Catena 259 (2025) 109386

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Soil and geomorphology in central Africa and C.G. Trapnell's contribution to our understanding

R. Webster[a], L.M. Chabala[b], S. Sichinga[c], R.M. Lark[d,*]

[a] Rothamsted Research, Harpenden AL5 2JQ, UK
[b] University of Zambia, Great East Road Campus, Lusaka, Zambia
[c] Soil Survey Unit, Zambia Agriculture Research Institute, Mt Makulu Central Research Station, Chilanga, Lusaka, Zambia
[d] University of Nottingham, Sutton Bonington Campus, Loughborough LE12 5RD, UK

ARTICLE INFO

Dataset link: Soil map units near Petauke Eastern Province, Zambia (Original data)

Keywords:
Zambia
C.G. Trapnell
Central African plateau
Upper valley
Soil fertility
Soil geomorphology

ABSTRACT

The Zambian landscape is dominantly one of gently tilted plateaux at 1100 to 1600 m above sea level. It is mantled by soil in the final stages of weathering of the underlying Precambrian rocks, during 1 or more million years. This soil is devoid any further weatherable minerals and poor in cations and other plant nutrients. The plateaux are bevelled at their margins as stream have cut back from the down-faulted Luangwa and Zambesi valleys. This bevelled terrain, designated by C.G. Trapnell as Upper Valley, bears relatively young rich soil and a characteristic vegetation that contrast markedly from those of the plateaux. This physiographic contrast is fundamental. It is geographically and agriculturally significant, and both were recognized by Trapnell in 1930s against the prevailing view that climate was the over-riding factor in soil distribution.

1. Introduction

As the populations of sub-Saharan African countries grow, their governments seek to increase agricultural production on strictly finite amounts of land. Improved varieties of crops, better understanding of crop nutrition, control of erosion by more astute land management, and so on all help. But to what extent can traditional knowledge be brought to bear? And is legacy information from the colonial past and early post-colonial times relevant? These are questions that current administrations and their advisers are asking. One group of soil scientists and historians in particular, namely Namwanyi et al. (2024), recently set out to provide answers. They review at length publications and unpublished records of ecological and sociological surveys in Zambia, formerly Northern Rhodesia, (see Fig. S1 in the Supplementary Material) dating from 1920 to the present day. They focus on the legacy of one man, C.G. Trapnell (1907–2004), whose ecological surveys of the territory from 1932 to 1943, largely on foot, included a great deal of information on traditional agricultural practice and its variation from place to place. The government of Northern Rhodesia published the results of those surveys in two substantial reports (Trapnell and Clothier, 1937; Trapnell, 1943) and a vegetation–soil map at 1:1 000 000 (Trapnell et al., 1947). More recently the Royal Botanic Gardens, Kew, published details of the surveys, traverse by traverse (Smith and Trapnell, 2001).

Trapnell was primarily a plant ecologist. Nevertheless, with a keen eye he noted the close associations between types of vegetation and the soil on which they grew. During the early phase of the ecological survey, while in the Kafue Basin, he advanced the hypothesis that local people had adapted their subsistence agriculture to accord with the potential of the soil to support it, which they inferred from the vegetation. His observations confirmed this hypothesis (Trapnell, 1937) and provided the basis for his practice in the rest of the survey.

With almost no laboratory analyses on which to draw, Trapnell correctly surmised that the soil on the extensive plateaux was so poor in plant nutrients that continuous cultivation of the same land could not be practised. Trapnell identified distinctive systems of cultivation on the northern and southern plateaux of Zambia, and variants within these (e.g. Trapnell and Clothier, 1937; paragraph 121 et seq.). Farmers would lop trees, pile the branches in small gardens and burn them so that the ash provided the necessary plant nutrients for their crops. On the southern plateau the land would then be hoed up and planted to sorghum and a smaller area of maize, and undersown with beans. Cultivation would be maintained for two to four years, with some extensions of the gardens opened in successive years as the first-burned land was abandoned. Sites would then be abandoned to restore their fertility under bush fallow. William Allan and colleagues (Allan et al., 1945; Allan, 1949) were to extend Trapnell's observations in more

* Corresponding author.
E-mail address: murray.lark@nottingham.ac.uk (R.M. Lark).

https://doi.org/10.1016/j.catena.2025.109386
Received 16 February 2025; Received in revised form 15 July 2025; Accepted 15 August 2025
Available online 26 August 2025

detailed surveys across parts of Zambia, and assessed what he called the 'carrying capacity' of the land: the number of people who could be supported by cultivating available land according to traditional practices and allowing restoration of fertility under a bush fallow of sufficient duration. In most of the Northern Province and Central Province the system could support no more than two or three people per square kilometre (Allan, 1965).

At the plateau margins in the western parts of Zambia where Trapnell began his field work (Trapnell and Clothier, 1937), he noticed that the vegetation cover, dominated by species of *Acacia* and *Combretum*, contrasted with that of the plateau, an observation confirmed by interpretation of limited airphotography of parts of southern and central Zambia. Trapnell surmised, again correctly, that the agricultural potential of this land, which he referred to as the Upper Valley, differed from the plateau. His field observations confirmed that the soil here was more fertile, able to support a denser population and maize production for markets to which farmers had access after development of the rail line from Lusaka to Livingstone. Subsequently Trapnell was to find similar soils in equivalent physiographic positions in the east of the country, although with somewhat different vegetation, although similarly distinctive from that on the plateau (Trapnell, 1943).

When Trapnell began his field work the only continental-scale account of the soils of Africa, and attempt at a map, was in the book by Shantz and Marbut (1923). The influence of V.B. Dokuchaev is shown where Shantz and Marbut (1923) wrote ... *climatic forces are the predominant soil-forming agencies of the world, obliterating or reducing to a subordinate position in a relatively short time the influence of the parent rock material* (page 120). This was explicitly rejected by Geoffrey Milne and colleagues when they produced the Provisional Soil Map of East Africa (Milne, 1932, 1936), emphasizing differences between soil over contrasting parent material. Jenny's (1941) account of six 'factors of soil formation', none of which is treated as dominant, is agreed by most soil scientists now but, when pioneering soils research was being done in Africa in the 1930s, Shantz and Marbut (1923) were very influential. We believe that Trapnell received too little recognition, both in his day and now, for his insight into the importance of relief as a factor controlling the distribution of the most productive soils in southern Zambia.

Our objective in this paper is to revisit and reassess Trapnell's conclusions about the soils of the Upper Valley using sources of information obtained subsequent to his work. These are details of the soil as recorded by one of us (RW) during survey in the late 1950s, and data collected more recently in a soil survey of Zambia's Eastern Province (Zambia Agriculture Research Institute, 2020) and soil sampling of farm plots that belong to rural households (Central Statistical Office et al., 2015) at sites on the plateau and Upper Valley near Petauke in Eastern Province. We also use these data to compare Trapnell's map units with those of a more recent soil map of Zambia (GRZ, 1991). We discuss the implication of our findings, with particular reference to what they tell us about the potential value of Africa's legacy of past surveys for addressing current problems.

2. The physiographic setting

The Zambian landscape is dominantly one of gently tilted plateaux at 1100 to 1600 m above sea level. It results from intermittent continental uplift since Karroo times (360–255 million years before present) with intervals long enough for peneplanation. Dixey (1942, 1944)) distinguished several erosion surfaces in Central Africa, the most extensive of which he dated to the Miocene and later Tertiary eras. He remarked on the near constant height of the Miocene land surface at 1200 to 1400 m from Angola in the west to Malawi in the east, a distance of approximately 2900 km, and from Zimbabwe in the south to the northern border of Zambia and beyond at least 3200 km away (Dixey, 1942). Recently, Daly et al. (2020) have examined the evidence geophysically. They conclude that Dixey's inference about the age and extent of the plateau (or plateaux) was essentially correct, but that the different levels of Tertiary age recognized by Dixey arose by local flexing and warping of the underlying rock mantle. They write '… the many different levels distinguished by Dixey (1944) … appear to be largely or entirely the result of deformation of a single, dominant surface'. They treat it as 'a singular "regional datum" from which to map'; their words. It is certainly an ancient land surface, several million years old. Further, it extends far beyond Zambia's boundaries north into the Katanga province of the Democratic Republic of Congo and East Africa and south into Zimbabwe and South Africa. In Zambia the rocks are dominantly gneisses and schists of Precambian age, the so-called 'Basement Complex'. They are deeply weathered to at least 10 m. Deeply weathered sandstones and shales of the Precambrian Katanga formation underly north Central Zambia. There are locally dolerites and limestones of similar age, and they too are deeply weathered. There are also quartzites that have resisted weathering, and some of these stand proud of the plateau surface.

There are smaller areas of higher land, in particular the Nyika Plateau on the north east border of Zambia with Malawi at 2100–2200 m above sea level and 3700 km^2 in extent. This is generally thought to be a remnant of a peneplain of Jurassic age, though the current surface has been eroded into rounded interfluves, and, according to McMillan et al. (2022), in multiple cycles. Webster (1970) describes the soil there. Another small remnant of an older surface standing at around 1700 m occurs along the border between Zambia and Tanzania, about which more below.

