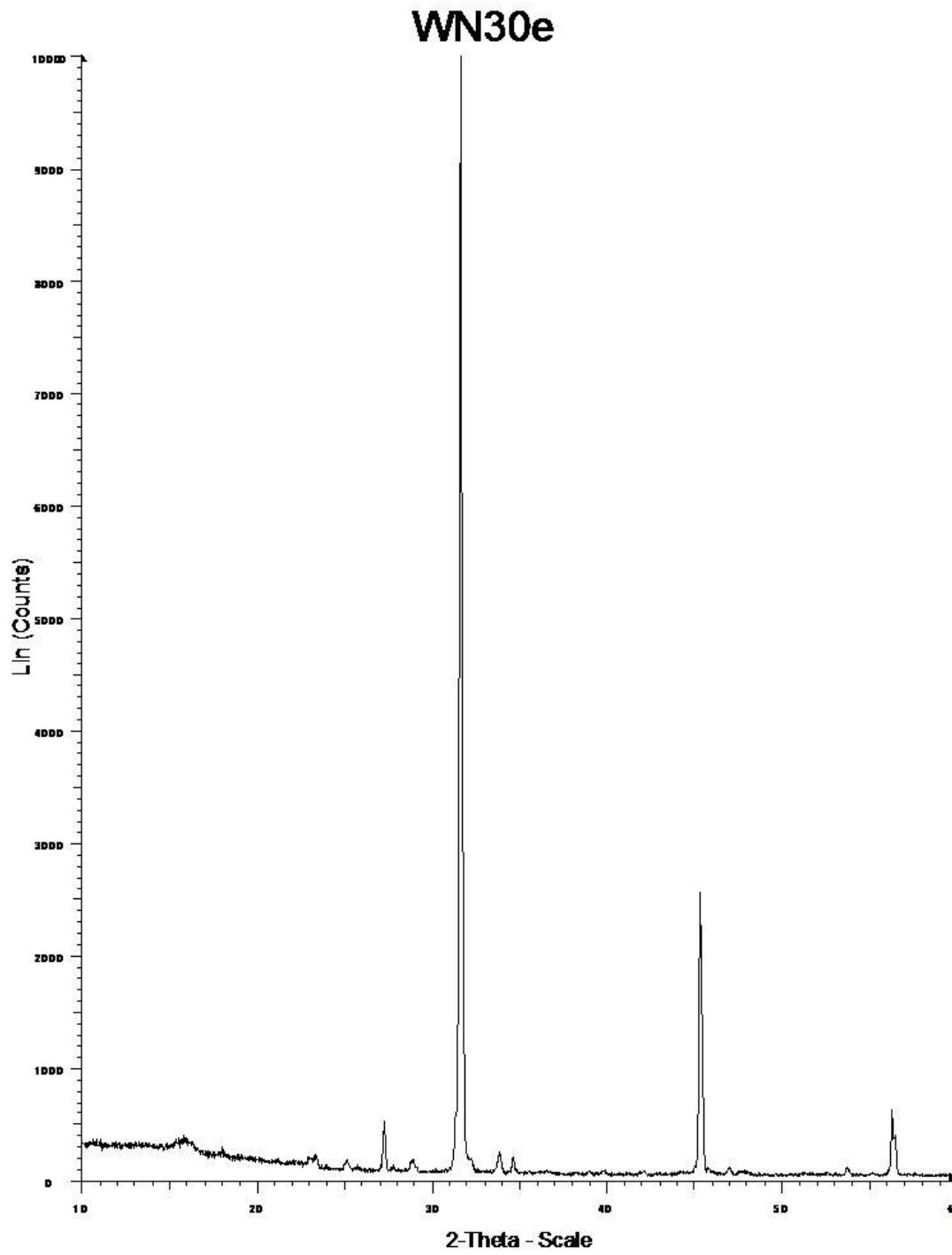


Figure 201: XRD result for WN30e

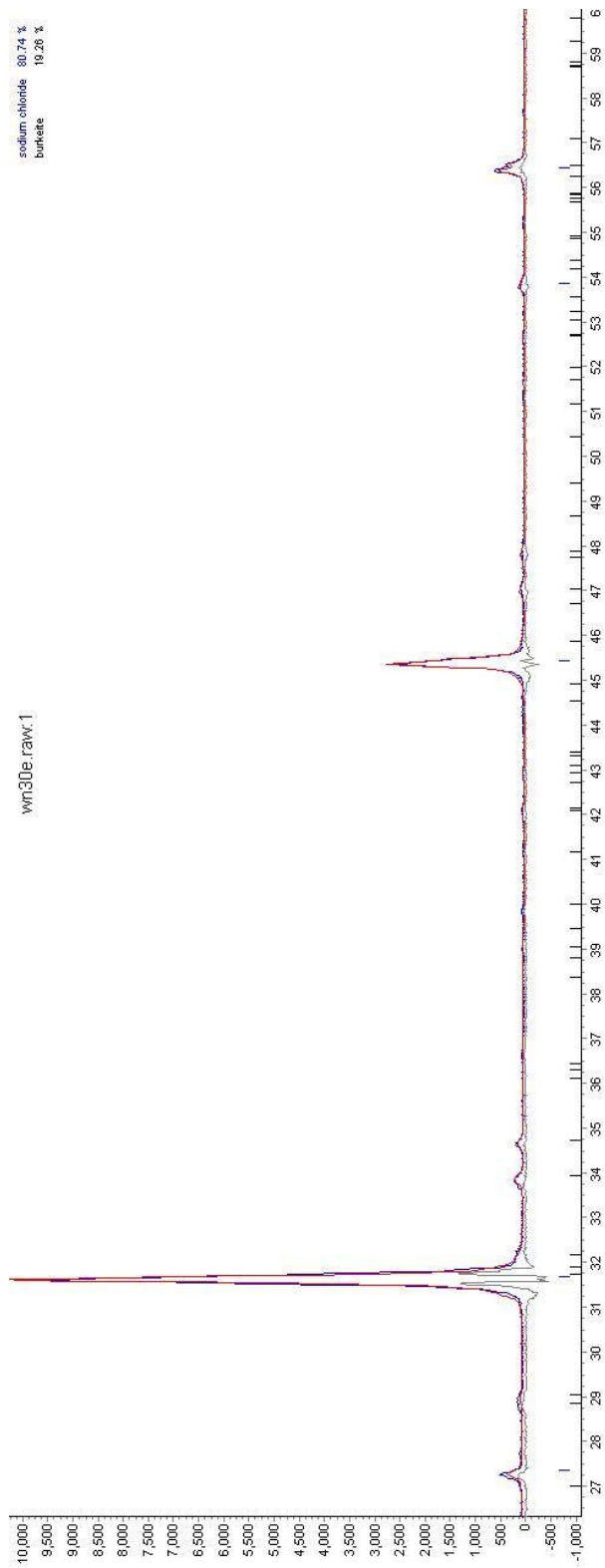


Figure 202: TOPAS result for WN30e

Appendix B

This appendix shows the remaining Geochemist Workbench results which were not expressed in other areas of this document. These are namely the results for Lake Fazda.

