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The contributions of C. F. Charter to tropical soil survey and classification

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ABSTRACT

Cecil Charter had taught botany and biology in China and Antigua for five years, when in 1931 he was engaged to conduct a soil survey of the sugarcane-growing areas of Antigua. This was followed by similar surveys elsewhere in the Caribbean. In 1944, he joined the West African Cacao Research Institute in the Gold Coast (now Ghana) to carry out soil investigations in the forest zones of West Africa. In 1949 he moved to organise the soil survey unit in the Gold Coast Department of Agriculture, and, in 1951, to found and direct the new Soil and Land Use Survey Department. He rapidly built up a highly professional unit that produced many practical and useful reports of high quality. He based the surveys on ecological principles, selecting river basins as mapping regions. In the initial absence of qualified soil scientists, he subdivided the soil survey process and trained school leavers as technicians for separate tasks. Teams of these technicians examined soils, vegetation and land use at regular intervals on regularly-spaced traverses cut across the topography. Charter's contributions to soil science included his recognition of non-residual tropical soils formed in material brought to the surface by soil fauna and treefall. Also, he differentiated between highly acidic upland Oxysols in high-rainfall areas, which he considered unsuitable for cocoa cultivation, and less acidic Ochrosols, which were more suitable. Based on farmers' experience and his ecological background, he differentiated between forest, thicket and savannah soils within these groups. He strongly advocated genetic and contextual classification of tropical soils.

1. Introduction

After 12 years of soil surveying in the Caribbean, Cecil Frederick Charter established modern systematic soil survey in the Gold Coast (now Ghana) in the late 1940s. The Gold Coast was one of the first territories in sub-Saharan Africa to set up a dedicated soil survey organisation. Charter took advantage of the territory's relative prosperity and the administration's progressive resourcing of agricultural development services, and built up a large and productive Soil and Land Use Survey. This rapidly produced a stream of practical and relevant soil maps, reports and land assessments of high quality. He was a gifted teacher and trained teams of local school leavers in separate soil survey tasks. This enabled Ghana to have the first fully localised, operational soil survey organisation in sub-Saharan Africa. Charter's achievements in Ghana can be compared with those of Geoffrey Milne in East Africa (Young, 2007). Milne's most significant work was undertaken in the 1930s, which overlapped with Charter's time in the Caribbean. However, the peak of Charter's career, in the Gold Coast, was more than a decade later. Milne was the coordinator and best known of an inter-territorial group in East Africa that collaboratively developed and applied the concept of the topographic catena to understanding soil distributions and pedogenetic interrelationships, and for mapping of complicated soil patterns (Borden et al., 2019). Nowadays, Charter lacks Milne's wide recognition, as he left no simple catch-phrase concept. His written output consisted mostly of reports and conference papers of high quality but with limited distribution, and he did not parallel Milne in authoring papers in mainstream academic journals. Nonetheless, Charter's achievements in rapidly establishing a highly productive unit *de novo* that focussed on practically useful soil surveys was widely appreciated by his peers.

In this paper, we review Charter's career in the Caribbean and particularly in the Gold Coast, and discuss his influence on methods of survey, and on tropical soil classification and pedology. We use a range of unpublished materials that came to one of the authors (HB) personally from Charter himself and later from his family, and also draw from legacy items held in the World Soil Survey Archive and Catalogue (WOSSAC) at Cranfield University, UK (www.wossac.com; Hallett et al., 2017).