2.1. Local land forms and patterns

Fig. 1 shows the broad distribution of landscape units in Zambia, generalized from a map of the former Central African Federation (Thompson et al., 1960). Note that the Kalahari Sand unit, dominated by the eponymous aeolian sand, also includes regions with clay and alluvial floodplain grasslands. These are of comparable size or larger to the Kafue Flats unit, which is shown on this map in the context of the drainage around the western delineation of the Upper Valley. The plateau region north of the Luangwa river and the Kafue Flats also includes areas of permanently flooded swamp, former lake basins and hydromorphic floodplain grasslands.

Apart from the few remnants of older land surfaces and isolated hills of quartzite that have resisted weathering the Plateau is a vast almost planar land surface. It is drained by more or less broad, shallow depressions, *dambos* a word in the Nyanja language for low-lying wet marshy areas, widely understood across Zambia, Zimbabwe and Malawi alongside local vernacular terms. Dambos are described in detail by Mäckel (1973).

. The interfluves are several km across. The local relief is typically 20–25 m from watershed to the dambo floor—see, for example, Fig. 1 in Webster (1965). The combinations form characteristic patterns, which can be viewed on satellite imagery on platforms such as Google Earth. Fig. 2 shows a 1-degree × 0.5-degree extract from a Landsat/Copernicus image obtained in 2021. The position of Petauke, a town in Zambia's Eastern Province is indicated. To the east of Petauke is seen typical catena country of the Plateau. The location of this extract is indicated on a map of Zambia in the Supplementary Material (Fig. S2).

The plateau country is cut by two major grabens in which lie the Luangwa and lower Zambezi valleys several hundred metres below the plateaux. The original faulting that produced them dates from Permo–Triassic times, though with further deepening as part of the East African Rift System (Daly et al., 2020). Steep escarpments produced by the faulting have been themselves cut into steep-sided narrow valleys by streams. Extending further back from this deeply indented terrain is land that slopes gently downwards away from the plateaux; Trapnell termed it 'Upper Valley', which he attributed to 'normal erosion'.

Namwanyi et al. (2024) present a generalized map of the Zambezi Escarpment, the Upper Valley terrain and Plateau in the south of

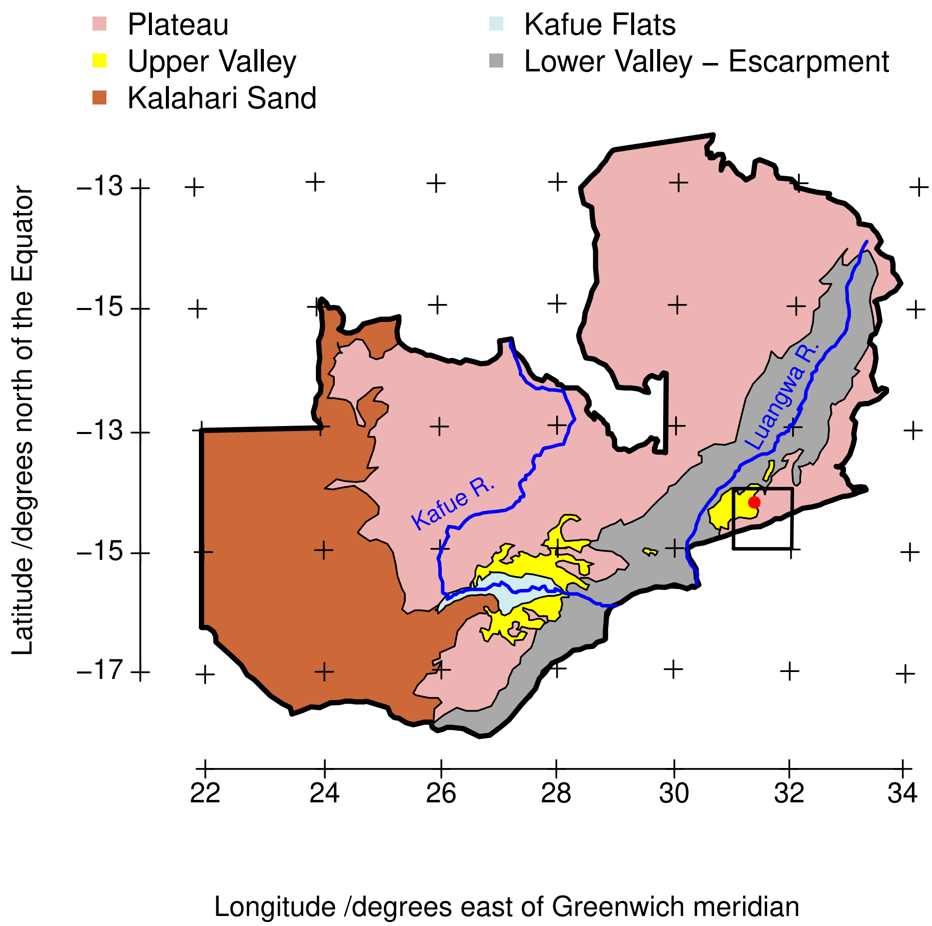

Fig. 1. Generalized map of Plateau, Upper Valley, Kalahari sand and Escarpment with Lower Valley units in Zambia based on Thompson et al. (1960). Also shown are the seasonally flooded hydromorphic soils of the Kafue Flats and the courses of the Kafue and Luangwa Rivers. The location of Petauke is shown (solid red disc) and the region represented in Fig. 3 (black box). Tick marks are at two-degree intervals of longitude and latitude.

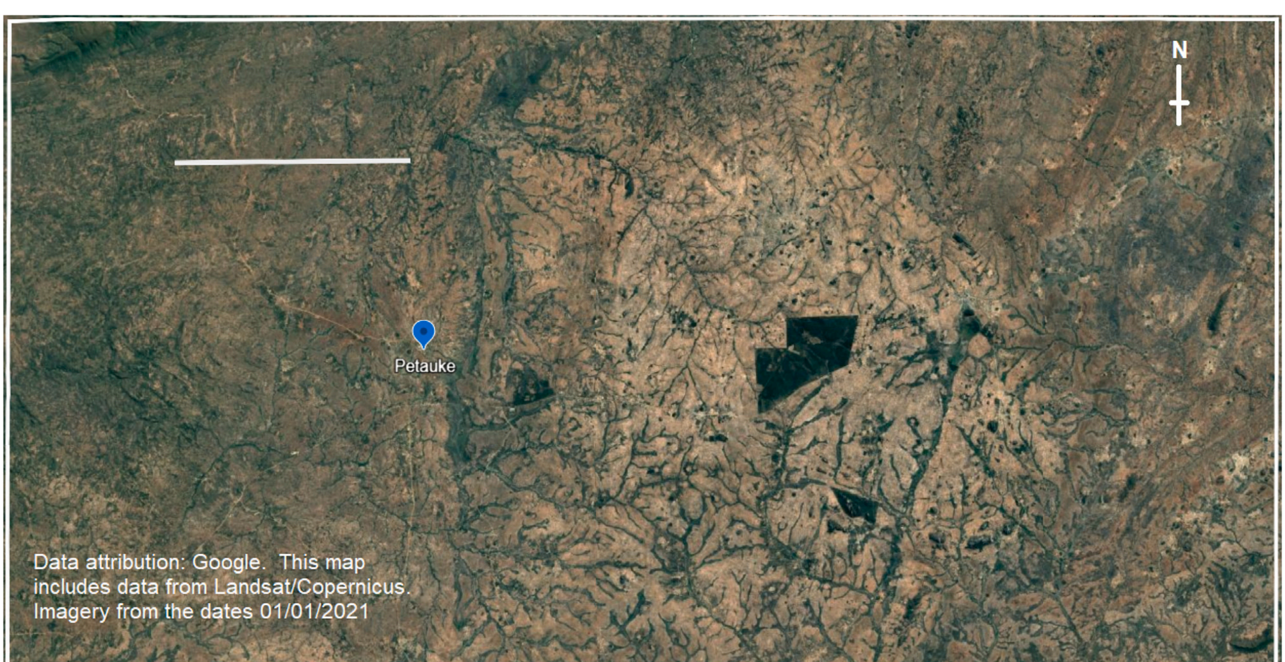

Fig. 2. Satellite image of the terrain near Petauke, Zambia, between 31 and 32 degrees East and 14 and 14.5 degrees South. The horizontal white scale bar is of length 20 km.

Zambia (their Fig. 2). The map has no contours. The towns shown, however, Mazabuka at 1067 m, Magoye at 1110 m and Monze at 1027 m above sea level are all more than 230 m lower than the plateau at Lusaka, which stands at 1297 m. One can readily imagine from the map that streams have cut back from the Escarpment in the south east of the map and from the down-faulted low-lying depression, the Kafue Flats, in the centre and north east. In doing so they could well have removed some 230 m worth of material as erosion products. Another large area of Upper Valley lies between the Luangwa Valley and the Plateau in the east of Zambia, and it appears prominently on the vegetation–soil map (Trapnell et al., 1947). Its principal town is Petauke at 1025 m above sea level, and is about 100 m lower than the plateau along the nearby border with Mozambique. This area is shown in Fig. 2, and the position of Petauke is shown on Fig. 2 of the supplementary material.

The Upper Valley landscape, as viewed from above, is quite different from that of the plateau. It can be seen in the area to the west of Petauke in Fig. 2. There are streams, but no evident dambos. Nor are there evident catenas. At the present time much of the land over both the plateau and the Upper Valley landscape is cultivated or cleared of woodland. In Trapnell's time cultivation was widespread in the Upper Valley, in contrast to the plateau where, away from the towns, the land remained under some form of woodland and was sparsely populated.