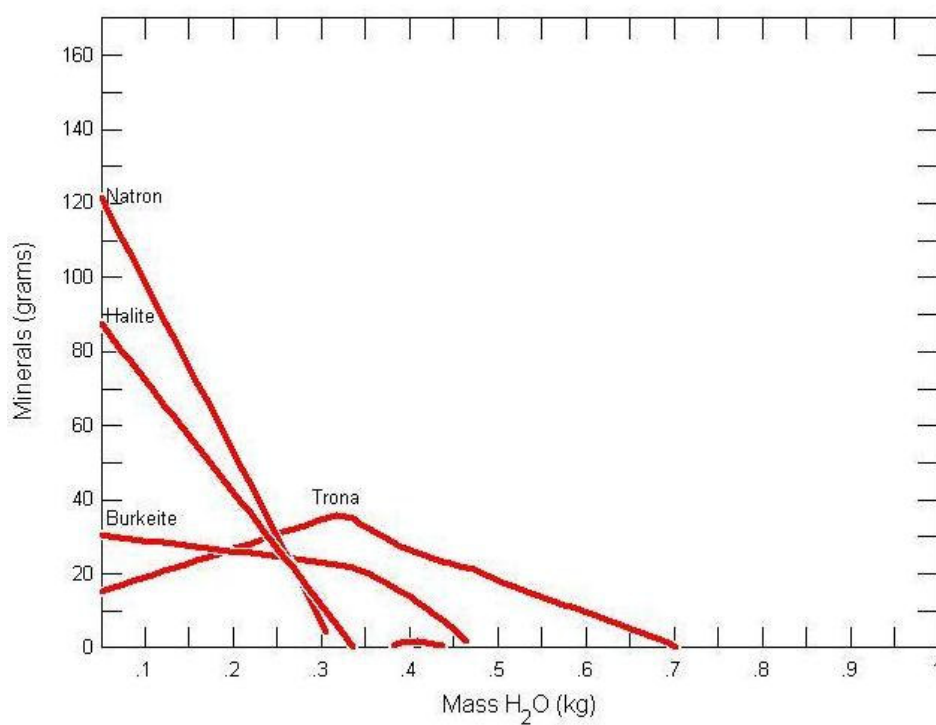


Figure 203: Geochemist results of Lake Fazda at 0°C

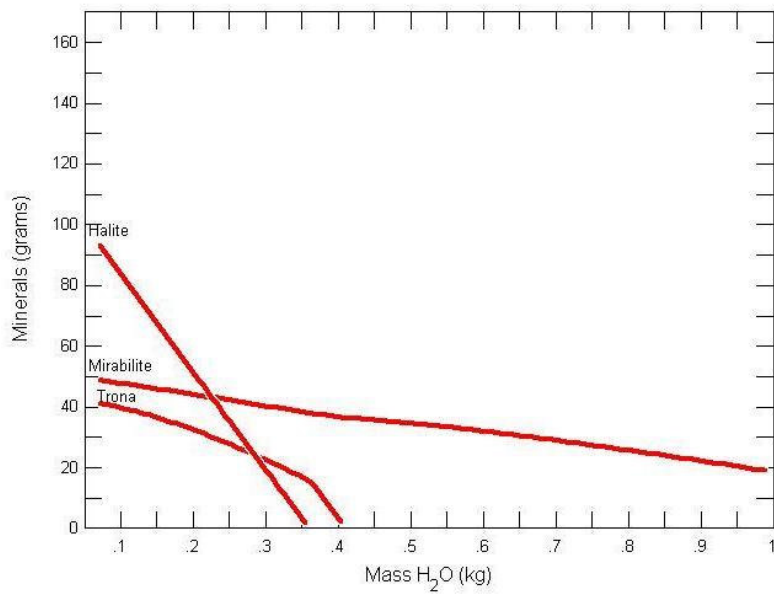


Figure 204: Geochemist results of Lake Fazda at 5°C

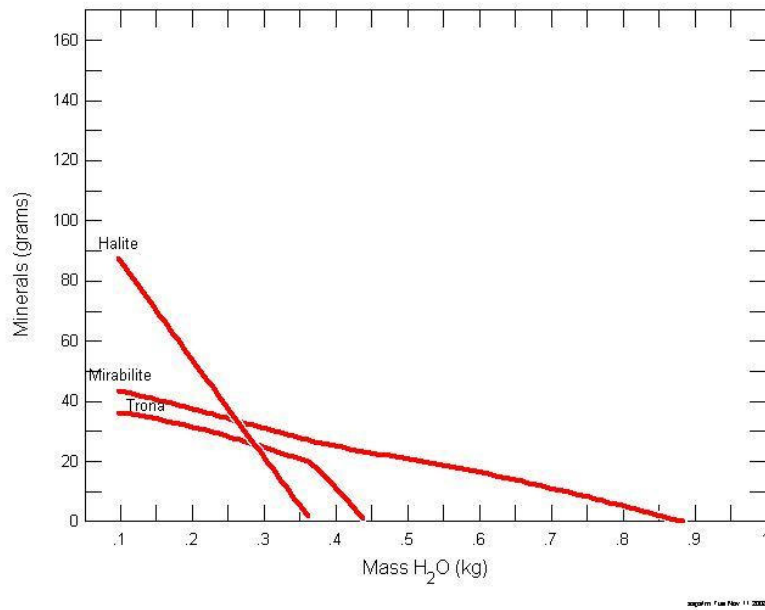


Figure 205: Geochemist results of Lake Fazda at 10°C

