Sequence stratigraphy of mixed clastic-carbonate systems – a case example from the Eocene of Jamaica

Ravidya Maharaj and Simon F. Mitchell

Department of Geography and Geology, University of the West Indies, Mona, Kingston 7, Jamaica

This paper was prepared for presentation at the GSTT 2000 SPE Conference held in Port of Spain, Trinidad 10-13 July 2000.

Abstract

The Yellow Limestone Group (Eocene) in the Central Inlier of central Jamaica consists of two sedimentary cycles, each represented by a lower clastic division and an upper carbonate division. The lower cycle has a more restricted distribution than the upper cycle, erosion having locally removed it particularly in the south. Only the upper cycle is considered in detail here. The upper cycle can be divided into a lower clastic division (Guys Hill Formation) characterised by fluvial conglomerates and sandstones and restricted marine sandstones, heterolithics and mudrocks, and an upper carbonate division (Chapelton Formation) characterised by more open marine foraminiferal and molluscan wackestones, packstones and grainstones.

Detailed mapping and logging have constrained the basin architecture, and four parasequences have been recognized within the Guys Hill Formation. Parasequences show a transition from fluvial dominated facies in the east to more open marine dominated facies in the west. Towards the western part of the basin, the marine flooding surface at the base of each parasequence is represented by thin shallow water limestones or fossiliferous lignitic shales, the latter having potential source rock characteristics. In this region, the upper part of the parasequences is represented by thick, clean-washed cross-bedded, ?tidally influenced arenites. Parasequences are stacked into a retrogradational parasequence set, which is attributed to the TST. To date, lowstand deposits have not been unequivocally recognized. The late TST and HST are characterised by carbonate deposition, and correspond to times of clastic starvation, related to relative sea level rise.

The Yellow Limestone Group of central Jamaica can be used as a model for mixed carbonate-clastic depositional systems where clastics are restricted to the TST and carbonates to the HST.

Introduction

In the Central Inlier of Jamaica (Fig. 1), an Eocene sedimentary succession was deposited comprising two major cycles of mixed clastic-carbonate sediments, each represented by a lower clastic division and an upper carbonate division. The clastic division of the upper cycle is significantly thicker and better developed than in the lower cycle. This unit, although predominantly comprising clastic facies, also shows complex stacking associations with carbonate facies, and has therefore been selected as a case example to demonstrate the complex evolution of a mixed clastic-carbonate depositional system.

Geological background

The Central Inlier is the second largest inlier of Cretaceous rocks in Jamaica. Around the Cretaceous rocks the Eocene clastics and carbonate of the Yellow Limestone Group are extensively developed (Fig. 1). The Yellow Limestone Group in the Central Inlier has been recently discussed by Robinson and Mitchell (1999) and their terminology is used here.

The Yellow Limestone Group (Robinson and Mitchell, 1999) of the Central Inlier (Fig. 1) comprises a early-middle to middle-Eocene sedimentary succession immediately overlying a succession of Cretaceous to ?late Paleocene volcaniclastic sediments. The sedimentary facies comprising the Yellow Limestone Group represent two major cycles of mixed clastic-carbonate deposition, and range from fluvial clastics to shallow marine impure carbonates. Each cycle is characterised by a lower clastic unit which grades into an upper carbonate division.

The lower cycle has a more restricted distribution than the upper cycle, erosion having locally removed it particularly in the south and east of the inlier. The lower clastic unit (the Freemans Hall beds of Robinson, 1996) of the lower cycle is generally thin (estimated maximum thickness of 10 to 12 m). It is represented by a lower unit of fluvial conglomerates overlain by shelf sandstones and mudrocks. The succession is interpreted as an incised valley fill. The upper carbonate portion of the lower cycle is represented by the Stettin Formation (Robinson and Mitchell, 1999), which grades from thinly bedded silty foraminiferal marlstones through clean-washed cross-bedded carbonate grainstones, and finally into thickly bedded micritic mudstones and wackestones. The maximum thickness of the Stettin Formation is ~100 m in the north-western part of the inlier.

