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The stratigraphy,chronology and palaeoenvironment of The Pleistocene Cave Fill, Gladysvale Cave, South Africa

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CHAPTER THREE
GEOMORPHOLOGY, STRATIGRAPHY AND SEDIMENTOLOGY

3.1 Introduction

Due to their complex nature and often massive stratigraphy, little research has been undertaken on the South African hominin-bearing cave fills themselves. The main aim of this chapter, therefore, is to document the nature of a well-stratified and exposed cave fill, using the chronostratigraphic model of Ayliffe *et al.* (1998) and Moriarty *et al.* (2000), and a facies approach, such as the one used by Kos (2001). This study focused on the Pleistocene aged (via ESR) internal cave fill at Gladysvale. This deposit is well stratified (Pickering, 2002), well exposed, and is within the 500 kyr age limit of the dating techniques required to meaningfully test a chronostratigraphic approach. The deposit has unique three-dimensional exposures, allowing for a sequence stratigraphic analysis of the internal architecture, using the terminology and approach pioneered by Miall (1985; 1997; 2000). To this end, stratigraphic columns and section drawings were created for all the exposed faces. Within this stratigraphic framework, sedimentary facies were identified and described, and facies changes through time and space analysed. In this chapter the morphology of the deposit is described, and the stratigraphic and sedimentary data are presented.

3.2 Geomorphology of the deposit

3.2.1 General fan morphology

The younger deposit at Gladysvale is confined to the upper part of the underground chamber, with no equivalents in the GVED (Pickering, 2002). Figure 2.1 shows the approximate position of the deposit within the underground section of Gladysvale Cave. The deposit is a fan shaped body, with both the proximal and distal reaches represented inside the cave.

The exposure of the fan was greatly augmented by the removal of significant amounts of material by the lime miners, who mined the cave for the speleothem deposits growing on the walls and floors during the early 1900s. The mining activity in the upper chamber of

Gladysvale Cave seems to have consisted of trenching and blasting, and further trenching around newly blasted areas.

The proximal areas of the fan are found along the south-facing, front wall of the chamber, which runs almost due east-west, and extends across the entire back wall of the cave (Figure 2.1).

The proximal region grades into the mid-fan region of the deposit, which is well developed and is at least 1m thick (Figure 2.1). Towards the lower reaches of the mid-fan, the deposit begins to thin, especially on the eastern side. On the western side of the cave, the deposit retains its mid-fan thickness, but is completely trenched away by a large east-west orientated trench. This trench stretches across the cave from west to east, and two north-south trenches branch off it back into the mid-fan and proximal regions of the deposit. The remains of a railway track were found in this east-west trench, which would have carried the coco-pans from the cave entrance to the shaft leading to the deeper underground chambers of the cave, which were also mined extensively. This major trench, and the two smaller ones, are at the same elevation. This level can be seen where the deposit is exposed along the western wall leading out of the cave, and consists of a thick upper flowstone at the top of FBI 2, as identified by Pickering (2002).

The distal reaches of the fan are only preserved along the back, north-facing wall, which also runs almost due east-west. In other areas the mid-fan deposits downlap onto the top surface of FBI 2. The distal deposits are confined to the north-western portion of the cave, and are particularly well-preserved and exposed in the small, concave chamber in the extreme north-western corner of the cave, recognised by Pickering (2002) as the Peabody Chamber (Figure 3.1). The position of the large east-west trench across the transitional area between the mid-fan and distal reaches of the fan makes it difficult to assess the extent of the distal reaches. The thinning of the eastern side of the fan, however, suggests that sediments did not reach the eastern side of the back wall of the cave, and that the distal sediments preserved in the north-western corner of the cave are the only true distal sediments of the fan system that are preserved. The north-eastern corner of the cave is partially obscured by miners' rubble; it is significantly deeper than the rest of the chamber, and leads down via a passage into the lower chambers of the cave in the far north-eastern corner. Any distal sediment in this area

was either destroyed by the mining or is obscured by rubble, but was probably not deposited in the first place.

3.2.2 Cave entrances

Today the cave has two entrances (Figure 2.1). The first is a small circular entrance in the south-eastern portion of the south wall, which is essentially a hole in the front wall and roof of the cave, and is situated above the deposit. The second entrance on the far south-western side of the front wall is much larger and cuts though the deposit to the present floor level. This entrance is up against the western wall, and there is none of the younger fan deposit preserved against the west wall. The nature of the deposit suggests that these entrances were true cave entrances, but the presence of significant rubble chokes in the vicinity of both entrances and an extensive rippled flowstone capping to the deposit, suggests that the cave was closed before mining activity began. The presence of drill holes for dynamite and blast scars on the walls at both entrances indicate that the enlarging, and perhaps even the opening, of these entrances was executed by the lime miners.

3.2.3 Fan lobes

Today the deposit consists of two major lobes, the Western and Eastern lobes, and a lesser far Eastern lobe. All three lobes are separated by large trenches (Figure 2.1). The presence of extensive stalactite development above all the major pits can be used as a proxy for the corresponding stalagmites, which would have grown up on the cave floor before sedimentation commenced, and which were the miners' targets and the reason behind the trenching of the deposit. Further evidence for this can be found along the edges of the trenched deposit and in the Porcupine Pit, where the remains of major stalagmites have been found associated with blast scars (Figures 2.1; 3.1). The surface of the Western Lobe of the fan was covered in mining rubble, as was the majority of the floor of the cave, but this particular rubble consisted of sub-10cm fragments of speleothem, which, from their coarse grained and clearly layered nature, are stalagmite fragments. These fragments were most likely emplaced by the fallout of the blast used by the miners to break up what must have been a major stalagmite between the Eastern and Western lobes.

The compelling evidence for the presence of significant stalagmite deposits in the present trenches, which divide the deposit into two lobes, advocates that these lobes are not a

function of modern mining, but are real geomorphological features. The stalagmites grew on the floor of the cave, underneath major drip sources, marked by corresponding stalactites, before sedimentation began, i.e. in a cave not receiving clastic sediment. Once the sedimentary infill began, accommodation for incoming sediment was limited by the presence of these stalagmites, and consequently sedimentation took place in the two major lobes on either side of the stalagmites, forming the Western and Eastern Lobe. Only minor sedimentation took place between the stalagmite in the Porcupine Pit and the eastern side-wall of the cave. The deposits in the Hinge area, which dips away to the east and west, provide further evidence for the contemporaneous deposition of the Eastern and Western Lobes.

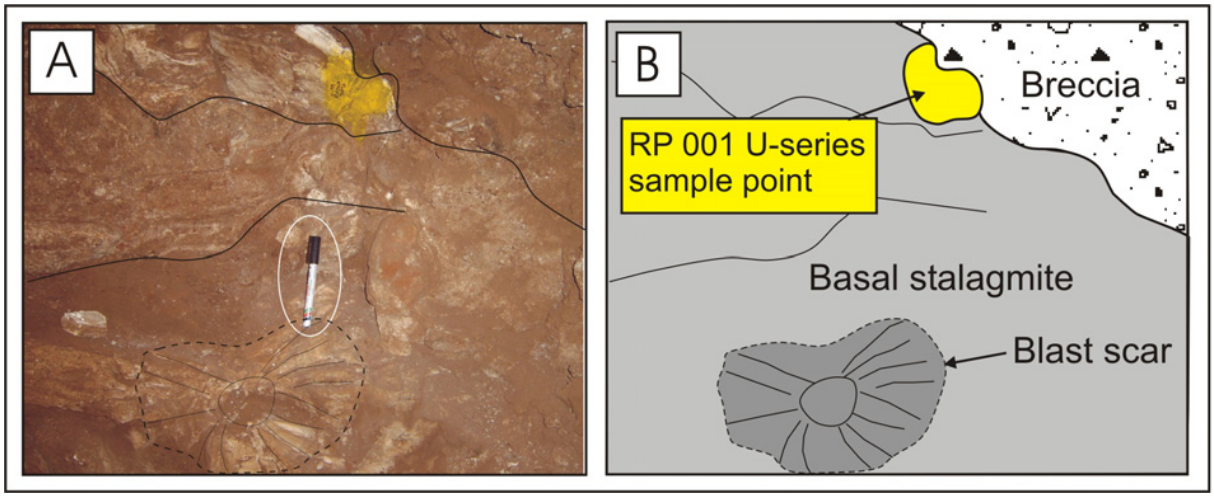


Figure 3.1. Photograph (A) and line drawing (B) showing blast scar and RP001 U-series sample point (yellow) in the Porcupine Pit (12 cm pen for scale, circled in white).