2. Biography

Cecil Frederick Charter was born in Suffolk, England, in December

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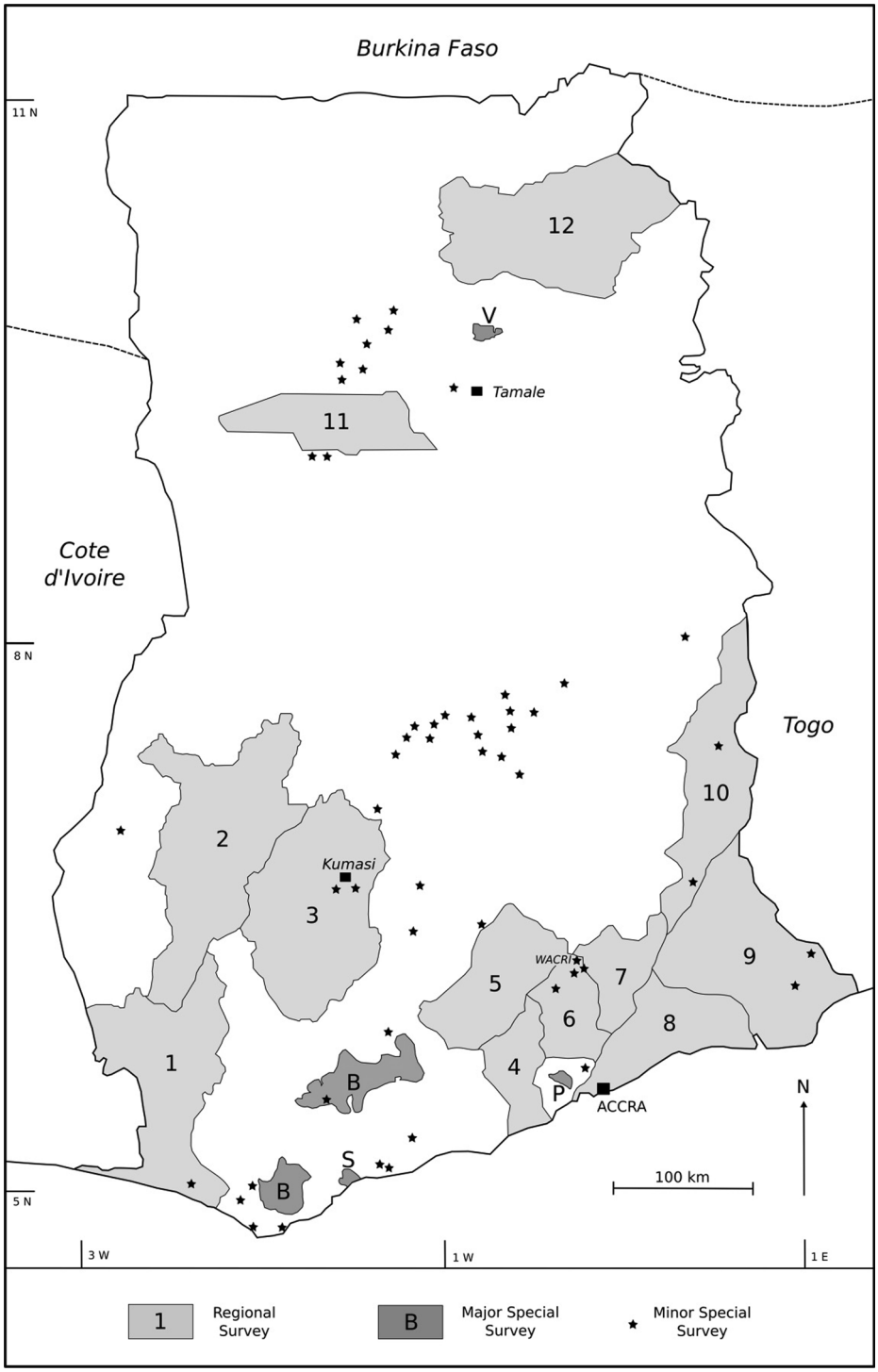

Fig. 1. SLUS surveys, December 1956. *Regional surveys:* 1 – Lower Tano Basin; 2 – Upper Tano Basin; 3 – Kumasi Region; 4 – Ayensu Basin; 5 – Birim Basin; 6 – Densu Basin; 7 – Pawmpawm Basin; 8 – Accra Plains; 9 – HoKeta Plains; 10 – T ogoland Cocoa Region; 11 – Yapei-Sawla Road Area; 12 – Nasia Basin. *Major Special Surveys:* B-Banana feasibility survey; P-Pineapple feasibility survey; S-Sugarcane feasibility survey; V – Veterinary Station (Kpong Tamale). *WACRI-* West African Cacao Research Institute. (Based on SLUS, 1958a).

1905 He was educated at Lowestoft Secondary School, and at Cambridge University, where he read Natural Sciences. When he graduated in 1927, he joined the Grammar School in Tientsin in China as the Botany and Biology Master. In 1930 he moved to become the Science Master at the Grammar School in Antigua in the West Indies.