The lower clastic division of the upper cycle consists of the Guys Hill Formation, which unconformably overlies the hard micrites of the Stettin Formation. The Guys Hill Formation is characterised by fluvial conglomerates and sandstones in the east and south, and a mixed a clastic-carbonate shelf succession in the west and north. The mixed clastic-carbonate succession comprises shallow marine sandstones, siltstones and mudrocks, lignitic shales, and at least one carbonate ramp succession (the Dump Member; Robinson and Mitchell, 1999). The major facies of this unit are described in detail below. The maximum thickness of this formation is about 350 m in the northwestern part of the inlier around the town of Lichfield. The clastic facies pinch out and grade into the upper carbonate division (Chapelton Formation) towards the northwest. The Chapelton Formation is characterised by foraminiferal and molluscan wackestones, packstones and grainstones.

The Yellow Limestone Group is succeeded by the pure limestones and dolostones of the White Limestone Group (Robinson and Mitchell, 1999). The boundary is sharp and planar where exposed, and marks the change from the fossiliferous limestones of the Yellow Limestone Group to the dolostones and dedolomitized limestones of the White Limestone Group. Although an easily recognizable and mappable boundary in the field, it may represent a diagenetic front and have little correspondence to critical sedimentary surfaces.

Guys Hill Formation

Clastic facies

The clastic facies of the Guys Hill Formation can be divided into two broad groups: (i) incised valley fill deposits and (ii) shelf deposits. The incised valley fill deposits predominate the succession in the eastern parts of the Central Inlier and are characterised by two main facies:

Facies GH 1. Conglomerates. Pebble to boulder conglomerates with well-rounded clasts in a sandstone matrix. The clasts consist of igneous rocks, metamorphic rocks, agate and quartz. Indistinct tabular and trough cross-bedding may be developed in some places, elsewhere the facies appears to be massive. The conglomerates are particularly well developed towards northeastern side of the inlier, but are also seen elsewhere. The facies is interpreted to be fluvial (braided stream) deposits.

Facies GH 2. Trough cross-bedded sandstones and siltstones. Trough cross-bedded sandstones and pebbly sandstones. The sandstones are moderately sorted; the pebble-sized clasts are well-rounded and consist of quartzite, agate and andesites. The trough cross-bedding occurs in sets up to 30 cm thick. Locally thin siltstone beds are intercalated. This facies occurs in the northeastern part of the inlier but is also seen in small quantities elsewhere. The poor sorting of the facies and presence of siltstone lenses suggests fluvial deposits. The trough cross-bedding suggests the migration of sinuous (three dimensional) medium-sized bedforms.

In the western part of the inlier, five characteristic shelf facies predominate the succession. These include tidal sandwave deposits and shoreface sands. The tidal sandwave deposits comprise heterolithics and sandstones that contain a complex hierarchy of internal bounding surfaces, pertaining to various scales of sedimentary bedform accretion in a meso-tidal environment. The tidal facies are best observed near Lichfield in the north-western part of the inlier, and comprise the thickest sandstone units in the Yellow Limestone Group.

Facies GH 3. Heterolithics. Interbedded fine-grained sandstones, siltstones and mudstones with bedding on a scale of ~6 cm (appears streaky). Lignite flakes are common. Sandstone beds may be lenticular. Starved ripples are present. Sandstones are yellow and mudstone beds are typically grey.

The presence of interbedded sandstone and mudstone beds suggests that there were fluctuations in current velocities, with periods of current activity alternating with slack water periods.

Facies GH 4. Trough cross-bedded sandstones. Well-sorted, trough cross-bedded sandstones (fine to coarse grained), arranged in macroforms. Macroform accretionary elements are defined by mudstone drapes. Trough cross-beds occur in sets up to 20 cm thick. The toes of macroform accretion units are commonly coarser grained and contain mudstone rip-up clasts. Sandstones are clean-washed.

Macroforms consisting of accretionary units consisting of medium-scale bedforms separated by clay drapes are commonly attributed to tidal sand wave deposits (e.g., Allen, 1980; Boersha and Terwindt, 1981). Such bedforms with their low degree of cementation and high porosity and permeability would make excellent reservoir rocks.