3.2.4 Fan lobe faces

The removal of the two major stalagmites and the trenching around the Eastern and Western lobes has significantly enhanced the exposure of the stratigraphy and internal architecture of these lobes. The faces of the lobes have been numbered from the western cave entrance towards the eastern side of the cave, and have been named after the direction they face; for example, the Eastern Face 1 is the first face exposed on the Western Lobe and is facing east (Figure 2.1). The stratigraphy of these faces has been documented through section drawings and stratigraphic columns.

3.2.5 Drip centres and stalagmites

The drip centres in the cave are significant as they feed stalactites and more importantly stalagmites, which control the amount of available accommodation space for sediments. At Gladysvale the major stalagmites have been removed by the lime miners, but it is possible to reconstruct their positions within the cave. This reconstruction is done by recording the position of the remnant stalagmites preserved in the fan lobe faces, the positioning of stalactites, old and modern, on the cave roof and the distribution of modern flowstone currently growing in the cave. Cave drip waters exploit pre-existing weaknesses in the cave roof, which in the case of the dolomites in the Cradle of Humankind World Heritage Site are major conjugate fault and joint sets, trending northwest and north northeast (McCarthy *et al*., 1986). Manifestations of these structures can be seen at Gladysvale, with major north-south trending faults controlling the extent of the cave itself, as the two side walls run parallel to these structures. Lesser faults run on the same north-south orientation through the cave roof, which act as conduits for groundwater flow into the cave, and control the position of drip centres. These drip centres on the cave roof are marked by rows of stalactites, which also run north-south. The trenches made by the lime miners in order to remove the major stalagmites lie directly below the lines of stalactites. Remnants of stalagmites have been found along the Western Face 1, the Eastern Face 2 and in the Porcupine Pit (see Figures 2.1; 3.2), which are all on the edges of the two major trenches through the deposit. Modern flowstone is also found growing on the floor of these two trenches, as well as on the sides of the deposit adjacent to the trenches, indicating that these major drip centres of the past are still active under the right conditions. The relative positions of all these features can be used to reconstruct the major drip centres within the cave (Figure 3.2).

The area around the Hinge section is exposed from the removal of the medium sized stalagmite some 1.5 m above the present cave floor (Figure 3.2). In the areas to the east and west of the Hinge the top flowstone is not present, and a roughly circular patch of the underlying sediment is exposed. These features are most likely the result of the removal of two smaller stalagmites growing on top of the sediment pile on either side of the Hinge (Figure 3.2).

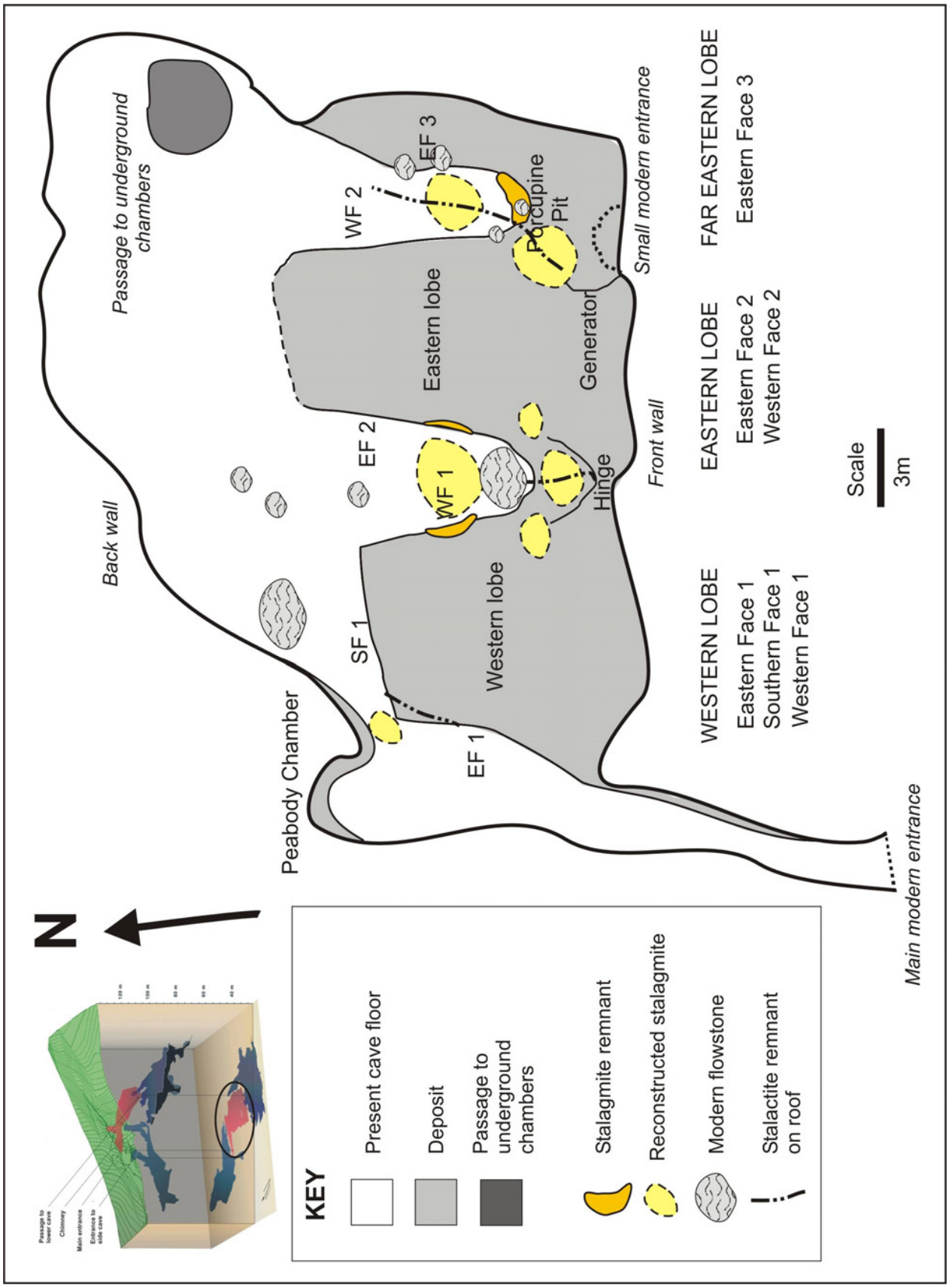


Figure 3.2. Schematic diagram of Gladysvale Cave in plan view showing drip centre reconstruction.

3.3 Stratigraphy and Sedimentology

3.3.1 Flowstone bounded units

The chronostratigraphic model of Moriarty *et al*. (2000) proposes that cave sediments are deposited during discrete time periods, preceded and followed by flowstone development, resulting in flowstone bounded units (FBU). Thus, the flowstones represent chemical precipitation during a hiatus in clastic sedimentation, and can be used to divide the clastic sediments into unconformity bounded units, which is the first step in the stratigraphic analysis of sediments (Miall, 1985; 1997; 2000). The FBU approach has been successfully tested at Gladysvale, on both the external deposits by Lacruz (2002) and Lacruz *et al*. (2003) and on the internal, Peabody Chamber deposit by Pickering (2002). In the study by Pickering (2002) the sediments of the Peabody Chamber (Figure 2.1) were divided into several FBU, which in turn were grouped into three Flowstone Bounded Intervals (FBI), FBI 1, 2 and 3. In this study, FBI 3 of the Peabody stratigraphy is included, and forms the basis of the identification of the FBU of the younger deposit at Gladysvale. Pickering (2002) identified six FBU in FBI 3, and systematic mapping of the rest of this younger deposit, exposed throughout the upper chamber, revealed that these same six FBU are found throughout the stratigraphy of the younger fan.

