Facies analysis of a Cretaceous-Paleocene volcaniclastic braid-delta

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Abstract

The Summerfield Formation of central Jamaica is the product of an important episode of Caribbean andesitic volcanism. The succession consists of a sedimentary sequence overlain by thick ignimbrite flows. The extensive exposures of this formation enable a detailed analysis of the sedimentary facies of a volcaniclastic braid-delta. The lower part of the sequence consists of interbedded 10 - 40 cm thick, normally-graded sandstones and siltstones (Unit S1), passing upwards into thickly bedded (80 cm - 4 m thick) sandstones (Unit S2). These thick sandstones are either massive, have amalgamated normally-graded beds, or exhibit weakly defined parallel lamination and soft-sediment deformation features. The upper part of the sequence (Unit S3) is represented by clast- and matrix-support conglomerates, consisting of rounded andesite and rare ignimbrite clasts up to 50 cm in diameter in a sandstone matrix. The beds are thick to very thick (0.8 m to 5 m) and much of the unit is massive. The succession is interpreted as a braid-delta.

Introduction

The late Campanian to Paleocene succession in the Central Inlier of central Jamaica (Fig. 1) consists of a transgressive-regressive cycle represented by the Slippery Rock, Guinea Corn and Summerfield Formations (Fig. 2). The Slippery Rock Formation (terrestrial to transitional marine) consists of red, brown or grey conglomerates and sandstones in relatively thick (a few tens of centimetres up to several metres), poorly defined, erosively based beds with tabular and trough-cross bedding (Robinson and Lewis in Robinson et al., 1972; Robinson, 1988; Robinson and Mitchell, 1999). The conglomerates pass upwards into unfossiliferous red mudstones, and grey laminated mudstones with ripple cross-laminated heterolithics and thin limestones (Williams, 1959a, b). The succeeding Guinea Corn Formation consists of rudist-bearing limestones varying from massive to thinly bedded to nodular (Coates, 1965; Mitchell, 1999). Rudist bivalves are abundant throughout, and locally thin clastic units are present, which are predominately mudrocks in the lower part and interbedded mudstones with graded sandstone beds in the upper part. Although controversy surrounds the dating of the Guinea Corn Formation, an early to mid Maastrichtian age is generally agreed for the upper part (Kauffman and Sohl, 1974; Jiang and Robinson, 1987; Kauffman and Johnson, 1988; Johnson and Kauffman, 1996; Underwood and Mitchell, 2000). The name Summerfield Formation was introduced by Coates (1965, 1968) for the rocks that had been called the Upper Tuffaceous Series by the Jamaican Geological Survey (Williams, 1959a, b). Coates (1968) recognised a two-fold division of the Summerfield Formation into a lower unit of sandstones and an upper unit of conglomerates. Robinson and Lewis (in Robinson et al., 1972) recognised the existence of a hornblende-pumice tuff in the upper part of the Summerfield Formation. Roobol (1976) described the Summerfield Formation and recognised a lower sequence of marine sandstones overlain by a sequence of terrestrial conglomerates that contained two ignimbrite horizons. Mitchell and Blissett (1999) showed by mapping that the Summerfield Formation consisted of four divisions, from the base upwards these were: S1, thinly bedded sandstones interbedded with siltstone and mudstone; S2, thickly bedded to massive sandstone interbedded with thin mudstones and siltstones; S3, a succession of conglomerates with subordinate interbedded sandstones; and S4, a hornblende-pumice ignimbrite. The hornblende-pumice ignimbrites, which have been dated as late Paleocene (Ahmad et al., 1988, using the Berggren et al., 1995, timescale). Since Summerfield-like sandstones are interbedded with the Guinea Corn Formation (Roobol, 1976; Mitchell, 1999), the Summerfield Formation probably ranges in age from mid Maastrichtian to late Paleocene. The Summerfield Formation is overlain unconformably by the Eocene Yellow Limestone Group (Mitchell and Blissett, 1999).

In this paper the lithofacies of the sedimentary facies in the Summerfield Formation (units S1 to S3) are described in detail, and related to a facies model. The descriptors S1 to S4 introduced by Mitchell and Blissett (1999) are used throughout.