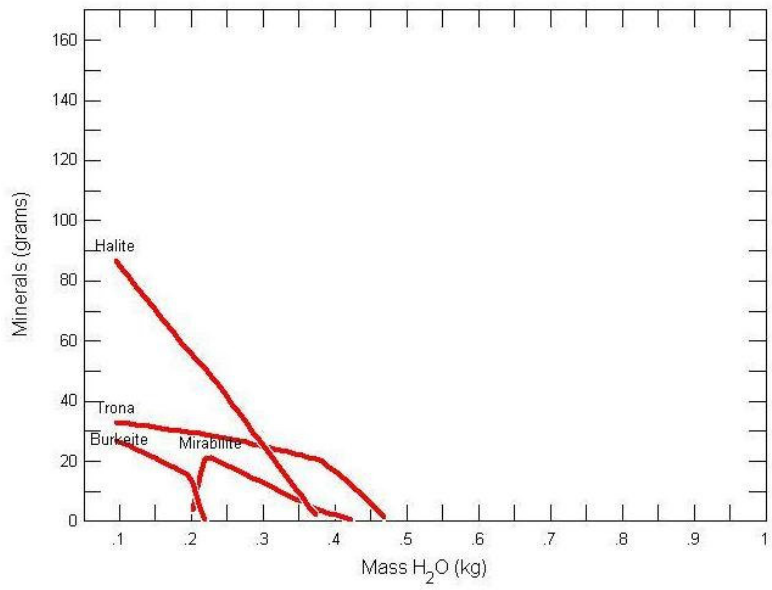


Figure 206: Geochemist results of Lake Fazda 15°C

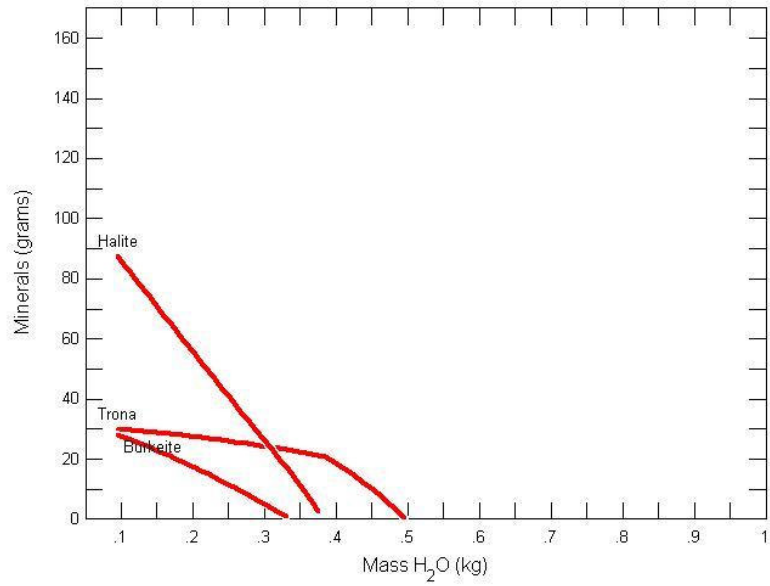


Figure 207: Geochemist results of Lake Fazda 20°C

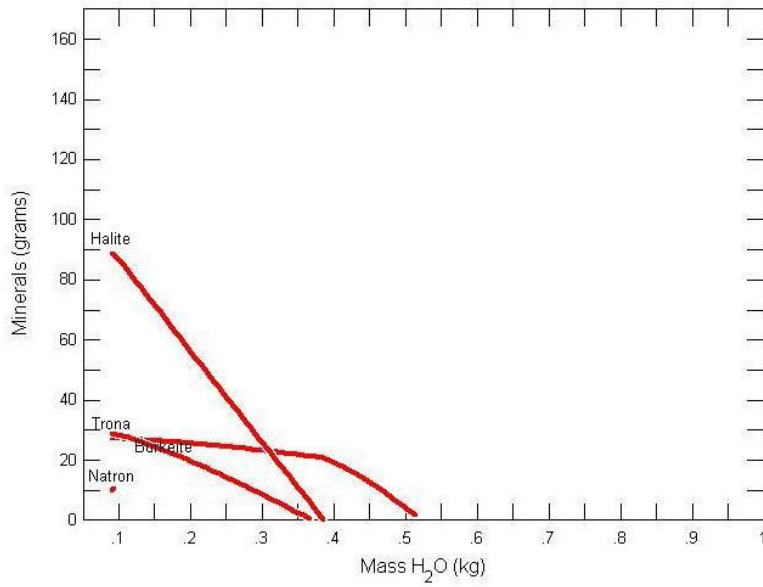


Figure 208: Geochemist results of Lake Fazda 25°C