The six major and two minor FBU of the deposit are named (from bottom to top): MK, LK, BM, JN, SR, JS, HL and FN, after members of the team of Fossil Trackers (Table 3.1). A non-numerical naming system was deliberately used to accommodate extra units, and to avoid becoming trapped in a presupposed sequence (Table 3.1).

In general, clastic sedimentary units are flowstone bound, and the flowstones vary in thickness and state of preservation. However, in areas of poorly calcified deposit, where units themselves are often completely decalcified, flowstones are not present between units. In these cases, distinct breaks are always visible. The boundary between units in this case would thus be a non-depositional unconformity. The incoming sediment may erode away some of the underlying sediment, forming an erosional boundary. The different types of boundaries found at Gladysvale are shown schematically in Figure 3.3.

Flowstone Bounded Units	Abbreviated names
Francinah	FN
Harriet	HL
Joe	JS
Sarah	SR
(Jabu)	JN
Brenda	BM
Laz	LK
(Meshack)	MK

Table 3.1. Table showing the six major FBU making up the basic stratigraphy of the younger deposit at Gladysvale Cave. Units are in stratigraphic order, from bottom to top. FBU MK and JN are in parentheses as these units occur only in the extreme proximal reaches of the deposit, and the Porcupine Pit respectively.

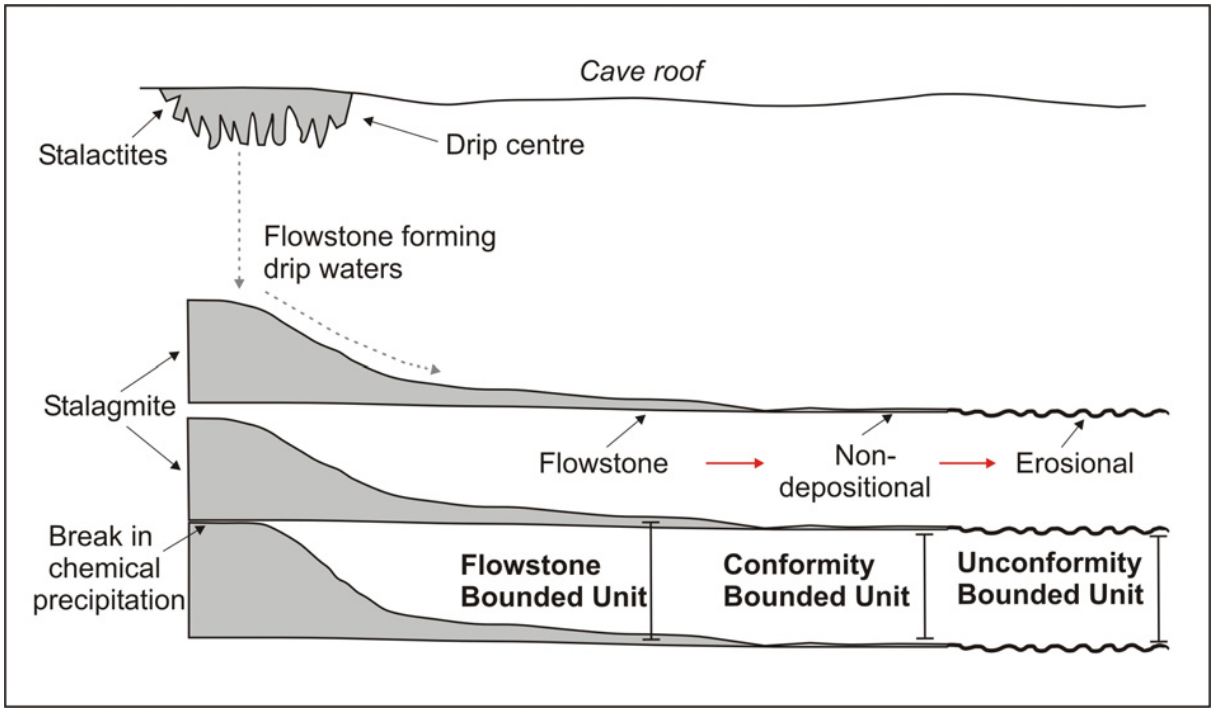


Figure 3.3. Schematic diagram showing a classic Flowstone Bounded Unit and its correlative conformity and unconformity bounded units, depending on the boundary conditions of the unit.

Taking the variation in flowstone distribution throughout the cave, units cannot be simply defined as flowstone bound, as a unit may be bound by a non-depositional unconformity or an erosional unconformity, or a combination of both. In areas directly under major drip sources, large stalagmitic bosses develop, and during periods of clastic deposition elsewhere in the cave, stalagmite formation would have ceased, creating a non-depositional

unconformity (Figure 3.3). Thus, breccia units are defined as being bound by flowstones, or their correlative conformities or unconformities.

Flowstones currently growing in the Naracoorte Caves in South Australia are often restricted laterally to areas directly below drip sources, and flowstones grow out from these drip sources, depending on the quantity and consistency of the drip waters (personal observations, Pickering, 2003; Steve Bourne, pers. comm.). It is proposed that a similar system was in operation at Gladysvale Cave: during conditions conducive to flowstone growth (closed cave, water surplus), flowstones grew out laterally from drip sources. If drip sources were limited and drip waters minimal, flowstones would have been restricted in size, and confined to areas below drip sources. Areas away from drip sources would, therefore, not receive a flowstone covering, and when conditions in the cave changed and sedimentation was renewed, younger sediments would be deposited directly above older, underlying deposits, with no flowstone layer separating them (Figure 3.3).

While this variation must be noted, for ease of communication, the clastic units identified in this project are referred to as Flowstone Bounded Units (FBU) throughout the deposit. Similarly, unit boundaries without flowstones were mapped as erosional boundaries (see Figures 3.13-3.28), although individual boundaries may be non-depositional.

In general, all six units are present in the exposed sections, from the proximal, to mid-fan to distal reaches of the deposit, making them true chronostratigraphic units. In the most proximal reaches of the deposit, a seventh unit is present, which is named MK, and is found between the top six FBU and the cave floor. Units LK and BL are not found in the Porcupine Pit, and the basal unit here is an eighth FBU, JN (Table 3.1).

3.3.2 Thin section petrology

Thin sections were cut from FBU and where possible binding flowstone from sections 3 and 4 of the Western Face 1, and from the Peabody Chamber. Thin sections were examined under 4 x magnifications using a standard petrographic microscope and photomicrographs were taken of representative features of each FBU (Figures 3.4, 3.5 and 3.6).

Western Face 1 thin sections

Photomicrographs Q, R, S and T in Figure 3.11 are of the top flowstone of FBI 2, which forms the base of the Western Face 1 section. The flowstone consists of bladed aragonite (Q) and equant calcite crystals (S and T), as well as smaller, blockier calcite crystals (R). Layers of fine grained, opaque detrital material are seen in all the thin sections from this layer, and can be seen even between the large, otherwise 'clean' calcite grains in photomicrographs S and T. The binding flowstones of BM and SR, as well as the small stalagmite from SR, all show similar features, with blocky to equant calcite crystals showing distinct layers of detrital contamination. The upper flowstone of BM (photomicrograph I and J in Figure 3.4) has reasonably heavy detrital contamination, with closely spaced layers of detritus. The lower flowstone and small stalagmite from SR (photomicrographs E to H Figure 3.4) show thicker layers of calcite crystals with less interbedded detritus. Photomicrographs A and B (Figure 3.4) show the interface between the sediments of SR and the underlying flowstone. This contact is sharp, with no grading between flowstone and sediment, and from the slightly concave nature of the contact (on a very small scale) could be erosive. The flowstones binding JS (Photomicrographs Q, R, U & V in Figure 3.5) show significant amounts of detrital contamination, with a distinct layer of opaque detritus in photomicrographs Q and R (Figure 3.5). The calcite crystals are smaller and blockier in these flowstones. One layer of calcite from the lower flowstone binding JS revealed clean, equant calcite grains, with minimal detrital contamination (photomicrographs W and X, Figure 3.5).