Lithofacies in the Summerfield Formation

Facies SUM 1. Graded sandstone. Arkosic sandstones in beds from 10 to 60 cm thick showing poorly- to well-defined, normal grading. Grain size grades from medium-coarse sandstone or granule conglomerate at the base to fine sandstone or siltstone at the top. The tops of some of the sandstone beds show diffuse mottling indicating bioturabation. Generally, no other sedimentary structures are present, although some of the sandstones show parallel lamination in their upper parts. The bases of individual sandstones are sharp to erosive; tool marks and scour marks are absent. Rare sandstone beds attributed to Facies SUM 1 show soft sediment deformation features, such as load casts and convolute bedding. The sandstones are tabular, of uniform thickness and can be traced across outcrop. It has not proved possible to trace individual sandstones to adjacent outcrops. Many of these graded sandstone beds are strongly cemented making them conspicuous in river beds and on cliffs. Similar graded sandstones are developed in the clastic intervals in the Guinea Corn Formation (unit E of Mitchell, 1999). Some of these sandstones in the Guinea Corn Formation contain reworked fossils (small oysters) at their bases.

The facies occurs abundantly in Unit S1 in the lower part of the Summerfield Formation, and is also a common component of the clastic intervals in the Guinea Corn Formation. It also occurs rarely in Unit S2 of the Summerfield Formation.

This facies is interpreted to represent the deposits formed by single events. The well-defined normal grading suggests deposition from a turbulent to hyperconcentrated flow. Where parallel lamination is developed in the upper part of the bed it suggests deposition from a fully turbulent flow. The presence of rare load casts on the base of some of these sandstones suggests that physical shocks (possibly associated with volcanic eruptions?) occurred prior to sediment dewatering.

Facies SUM 2. Siltstone and sandy siltstone. Poorly sorted sandy siltstones and siltstones. These units may show lamination. Occasional lignite laminae are present, but only rarely.

The facies is common in Unit S1 in the lower part of the Summerfield Formation and in the clastic intervals in the upper part of the Guinea Corn Formation. The facies also occurs in Unit S2 of the Summerfield Formation.

The facies is interpreted to represent ‘background’ sedimentation between distinct event beds. It may be the result of bioturbation of minor event beds which are no longer recognisable.

Facies SUM 3. Laminated sandstone. Thin- to medium-bedded, fine- to medium-grained sandstones with parallel lamination. Some units show gently inclined laminae that erosively truncate underlying laminae. These laminated units are similar to hummocky cross-stratified (HCS) sandstones and they are provisionally interpreted as such, although exposure is rarely good enough to prove this unequivocally. The sandstones have sharp to erosive bases; no sole marks have been identified. The sandstones are tabular, of uniform thickness and can be traced across outcrop. They have not be traced to adjacent outcrops.

This facies occurs in the upper part of unit S1 in the Summerfield Formation.

The facies is provisionally interpreted as HCS sandstones that were produced by oscillatory currents associated with storms. It indicates storm dominance in the deposition of the upper part of Unit S1.

Facies SUM 4. Massive sandstones. Thickly to very thickly bedded fine- to medium-grained sandstones. The beds generally lack internal stratification, although defuse lamination, defuse layers with granule to pebble sized pumice clasts and stringers of mudstone rip-up clasts maybe present (Fig. 3). Locally units have amalgamated and are separated by thin units of ripple cross-laminated siltstones and sandstones (the siltstones are similar to the mudstone rip-up clasts). Some levels may show preferential cementation producing concretion layers. Soft sediment deformation features (convolute bedding) occur occasionally.

The facies is developed in the lower part of Unit S2, and more rarely higher in Unit S2.

The homogenous nature of these beds suggests that these beds were created as single event beds. The presence of the mudstone rip-up clasts suggests that the flows that created these beds were capable of erosion, while the lack of well-defined sedimentary structures suggests that the flows were not fully turbulent. This facies is therefore attributed to be the deposits of hyerconcentrated flows. The facies is interbedded with sandstones containing rare ‘U- shaped trace fossils, indicating deposition in a marine environment.