With his background, it did not take long for the sugar estate owners and the government to recognise his ecological interest and expertise. In 1931, he was asked by the government to survey the soils of Antigua and Barbuda (Young, 2007). His report (Charter, 1937) was reprinted in 1947 by the Government of Antigua. In 1932, he resigned from the Grammar School to become a scientific advisor with the Sugar Estates Syndicate, based at the Gunthorpes Estate, with responsibility for carrying out experimental work for the Antigua Sugarcane Investigation Committee (Moody-Stuart, 1932). He moved to the Trinidad Department of Agriculture in 1935 as a sugar agronomist. In August 1937, he returned to Britain to the University College of Wales at Bangor to

complete the analyses of some samples collected during his survey of Antigua and Barbuda (Moody-Stuart, 1937) and take a short course on field and laboratory methods under Professor G.W. Robinson. Charter then took up a contract with the Trinidad Sugarcane Investigation Committee, and later moved to the Trinidad Department of Agriculture, as a soil surveyor (Turner and Charter, 1939). He also undertook feasibility studies for sugarcane and other crops in Trinidad, Guadeloupe, Martinique, St Lucia, British Guiana and British Honduras (Charter, 1940; Brammer, 1958).

In 1944, Charter moved to the then Gold Coast (now Ghana) as Soil Chemist in the West African Cacao Research Institute (WACRI). As with Milne and his colleagues in East Africa, the title 'Soil Chemist' then encompassed many aspects of soil science, and required work in the field as well as the laboratory. At WACRI, Charter conducted soil investigations related to declining cocoa yields (Charter, 1949a, b) and also undertook soil feasibility studies for sugar cane and other crops. He worked mainly in the Gold Coast, but also visited Nigeria and Cameroun. In 1949, he became Chief Soil Scientist of the Soil Survey Division of the Gold Coast Department of Agriculture, and in 1951 was appointed as the founding Director of the newly established Department of Soil and Land Use Survey (SLUS), and rapidly built it up into a highly professional and productive unit.

His achievements, particularly his analysis of the soil-related failings of the Groundnut Scheme in Tanganyika (now Tanzania) (Charter, 1958) were recognised by the award of the Order of the British Empire (OBE) when he was only 49. He died in London after a short illness in January 1956. (Greene, 1956; Brammer, 1958). Brammer was the Officer-in-Charge of SLUS from 1956 until full localisation in 1961 (SLUS, 1958).

3. Soil survey in the Caribbean (1932–1944)

Charter focused on the management aspects of soils from the very outset of his soil survey career. In the Antigua survey, he concentrated on soil for sugar cane cultivation. Similarly in Trinidad, his initial remit was to:

> "*determine the fundamental differences between soils capable of producing paying yields of noble canes and soils on which it is only profitable to grow hardy canes, and on the basis of these studies to put forward suggestions with regard to the future allocation of varieties.*" (Turner and Charter, 1939, Foreword).

He and his clients were also interested in diversification out of plantation sugar cane, and he examined the potentials for non-cane crops and non-plantation farming (Charter, 1943). His Caribbean reports (e.g. Charter, 1940; Turner and Charter, 1939) set the tone of structural and verbal clarity, supported by helpful and informative graphics that characterised all of his output.

4. The Gold Coast

Charter's most influential work was undertaken in the dozen years (1944–1956) that he spent in the Gold Coast. Whilst at WACRI in 1944–1949, he conducted soil surveys and authored his own reports (Charter, 1947, 1956). After he became the Director of SLUS, he concentrated on building up an institution capable of producing high quality, ecologically- and environmentally-oriented soil surveys of practical use to farmers, land managers and planners. He selected major river basins as the regional survey areas (Fig. 1). These were surveyed using the methods that he had developed at WACRI (Charter, 1948) for work in the forest zone. He instituted a soil classification that encompassed the natural vegetation and other environmental attributes and devoted much time and effort to the development of a cadre of competent soil technicians. Although he rarely included personal statements in official publications, a forthright (especially for a senior civil servant!) comment in his Ayensu and Densu report is revealing:

> '*The opportunity is taken here to deprecate in the strongest manner possible any attempts to perpetuate the worst characteristic of colonialism, namely the practice of removing nutrients in crops for export without replenishing the depleted soils. This condemnation includes the use of specially vigorous strains capable of extracting the last remnants of fertility from already exploited soils where such strains are grown without due regard to the maintenance of soil productivity*' (Charter, 1955, p 2).