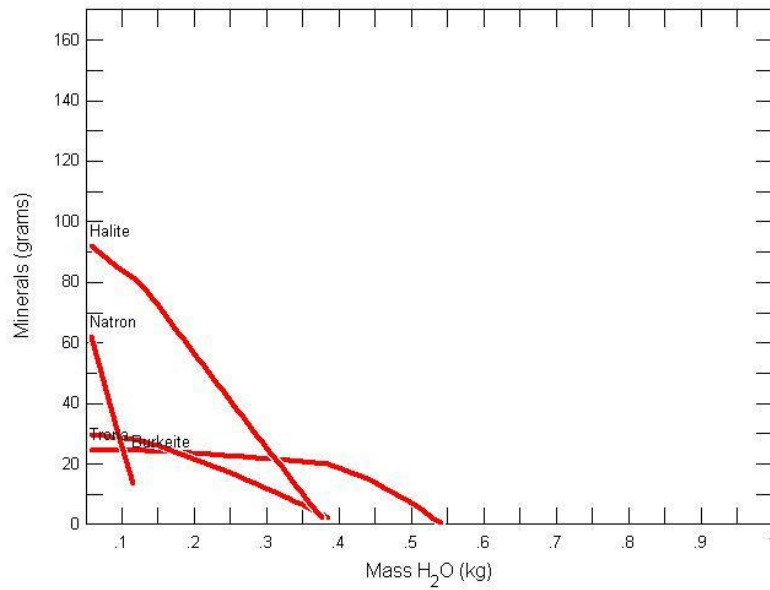


Figure 209: Geochemist results of Lake Fazda 30°C

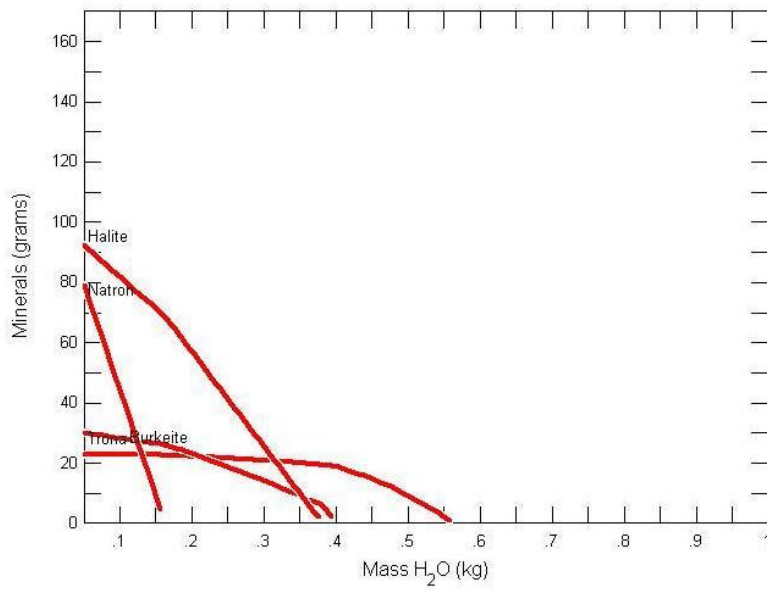


Figure 210: Geochemist results of Lake Fazda 35°C

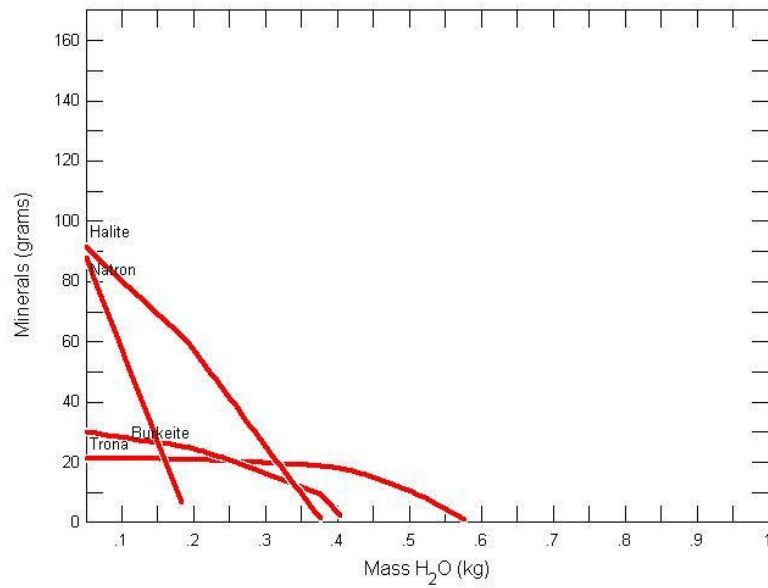


Figure 211: Geochemist results of Lake Fazda 40°C