Facies SUM 5. Thick graded sandstones. Arkosic sandstones in beds from 60 cm to 1.4 m thick showing poorly- to well-defined, normal grading. Grain size grades from coarse sandstone or granule conglomerate at the base to fine sandstone or siltstone at the top. No other sedimentary structures are present. Similar graded sandstone beds are rarely developed in the clastic intervals in the Guinea Corn Formation (unit E of Mitchell, 1999). Some of these contain scattered reworked rudists and the trace fossil *Taenidium*. The trace fossil *Taenidium* isp. has also been observed in Unit S2 within the Summerfield Formation.

The facies occurs predominantly within Unit S2 of the Summerfield Formation, although rare examples of similar sandstones also occur within the clastic divisions in the upper part of the Guinea Corn Formation. Although there is clearly a continuum between the thinner graded sandstones of Facies SUM 1 and the thick graded sandstones of SUM 5, the dominance of the former in Unit S1 and the latter in Unit S2, warrants their separation as separate lithofacies.

The well-defined normal grading suggests deposition from a waning flow with turbulent to hyperconcentrated characteristics.

Facies SUM 6. Tabular cross-bedded sandstones and granule conglomerates. Medium to thick bedded sandstones and granule conglomerates with tabular cross-bedding extending throughout the thickness of the beds. The beds may also show normal grading.

The facies is found in Unit S2.

The facies clearly results from the migration of medium- to large-scale bedforms such as two-dimensional dunes or bars. It is unclear if the large-scale features could be produced by Gilbert-type deltas.

Facies SUM 7. Massive sandstone. Medium- to coarse-grained, massive sandstone with occasional pebbles.

The facies occurs in the lower part of Unit S3, where it is associated with facies SUM 8 and SUM 9.

The facies is probably associated with deposition from sandy braided stream deposits.

Facies SUM 8. Clast supported conglomerate. Thin to thickly bedded conglomerates. The clasts range in size from pebble to boulder, and they are strongly rounded. Clasts are predominantly composed of pale andesite with prominent zoned tabular plagioclase and hornblende phenocrysts. Commonly a single conglomerate bed is characterised by having clasts with a similar composition, and different from adjacent beds. Sedimentary structures are largely absent from the conglomerates, other than from minor variations in grain size and the presence of imbrication. The bases of individual conglomerate beds are generally sharp. The conglomerate beds are mainly tabular units that can be traced across outcrop, but occasional lenticular units that pinch out rapidly are also present. Strongly incised erosional channels are absent.

The facies is characteristic of Unit S3 (Fig. 4) and does not occur below this.

The presence of strongly erosive bases of beds and the presence of imbrication, suggests deposition from turbulent stream-flow processes. The lack of abundant well-defined channels suggests a relatively mobile stream system on a braid plain.

Facies SUM 9. Matrix-supported conglomerate. Conglomerates with clasts ranging from pebble to cobble size floating in a sandy matrix. The clast are well-rounded and are composed of andesite. The bases of individual units are sharp, but not clearly erosive. Individual units tend to be tabular and maintain their thickness across the exposure.

The facies only occurs in Unit S3 of the Summerfield Formation. It forms a relatively minor component of the total facies present.

The lack of sedimentary structures, the tabular nature of the beds and the matrix support fabric suggest that this facies can be attributed to the deposits of debris flow processes.

Facies Associations in the Summerfield Formation

A progressive change in lithofacies associations occurs in the transition from the Guinea Corn Formation to the conglomerates (Unit S3) of the Summerfield Formation. The lower part of Unit S1 is characterised by lithofacies SUM 1 (Graded sandstones) and SUM 2 (Siltstones and sandy siltstones). In the upper part of Unit S1 facies SUM 3 (Laminated sandstones) is also present. This facies is interpreted as storm sandstone beds and suggests the passage from below to above storm wave base.

A major change in facies association occurs across the Unit S1 – S2 boundary, where facies SUM 1 and SUM 3 are replaced by facies SUM 4 (Massive sandstones) and SUM 5 (Thick graded sandstones). While SUM 5 might be a more proximal to shore version of SUM 1, it also might represent the decaying of a hyperconcentrated flow (SUM 4) into a turbulent flow (SUM 5). In the higher part of Unit S2, facies SUM 6 (Tabular cross-bedded sandstones and granule conglomerates) appears. It represents large-scale bedform migration and might include small Gilbert-type deltas building into shallow water.