The breccias from the FBU sampled from the Western Face 1 are very similar to each other (photomicrographs C, D, K, L, M, N, O and P in Figure 3.4 and photomicrographs A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, S and T in Figure 3.5). In thin section the breccias consist predominantly of quartz grains, which are sub-angular to rounded and often polycrystalline, set in a muddy, clay rich, opaque matrix. Some quartz grains have distinct black rims (photomicrographs C, D, K and L in Figure 3.4 and photomicrographs E and F in Figure 3.5), which are due to iron staining. These rimmed grains consist of fine grained polycrystalline quartz. Other quartz grains, without distinct iron stained rims are larger, and consist of coarser grained polycrystalline quartz (photomicrographs M and N in Figure 3.5 and photomicrographs M, N, S and T in Figure 3.4). A distinct feature of all the breccias are brown coloured, rounded agglomerations of polycrystalline grains and other smaller quartz grains (Figure 3.5 photomicrographs A, B, C, D, O and P). These are identified as micropeds

(Retallack, 1990) or pedo-relics, such as those described by Moriarty *et al*. (2000) in the cave sediments of the Naracoorte Cave. A very limited quantity of fossil bone was observed in this set of thin sections. Three isolated, subrounded to rounded fragments were found in LK (Figure 3.4 photomicrograph P) and HL (Figure 3.5 photomicrographs G, H and L). The breccias are not heavily calcified at this scale, and do not display distinctive calcite rims on grains. Calcite is present as cement rather than a matrix.

Peabody Chamber thin sections

There are far fewer flowstones present between FBU in the Peabody Chamber, and those present are very thin. The only flowstone layer which could be successfully sampled is the top of FBI 2, which forms the basal flowstone of the sequence. This flowstone consists of clean, equant calcite crystals (Figure 3.6 photomicrographs U and V) and radiating bladed aragonite (Figure 3.6 photomicrographs W and X), with very little detrital contamination.

The Peabody Chamber breccias are basically similar to those of the Western Face 1, in that they consist of polycrystalline quartz grains set in a muddy matrix (photomicrographs A, B, E and F, Figure 3.6). The Peabody breccias are different in that their matrix is much more calcite rich and grains have distinct calcite rims (Figure 3.6 photomicrographs A, B, G and H). Very thin, pervasive flowstones are present within the breccias, but are limited in extent, and are not laterally extensive (Figure 3.5 photomicrographs M and N). Micropeds or pedo-relics are present, and also have calcite rims (photomicrographs K and L in Figure 3.5). Bone fragments are more frequent and are well preserved, with spongy and cancellous bone observed in units LK, JS and HL (photomicrographs C, D, I, J, S and T, figure 3.6).

Discussion

The thin section petrography of the flowstones from the Western Face 1 and the Peabody Chamber illustrate the importance of thin section microscopy in identifying detrital contamination within otherwise clean looking flowstones. All the flowstones examined displayed a level of detrital contamination, from extreme contamination in the form of actual layers of detritus (e.g. JS top flowstone, Figure 3.5 Q and R) to extremely thin layers, as thick as individual detrital particles (e.g. BM flowstone, Figure 3.4 I and J). The best flowstones for uranium-series dating are those with large, equant calcite crystals with minimal detrital contamination (e.g. FBI 2 top flowstone, Figure 3.6 U and V).

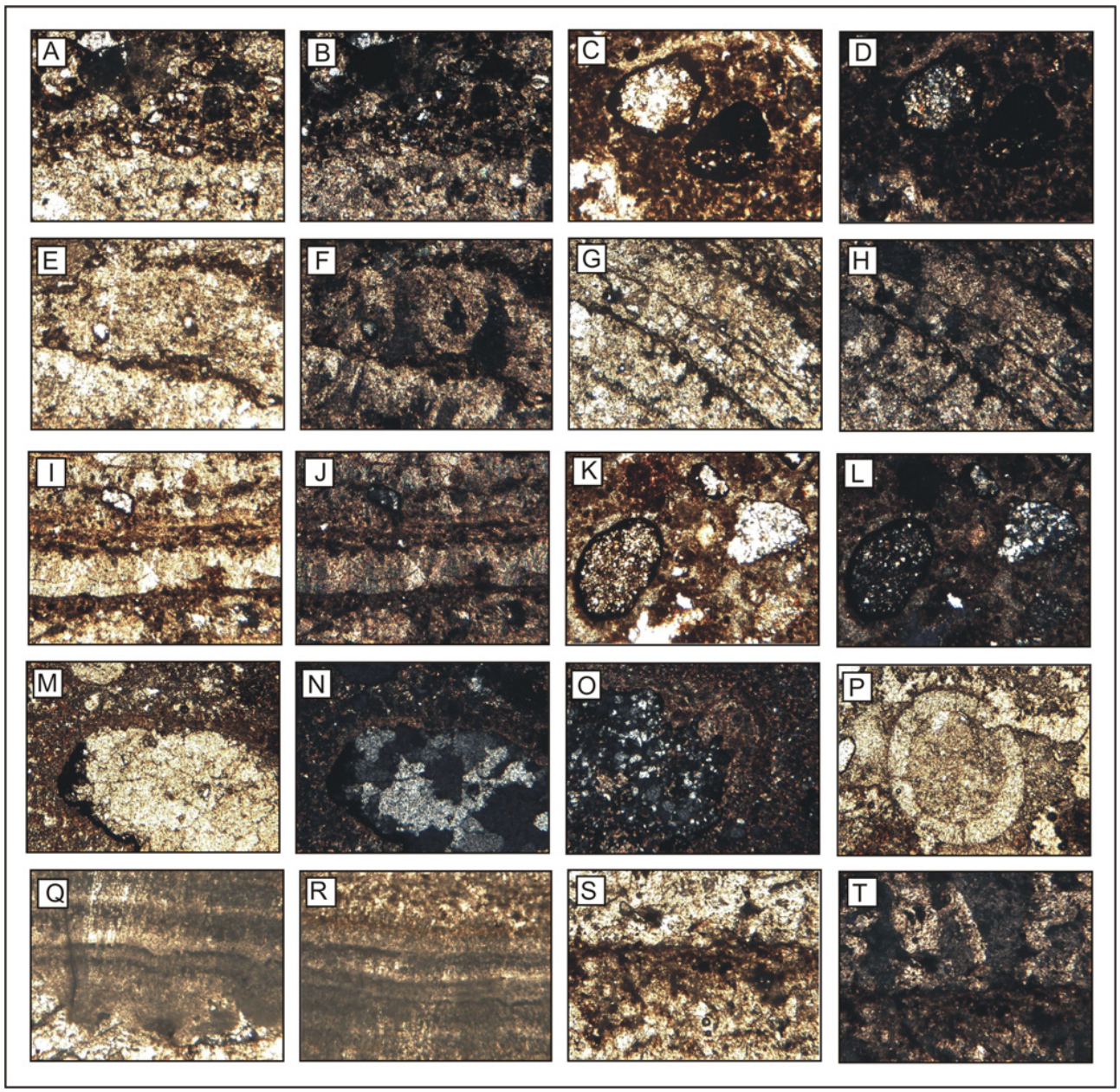


Figure 3.4. Photomicrographs of thin section from the basal units of the Western Face 1, in plane polarised (pp) and crossed polarised (xp) light. Scale on all pictures is 1.6mm across the base of the image. A: Flowstone sediment interface from SR (pp), B: Flowstone sediment interface from SR (xp). C Sediment from SR showing polycrystalline quartz grains (pp), D: Sediment from SR showing polycrystalline quartz grains (xp). E: SR lower flowstone, showing detrital contamination (pp), F: SR lower flowstone, showing detrital contamination (xp). G: SR lower flowstone, showing detrital contamination (pp), H: SR lower flowstone, showing detrital contamination (xp). I: BM flowstone (pp), J: BM flowstone (xp). K: BM sediment showing polycrystalline quartz grains (pp), L: BM sediment showing polycrystalline quartz grains (xp). M: LK sediment showing polycrystalline quartz grain (pp), N: LK sediment showing polycrystalline quartz grain (xp). O: LK sediment showing polycrystalline quartz grain (xp). P: Fossil bone from LK (pp). Q and R: FBI 2 upper flowstone, showing bladed aragonite crystals and detrital contamination (pp). S: FBI 2 upper flowstone with detrital contamination (pp), T: FBI 2 upper flowstone with detrital contamination, calcite crystals seen better under crossed polars (xp).