Facies GH 5. Ripple cross-laminated sandstones. Ripple cross-laminated sandstones interbedded with mudstones. The ripple cross-lamination is unidirectional and sets are up to 3 cm thick. The mudstone units are up to 13 cm thick and are interbedded with the sandstones. The main bedding is composed of very low-angle surfaces. The upper 1 to 5 cm of many of the ripple cross-laminated sandstones contain small (~2 cm) subvertical burrows (*Skolithos* isp.).

The shelf sandstones are notably better sorted than the fluvial sandstones and they do not contain clastic pebbles, although mudstone rip-up clasts are common. The shelf sandstones are generally not cemented, and in outcrop are variably leached. Consequently, fossils are generally absent.

Facies GH 6. Oyster-rich mudstones. Mudstones containing abundant thin-shelled oysters. The oysters are aligned parallel to bedding and produce a laminated appearance. Other fossils, including gastropods and small infaunal bivalves, are also present Abundant lignite fragments occur in many of these shell beds. Locally, the unit may be cemented with calcite to form septarian concretions or thin semicontinuous concretionary limestones.

Facies GH 7. Calcareous sandstones. Calcareous sandstones that may merge to form concretionary sandstones with abundant bioclastic material (mainly molluscan debris). These are generally less than a metre thick and a usually separated by thin marl partings (2-8 cm). Plant fragments are common.

Carbonaceous facies

The shelf sandstones described above commonly contain lignitic flecks, and other plant debris. These sandstones are closely associated with two facies that contain relatively higher quantities of carbonaceous material.

Facies GH 8. Laminated grey shales. Thinly laminated grey mudstones with scattered plant fragments and lignite streaks. No fauna or trace fossils observed.

Facies GH 9. Lignitic shales. Black, thinly laminated mudstones and calcareous mudstones with abundant lignite material. Larger chunks of lignite are abundant.

The distribution of these mudrocks is restricted to the western part of the inlier. A palynological study of these lignites by Graham (1993) confirmed the presence of dinoflagellates mixed with pollen and spores. The poor preservation, and dominance of thick walled palynomorphs suggests transportation, and Graham (1993) suggested deposition in a near offshore environment.

Carbonate facies

There are several thin carbonate units contained within the main Guys Hill Formation clastic succession. The most significant of these is the Dump Member (Robinson and Mitchell, 1999). This unit achieves its maximum thickness (~21 m) in the western part of the inlier, near its stratotype locality, where facies grade from foraminiferal marls and thin oyster limestones to thicker micritic limestones with more diverse marine faunas.

Discussion

Parasequences are genetically related progradational successions bounded by marine flooding surfaces across which there is evidence of an increase in water depth (Posametier et al., 1988; Van Wagoner et al, 1988, 1990).

The facies of the Guys Hill Formation indicate a genetically related range of environments, including clastic-dominated fluvial incised valleys, sandy beaches, tidally influenced nearshore environments (sand wave complexes, lagoons and possibly estuaries) and marine carbonate-dominated environments. Typically, this range of environments may be expected to produce parasequences that show a coarsening and thickening upwards stacking pattern, indicating shoaling conditions and a significant seaward shift in depositional facies. Parasequence boundaries in the Guys Hill Formation are represented by three major types (i) shelf sandstone facies (shoreface and tidal sand wave complexes) resting on fluvial sandstones, (ii) marine mudstones and lignitic shales resting on fluvial or shelf sandstones, and (iii) limestones resting on marine mudstones.

Detailed mapping (Fig. 2) and logging in the Lichfield area in the north-western part of the inlier (where the maximum thickness of the Guys Hill Formation is developed) have enabled the recognition of four parasequences the Guys Hill Formation (Fig. 3). Each parasequence in this region shows the typical shoaling upwards succession. The basal part of each parasequence is consists of laminated mudrocks, concretionary sandstones with a shelly fauna, or thin oyster-rich limestones. The limestones become thinner towards the east. Parasequences subsequently show a general coarsening upwards trend and terminate in thick mappable sandstone units (Fig. 2).