As well as his assessment of the soil problems of the failing Groundnut Scheme in Tanganyika (now Tanzania), Charter and the staff of SLUS maintained wide international contacts and these substantially influenced their assessment of soil potentials for irrigation and other forms of land use.

4.1. Soil survey organisation

Because of its predominance in the global cocoa trade, the Gold Coast was relatively prosperous in the 1940 −50s, and the administration was able to fund a substantial and well-resourced soil survey organisation. Charter was therefore able to establish a fully functioning base at Kwadaso-Kumasi, with offices, laboratories, photographic and cartographic facilities, and vehicle, fitter, carpenter and blacksmith workshops (Charter, 1954a; SLUS, 1958). He initially experienced problems in recruiting graduates as soil surveyors but eventually contracted ten expatriates, mostly geographers. The eventual SLUS establishment of about 60 included the soil chemist, a grassland ecologist, compilation officer, survey technicians, and support staff (SLUS, 1957).

This substantial setup enabled SLUS to rapidly undertake an ambitious programme of surveys, of which there were two main types. The first were the special *ad hoc* surveys of varying extent and scale that addressed the soil aspects of specific agricultural development problems or proposals, such as planned plantations of non-cocoa crops. However, the main focus was on the systematic reconnaissance surveys (published at scale 1:250000) of rivers basins, each covering several thousands of square kilometres (Fig. 1).

SLUS surveys were based on ecological survey and forest inventory techniques, and used traverses, similar to *rentises* cut for soil survey in forested areas of Southeast Asia (Young, 1968). For the regional surveys, teams of technicians trained by Charter cut lines at intervals of 1.5–2 km across the landscape, and marked soil inspection points at 200 m intervals. Holes were dug by soil chisel and samples from deeper layers were obtained by augering.

A distinctive feature of the SLUS surveys was the deployment of substantial field teams. As well as the line cutters and peggers, a soil survey technician, with labourers, described and sampled the soils, and another specialist described the vegetation and land use. Samples from doubtful plant identifications were collected and checked at headquarters, often by Charter himself. Another distinctive feature was the off-site corroboration and amplification of the soils data. Bagged soil samples were taken to the base camp where experienced technicians recorded colour, hand texture and other features (Fig. 3). A professional soil surveyor examined the samples in order to determine soil boundaries and decide which traverses and sites warranted further inspection (Charter, 1948).

Sample strips of 0.3–1.5 km^2 were mapped within each region at scale 1:6250 in order to fully characterise the soils and their topographic relationships. (Fig. 2). Soil profiles pits were located in the sample strips, and described and sampled for all of the soil series and phases identified. Soil boundaries were delineated on good quality topographic maps by interpolation from the observations, taking account of topographic and vegetation indicators of soil change. The aerial photography then available was of poor quality and was therefore little used (Adu, 1969).

Soil samples were taken to headquarters for laboratory analysis, after which representative soil profile samples were placed in