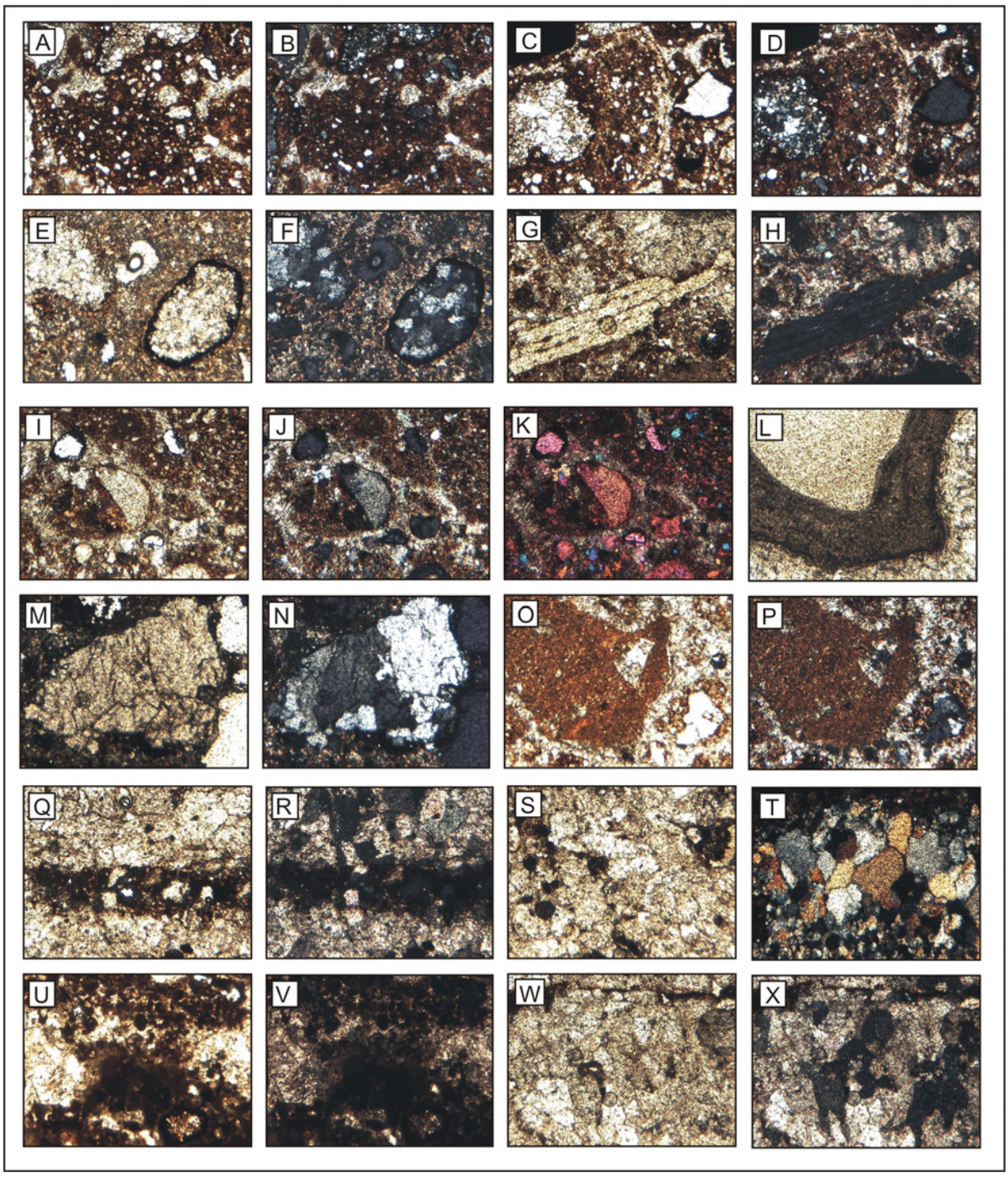


Figure 3.5. Photomicrographs of thin section from the upper units of the Western Face 1. Scale on all pictures is 1.6mm across the base of the image. A and C: Sediment from FN showing pedo-relic particles (pp), B and D: Sediment from FN showing pedo-relic particles (xp). E: Sediments from HL showing polycrystalline quartz grains (pp), F: Sediments from HL showing polycrystalline quartz grains (xp). G: Bone fragment from HL (pp), H: Bone fragment from HL (xp). I: HL sediments (pp), J: HL sediments (xp), K (xp, gypsum plate). L: Bone from HL (pp). M: polycrystalline quartz grain from HL (pp), N: polycrystalline quartz grain from HL (xp). O: Pedo-relic particle from HL (pp), P: Pedo-relic particle from HL (xp). Q: JS top flowstone with layer of detritus (pp), R: JS top flowstone with layer of detritus (xp). S: Sediment from JS showing polycrystalline quartz grain (pp), T: Sediment from JS showing polycrystalline quartz grain (xp). U: JS lower flowstone, with significant detrital contamination (pp), V: JS lower flowstone, with significant detrital contamination (xp). W: JS lower flowstone with slightly less detritus (pp), X: JS lower flowstone with slightly less detritus (xp).