A further important change occurs at the Unit S2 – S3 boundary, which corresponds to the change from marine to fluvial sedimentation as recognised by the loss of marine trace fossils (*Planolites* isp. and ‘U’-shaped burrows). The lithofacies present in Unit S3 are SUM 7 (Massive sandstones), SUM 8 (Clast supported conglomerates) and SUM 9 (Matrix support conglomerates). Facies SUM 8 is proportionally the most important and is interpreted as the product of coarse-grained braided stream processes, while the subordinate facies SUM 7 and 9 are interpreted as, sandy braided stream deposits, and debris flow deposits, respectively.

The Summerfield succession from Units S1 to S3 is interpreted as a shallowing upwards succession, passing from offshore, relatively deep water (below storm wave base), to shallow water marine and finally overlain by a great thickness of terrestrial braided stream deposits. The succession is therefore attributed to the progradation of a volcaniclastic apron around an active, subaerial volcanic cone.

Discussion

Many volcaniclastic apron deposits have been described (e.g., Kuenzi et al., 1979; Mathisen and Vondra, 1983; Busby-Spera, 1988; Houghton and Landis, 1989; Mathisen and McPherson, 1991; Palmer and Walton, 1990; Palmer et al., 1993). These studies generally distinguish proximal, medial and distal facies. Proximal facies are characterised by valley fills and primary pyroclastic deposits together with primary eruptive deposits. Medial deposits are characterised by extensive alluvial fans flanking the active volcanoes. Distal facies are represented by braided and meandering river facies on the coastal plain. Although most primary eruptive deposits are limited to the proximal facies, ignimbrites can travel extensive distances from the source volcano, and may be associated with the medial and even the distal facies. The Summerfield terrestrial volcaniclastic deposits are characterised by braided alluvial deposits, indicating a distal position on the volcaniclastic apron. The presence of the ignimbrite (Unit S4) indicates a major ignimbritic eruption (or sequence of eruptions) with the pyroclastic flows reaching the distal volcaniclastic apron.

Smith (1991) discussed the significant morphology in continental volcaniclastic successions that developed during times of volcanic activity (syneruptive) and quiescence (inter-eruptive). He suggested that at times of volcanic activity, extensive volcaniclastic sediment was supplied to the distal fluvial systems leading to extensive aggradation of the alluvial plain with the deposition of sheet-like shallow braided stream, debris flow and hyperconcentrated-flow deposits. At times of volcanic quiescence, sediment supply was cut off and the river systems incised into the deposits of the syneruptive phase. The deposits of Unit S3 of the Summerfield Formation consist predominantly of braided stream and minor debris-flow deposits which are predominantly sheet-like in form. This suggests syneruptive deposition. The lack of well-defined erosive channels in the Summerfield Formation is noteworthy. This would suggest that Unit S3 is the result of a single episode of volcanic activity and was deposited rapidly. In this context it is noteworthy that Kuenzi et al. (1979) reported that an elongate deltaic platform prograded about 7 km seaward between 1902 and 1922 following the catastrophic eruption of Santa Maria Volcano (Guatemala) in 1902 indicating that rapid progradation of volcaniclastic sequences does occur. If the Summerfield Formation represents a single episode of volcanism, there is a significant problem with the dating. Summerfield–like volcaniclastic deposits are interbedded with the upper part of the mid-Maastrichtian Guinea Corn Formation, suggesting that the lower part of the Summerfield Formation is also of mid Maastrichtian age. If the whole of the Summerfield Formation was deposited rapidly, it seems unlikely that the overlying ignimbrites are of late Paleocene age. Care must be taken, however, in assuming that the Summerfield Formation represents a single episode of andesitic volcanism, as Smith (1991) notes that shallow broad erosion surfaces of inter-eruptive episodes may be difficult to recognise unless exposures are very good. There are several possibilities regarding the possible relative age of the deposits of the Summerfield Formation: (i) inter-eruptive episodes are represented in the Summerfield Formation, but have not been identified in the field, (ii) there is a significant time gap between the deposition of the Summerfield Formation sediments and the overlying ignimbrites, and (iii) the age obtained on the ignimbrites may be inaccurate. Further dating is needed to address these possible alteratives.