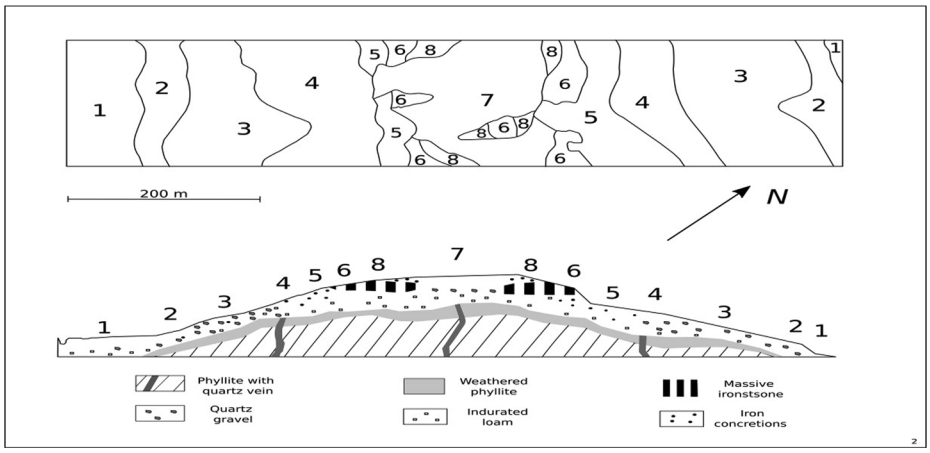

Fig. 2. Soil series of a sample strip, Kumasi (6.660 N, 1.640 W). 1. Oda – Mottled over grey clay in valleys; 2. Kokofu – Yellow brown silty clay on lower slopes; 3. Nzima – Brown gravelly clay over indurated saprolite on mid- & lower slopes; 4 Bekwai – Reddish brown gravelly clay over indurated saprolite on upper & midslopes; 5. Dominase – Reddish gravelly silty clay over indurated saprolite on upper & midslopes; 6. Wenchi – Ironstone at surface on plateau edge; 7. Akumadan – Deep red clay on summit; 8. Nsuta – Red clay with concretionary gravel over ironstone on summit. (Based on Brammer, 1962, p 96). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. Soil technician and surveyor processing soil samples at base camp. (Photograph by H Brammer).

Fig. 4. Soil technicians processing soil samples in Correlation Room at SLUS headquarters, with correlation boxes on the left. (Photograph by H Brammer).

35 × 8 × 5 cm wooden 'correlation boxes' for retention in the Soil Correlation room (Fig. 4) and were used to aid consistency of soil identification between surveys (Brammer, 1965). Vegetation collections were similarly retained in the SLUS herbarium.

This style of soil survey needed many technicians and much logistic support, but it was highly productive. Striking features of the early years of SLUS include the rapid coverage of large areas and the consistently high quality of the output. The reports are comprehensive, well-structured and clearly written. The graphics are outstanding, with many profile diagrams and topographic sections, as well as clearly drawn and well annotated maps. More than 60 years later, the reports still give full and informative accounts of the soils, their environmental settings and ecological relationships, and their management potential and constraints.

The system suited its time and place, but its substantial demands on staff resources made it impractical and uneconomic almost everywhere else, and also later on in Ghana. However, A. J. Smyth described a reconnaissance soil survey of the Nigerian cocoa areas:

> 'The only air photography available was of such poor quality as to be almost useless….The reconnaissance survey was conducted using… compass traverses…Trained recorders sketch-mapped the vegetation and land use …around each sample point, and altitude was measured with an aneroid barometer. Soil horizons were laid out in lengths of split bamboo. These methods, developed by Harry Vine after experience with Charter in the Gold Coast, proved very effective. '(Young, 2007, p 74).

A variant of the large team approach was used in Northern Rhodesia (now Zambia) (Ballantyne, 1962). However, it was soon scaled back, and Brammer (1973) later worked there with one helper and one vehicle.

There are limited references in the SLUS reports to the soils of, and publications from, neighbouring Francophone territories. However, Charter (1949a). Brammer (1956a), Radwanski (1956a), Radwanski (1956b) mention *'boval'* landscapes which are widespread in Francophone West Africa (Aubreville, 1947). They are formed where initially low-lying areas of plinthitic soils were elevated by tectonic uplift or base level depression. The soils were drained, dried out and became indurated. The resultant ironstone is more competent than the surrounding non-indurated soils, and differential erosion left them as scarps and plateau edges in the inverted topographies (Fig. 2). Brammer (1956a) described iron crust soils observed during a study tour in Haute Volta (now Burkina Faso). Charter's (nd.) notes show his familiarity with concepts and terminology of Francophone tropical soil science.

4.2. Staff development

The need for a cadre of competent technicians for the SLUS style of surveys meant that Charter gave much attention to staff development. He personally trained many middle school leavers to become soil survey technicians. He was a gifted natural teacher, and he was helped by high education standards in the lower and middle schools. He disaggregated the soil survey process into separate tasks, and trained specialist technicians for each discrete segment (Charter,1948). His systematic training resulted in SLUS having enough technicians to undertake its ambitious survey programme, and resulted in Ghana having a fully

localised soil survey before other sub-Saharan African territories. As well as training technicians in-country, SLUS facilitated the professional education of future soil surveyors and S.V. Adu studied soil science at Aberdeen University, UK (Adu and Asiamah, 2003).