3. Trapnell's observations of the soil and vegetation

3.1. Plateau soils

Trapnell introduced 'Plateau group' as a class of soils with characteristic vegetation in his contribution to the proceedings of the Second Meeting of East African Agricultural and Soil Chemists held in Zanzibar in 1934 (Trapnell, 1935). Trapnell and Clothier (1937) observed that the Plateau soils show some variation in colour and texture but are all formed by 'long periods of seasonal leaching on eroded topography' (paragraph 20). They noted a tendency for nodular or concretionary ironstone to be present at depth, near the underlying regolith, particularly where drainage is most restricted. Within the group they distinguished Older Ironstone Soils, pallid, shallow and partly denuded with nodules or concretionary ironstone and very limited agricultural potential except for millets, from younger Light-Coloured Plateau Soils formed on partially regraded plateau surfaces and more fertile but restricted Red and Brown Plateau soils formed in residual or colluvial material.

Because of the financial constraints on the government of Northern Rhodesia in the 1930s there was no soil chemist at the time of Trapnell's survey, so detailed analytical data on Plateau soils were not provided at the time. Subsequently, descriptions of soils on the plateaux with supporting chemical analytical data have been undertaken — see, for example, Ballantyne (1957), Webster (1965), Wilson et al. (1956) and others, including Anderson (1957) for the Kongwa district of Tanzania. We provide a profile description for a Plateau soil from the Copperbelt province, made by one of us (Webster, 1965) in the supplementary material (Profile RW.0).

There are also four descriptions of soil profiles published in the report of the Central African Rail Link Development Survey (Anonymous, 1952). One objective of this survey was to identify a viable route for a central African rail line by taking in areas of productive soil where crops could be produced for transport to remote markets. For the then Northern Rhodesian section of the survey the team used Trapnell's soil classes as basic organizing units. They identified Plateau soils with the Latosol great soil group of the then USDA soil classification (Baldwin et al., 1938) which preceded the Soil Taxonomy, and divided the profiles into subgroups based on colour and organic content. See Profiles CARLDS 6, 10, 21 and 32 in the Supplementary Material.

The Plateau soils occur in repetitive catenary sequences, typically red or reddish brown (2.5 YR on the Munsell scale) on interfluve crests to yellowish brown or greyish brown (10 YR) at dambo margins. The sequences from the crest to the dambo margins are accompanied by increases in the proportions of sand, the actual amounts depending on the mineral composition of the original rock, and corresponding decreases in the proportions of clay (< 2 μm). Proportions of clay range in the subsoils (below 30 cm) from around 45% to less than 20%. Above 30 cm the soil is typically more sandy, having lost much of its clay selectively by surface wash. Particles of silt size (2–20 μm) rarely comprise more than 5%, although this might be exceeded over some parent materials including Katanga sediments (see Profiles CARLDS.6, 10 and 32 in the supplementary material).

Recorded larger proportions, in particular those of the redder soil, can result from incomplete dispersion for mechanical analysis (Webster, 1965). The structure is one of microaggregates of varied stability to wetting. Trapnell et al. (1986) illustrate it with colour photographs. Iron-rich gravel, larger nodules and in many places a massive concretionary layer (now almost always called 'laterite') occur within the uppermost 2 m. The records rarely describe profiles to greater depth. Nevertheless, we know from wells and road cuttings that intensely weathered rock is much thicker—at least 10 m.

These soils are Ferralitic in the terminology of the Soil Map of Africa (D'Hoore, 1964) and as Ferralsols in World Reference Base (WRB, 2022).

All reports on the Plateau soils comment on their paucity of exchangeable cations, Ca^{2+}, Mg^{2+} and K^{+}, and of P, their small cation exchange capacities (CECs) (around 4 $cmol_c\ kg^{-1}$), base saturation (10–20%) and acidity (pH in water, 5 to 6).

Dambo soils of Zambia are typically seasonally waterlogged and are associated with drainage networks on the plateaux; they are hydromorphic variants of the well-drained plateau soils. The centres of some dambos over acidic and kaolinitic parent material are permanently waterlogged, particularly in the Northern Province of Zambia. Dambo soils are more or less organic; in the wettest situations their uppermost horizons are peat. Their CECs depend largely on their contents of organic matter. These dambos are topographically the same as the 'mbugas' of East Africa and the dambos of drier Zimbabwe, but they are not rich in cations, they lack carbonates, and their clay fractions are more kaolinitic than smectitic, unlike soils of the mbugas.

At the time of Trapnell's surveys the vegetation on the plateau was 'miombo' woodland, dominated by species of *Brachystegia* and *Julbernardia* with a more or less sparse understorey of herbs and woody shrubs.

On the plateau south and east of Petauke, Trapnell (1943; paragraph 243 et seq.) observed what he called the Eastern Plateau cultivation system. As elsewhere on the plateau, cutting branches to burn for ash was a standard practice. Crops were typically grown on small mounds of hoed-up grass and soil. Maize was the staple crop, with some millet grown for beer-making and beans undersown. The system showed pronounced variations, however, with climatic variation across the plateau, and variations among ethnic groups with greater or lesser emphasis on millet crops. Poorer land was cultivated this way for two or three years, followed by 20 to 30 years of bush fallow. On better land, extensions of the gardens could be opened and cultivation sustained for up to five years, the fallow period was typically 10 to 25 years, but Trapnell noted that already in places there was pressure to shorten, or even abandon, the fallow.

4. Upper valley soils

The Upper Valley group was one of the physiographic associations of soils which Trapnell (1935) described for the Zanzibar meeting. Trapnell and Clothier (1937) noted that this group was first identified because of its vegetation cover 'wholly distinct from that of the Plateau soils which surround them' (paragraph 28). Trapnell et al. (1947) note that the Upper Valley soils are associated with 'lower areas of younger relief' relative to the Plateau. Their distinct physiographic origin is reflected in larger cation exchange capacity and base saturation than the Plateau soils because of their formation in materials made available by normal erosion of the plateaux, and in drier and warmer conditions than those thought to have pertained during most of the period of pedogenesis on the plateaux themselves (Trapnell, 1943).

Trapnell's (1943) description of the Upper Valley soils around Petauke in the Eastern Province of Zambia so well matches the field observations made by one us (RW) in a subsequent survey of Petauke District prior to its being opened for re-settlement that we repeat it here. It is from paragraph 23 of Trapnell's report.

> … these eastern soils … take the form of very rich, deeper coloured and heavier loam soils with a pronounced clod structure. Dark chocolate and chocolate-brown soils of this type, varying to chocolate-red, are found in quite considerable belts near Nyimba and elsewhere in Petauke District, and recur again towards the Lutembwe and in some valleys beyond it in Fort Jameson [now Chipata] District. In one area near Fort Jameson they give place to practically black clay-loam. Typical residual profiles show one or two feet or even two feet six inches of dark chocolate-brown "nutty" to cloddy soil with small glossy cleavages—or in the best examples a more friable crumb-structure surface soil—grading downwards into a cloddy, more coherent and finally more clayey subsoil of reddish-brown colouration, through which small black, softish nodular concretions or harder pellets are sometimes distributed. Chocolate loams with definite iron nodules from within eight inches to three feet below the surface are occasionally found in immediate contact with the red loams of Fort Jameson District, while shallower, brownish-red and gravelly or more clayey variants occur on denuded rises in Petauke District. In Fort Jameson District, however, such contact soils more often take the form of restricted belts of a deep somewhat clod-structured but friable chocolate-red loam with a coarse sand fraction, which grades downwards after some eighteen inches towards a redder clay-loam subsoil. These soils, of admirable texture and absorptive qualities, are of considerable local agricultural importance. They are very occasionally replaced by a heavier deep brown to chocolate-brown cloddy loam of an exceptionally strong-textured type, …'

We can add little to Trapnell's summary even though some of his terms might seem old-fashioned. The soil occurs almost everywhere on gentle slopes. The subsoil below about 30 cm is blocky with clay skins, The structure that Trapnell (1943) called 'cloddy' we should now call 'angular blocky', and his 'glossy cleavages' are evidently clay skins, which appear in thin section as birefringent flow structures. In many profiles there is a horizon line of angular quartz stones (originating from quartz veins in the rock), and this overlies weathering rock within 2 m. Weatherable primary minerals such as feldspars and mica are abundant throughout the profile. The iron-rich nodules mentioned by Trapnell are exceptional; we have not seen any forming distinct horizons as they do in plateau soils.

The Soil–Vegetation map made by Trapnell et al. (1947) showed a large area of Upper Valley terrain around the township of Petauke in Zambia's Eastern Province. Trapnell (1943) had judged it suitable for agriculture. In 1959 the Northern Rhodesia government took the hint and planned to re-settle people from overcrowded 'Reserves' on to some 200 km^2 of previously unpopulated land there. In preparation it commissioned a survey of the soil and land resources, which was undertaken by one of us (RW). In the Supplementary Material we provide descriptions of four representative profiles of Upper Valley soils from this survey with supporting laboratory analyses (Profiles RW1–RW4). In addition we include a description and analyses from one profile in Zambia which the Central African Rail Link Development Survey (Anonymous, 1952) identified as an Upper Valley soil (Profile CARLDS 30).