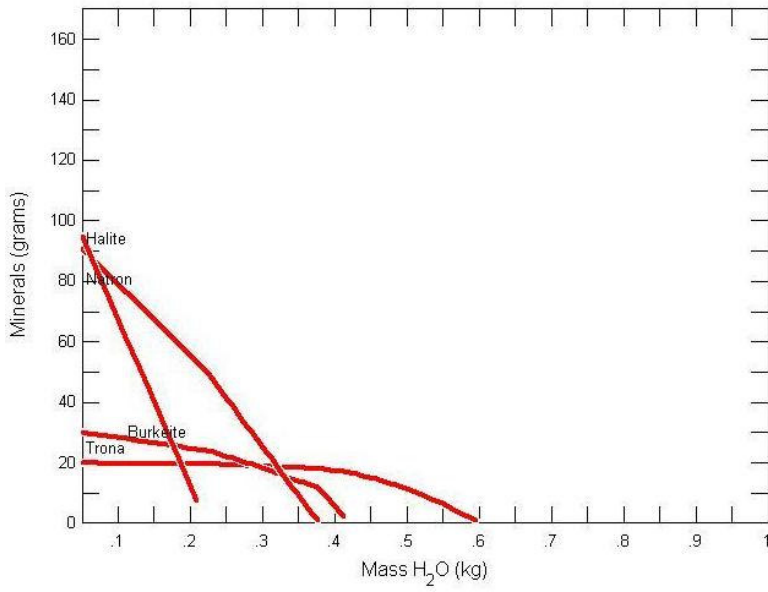


Figure 212: Geochemist results of Lake Fazda 45°C

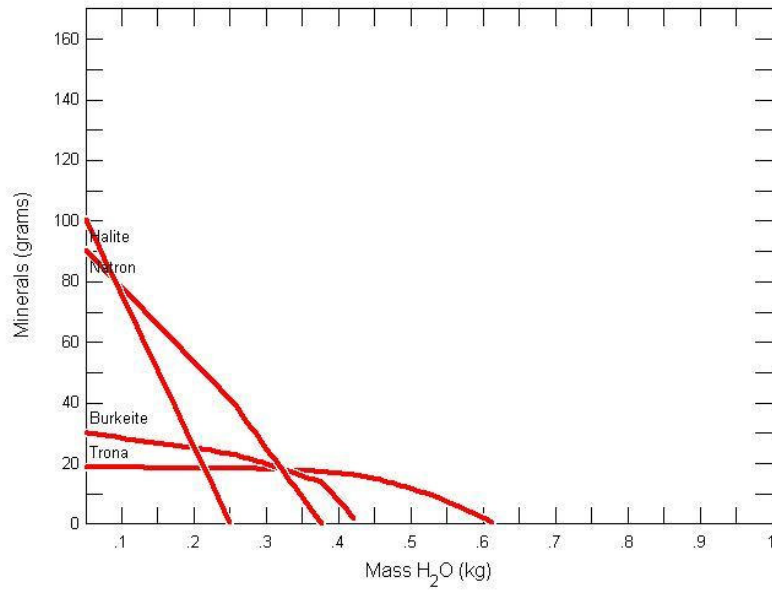


Figure 213: Geochemist results of Lake Fazda 50°C

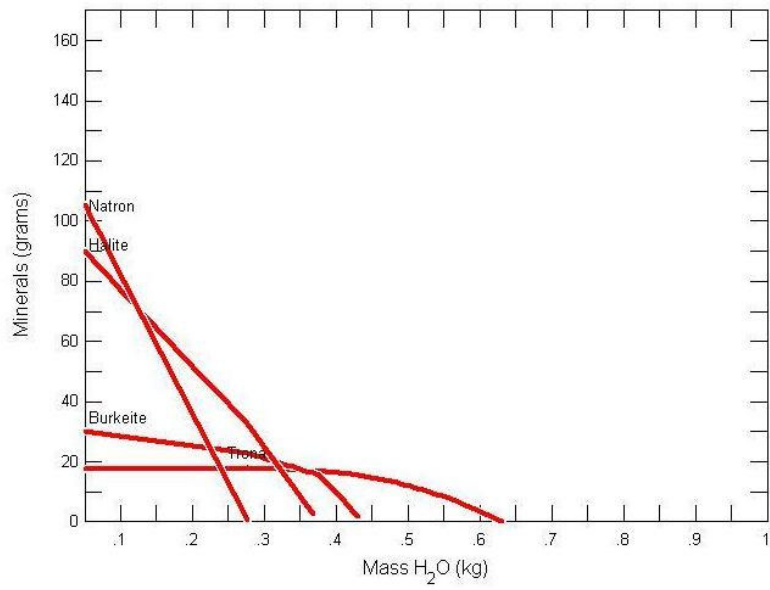


Figure 214: Geochemist results of Lake Fazda 55°C