The Guys Hill Formation is succeeded by the Chapelton Formation with its diverse shallow water molluscan and foraminiferal assemblages. Provisionally, the Guys Hill Formation is placed in the Transgressive Systems Tract and the Chapelton Formation in the Highstand Systems Tract. Lowstand deposits have not be recognised in the western part of the inlier. This suggests the partitioning of clastic and carbonate deposition to different parts of the sea-level curve.

Conclusion

The Guys Hill and Chapelton Formations contain a diverse suite of sedimentary facies. A detailed analysis of the Guys Hill Formation demonstrates the presence of 9 sedimentary facies. These Facies are arranged into parasequences with characteristic shallowing upwards successions. Four such parasequences are recognised in the Lichfield area, each terminating in a thick mappable sandstone unit. Provisional analysis suggests that the Guys Hill Formation represents the TST and the Chapelton Formation the HST, lowstand deposits being absent.

It looks likely that the Yellow Limestone Group of central Jamaica can be used to develop a model for deposition in mixed carbonate-clastic depositional systems. Further work towards this is currently in progress.

Acknowledgements

Thanks are due to the people who have helped us during the course of this work in the field, including Dean Burrowes and Edward Robinson.

References

Allen, J.R.L. 1980. Large Transverse Bedforms and Character of Boundary Layers in Shallow Water Environments. *Sedimentology,* 27, 317-323.

Boersma, J.R. and Terwindt, J.H.J. 1981. Neap-spring tide sequences of intertidal shoals in a mesotidal estuar *Sedimentology*, **28**, 151-170.

Graham, A. 1993. Contribution toward a Tertiary palynostratigraphy for Jamaica: the status of Tertiary paleobotanical studies in northern Latin America and preliminary analysis of the Guys Hill Member (Chapelton Formation, middle Eocene) of Jamaica. In Wright, R. and Robinson, E. *Biostratigraphy of Jamaica*, Geological Society of America, Memoir **182**, (Eds.) 443-461.

Posametier, H.W. et al. 1988. Eustatic controls on clastic deposition II - sequences and systems tract models, in Wilgus C.K. et al. (eds.), *Sea-level changes - and integrated approach*, SEPM Special Publication No. 42, 125-154.

Robinson, E. 1996. Freemans Hall beds and Stettin Member, Chapelton Formation, Jamaica: a revision of Geological Sheets 8, 9, and 12. *Journal of the Geological Society of Jamaica*, **31**, 23-32.

Robinson, E. and Mitchell, S.F. 1999. *Middle Eocene to Oligocene stratigraphy and palaeogeography in Jamaica: a window on the Nicaragua Rise, Prepared for the fourth annual meeting of IGCP 393, 12-18 July, 1999. Contributions to Geology, UWI Mona* #4, 1-47.

van Wagoner, J.C. et al. 1988. An overview of the fundamentals of sequence stratigraphy and key definitions, in Wilgus C.K. et al. (eds.), *Sea-level changes - and integrated approach*, SEPM Special Publication No. 42, 39-45.

van Wagoner, J.C., Mitchum, R.M., Campion, K.M., Rahmanou, V.D. 1990. *Siliciclastic sequence stratigraphy in well logs, cores, and outcrops*. AAPG methods in exploration series No. 7, 1-55.