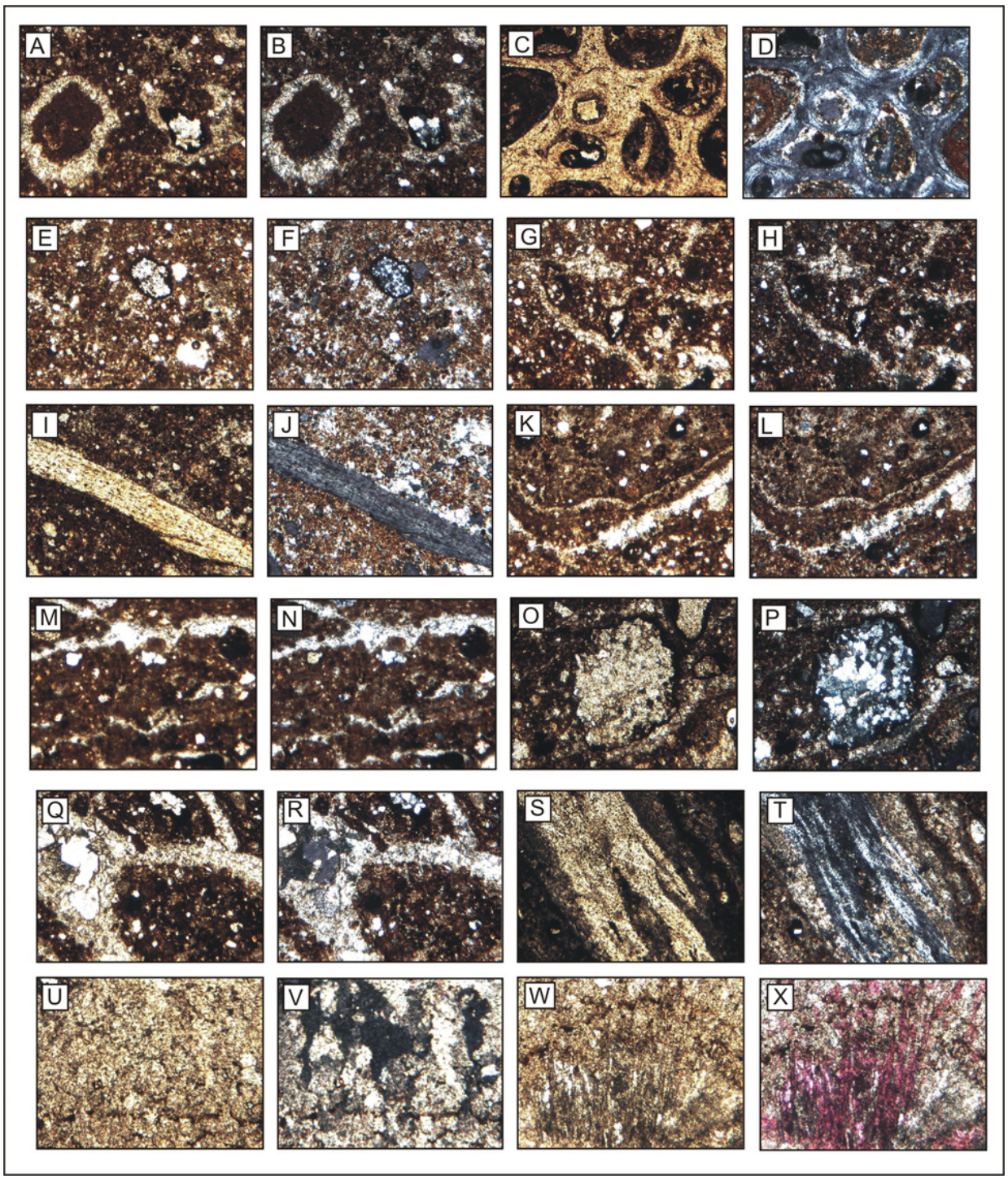


Figure 3.6. Photomicrographs of thin section from the Peabody Chamber. Scale on all pictures is 1.6mm across the base of the image. A: Sediment from FN showing calcite rims around grains (pp), B: Sediment from FN showing calcite rims around grains (xp). C: Spongy bone from HL (pp), D: Spongy bone from HL (xp). Sediment from HL showing polycrystalline quartz grain (pp), F: Sediment from HL showing polycrystalline quartz grain (xp). G: Sediment from JS showing calcite rims on grains (pp), H: Sediment from JS showing calcite rims on grains (xp). I: Bone from JS (pp), J: Bone from JS (xp). K: Pedo-relic with calcite rim from SR (pp), L: Pedo-relic with calcite rim from SR (xp). M: Calcite rich sediment from BM (pp), N: Calcite rich sediment from BM (xp). O: LK sediment showing polycrystalline quartz grain (xp), P: LK sediment showing polycrystalline quartz grain (xp). Q: pedo-relic and polycrystalline quartz grain with calcite rims from LK (pp), R: pedo-relic and polycrystalline quartz grain with calcite rims from LK (xp). S: Bone from LK (pp), T: Bone from LK. U: FBI 2 top flowstone (pp), V: FBI 2 top flowstone (xp). W: FBI 2 top flowstone showing bladed aragonite crystals (pp), X: FBI 2 top flowstone showing bladed aragonite crystals (pp with gypsum plate).

The breccias consist of matrix supported polycrystalline quartz grains, some with iron stained rims, and pedo-relics or micropeds (Partridge, pers. comm.). Soil peds are aggregates found in soil, and form persistent clods (Retallack, 1990). Small (1-2mm, never <5mm), equidimensional soil peds are termed granular and crumb peds, are found in the upper parts of the soil (Retallack, 1990), and are best identified in thin section (Stoops, 1983). These structures consist of spherical aggregates of claystone, usually kaolonitic, with small included quartz grains, and stained red with opaque haematite. Micropeds are physically tough, chemically inert and originate in part from faecal and oral pellets of soil invertebrates, such as earthworms (Retallack, 1990). Moriarty *et al*. (2000) describe similar features in the breccias from the Naracoorte Caves in South Australia.

The somewhat subtle difference between the breccias of the Western Face 1 and the Peabody Chamber, such as in the levels of calcification and the amount of fossil bone preserved, can be explained by the position of these two areas with the deposit. The well developed binding flowstones of the Western Face 1, less calcite matrix and very little fossil bone preserved are characteristic of mid-fan area of the deposit. The lack of preserved fossil bone is most likely due to the low levels of calcite in the matrix, which would hinder the fossilisation of bone. Further more, these sediments probably never did contain significant amounts of bone, as the bones do not naturally accumulate in the mid-fan region of the deposit. The Peabody Chamber thin sections are characterised by a calcite rich matrix and well preserved bone, which are products of the distal depositional environment.

3.3.3 Fossil bone and coprolites

Gladysvale Cave is not particularly rich in hominin fossils, with only two *ex situ* teeth (Berger, 1992) and one *in situ* fossil (Schmid & Berger, 1997) recovered to date. However, there is a rich diversity of other faunal remains (Berger & Tobias, 1994; Lacruz *et al*., 2003), including well preserved microfauna (Avery, 1995). During this study, abundant fossil bone was observed *in situ*, and seen in thin section (Figure 3.7) but were restricted to well calcified areas in the vicinity of palaeodrip sources, the Western Face 1 (Figure 3.7 A) and the Peabody Chamber (Figure 3.7 G, H). In the Western Face 1, in sections 3 and 4 a collection of *in situ* fossil coprolites were identified in unit SR (Figure 3.7 A, F). The coprolites are hyaena in origin and are restricted to the middle layer of SR, suggesting that this is a hyena den (Berger, pers. comm.). Further detailed analysis of this feature is being conducted by others.

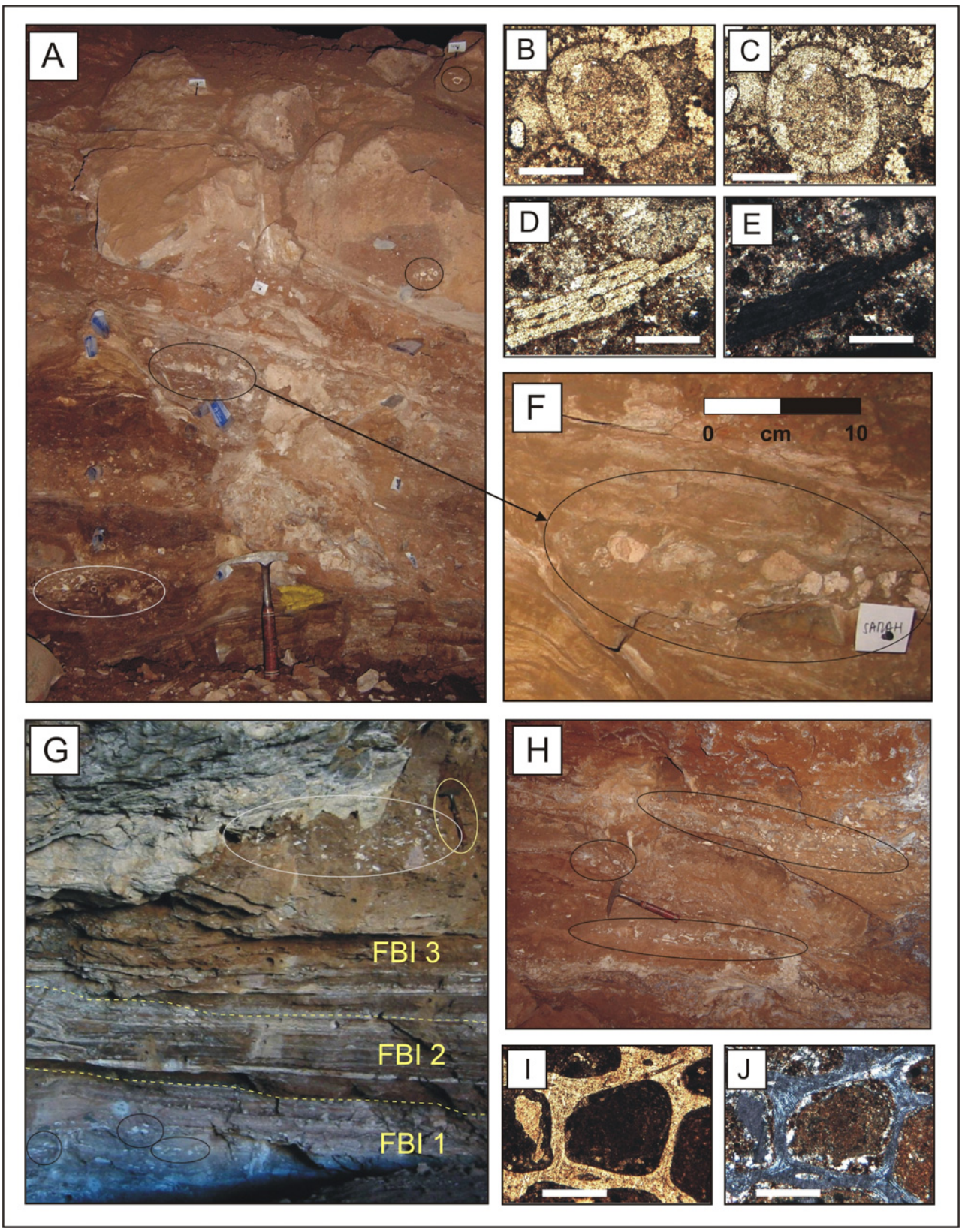


Figure 3.7. Fossil bone and coprolite occurrence in the younger internal deposits at Gladysvale Cave. A: Fossil bone occurrences in the Western Face 1 (30cm geopick for scale); B – E: photomicrographs of bone from the Western Face 1 (scale bar 0.5mm, B & D plane polarised light, C & E crossed polars); F: an enlargement of the accumulation of hyena coprolites in unit SR; G: Bone occurrence in the Peabody Chamber, including those in FBI 1 (30cm geopick for scale, circled in yellow); H: Dense bone accumulations in the Peabody Extension section; I & J: photomicrographs of spongy bone from the Peabody Chamber (scale bar 0.05mm, I plane polarised light, J crossed polars).