The soils are Ferruginous Tropical soils in the terminology of the Soil Map of Africa (D'Hoore, 1964), and Nitisols in the classification of WRB (2022).

In Fig. 3 we plot the particle size distribution for the top sample layer which was analysed for each of the Plateau and Upper Valley soils with profile descriptions in the Supplementary Material. The radius of the plotting symbol is proportional to CEC. This shows the finer texture of the Upper Valley soils relative to the Plateau soils, and the associated larger CEC.

Fig. 4a shows a generalization of the map units of Trapnell et al. (1947) in a 1-degree × 1-degree area around Petauke. This shows an area of Plateau soils with a large extent of Upper Valley. The dominant map units in this area are listed in Table 1.

In western parts of the country, described by Trapnell and Clothier (1937), the Upper Valley soils supported two vegetation types. At the transition between the plateau and the Upper Valley terrain the soils were mainly residual, well-drained, light-textured and friable. The vegetation was primarily *Combretum molle*, a shrub or small tree, in association with *Pericopsis angolensis* or other tree legumes of the pea subfamily (*Papilionoideae*). Finer and more coherent soils formed in colluvial material on the Upper Valley supported *Acacia* spp., in particular *A. polyacantha campylacantha*, and these 'Thorn soils' were 'the best maize land and dryland grazing in North-Western Rhodesia' ((Trapnell and Clothier, 1937); paragraph 30).

In the eastern parts of the country (Trapnell, 1943) the *Acacia* and *Combretum* – *Pericopsis* vegetation was largely absent, and the Upper Valley was associated primarily with *Pterocarpus–Combretum* scrub woodland, low woodland or scrub grassland.

The Upper Valley soils which Trapnell (1943) observed in eastern Zambia were of higher quality for farming than the associated plateau soils. The red loams of the Upper Valley might be cultivated for up to eight years, with a recovery period of similar length (eight to ten years). The best soils of the Upper Valley were used in permanent or semi-permanent cultivation, with eight to ten years cultivation practiced on one patch of land while a neighbouring area goes through a recovery period of similar duration.

5. Northern hill soils

The Upper Valley soil, the vegetation identified and the areas mapped as such by Trapnell et al. (1947) all occur in the drier parts of Zambia with mean annual rainfall of less than 750 mm and mean annual temperature of approximately 21 °C. Along the border with Tanzania near Tunduma (in Tanzania) and Nakonde (Zambia) there is a remnant of a pre-Miocene land surface at around 1720 m above sea level. Trapnell (1943) mentioned it (in paragraph 2), and he speculated that there might be similar soil in that wetter north of the country, but he did not record it (Trapnell, personal communication to RW). It is notable that, in the Soil Map of Africa, to which Trapnell contributed (D'Hoore, 1964) the delineation of undifferentiated Ferrisols, associated with Ferralitic soils is extended somewhat across the border into Zambia. There are indeed small areas of dissected land with what might be considered wetter analogues of the Upper Valley soil there. These are present on the side slopes of 6 to 10% of narrow valleys cut into the plateau. The climate is both wetter and cooler than in the lower south: mean annual rainfall at Tunduma is 976 mm and mean annual temperature is 18 °C. It has the potential for faster weathering and leaching of the weathered products than in the south of the country. Profile 5 and 6 in the Supplementary Material are typical examples.

Two features in particular are noteworthy. (1) The CECs range from 9.04 $\text{cmol}_c\ \text{kg}^{-1}$ in the topsoil to 14.36 in the subsoil at 90–120 cm in Profile 5, and there are mica flakes throughout the profile. The silt fractions (2–20 μm) lie in the range 10 to 18%; they contain weatherable minerals. In that respect they are like the Upper Valley soils and contrast with the plateau soils which contain no weatherable minerals and rarely have silt contents of more than 4%. (2) The concentrations

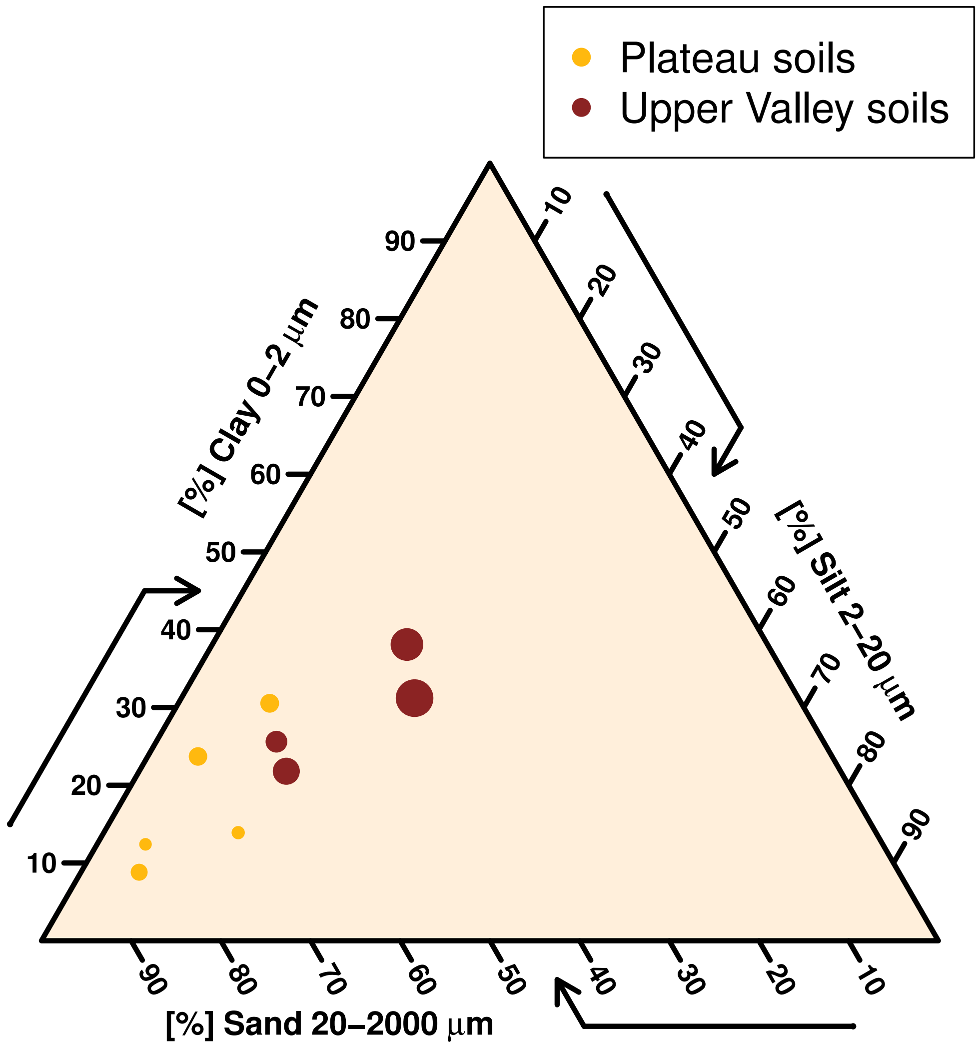

Fig. 3. Texture triangle showing particle size distribution at in the top sample layer for Plateau and Upper Valley soil profiles presented in the Supplementary Material. Silt and fine sand particles are defined according to the International standard (0.02 – 0.002 mm limits for silt). The radius of the plotting symbol is proportional to cation exchange capacity.

of cations and base saturation are small, like those of plateau soils, and they are acid (pH< 6 below 15 cm), unlike the Upper Valley soils.

Clay skins were not evident in the field, but flow structures were evident in thin sections under the microscope.

The soil is Ferrisol in the terminology of the Soil Map of Africa (D'Hoore, 1964), and the small area of it in the north of Zambia appears on the map in association with Ferrallitic soils. They are identified as Nitisols in the classification of WRB (2022).

6. After Trapnell: D'Hoore's (1964) *Soil Map of Africa* , Brammer's (1973) *Soils of Zambia* and *Land Resources of the Northern and Luapula Provinces of Zambia* (Mansfield et al., 1976)

The Soil Map of Africa (D'Hoore, 1964) was a collaborative effort between soil scientists across the continent, who correlated their observations with a common classification which was strongly influenced by previous work in Francophone Africa (D'Hoore, 1968). The Zambian contribution was based on the map of Trapnell et al. (1947) with Plateau soils represented predominantly as Ferralitic soils in D'Hoore's classification.

Somewhat later Brammer (1973) presented his small-scale Soil Map of Zambia with a dual legend in which map units based on classes reflecting parent material were supplemented with class symbols from the Soil Map of Africa. Brammer assigned the Plateau soils predominantly to what he called Sandveldt and Leached Sandvelt. The symbols from D'Hoore (1964) are primarily for Ferralitic soils, although some Ferrisols are also shown, which indicates somewhat less extensive leaching than is typical for Ferralitic soils.

The largest area of Upper Valley soils in the western sheet of the map of Trapnell et al. (1947) surrounds the Kafue flats. D'Hoore (1964) calls the soils of this area Ferruginous Tropical soils. Brammer (1973) includes some symbols for Ferrisols in this area as well. In contrast, the area in Eastern Province mapped by Trapnell et al. (1947) as Upper Valley soil appears as Ferrallitic soil on D'Hoore's map; that is clearly a mistake, rectified by Brammer (1973) who shows Ferruginous tropical soils in the Petauke area south of the Escarpment hills, and Ferrisols on the plateau area.