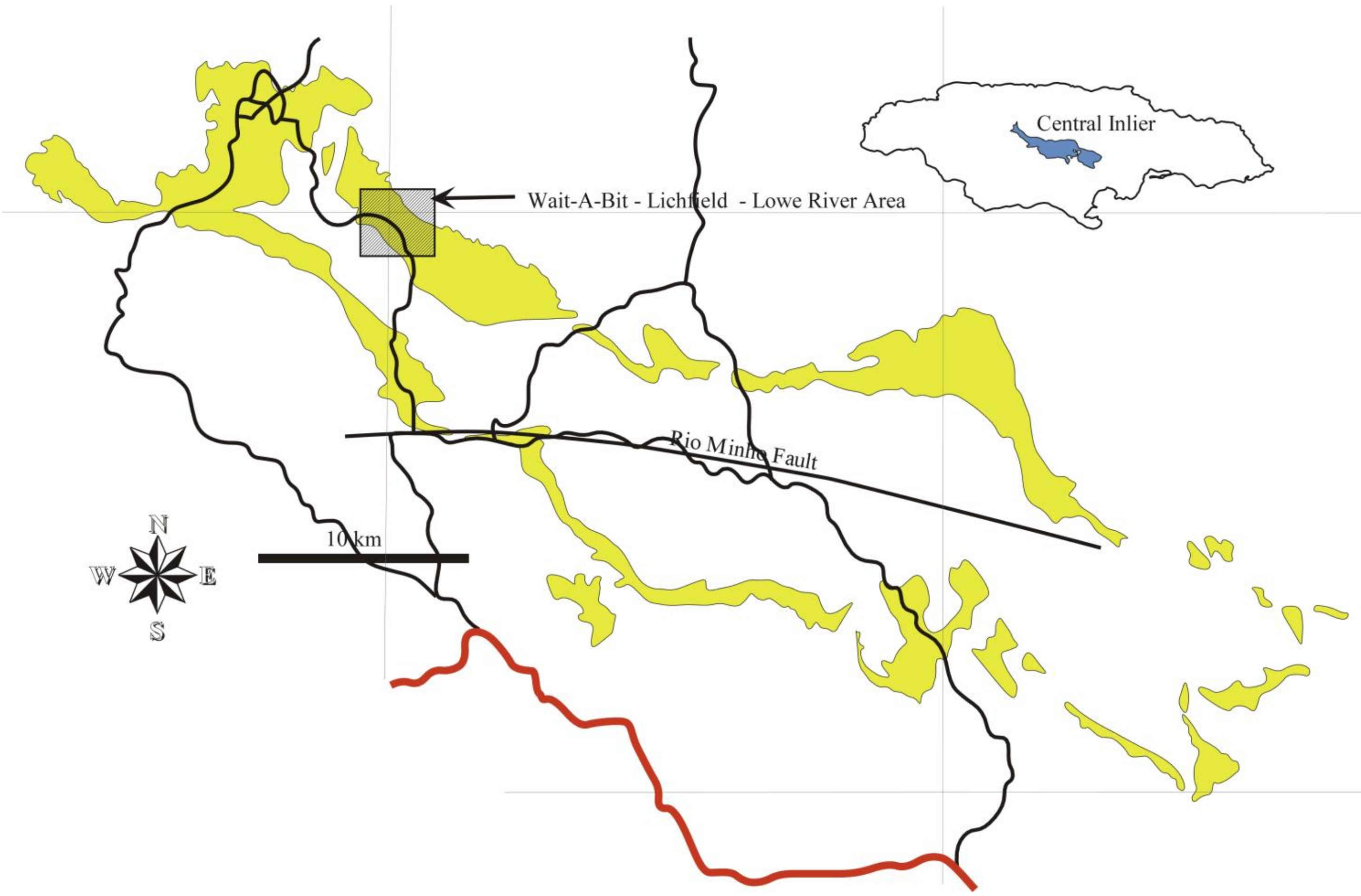

Figure 1. Distribution of the Yellow Limestone Group (stippled) around the edge of the Central Inlier, Jamaica. Inset - location of the Central Inlier in central Jamaica.