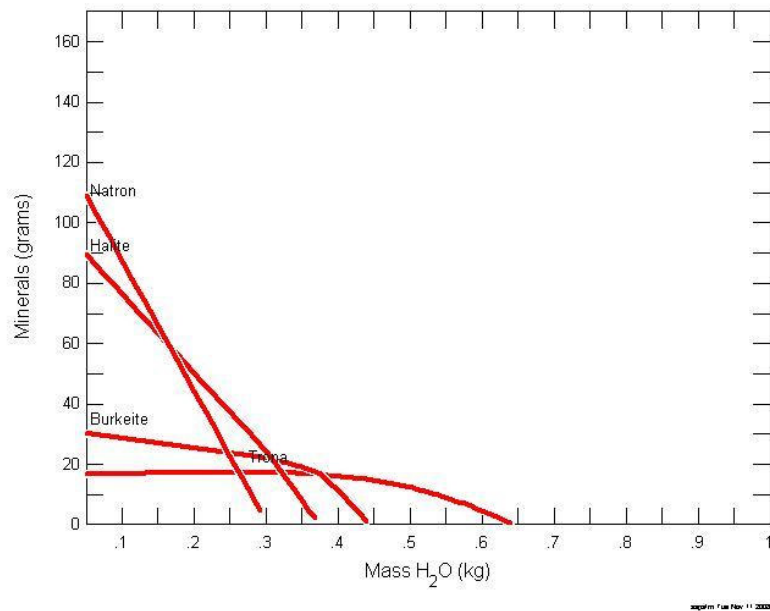


Figure 215: Geochemist results of Lake Fazda 60°C

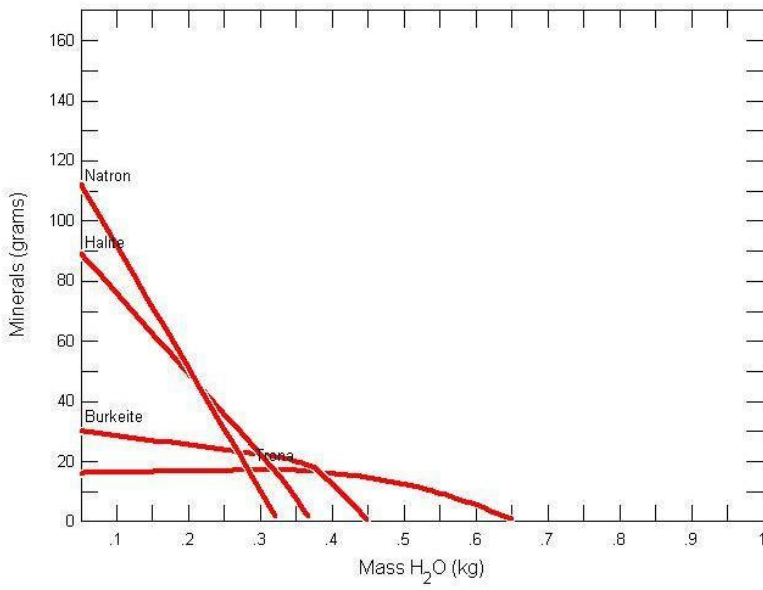


Figure 216: Geochemist results of Lake Fazda 65°C

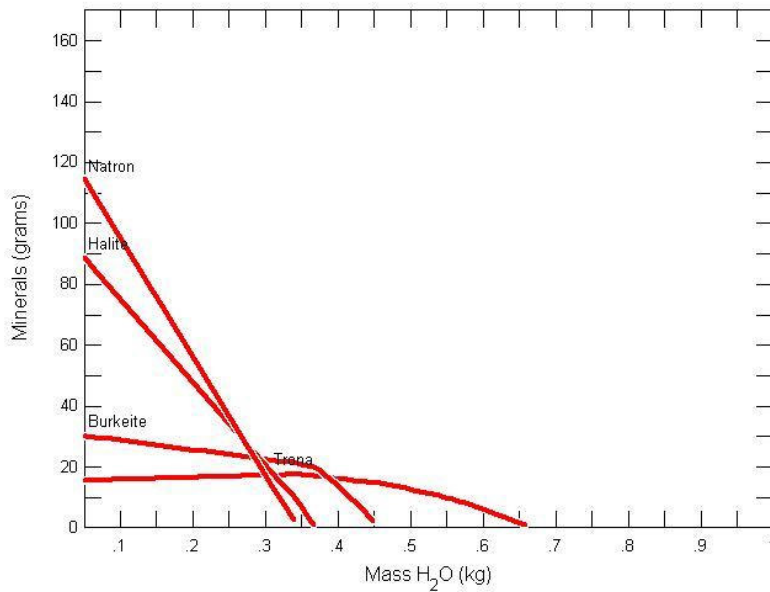


Figure 217: Geochemist results of Lake Fazda 70°C