3.3.4 Fossil Snails

A number of small, approximately 1cm in diameter, fossil snails were found throughout the stratigraphy in the cave. The snails are present in the calcified and decalcified sediments and are found predominantly in the mid-fan and distal reaches. Snails are generally found in clusters of several individuals. Figure 3.8 shows two views of two isolated specimens (A) and an impression of a snail *in situ* from unit LK, in section 6 of the Eastern Face 1.

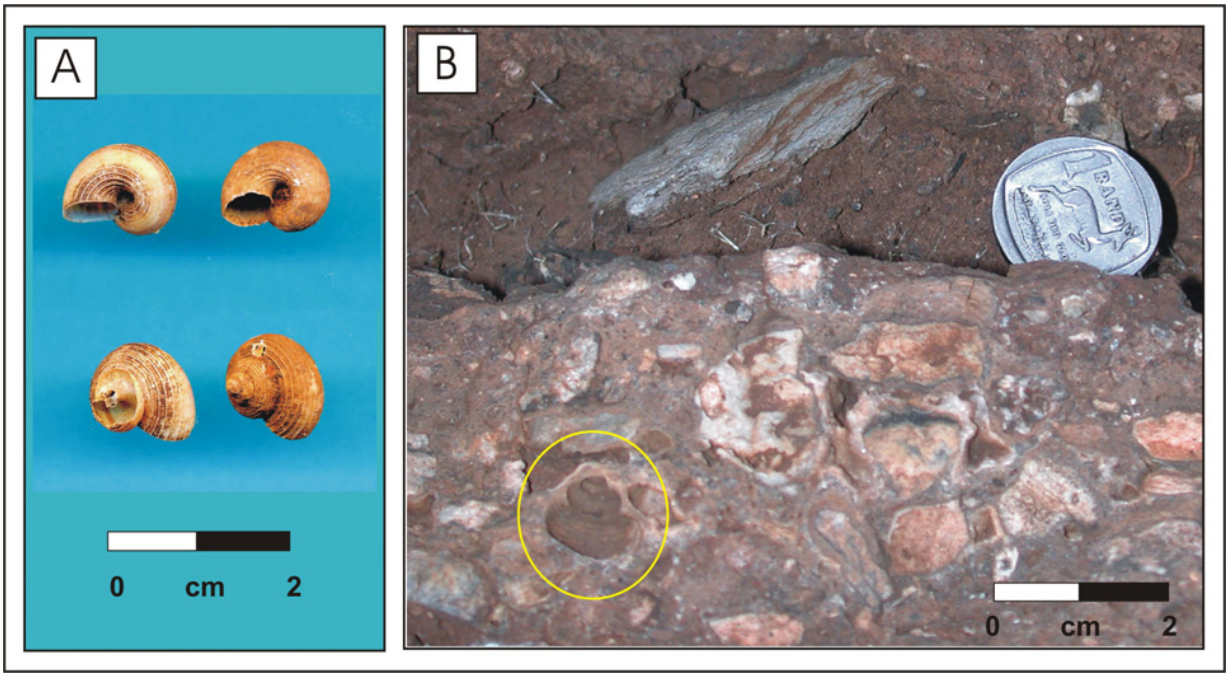


Figure 3.8. Specimens of the snail *Trophidophora insularis*, A: Isolated specimens recovered from decalcified sediments, B: Snail impression in breccia FBU LK from the Eastern Face 1.

The snails were identified by Dr Dai Herbert of the Natal Museum as belonging to the generus *Trophidophora*, and are probably *Trophidophora insularis* (Pfeiffer, 1852). Today this genus is common and widely distributed down the eastern side of Africa, from Kenya to Zimbabwe, to the Limpopo and Kruger Park, down through Natal, with their most southerly known occurrence in the Eastern Cape around Port Elizabeth (Herbert & Kilburn, 2004). *T. insularis* live in a variety of habitats, from forest to woodland and thicket to thorn savannah, and live on tree trunks and in leaf litter, both of which provide sheltering micro-habitats. *T. insularis* bury themselves in the soil during dry periods to avoid desiccation. These snails are quite common in the archaeological record and are quite tough and persist in the environment long after death; the specimens preserved in the Gladysvale deposit were most likely already dead when they were washed into the cave (Herbert & Kilburn, 2004).

3.3.5 Cave pearls

In the Hinge area of the cave, on the present cave floor, as excavated by the lime miners, there is a covering of modern flowstone growing out from underneath the major drip source on the roof. The surface of this modern flowstone is pitted from later drip waters, which during more evaporative conditions have caused the pitting of the deposit (Figure 3.9). Features such as these are observed in other caves (e.g. Kos, 2001), and are found in the deposit itself at Gladysvale (the Southern Face 1, Figure 3.15, 3.16).