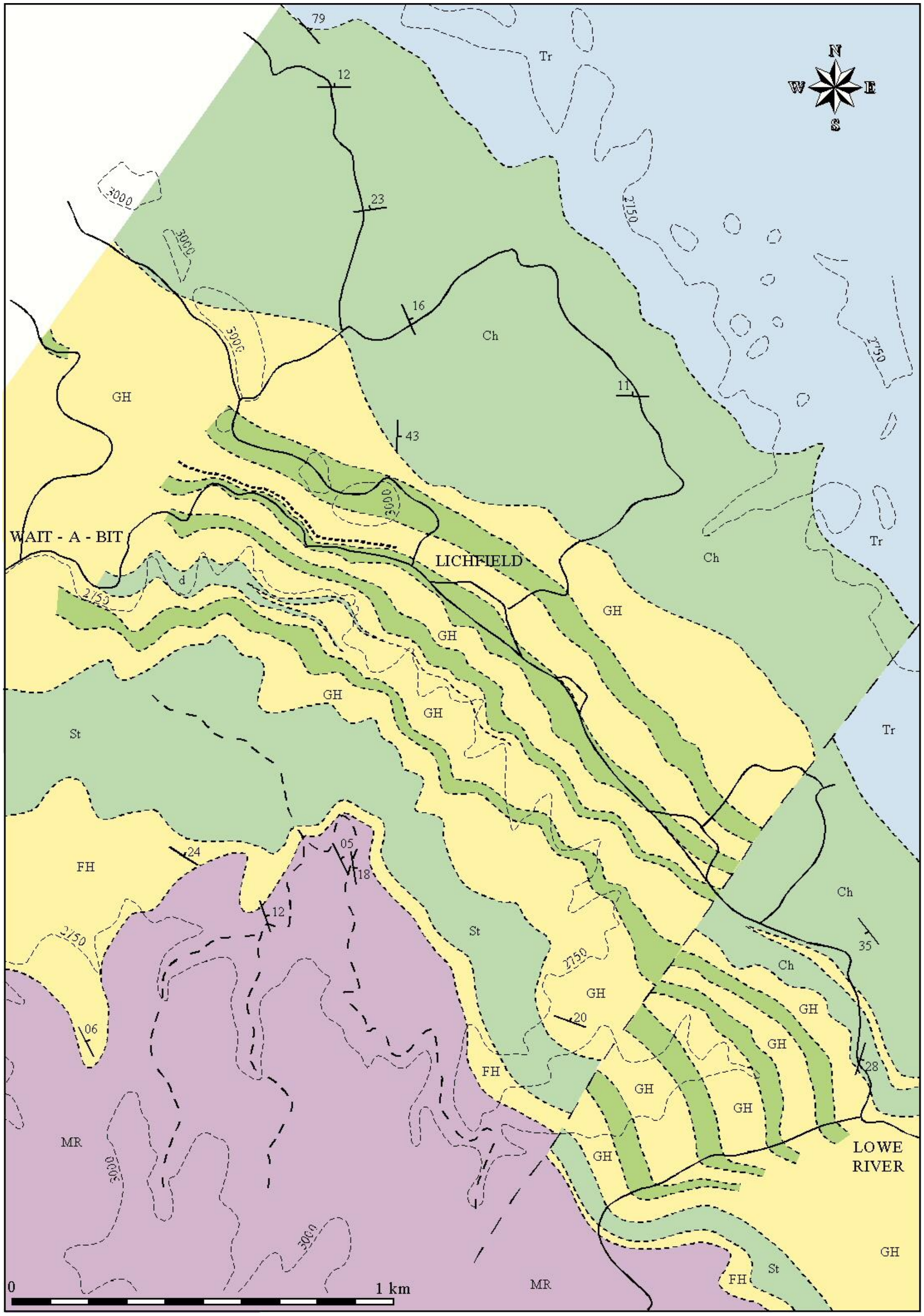

Figure 2. Geological map of the area around Lichfield on the northern margin of the Central Inlier (see Fig. 1 for location) Summerfield Formation (MR) – white; Freemans Hall beds (FH) – grey; Stettin Formation (St) – brick pattern; Guys Hill Formation (GH) – grey with mapped sandstones in dark grey and carbonates in brick pattern; Chapelton Formation (Ch) – brick pattern; White Limestone (Tr) – white. Note, the major sandstones at the tops of parasequences can be mapped out.