The terms fan-delta and braid-delta have been used for different types of coarse grained deltas (Wescott and Ethridge, 1980, 1984; McPhearson et al., 1987; Soegaard, 1990). McPhearson et al. (1987) defined fan-deltas as gravel-rich deltas formed where an alluvial fan from a mountainous (often fault-controlled) region is deposited directly into a standing body of water. In contrast, braid-deltas are gravel-rich deltas that form where a braided river fluvial system progrades into a standing body of water. In the geological record, the two types of delta are distinguished by their subareial deposits. Fan-deltas are characterised by interbedded sheet flood, debris-flow and braided stream deposits, they are small wedge-shaped bodies of poorly sorted sediment (up to a few tens of square kilometres) with poorly rounded clasts. Braid-deltas in contrast are characterised by braided river deposits that are better sorted and have rounded clasts; they commonly have a sheet-like geometry and high lateral continuity (tens to hundreds of square kilometres).

The conglomerates of Unit S3 of the Summerfield Formation are dominated by clast supported braided stream deposits with well-rounded andesite clasts and cover an area of at least 300 km^2. Furthermore, there is no evidence for an extensive land area adjacent to the Summerfield Formation. Consequently, the characteristics of the Summerfield Formation indicate that it represents a volcaniclastic braid-delta sourced from a distant active andesitic volcano.

Conclusions

The Summerfield Formation represents an important episode of andesitic volcanism in the late Cretaceous to late Paleocene interval. It is characterised by a shallowing upward, progradation succession of deposits and nine lithofacies have been recognised. The conglomerates contain well-rounded clasts of andesite in clast supported beds of braided stream origin. The succession is therefore interpreted as a braid-delta associated with a distal volcaniclastic apron.

The terrestrial deposits of the Summerfield Formation show typical syneruptive characteristics. This suggests that the Summerfield Formation was deposited rapidly. This is at variance with the suggested age range of the deposits, from mid Maastrichtian to late Paleocene. This suggests that either (i) inter-eruptive episodes are represented in the Summerfield Formation, but have not been identified in the field, (ii) there is a significant time gap between the deposition of the Summerfield Formation sediments and the overlying ignimbrites, or (iii) the age obtained on the ignimbrites may be inaccurate.

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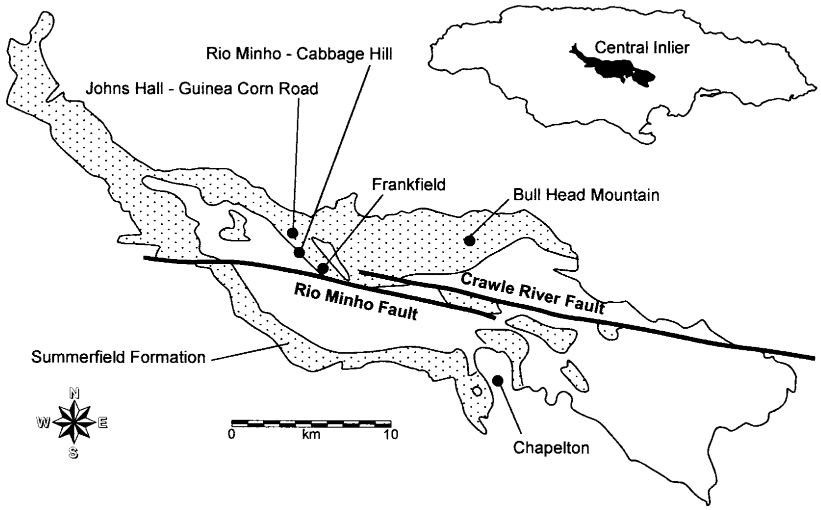

Figure 1. Distribution of the sediments of the Summerfield Formation in the Central Inlier, Jamaica. Inset is the location of the Central Inlier in Jamaica.