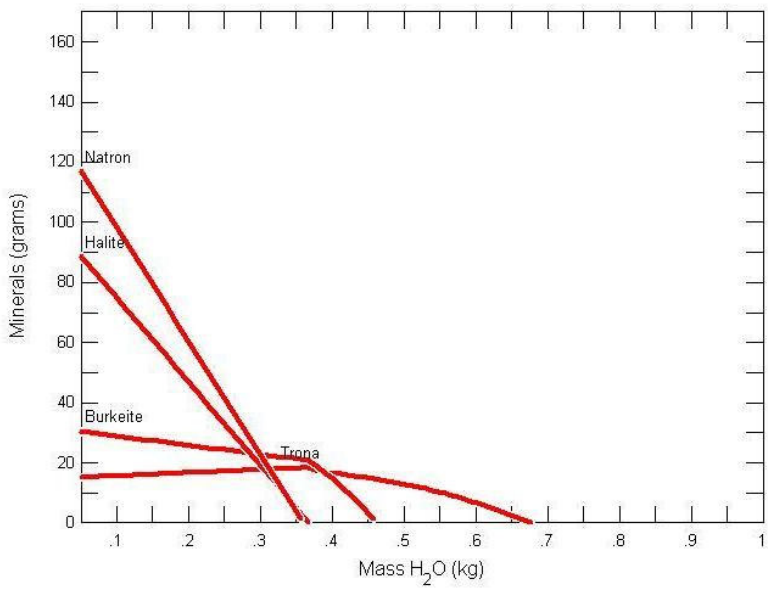


Figure 218: Geochemist results of Lake Fazda 75°C

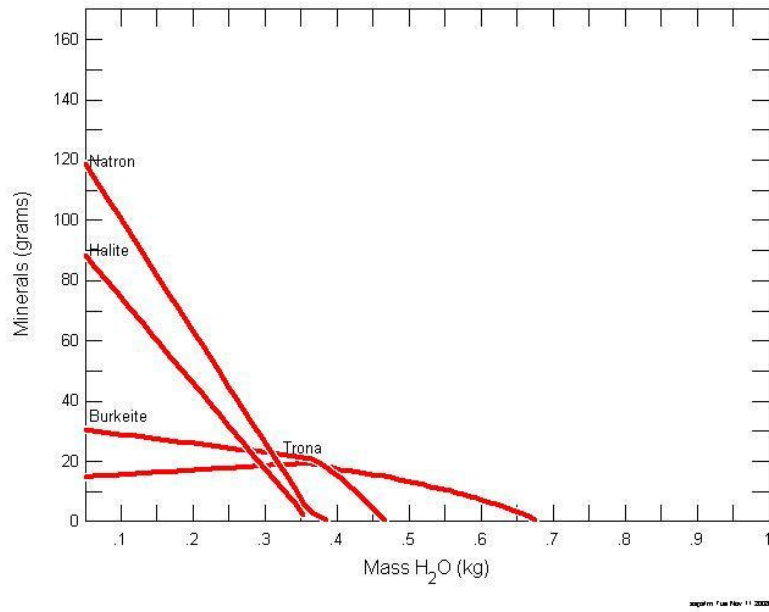


Figure 219: Geochemist results of Lake Fazda 80°C

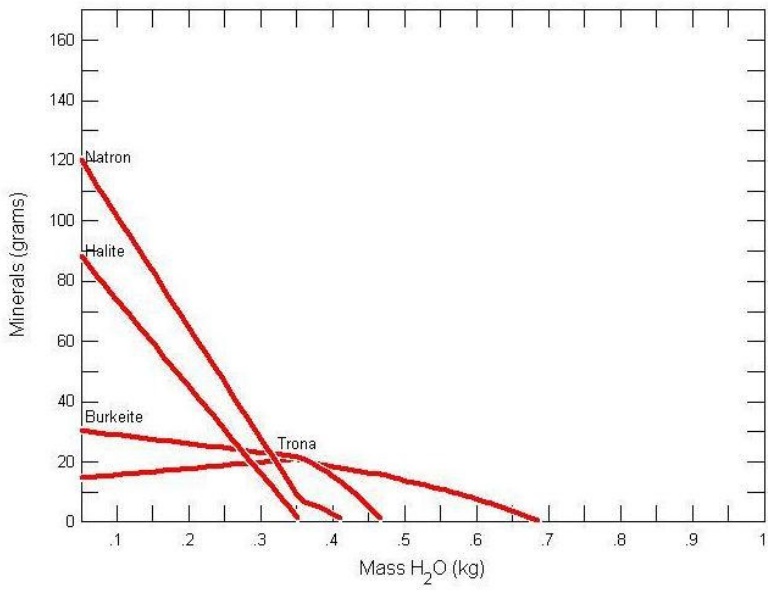


Figure 220: Geochemist results of Lake Fazda 85°C