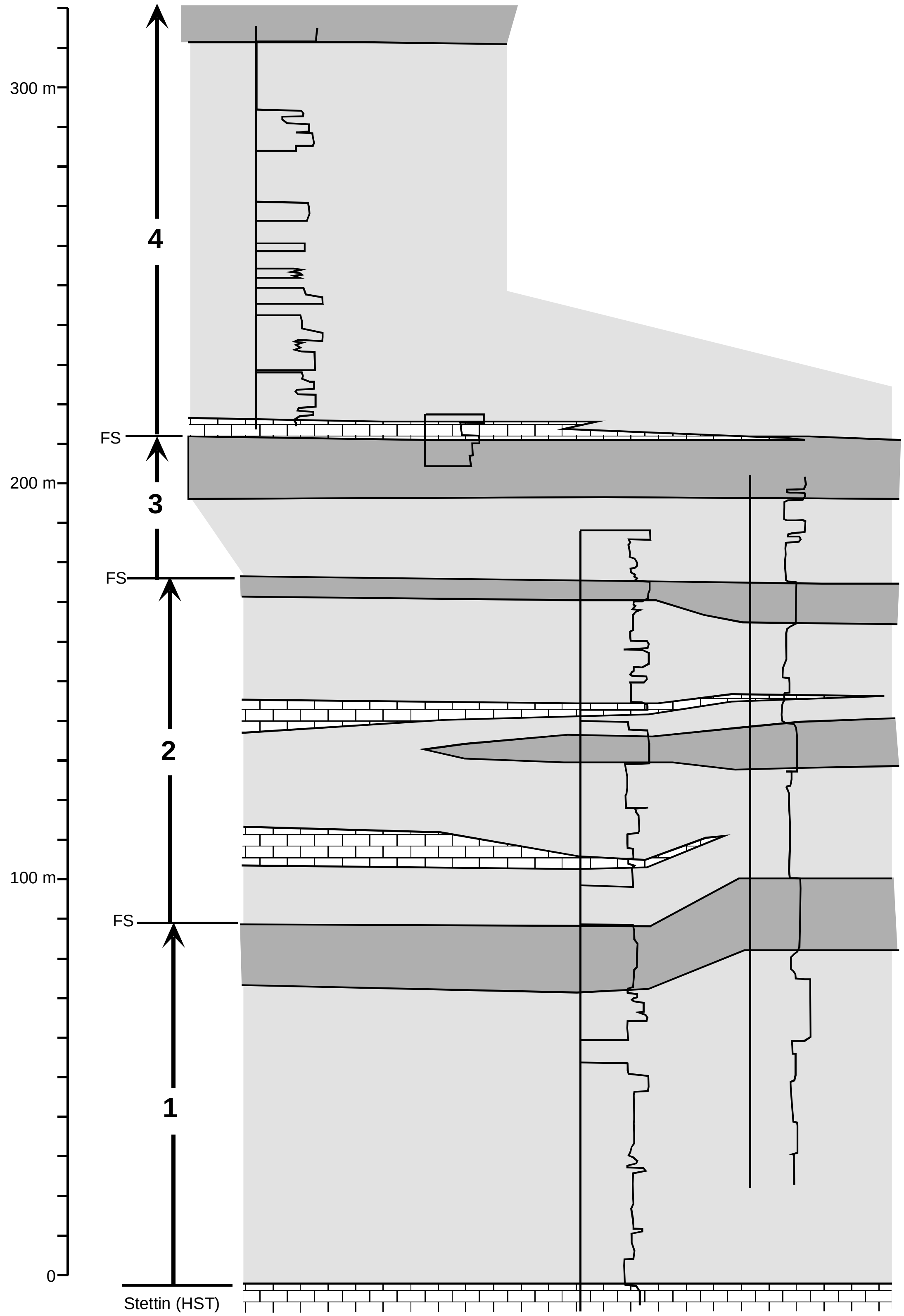

Figure 3. Detailed logs (shown as grain size profiles through the lower 320 m of the Guys Hill Formation in the Lichfield area. Limestones shown a brick patterns, clastics in pale grey and shallow water sandstones in dark grey. Parasequences numbered 1 to 4, marine flooding surfaces indicated by FS. Each parasequence is represented by fine grained clastics with or without a limestone division in the lower part. The top of parasequences is represented by massive sandstones.