The government of Zambia, following independence in 1964, was immediately concerned with the poverty of the Northern and Luapula provinces arising principally from the poor fertility of the dominant Ferralitic soils. The Land Resources Division of the United Kingdom's Ministry of Overseas Development undertook a new survey (Mansfield et al., 1976). This added much detail to the 1947 map, mainly by distinguishing and mapping various forms of the catenary patterns of the plateau landscapes and their soils. Essentially it confirmed Trapnell's judgement.

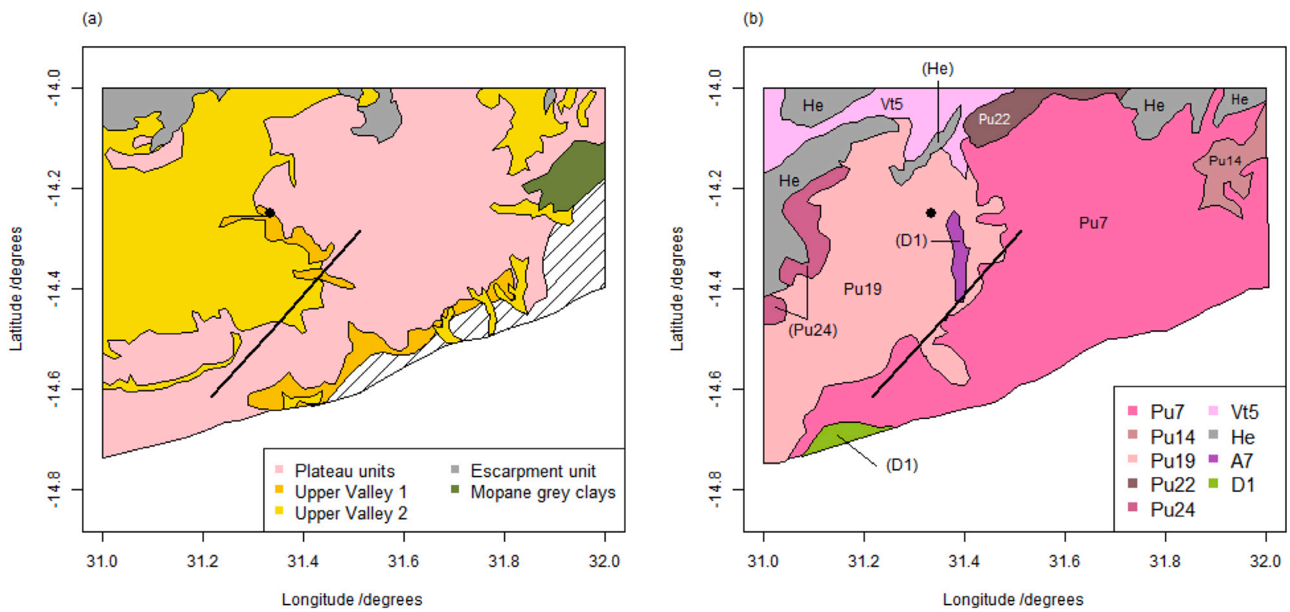

Fig. 4. Generalization of map units from (a) Trapnell et al. (1947) and (b) GRZ (1991) between 31 and 32 degrees East and 14 and 15 degrees South within Zambia. The cross-hatched area in (a) was not surveyed. In (b) the polygons are labelled, labels in brackets do not refer to the polygon which contains them but to the one indicated by a straight line. On both maps, the thick black line is the position of the transect shown in Fig. 5 and the solid black disc shows the modern-day location of Petauke.

Table 1
Map Units referred to in this paper from Trapnell et al. (1947) and from GRZ (1991).

Survey	Unit	Description
Trapnell et al. (1947)	P5	Central *Julbernardia paniculata*[a]–*Brachystegia* woodlands on Plateau soils
	P6[b]	Eastern *Brachystegia–Julbernardia* woodlands on Plateau soils
	U1	*Brachystegia spiciformis*[c] woodlands on marginal Upper Valley soils
	U2	*Combretum – Pericopsis*[d] & *Pterocarpus – Combretum* woodlands on Upper Valley soils
	E1	Eastern *Brachystegia–Julbernardia* woodlands on Escarpment soils
	S2	*Colophospermum mopane*[e]–grassland mixtures on grey alluvial clays
GRZ (1991)	Pu	Undulating plateau units
	Pu7	Acrisols.[f] Well-drained deep to very deep fine loam to clay
	Pu14	Alisols. Imperfectly-drained moderately drained fine loam to clay
	Pu15	Alisols. Well-drained moderately deep to deep friable, gravelly, fine loam to clay
	Pu19	Lixisols. Well-drained, very deep fine loam to clay
	Pu22	Luvisols. Well-drained, very deep, clay with humic topsoil
	Pu24	Phaeozems. Well-drained, very deep, friable clay to fine clay with humic topsoil
	Vt5	Rift Valley unit. Association of Vertisols and Phaeozems.
	H2	Hills and minor scarp unit. Leptosols. Well-drained, shallow, fine loam in places gravelly
	He7	Hills & faulted scarps of Rift Valley. Leptosols. Excessively – well drained, gravelly, coarse to fine loam
	A7	Floodplain unit. Vertisols. Poorly drained, very deep cracking clays
	D1	Dambos. Planosols. Imperfectly to poorly drained, very deep clay

[a] Called *Isoberlinia paniculata* by Trapnell et al. (1947).
[b] P6 is the dominant Plateau Soil unit in Eastern Province, small areas of P5 occur.
[c] Called *Brachystegia hockii* by Trapnell et al. (1947).
[d] Called *Afrormosia* spp. by Trapnell et al. (1947).
[e] Called *Copaifera mopane* by Trapnell et al. (1947).
[f] Dominant classes from FAO (1985) are quoted.

7. After Trapnell: More recent observations

7.1. The exploratory soil map of Zambia

In 1991 the Soil Survey Section of the Zambia Agriculture Research Institute (ZARI) published an Exploratory Soil Map of Zambia at a scale of 1:1 000 000 (GRZ, 1991). This map was compiled from published or draft soil survey reports, in particular a series of Province-level surveys. The legend of this map was based on physiographic units taken from the Geomorphic Legend produced by Dalal-Clayton et al. (1985). Subunits were defined within these: either simple or complex units named for soil classes (subunit level) from the revised legend to FAO's (1985) Soil Map of the World (third draft). Thus, for example, legend unit **Pu7** belongs to the Undulating Plateau physiographic unit (**Pu**), and the dominant soils are Acrisols.

The geomorphic legend of Dalal-Clayton et al. (1985) comprises four broad first-level units of which Unit 2, the Central African Plateau, underlies the soils of interest here. Unit 2 is divided into two second-level units, the Degraded and Aggraded plateaux. The former includes the 'Level to Undulating Plateau' which accounts for almost all the plateau region south and east of the Luangwa Valley with the exception of one region of 'Dissected Plateau'. Dalal-Clayton et al. (1985) describe the Level to Undulating Plateau as primarily degraded plateau surface with a dendritic pattern of drainage, including dambos, separated by 'level or broadly convex' interfluves. They note that the unit includes colluvial material on footslopes.

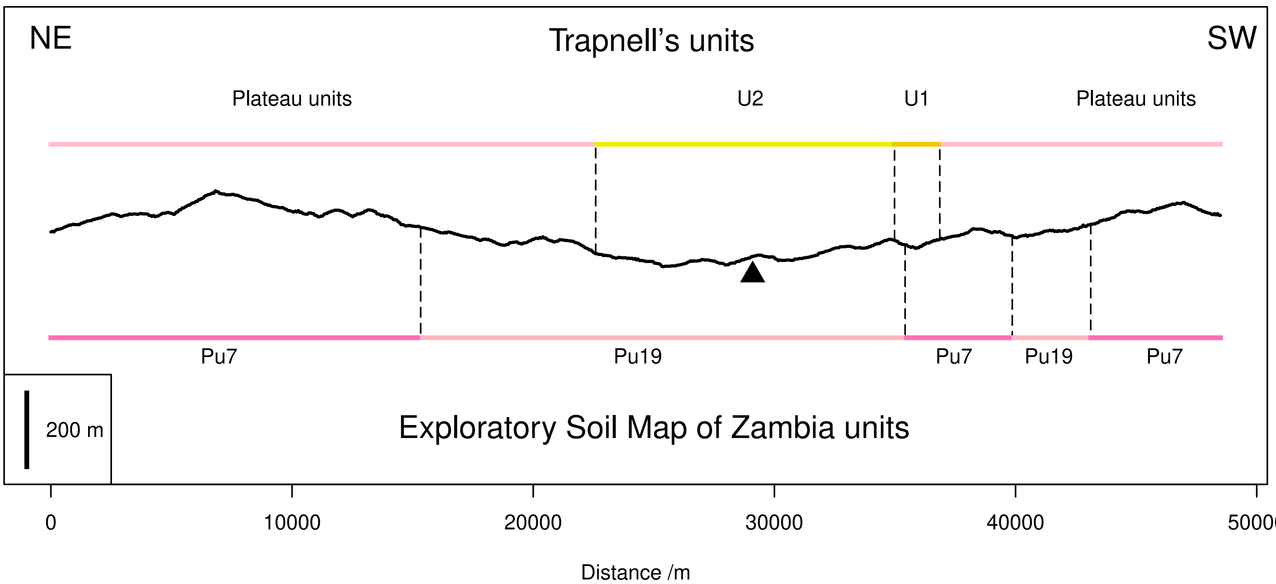

Fig. 5. Relative elevation at locations on the 50-km transect from location {31.51233, −14.28393} to {31.21722, −14.61442} (decimal degrees). Note the 200-m vertical scale bar. The absolute elevation at the north-eastern extremity of the transect is 1037 m asl. Mapping units from Trapnell's map and from the Exploratory Soil Map of Zambia are indicated above and below the elevation plot respectively by labels and bars of colour which correspond to the legends of Fig. 3(a) and 3(b) respectively. The triangular symbol shows where the transect just intersects mapping unit A7 of the Exploratory Soil Map of Zambia.