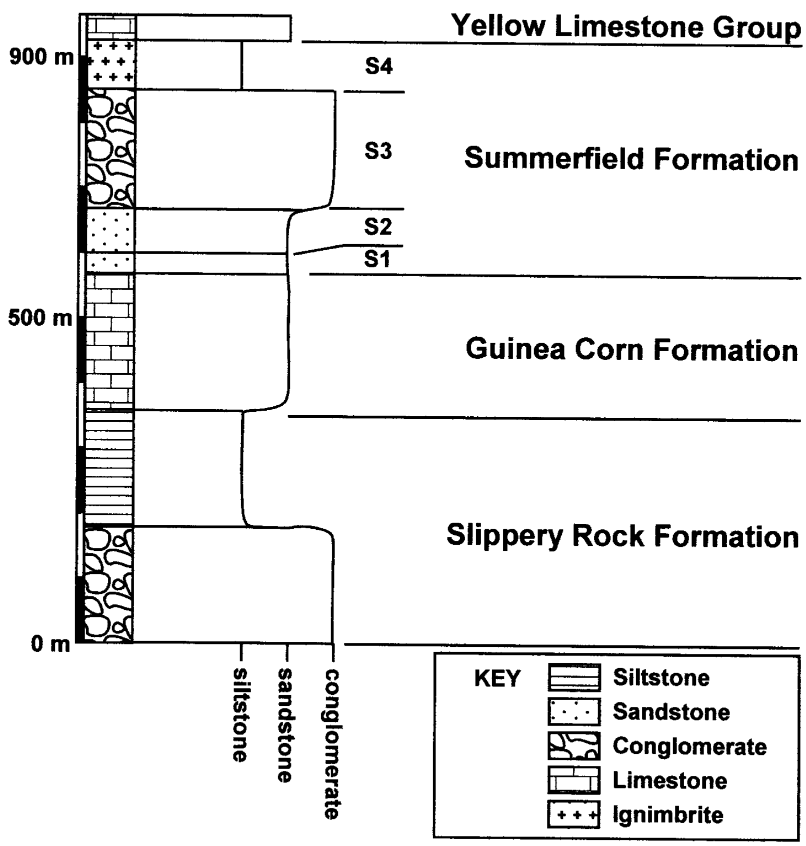

Figure 2. Geological succession in the Central Inlier of Jamaica. Nearly 1000 m of ?late Campanian to ?late Paleocene sediments are present.