5. Charter and soil classification

Because Charter intended his Caribbean and Gold Coast reports to be of practical use to land managers and policy makers, he concentrated on soil series as the fundamental units. These were what the surveyor differentiated in the field and were the practical entities that varied in management attributes. In SLUS reports the series were usually described together with their toposequential spatial associates in soil mapping units, such as consociations, simple and compound associations, and complexes, rather than by taxonomic groups.

However, Charter was always interested in the classification of tropical soils. He identified 24 soils *series* and grouped them in five *suites* on Antigua, with four *series* in one *suite* on Barbuda. The suites were differentiated on soil parent materials (Charter 1937). Charter's classification was based on the system then current in the USA (Hardy, 1949), with some tropical modifications by Robinson (1929).

Turner and Charter's (1939) classification of the soils of the Trinidad sugar estates was more locally oriented. It was a hierarchy with three levels; Fasc, *Suite,* and *Series*. The well-drained Esperanza Fasc had one suite with three series. The soils with seasonally impeded drainage in Waterloo Fasc were grouped in six suites with 22 series. The Nariva Fasc consisted of undifferentiated poorly drained soils. For detailed agricultural applications, series could be subdivided into *types* on texture and *phases* on other minor differences (Turner and Charter, 1939).

Charter classified the soils in his reconnaissance survey of northern British Honduras in another one-off hierarchy (Table 1). It is quite complex and the three upper ranks were differentiated mainly on environmental factors, with differentiation on soil morphology only in the fourth (*Suite*) and fifth (*Series*) ranks. As in Trinidad, the subdivision of series into *phase* and *type* was optional (Charter, 1940).

The classification that Charter developed at WACRI and instituted at SLUS (Table 2) was also hierarchical (Brammer, 1956b, 1959, 1962). There was some variation in the designation of the third and fourth ranks (Table 2), with 'Family' being dropped and 'Great Soil Group' (GSG) retained alone for the third rank, with the fourth rank becoming 'Great Soil Subgroup' (GSS) in later versions (Brammer, 1959, 1962). The system is genetic, with environmental factors identified as important criteria at several levels. Although not mentioned in the formal structure, it is clear from the SLUS reports that series could be subdivided into types and phases as needed.

The Climatophytic Earths of Order 1 are equivalent to mature and well-drained zonal soils in the USDA genetic classification of 1938 (Baldwin et al., 1938). It includes all of the bright yellowish and reddish well-drained soils of the uplands. This order contains virtually all of the cocoa soils and therefore became the most studied and subdivided. The Topohydric Earths of Order 3 includes nearly all of the soils with impeded drainage, and is extensive and much subdivided. It is more or less equivalent to the intrazonal soils in the 1938 USDA system. The Lithochronic Earths of Order 4 are shallow, stony and immature and are azonal in the 1938 USDA terminology. They are not subdivided below suborder rank, and the GSS are renamed versions of the suborders. The montane soils of Order 2 do not occur in Ghana and their separation reflects Charter's familiarity with the pantropical pedological literature, and allowed for possible later extension of the system to become pantropical.

Table 1
Structure of Charter's classification of soils of northern British Honduras (Charter, 1940).

Rank	Taxon name	Main criteria
1	Division	Regional topography – flatland or mountain
2	Group	Permeability of parent material
3	Fax	Internal and external drainage
4	Suite	Similar profile morphology on lithologically similar parent material
5	**Series**	**Same profile morphology on lithologically identical parent material**
*6**	*Types*	*Minor textural variants of series*
*7**	*Phase*	*Subdivisions of series based on depth and/or stones*

* Optional subdivisions.

The names of the taxa were eclectic, derived from English, Russian, German, Afrikaans, and the USDA 1938 system. Important new local names were 'Oxysol' and 'Ochrosol' for subdivisions of the Latosol GSG. The Oxysols are brownish, well drained and occur mainly in areas of high rainfall. The Ochrosols tend to be redder and occur in areas of lower rainfall. They are both divided on vegetation, into forest, savannah, and thorn thicket variants. The forest soils have higher contents of organic matter but lower base status. Another locally coined name in the Climatophytic Earths was Basisol for strongly structured, eutrophic, and dark reddish soils derived from mafic parent materials. At GSS level these are designated as Rubrisols. The ecological and agronomic need to differentiate these soils at a high taxonomic level has been reiterated several times since Charter (Young, 1976; Baillie, 1996).