Fig. 4 shows generalizations of the map-units from (a) Trapnell et al. (1947) and (b) the Exploratory Soil Map of Zambia (GRZ, 1991) for a 1-degree × 1-degree region including Petauke in the west of Zambia. Visually, the large area of Upper Valley mapped by Trapnell et al. (1947) west of Petauke corresponds mainly to unit **Pu19** on the 1991 map with some of the area under **Pu24**. If one considers just the physiographic component of the 1991 map legend units then in this region both the Plateau and Upper Valley of Trapnell correspond to **Pu** undulating plateau, presumably with the Upper Valley corresponding, at least in part, to the colluvial footslope material to which Dalal-Clayton et al. (1985) refer.

The transect shown as a solid black line on each of Fig. 4 a,b was extracted from the Shuttle Radar Topography Mission (SRTM) 3-arc second data, accessed with the terra library functions for the R platform (Hijmans, 2024; R Core Team, 2024). Elevation is plotted on Fig. 5 along with boundaries read from the two original maps (not from the generalizations in Fig. 4 a,b). Unit **U2** of Trapnell's map occurs on the lowest topography on the transect with **U1** at the southern margin. The extent of Trapnell's unit **U2** on the transect is included within **Pu19** of the Exploratory Soil Map of Zambia. Unit **Pu7** includes much of Trapnell's **U1**, and is the main unit of the 1991 map on those segments of the transect which belong to Trapnell's Plateau unit.

It is clear that the physiographic concepts of Dalal-Clayton et al. (1985) level-3 units are too broad to make what, for Trapnell, was a critical distinction between the soils of the plateaux and the Upper Valley and the farming systems which they supported. Some of the distinctions within the **Pu** units expressed by FAO soil classes might capture this distinction. Acrisols (**Pu7**) are recognized as requiring both liming and the application of fertilizer for production of rain-fed crops in Zambia, having restricted base saturation (GRZ, 1991) whereas the base-saturation of Lixisols (Pu19) characteristically exceeds 35%.

While the use of the FAO soil classification, or the newer World Reference Base, is widespread in Africa, a question for consideration, given these observations, is whether Trapnell's comparison of Plateau and Upper Valley soils is more useful in the Zambian setting. The broader physiographic classes of Dalal-Clayton et al. (1985) might also be less useful than the distinction Trapnell made between Plateau and Upper Valley. Trapnell's approach could be characterized as a 'narrative' account of the geomorphology, identifying features (the erosion of plateaux margins) associated with particular episodes of base-level adjustment and rejuvenation. In contrast, the units of Dalal-Clayton et al. (1985) are more 'geomorphometric' defined in terms of land form. It is also worth noting that, while the distinction Trapnell made is, indeed, physiographic, it was first recognized because of the differences in vegetation cover (see, for example, Namwanyi et al., 2024).

Table 2
Joint allocation of representative profiles from Soil Survey of Eastern Province Petauke, Katete, Sinda, Chadiza and Nyimba camps to map units of Trapnell et al. (1947) and GRZ (1991).

	Units from GRZ (1991)		
Units from Trapnell et al. (1947).	Pu7	Pu19	Pu24
U1	0	1	0
U2	1	3	2
P5	2	0	0
P6	2	1	0

7.2. Soil survey report of the Eastern Province, Zambia

A report on the soils of the Eastern Province of Zambia was published in 2020 as part of the Integrated Forestry Landscape project (Zambia Agriculture Research Institute, 2020). This contains some soil profile descriptions and analytical data. The locations of georeferenced profiles, southeast of the Escarpment Hills from Petauke, Katete, Sinda, Chadiza and Nyimba survey camps, were projected on to the map sheets of Trapnell et al. (1947) and GRZ (1991). Table 2 shows how these twelve observations are distributed between the units of the two maps so, for example, there were twelve which lie within U2 on Trapnell's map and Pu19 on the map of GRZ (1991).

Texture classes (as recognized in the field, not by mechanical analyses) were reported for horizons of these profiles. Fig. 6 shows the texture class of the topmost horizon (solid disc) and the lowest horizon of each georeferenced profile plotted on the texture triangle and joined by a line. For clarity the points are jittered within the textural classes, they are placed on the boundary between two classes when the description indicated intermediate status. Note that for most sites there

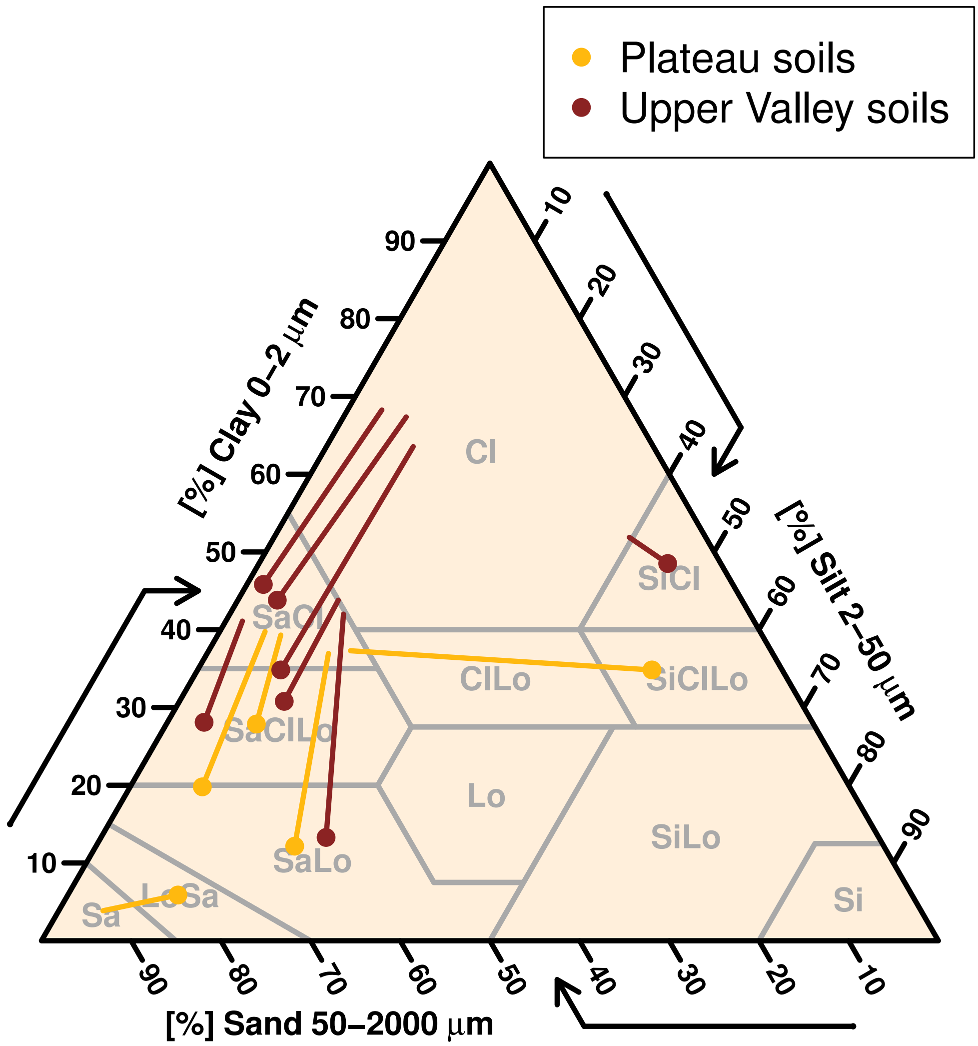

Fig. 6. Texture triangle showing particle size classes from the USDA system now used in Zambia. Profile descriptions given by Zambia Agriculture Research Institute (2020) from Petauke, Katete, Sinda, Chadiza and Nyimba which correspond to sites delineated as Upper Valley or Plateau by Trapnell et al. (1947) are represented by lines indicating the texture class of the uppermost horizon (with solid disc) and the corresponding lowest horizon (no symbol). Note that only the texture class is given in the description so the exact placings are selected for clarity, horizons indicated as intermediate between two texture classes are located at some convenient location on the boundary between those classes.

is a heavier texture at depth, and that the sites mapped as Upper Valley soils by Trapnell et al. (1947) are (all but one) in or on the boundary of clay at the lowest horizon, in contrast to all Plateau soils. The modern observations are, in this respect, consistent with Trapnell's mapping.