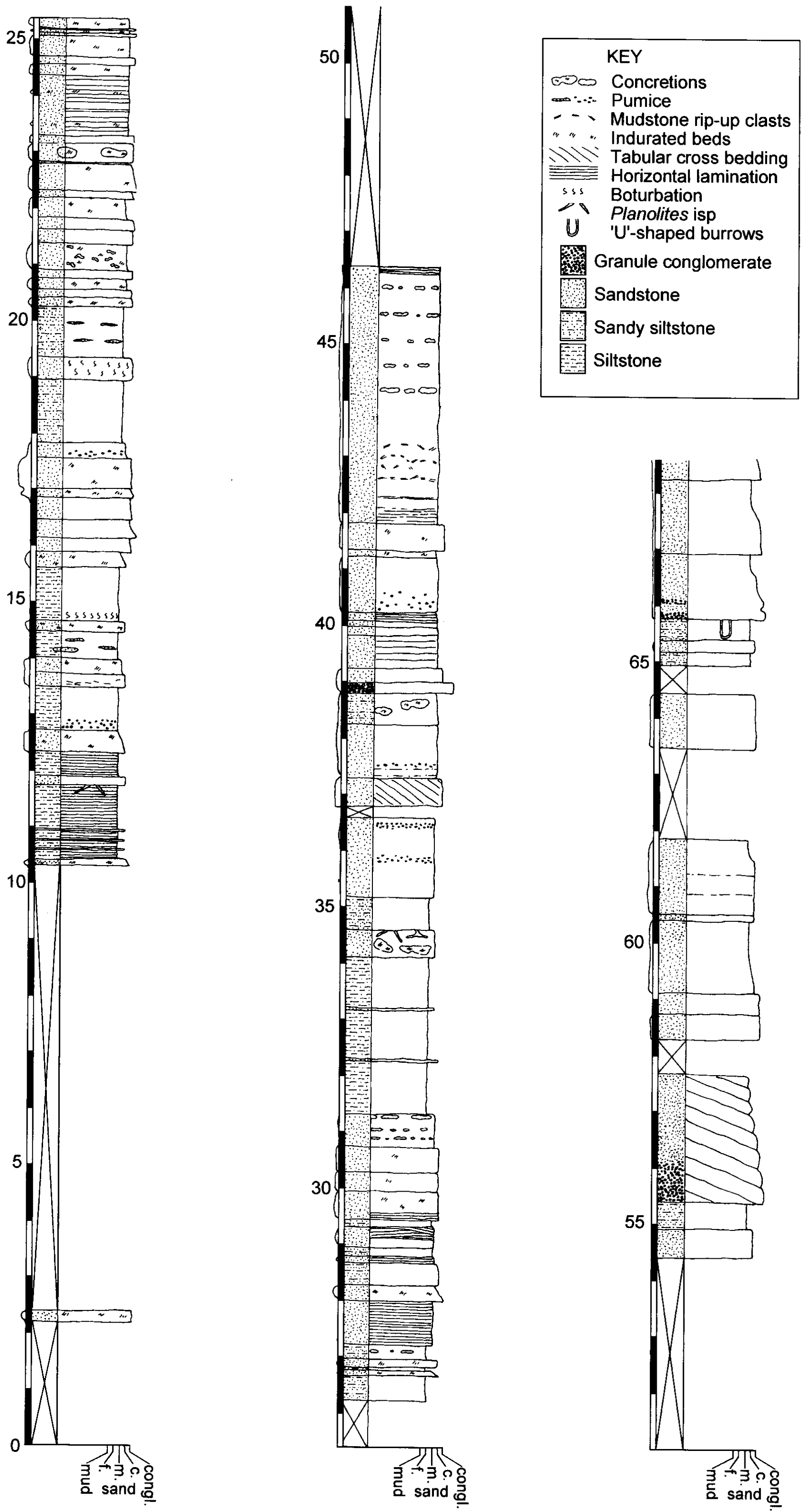

Figure 3. Measured section through Units S1 and S2 of the Summerfield Formation at Cabbage Hill. The right hand profile is grainsize, the profile to the left of the scale bar is a weathering profile. The scale is in metres.

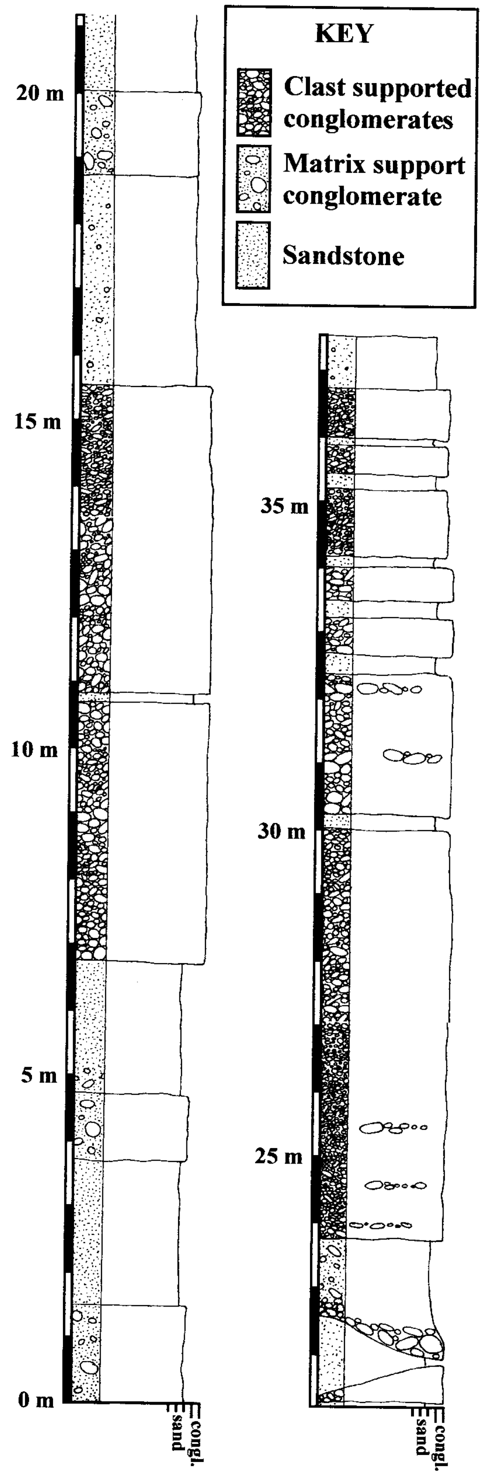

Figure 4. Measured section through Unit S3 of the Summerfield Formation on the road between Guinea Corn and Johns Hall (see Figure 1 for location).