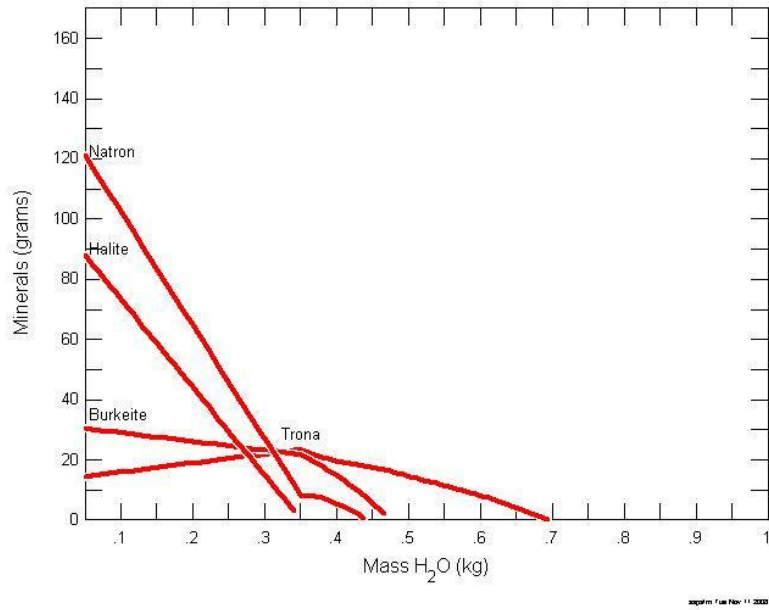


Figure 221: Geochemist results of Lake Fazda 90°C

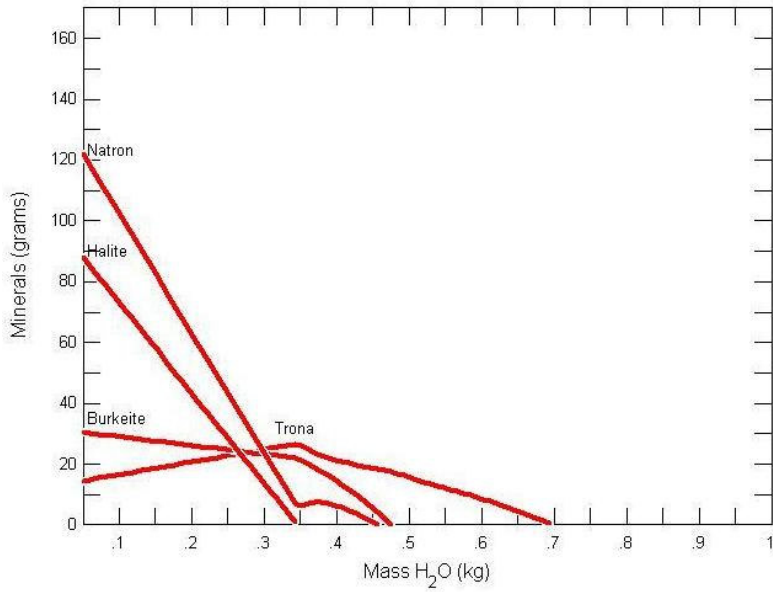


Figure 222: Geochemist results of Lake Fazda 95°C

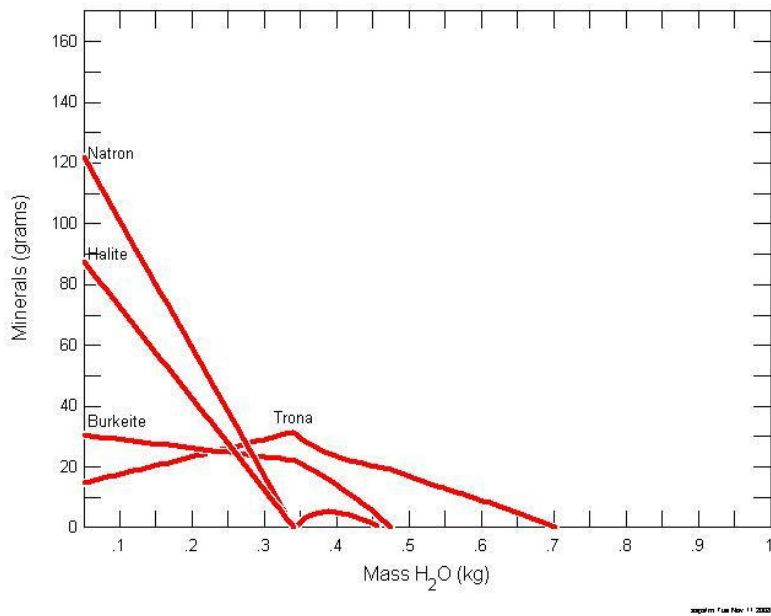


Figure 223: Geochemist results of Lake Fazda 100°C