Mapping unit 1 of this soil survey comprises Lixisols and Nitisols, the latter consistent with Trapnell's description of Upper Valley soils and both consistent with the correspondence of unit **Pu19** of GRZ (1991) with the Upper Valley soils as noted in Section 7.1. The report of the Eastern Province survey indicates that Map Unit 1 contains the most productive agricultural soils in the vicinity of Petauke, so although the map unit is broader than the Upper Valley soils, its interpretation remains consistent with Trapnell's observations.

7.3. IAPRI surveys

The Indaba Agricultural Policy Research Institute (IAPRI) in Zambia, along with the Central Statistical Office and Ministry of Agriculture, has sampled soil on plots managed by smallholder farmers across much of the country. This activity was an adjunct to the Rural Agricultural Livelihoods Survey, done in a two-stage cluster sampling design, with census enumeration areas (EA) as the primary sampling units (or combinations of adjacent units with fewer than 30 households in each). Households were then selected within the primary units. We used the RALS 2012 survey data (Central Statistical Office et al., 2015), and extracted the observations for EAs which fell within the region around Petauke. We elected to examine the data on cation exchange capacity, as this is a fundamental soil property, related to its fertility, and not affected by management in the way that nutrient concentrations or pH might be. We extracted the primary sample unit mean value for each of 64 EAs in the region around Petauke, and projected the centroid coordinates of the EA onto the maps of Trapnell et al. (1947) and GRZ (1991) to identify the corresponding map units (Upper Valley, **U2**, or Plateau, **P6**, in the former case and 7 map units in the latter).

The EA mean values of CEC are shown as boxplots in Fig. 7 for (a) the two units from the map of Trapnell et al. (1947) and (b) the seven map units of the map of GRZ (1991). On examination of the residuals from the means for both sets of map units we transformed CEC to natural logarithms to stabilize the variance. The null hypothesis of equal means could be rejected for Trapnell's map units ($p = 0.22 \times 10^{-3}$), and the intra-class correlation was 0.37 (the proportion of the variance of the variable represented by the between-class variance). For the GRZ (1991) map the null hypothesis could also be rejected ($p = 0.03$) and the intra-class correlation was 0.21. Although there

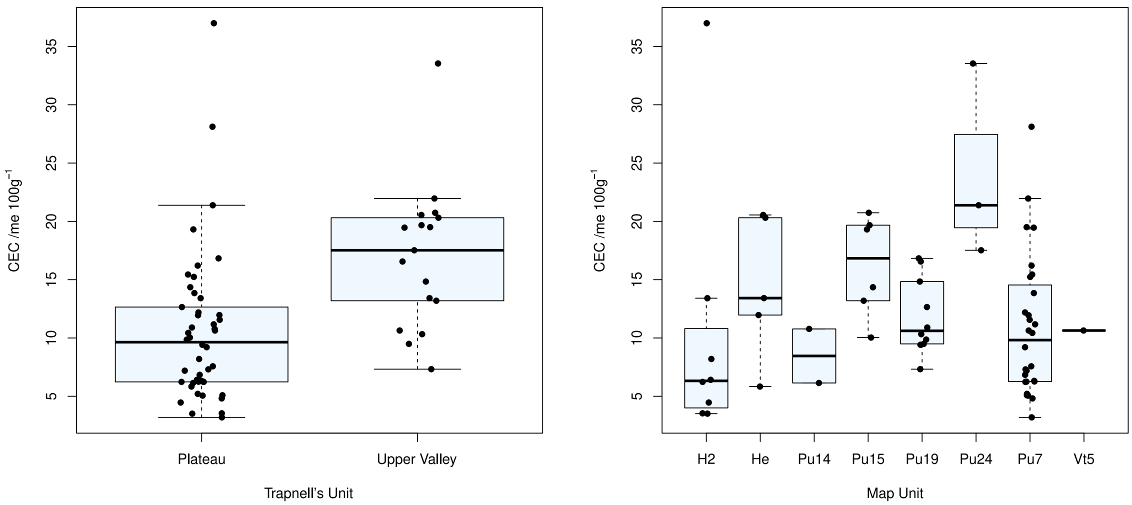

Fig. 7. Boxplots showing distribution of soil cation exchange capacity within (a) Plateau and Upper valley units of Trapnell's classification and (b) units of the exploratory soil map of Zambia. Jittered data points are superimposed on each boxplot.

are more units in the latter map, a markedly smaller proportion of the variance of the CEC (transformed to logarithms) is accounted for by these differences. This indicates the value of the geomorphological and ecological distinction that Trapnell observed on the plateau margins when accounting for soil variation and agricultural potential.

8. Discussion: Trapnell's insight

In assessing Trapnell's legacy we need to consider pedological thinking in the 1930s and '40s, the time of Trapnell's survey work. In the previous century Dokuchaev had observed how the soil varied from north to south in Russia; from podzol, brown earth, chernozem, chestnut soil, and so on to the desert. The sequence was clearly matched geographically to the variation in climate from the cold wet north to the drier hotter south. Glinka, a student of Dokuchaev's, writing in German, promoted the Russian view that the climate itself was primarily responsible for this variation: climate determined processes in the soil and the way these led to the different of soil profiles. We should bear in mind that these processes were operating on fairly fresh material, such as glacial moraines and loess laid bare after the last Ice Age in the current climate. This view was taken up in the USA by soil scientists such as Marbut, who translated Glinka's writing (Glinka, 1927). There the sequence was essentially from east to west on similarly fresh parent materials. Shantz and Marbut (1923) applied this conceptual model to interpret very few first-hand observations of soil in Africa with respect to climate information. They produced the first attempt at a map of the continent's soil.

That map did little justice to central Africa. Africa was not buried beneath ice when Europe and North America were. It was not swept by glaciers, nor were its rocks submerged by moraines. In contrast, the plateau country of central Africa has largely been at the land surface for what we now know to be several million years, although Trapnell and Clothier (1937) noted that, in much of western Zambia, the variable thickness of wind-borne Kalahari Sand, deposited in the Quaternary, was a factor of soil variation. In that time the rocks weathered, and with little erosion the weathered products remained in place. All that are left are the most resistant minerals such as quartz and the final products of long weathering: kaolinite and more or less hydrated iron and aluminium oxides. These products are 10 and more metres thick.

Further, although the climate of Zambia varies from the dry south to the wetter north, the effects of this variation on parent materials with nothing more to weather are limited, although the kaolinite could decay and release aluminium if the soil were to become more acid. Trapnell et al. (1947) introduced an overall system of soils for Zambia in which climate variations were one factor. Notably, the soils of the lower valleys in the south include those with pedocal features and a larger pH than the acid soils of the north. However, these are not the climatically-determined soil classes of Dokuchayev's system as imposed on the African landscape by Shantz's and Marbut's (1923) map, and in the scheme of Trapnell et al. (1947) the climatic 'series' cut across variations in parent material.

The biggest differences in soil type occur at the plateau margins where the old plateaux are bevelled by erosion as streams have cut back from the Luangwa and Zambesi rift valleys. The residues of a million or more years of weathering have been stripped away, and now we see relatively young soil in which 'normal erosion' and rock weathering seem in balance. Trapnell recognized it and saw that it underlay not only the spatial patterns of soil but also the vegetation, the traditional agricultural practices and the potential for more productive agriculture in a cash economy.

Our reappraisal of Trapnell's insight into soil variation in the landscape of Zambia raises the question of whether contemporary methods to predict and map soil variation bring the same insight. We noted that Trapnell's incorporation of geomorphology into his map could be characterized as 'narrative' identifying strongly localized features associated with the process of adjustment of the base level for drainage and resulting rejuvenation at the margin of the plateau. This contrasts with the approach incorporated into the more recent soil map of Zambia (GRZ, 1991) which starts with basic landform units. In these the rejuvenated plateau margins are simply incorporated into the plateau units, and the differences of critical ecological and agronomic significance are lost.

It is interesting to speculate on how pedological thought would have developed had the subject begun in Central Africa rather than Northern Europe. Physiography, tectonics and age would almost certainly have figured larger than climate. They are the factors that have determined the geographical distribution of soil. Milne is rightly remembered for his concept of the catena to describe local geographic patterns. Greene (1945), who had worked in Sudan during the 1920s and 1930s, commented on the theme: on these old plateaux the soil patterns developed, not from trends in climate, but from the lateral movement of water and with it solutes and other soil materials. But we believe that Trapnell's recognition of the contrast between the ancient soil of the plateaux and the youthful soil of the upper valleys was fundamental to understanding and of greater practical value. At this late stage let us honour Trapnell as a pedological pioneer on the African continent.

Data

Availability of data presented in this paper is as follows.

1. Data on particle size distributions and cation exchange capacity presented in Fig. 2 (Section 4) are published in the Supplementary Material in the form of profile description tables.
2. Data on particle size distribution in the top horizon and lower horizon of soil profiles presented in Fig. 5 (Section 7.2) are published in the cited report of the Eastern Province Soil Survey (Zambia Agriculture Research Institute, 2020) and so are copyright by the Government of the Republic of Zambia. A copy of this report may be obtained from author SS (staligan@yahoo.com).
3. Data on cation exchange capacity of soil in the vicinity of Petauke (Section 7.3), presented in Fig (6), were collected by IAPRI (Central Statistical Office et al., 2015), and used by us with permission, which does not extend to sharing for reasons of confidentiality.
   Observations of the map units delineated at the each of these locations (from Trapnell et al., 1947; GRZ, 1991) are available from the Mendeley repository here https://data.mendeley.com/datasets/7wg9h2hjsr/1.