Charter did not see the SLUS classification as final, but his early death precluded him from updating it. Whilst at the International Congress of Soil Science in Leopoldville, he wrote and presented an impromptu overview of tropical soil classification (Charter, 1954c). He revised it during the remainder of his life, and SLUS issued a modified version posthumously (Charter, 1957). He strongly recommended that soil classification should continue to be *'genetical'*. He perceived soils as part of landscape, and felt that their classification should reflect their ecological and environmental contexts. He was uncharacteristically scathing about phenetic classifications that are based solely on profile attributes, with few assumptions or interpretations of a soil's formation. Charter used terms like '*emotionally feeble*' and '*completely devoid of … philosophical harmony*' (Charter, 1957, p2) for such systems. However, both of the main current international systems, the World Reference Base (FAO-IUSS, 2015) and Soil Taxonomy (Soil Survey Staff, 1999), are basically phenetic, and take little account of external environmental factors, except for rainfall and temperature. Charter's contextual paradigm has therefore not been adopted internationally.

Charter (1957) does not propose a new system but discusses the main SLUS classes, including some with their former names, such as pedalfer and pedocal. He goes into more detail for possible tropical pedotaxonomic developments in a set of undated personal longhand pencil notes (Charter, nd). Considering their personal nature and two thirds of a century of paper yellowing, the notes are remarkably legible and easy to follow, even now. He made several fresh starts at classification, and these are mixed in with material on pedology and agronomy. Some of his proto-classifications use van der Merwe's (1940) Si:Al molar ratios as indicators of mineral weathering and clay mineralogy. This emphasis on weathering stage echoes that in Francophone and Lusophone Africa at that time, and in the pan-African system of the Commission for Technical Cooperation in Africa (CCTA) (D'Hoore, 1964). Charter uses CCTA terms such as 'ferralitic' and 'allitic' to indicate degrees and outcomes of weathering. He uses the term 'eluvial' but to indicate general leaching rather than specifically for translocation processes. As in the SLUS system, he borrows class names from a variety of sources.

Charter's soil classifications in the Caribbean (Charter, 1940; Turner and Charter, 1939) were genetic, and somewhat similar to USDA systems, particularly that of Baldwin et al. (1938). Charter continued to interact with US soil scientists, especially C.E. Kellogg, one of the authors of the 1938 system. They had met in the Belgian Congo, and

Table 2
Structure of Charter's classification of soils of the Gold Coast. (Brammer, 1956a, 1956b, 1962).

Rank	Taxon name	Main criteria
1	Order	Four Orders differentiated on dominant soil forming factor or factors
2	Suborder	Drainage for Orders 1 and 3. Parent material in Order 4. Order 2 is not subdivided.
3	Great Soil Group (GSG) *(later GSG family)*	Profile macro-morphology & base status for Suborders in Orders 1 and 3. Suborders in Order 4 & all of Order 2 & are not subdivided
4	Great Soil Subgroup (GSS)*(Later GSG)*	Vegetation and base status for Order 1. Profile morphology and base status in Order 3
5	**Series**	**Profile morphology and chemistry**

Charter adopted the name 'latosol' (Kellogg and Davol, 1949) for the brightly coloured well drained upland soils that make up most of the Climatophytic Earths. The two continued to communicate, and Kellogg spent two weeks in the Gold Coast in 1954, and Charter went on an extended study tour of the USA in 1955. His notes (Charter, nd) include references to soils he observed in California and the Piedmont of south-eastern USA.

Charter took full account of toposequences in his mapping, and they figure prominently in SLUS reports and maps (Fig. 2), and he clearly appreciated Milne's work on the soil catena (Borden et al., 2019; Charter, 1949c; Milne, 1947). Milne (1940) made a study tour of the Caribbean, at a time when Charter was in Trinidad, but there is no documented record that they met there. Charter lists Milne as a source reference in his notes, but makes no mention of discussions with him, unlike Herbert Greene, the UK advisor on tropical soil survey, who wrote Charter's obituary in *Nature* (Greene, 1956).