CRediT authorship contribution statement

R. Webster: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **L.M. Chabala:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **S. Sichinga:** Writing – review & editing, Methodology, Funding acquisition, Data curation. **R.M. Lark:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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.

Acknowledgements

The contributions by RML, LMC and SS were funded by the United Kingdom Research and Innovation (UKRI) Arts and Humanities Research Council [Grant No. AH/T00410X/1] through their Programme 'Cultures, Behaviours and Histories of Agriculture, Food, and Nutrition', part of UK Research and Innovation's Global Challenges Research Fund. We thank Indaba Agricultural Policy Research Institute (IAPRI) for allowing us to use their RALS 2012 survey data.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.catena.2025.109386.

Data availability

Soil map units near Petauke Eastern Province, Zambia (Original data) (Mendeley Data)

References

Allan, W., 1949. Studies in African land usage in Northern Rhodesia. In: Rhodes–Livingstone Papers No 15. Oxford University Press for Rhodes–Livingstone Institute, Cape Town.

Allan, W., 1965. The African Husbandman. Oliver & Boyd, Edinburgh.

Allan, W., Gluckman, M., Peters, D., Trapnell, C.G., McNaughton, J., Conroy, D., 1945. Land Holding and Land Usage Among the Plateau Tonga of Mazabuka District: A Reconnaissance Survey. Oxford University Press for Rhodes–Livingstone Institute, London, Paper no 14.

Anderson, B., 1957. A Survey of Soils in the Kongwa & Nachingwea Districts of Tanganyika. University of Reading.

Anonymous, 1952. Report on Central African Rail Link Development Survey, vol. 2, United Kingdom Government Colonial Office, London.

Baldwin, M., Kellogg, C.E., Thorp, J., 1938. Soil Classification. Soils and Men: Yearbook of Agriculture 1938. U.S. Government Printing Office, Washington, D.C, pp. 979–1001.

Ballantyne, A.O., 1957. A reconnaissance soil survey of the copperbelt of Northern Rhodesia. Rhod. Agric. J. 54, 558–571.

Brammer, H., 1973. Soils of Zambia. Department of Agriculture, Land Use Branch, Rural Information Services. Ministry of Rural Development, Lusaka.

Central Statistical Office, Ministry of Agriculture and Livestock, Indaba Agricultural Policy Research Institute (CSO/MAL/IAPRI), 2015. Rural Agricultural Livelihoods Survey. CSO/MAL/IAPRI, Lusaka, Zambia.

Dalal-Clayton, D.B., English, C., Williams, G.J., Spaargaren, O.C., 1985. The geomorphic legend of zambia. In: Technical Guide 15. Soil Survey Unit. Chilanga, Lusaka.

Daly, M.C., Green, P., Watts, A.B., Davies, O., Chibesakunda, F., Walker, R., 2020. Tectonics and landscape of the central African plateau and their implications for a propagating southwestern rift in Africa. Geochem. Geophys. Geosyst. 21, http://dx.doi.org/10.1029/2019GC008746, e2019GC008746.

D'Hoore, J.L., 1964. Soil map of Africa. In: Scale 1:5 000 000: Explanatory Monograph, Commission for Technical Co-operation in Africa. (Publication No 93), Lagos.

D'Hoore, J.L., 1968. The classification of tropical soils. In: Moss, R.P. (Ed.), The Soil Resources of Tropical Africa. Cambridge University Press, Cambridge, pp. 7–28.

Dixey, F., 1942. Erosion cycles in central and southern Africa. Trans. Geol. Soc. South Afr. 45, 151–181.

Dixey, F., 1944. The geomorphology of Northern Rhodesia. Trans. Geol. Soc. South Afr. 47, 9–45.

FAO, 1985. The Soil Map of the World. Revised Legend World Soil. Resources Report, FAO, Rome, Revised third draft.

Glinka, K.D., 1927. The great soil groups of the world and their development. In: Translated from the German By C.F. Marbut. Edwards Brothers, Ann Arbor, Michigan.

Greene, H., 1945. Classification and use of tropical soils. Soil Sci. Sci. Am. Proc. 10, 392–396.

GRZ (Government of the Republic of Zambia), 1991. Exploratory Soil Map of Zambia; 1:1, 000 000. Ministry of Agriculture, Soil Survey Section Research Branch Mapsheets available from ISRIC at https://edepot.wur.nl/486756. https://edepot.wur.nl/486757.

Hijmans, R., 2024. Terra: Spatial data analysis. R package version 1.7-78, https://CRAN.R-project.org/package=terra>.

Jenny, H., 1941. Factors of Soil Formation: A System of Quantitative Pedology. McGraw-Hill, New York.

Mäckel, R., 1973. Dambos: a study in morphodynamic activity on the plateau regions of Zambia. Catena 1, 327–365.

Mansfield, J.E., Bennett, J.G., King, R.B., Lang, D.M., Lawton, R.M., 1976. Land Resources of the Northern and Luapula Provinces of Zambia: A Reconnaissance Assessment. Land Resources Division. Ministry of Overseas Development, Surbiton.

McMillan, M.F., Boone, S.C., Kohn, B.P., Gleadow, A.J., Chindandali, P.R., 2022. Development of the Nyika Plateau, Malawi: a long-lived paleo-surface or a contemporary feature of the east African rift? Geochem. Geophys. Geosyst. 23, http://dx.doi.org/10.1029/2022GC010390, e2022GC010390.

Milne, G., 1932. Proceedings of a conference of east African soil chemists. In: Agricultural Research Station, Amani, Tanganyika Territory, May 21st – 26th 1932. Government Printer, Nairobi.

Milne, G., 1936. A Provisional Soil Map of East Africa (Kenya, Uganda, Tanganyika and Zanzibar) with Explanatory Memoir. East African Agricultural Research Station, Amani.

Namwanyi, N.L., Hutton, M.J., Mukumbuta, I., Chabala, L.M., Chongo, C., Sichinga, S., Lark, R.M., 2024. Trapnell's upper valley soils of Zambia: the production of an integrated understanding of geomorphology, pedology and land use. SOIL 10, 887–911. http://dx.doi.org/10.5194/soil-10-887-2024.

R Core Team, 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/.

Shantz, H.L., Marbut, C.F., 1923. The vegetation and soil of Africa. In: American Geographical Society Research Series No. 13, National Research Council and American Geographical Society, New York.

Smith, P., Trapnell, C.G., 2001. Ecological Survey of Zambia, the Traverse Records of C.G. Trapnell 1932–43. Royal Botanic Gardens, Kew, London.

Thompson, J.G., Webster, R., Young, A., 1960. Soils Map of the Federation of Rhodesia and Nyasaland. Scale 1:2 500 000. Federal Department of Trigonometrical and Topographical Surveys, Rhodesia and Nyasaland. Federal Government Printer, Salisbury.

Trapnell, C.G., 1935. A vegetational grouping of soils in Northern Rhodesia south of latitude 15°30′. In: Proceedings of the Second Conference of East African Agricultural and Soil Chemists, Held At Zanzibar, 3–9 1934 (Edited By G. Milne). Government Printer, Nairobi, pp. 53–55.

Trapnell, C.G., 1937. Ecological methods in the study of native agriculture in Northern Rhodesia. Bull. Misc. Inf. (Royal Bot. Gard. Kew) 1937 (1), 1–10.

Trapnell, C.G., 1943. The Soils, Vegetation and Agriculture of North-Eastern Rhodesia: Report of the Ecological Survey. Government Printer, Lusaka.

Trapnell, C.G., Clothier, J.N., 1937. The Soils, Vegetation and Agricultural Systems of North-Western Rhodesia: Report of the Ecological Survey. Government Printer, Lusaka.

Trapnell, C.G., Martin, J., Allen, W., 1947. Vegetation–Soil Map of Northern Rhodesia. Government Printer, Lusaka.

Trapnell, C.G., Webster, R., Hesse, P.R., 1986. Microaggregates in red earths and related soils in east and central Africa, their classification and occurrence. J. Soil Sci. 37, 109–123.

Webster, R., 1965. A catena of soils on the Northern Rhodesia plateau. J. Soil Sci. 16, 31–43.

Webster, R., 1970. Soils. In: The Evergreen Forests of Malawi. J.D. Chapman and F. White. Commonwealth Forestry Institute, Oxford, pp. 18–27.

Wilson, A.T., Ballantyne, A.O., Brockington, N.R., Rees, A.M., 1956. Report of a Soil and Land-Use Survey, Copperbelt, Northern Rhodesia. Department of Agriculture, Lusaka.

WRB, 2022. World reference base for soil resources. In: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps, 4th ed. International Union of Soil Sciences (IUSS), Vienna, Austria.

Zambia Agriculture Research Institute, 2020. Soil Survey Report of the Eastern Province. Zambia integrated Forestry Landscape Project, National Soil Survey Programme. Soils Research. Zambia Agriculture Research Institute, Mount Makulu Research Station, Chilanga, Lusaka, Zambia.