Although Charter's views on soil classification have not been widely adopted, they are still influential in their homelands. Ghana uses a local soil taxonomy that is modified from the 1956 SLUS system. The hierarchy now has an extra rank of 'family' between suborder and great group, i.e. order – suborder – family – great group – subgroup – series (Adeji-Gyapaong and Asiamah, 2003; Effland et al., 2009). The classification is practical and relevant, and ecologists differentiate the edaphic environments of Ghanaian forests according to the local soil classes, such as Ochrosol and Oxysol (Hall and Swaine, 1976). Ghana and South Africa appear to be the only countries in sub-Saharan Africa that still use local systems of soil classification, and they are the only African systems mentioned in a recent global review of soil classification (Nikiforova, 2019).

Charter's influence still persists in Belize (formerly British Honduras). Wright et al. (1959) characterised the soils there in their environmental and agricultural contexts, and classified them in *suites*, *sub-suites* and *sets*. This local classification, with some modifications, was preferred to the international taxonomies for country-wide land systems surveys in the 1980s and 1990s (King et al., 1992; Baillie et al., 1993). However, Charter's system seems to have fallen into disuse in Trinidad, and soil series there are now classified according to Soil Taxonomy (Wuddivira and Stone, 2006).

6. Charter and tropical soil science

Charter (1949a) recognised early on that many soils in the Gold Coast are not formed in residual regoliths. Many parent materials, designated as 'drift' in SLUS reports, have been moved from the site of their original weathering (Brammer, 1959; Brash, 1962; Charter, 1949a; Radwanski, 1956a, 1956b). They were mostly moved vertically by termites earthworms other soil animals, and also by treefall (Nye, 1955). As soil macrofauna preferentially excavate fine earth for the construction of their nests, termitaria, walkways and casts, the upper horizons gradually became stone-free and biogenically structured. Thus, Charter describes some forest topsoils in the Gold Coast:

'*The upper part of this horizon is finer in texture, crumbly in structure, more humic and consists almost wholly of worm casts.*'

and further notes that stones

'*would accumulate on the surface but the activity of the exceedingly numerous soil animals, earthworms, ants, termites, etc. results in fine earth being continually brought to the surface which keeps the ironstone and quartz covered.*' (Charter, 1949a).

This leads to the formation of buried stone layers, up to a metre deep. (Brammer, 1967). The development of non-residual soils of this type is exemplified by Akumadan *series* on the plateau in Fig. 2.

Some soils also receive allochthonous contributions, such as volcanic ash and especially harmattan dust (Vine, 1987). Surface wash, soil creep and mass movements laterally redistribute and mix parent materials (Charter, 1949a). Charter's (1958) visit to Tanganyika showed him that non-residual parent materials are extensive in the tropics.

Charter was interested in the improvement of smallholder agriculture throughout his career in the Caribbean (Charter,1943) and the Gold Coast (Charter, 1954b). His ecological background led to a particular interest in smallholder manipulation of bush fallows for soil management and the maintenance of fertility (Charter, 1955). This interest coincided with seminal research on shifting agriculture being conducted at University College, Legon in the Gold Coast (Nye and Greenland, 1960). Elsewhere, Charter noted that cocoa in the Gold Coast failed on acid Oxysols that were deficient in bases, but survived on the less acid and more fertile Ochrosols. He stressed the importance of magnesium as a nutrient for cocoa, and advocated its inclusion in fertilizer trials (Charter, 1953).

7. Conclusions

Charter clearly made a substantial impact on soil science and survey in Ghana. He established SLUS as a pioneering soil survey unit in Africa, and it rapidly produced high quality reports and maps. The impact of his training has faded with time as his trainees aged and retired, but his contribution is still acknowledged today by Ghanaian authors (Effland et al., 2009). His proposals for the classification of tropical soils survive in modified forms in their homelands but are neglected elsewhere. However, there is a growing recognition of the need to perceive, characterise, classify and manage soils as part of their local environment and ecology (Farewell et al., 2011; Nikiforova, 2019), and Charter's pedotaxonomic ideas may yet resurface.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.catena.2020.104957.

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