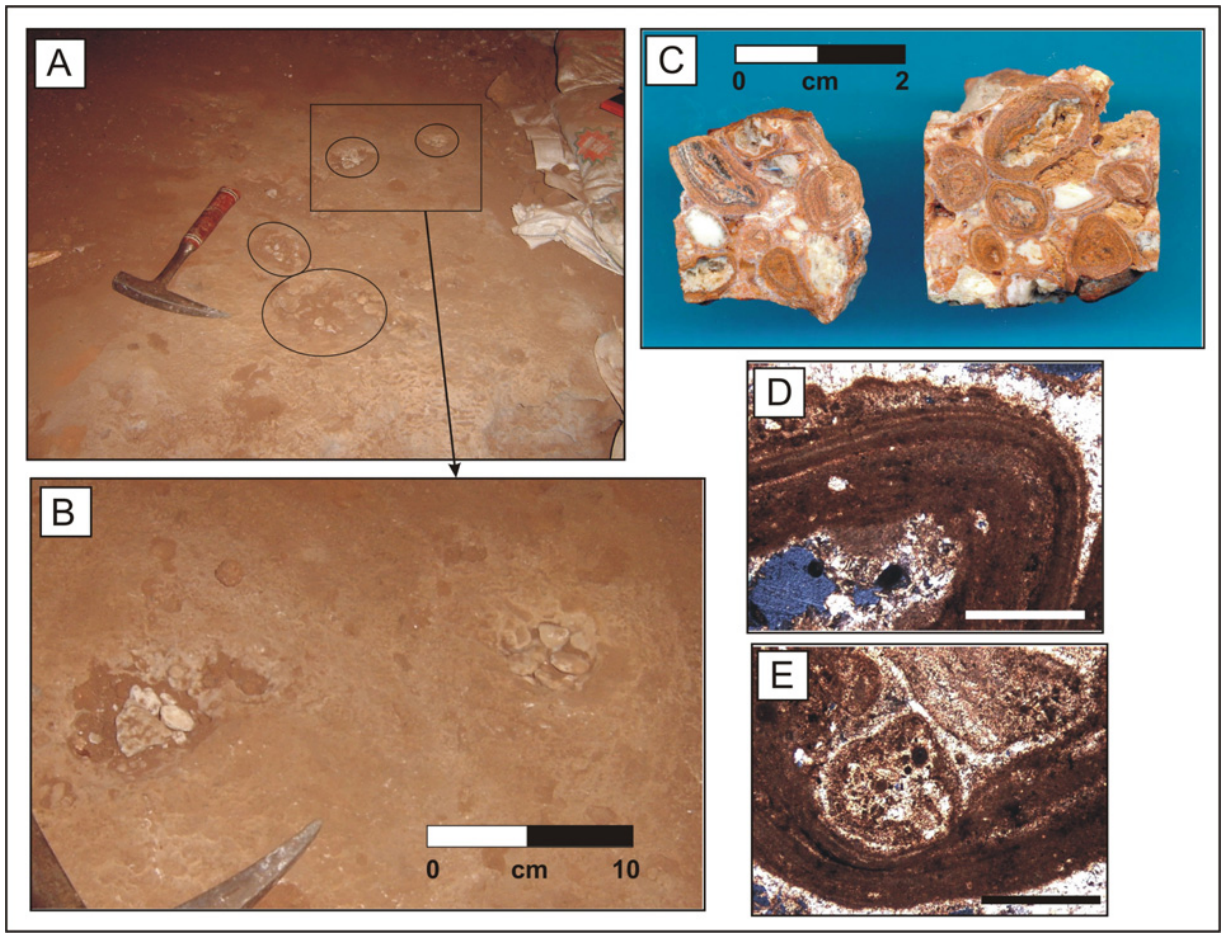


Figure 3.9. Cave pearls at Gladysvale Cave: A: Modern flowstone growing in the Hinge area, showing pits with cave pearls (30 cm geopick for scale); B: enlargement of cave pearls from Figure A; C: Cave pearl 'conglomerate'; D & E: photomicrographs of cave pearls, showing multi-layered coatings and single grain nuclei (D) and multi-grain, micropeds nuclei (E) (0.5mm scale bar, crossed polars).

The modern pits at Gladysvale are filled with cave pearls (Figure 3.9), which are small, spherical concretions of calcite formed by the accretion of layers around a nucleus, such as a grain of sand (Lapidus & Winstanley, 1990). In thin section, the cave pearls consist of multiple layers of fine mud and calcite around either single or multiple nuclei. Some larger cave pearls have soil micropeds or other smaller cave pearls as nuclei.

3.3.6 Facies descriptions

The importance and value of a facies approach is championed by Miall (1985, pg. 261), who describes the facies concept as "the most powerful and successful tool devised by sedimentologists for classifying and explaining ancient sediments". During the course of measuring stratigraphic columns, distinctive similarities in the appearances of laterally persistent sediments (both clastic and chemical) were observed. These were developed into a set of six primary sedimentary facies, termed Facies A, B, C, D, E and F (see also Figure 3.10). Variations of the primary facies are termed Facies A_1 etc. Facies colours are assigned using a standard Munsell colour chart.

Facies A

Facies A is easily identifiable by the moderate brown (2.5 YR 5/4) to pale reddish brown (10 R) of the sediments. The facies is generally massive, reasonably clast poor, with clasts randomly orientated throughout the layer, showing no internal layering or microstratigraphy. Clasts are generally restricted to sub-1cm, angular white calcite fragments, but medium sized (5-10 cm) sub-angular to sub-rounded chert, dolomite clasts and angular speleothem clasts do also occur. The matrix consists of fine to medium-grained, quartz-rich sand. Little to no bone is preserved. Calcification levels vary, but units are often decalcified, consisting of friable sediments, often with calcareous nodules.

Facies A_1

Facies A_1 is a variation of Facies A, and has a slightly different dark yellowish brown colour (10 YR 2/2). Facies A_1 is massive, with no internal layering or microstratigraphy. Clasts are relatively common, and are the usual medium size fraction (10 – 5cm) sub-angular to sub-rounded chert and dolomite clasts. The matrix is a fine to medium grained sand. Little to no bone is preserved. Facies A_1 is either poorly calcified or commonly decalcified, with abundant calcite nodules and some pervasive calcite.

Facies B

Similar to Facies A in that sediments are also pale reddish brown in colour (10 R 5/4), although they can occur as darker moderate brown colour (5 YR 3/3), but characterised by poorly to well developed internal layering and lenticular to horizontal laminations of sediments. Relatively clast poor, with some small (1-5 cm) clasts present. Matrix is fine to medium sand. Bone is well preserved and in places abundant. Sediments are well calcified, sometimes with thin, laterally persistent internal flowstones. Binding flowstones of units are well developed, and this facies is often associated with stalagmite growth up from the lower flowstone. If also found in the vicinity of major palaeo-drip sources, the facies is marked by stalagmite remains.

Facies C

Facies C is characterised by fine grained, greyish brown (5 YR 3/2) to brownish grey (5 YR 4/1) muddy sediments and the unambiguous presence of microstratigraphy in the form of fine horizontal laminations. Generally clast poor, although some very small (sub 1cm) clasts may be present. Bone is often well preserved but not abundant. Facies C is well calcified and invariably is found at the base or top of a unit, where it often intercalates with the binding flowstone, forming fine layers of sediment and flowstone.

Facies C_1

Facies C_1 is a variation of Facies C, and is characteristically light greyish brown in colour (5 YR 3/2) to pale brown (5 YR 6/2), with poorly developed microstratigraphy. The facies is usually clast poor, with limited amounts of very small (sub 1cm) angular, white calcite clasts present. The matrix is fine grained muddy sand. Bone is generally absent, and when it does occur, is poorly preserved. Decalcification is common, leaving Facies C_1 quite porous. This facies often lacks binding flowstones.

Facies C_2

Facies C_2 is a second variation of Facies C, and is typified by dark brown sediments (strong brown 5 YR 4/6 to yellowish brown 10 YR 5/8), which are clast rich. Variation is

distinctive from facies C in that it has no clear microstratigraphy, as the sediment is too clast rich. Clasts consist mainly of small (1-5 cm) and very small (sub 1cm) angular white fragments of calcite, and subrounded to subangular dolomite and chert clasts. The matrix is fine muddy sand. Some bone may be present, but is rare. Facies C_2 is well calcified and occurs capping fining upwards sequences of other facies.

Facies D

Facies D is defined by the presence of large (over 15cm) boulders, which consist mainly of subrounded dolomite. This dolomite often contains chert bands and is extensively weathered. Facies D may have some poorly developed internal stratigraphy, but is mostly massive and clast supported, with boulders stacked one on top of the other, with little to no matrix present. Any matrix between boulders is decalcified reddish brown medium grained sand. Few other clast types are present, and little to no bone has been observed. The facies is commonly decalcified, and while extensive flowstone drapes may occur over the boulders, there is very little internal calcification, and deposits often display grey surface weathering. This facies occurs exclusively in the proximal reaches of the fan, and is limited to areas around past cave entrances.

Facies E

Facies E is typified by powdery, decalcified, fine grained sediments, which range in colour from yellow, to orange, to pink, to white. In Figure 3.10 Facies E is pale yellowish orange (10 YR 6/6). The facies is clast poor, with virtually no clasts or no bone recorded. Sediments are highly decalcified and quite porous, and may display some pervasive calcite, but this is rare. The occurrence of this facies is limited to Southern Face 1 and the southern portion of the Western Face 1 (see Figure 2.1).

Facies F

Facies F is the only chemical sedimentary facies, consisting of the speleothem deposits, and specifically the flowstone horizons found intercalated between the clastic sediments. Speleothems are chemically precipitated calcium carbonate deposits which form in caves. Flowstones are the horizontally laminated speleothems, which occur as draperies on

the cave walls and as lateral covering on the cave floor, or over sediments on the floor. The flowstones at Gladysvale included in facies F are layered accumulations of calcium carbonate. These extend laterally through the deposits and occur between sedimentary units; they are used to divide the clastic sediments into FBU. Facies F ranges in colour from yellowish grey (5 Y 8/2) to medium light grey (10 Y 6/2).

Within facies F three types of flowstone are identified, and can be ranked in order of thickness and lateral persistence. From a lithological perspective all are made up of similar calcium carbonate deposits, which formed in the same manner and are therefore treated as a single facies, with a single facies code. The difference between the types lies in their thickness and lateral extent, which is a function of time and rate of deposition (drip rates etc.), and not different depositional mechanisms. The three types of flowstone are composite flowstone, binding flowstone and intra-unit flowstone.

Composite flowstones are major flowstone, which exceed 10cm in thickness, and consists of several layers of calcium carbonate material. These deposits accumulated over a long period of time, without clastic input, therefore representing a major sequence break, and are treated as major sequence boundaries, or 1st order boundaries. This order of flowstone is only found at the base and top of the entire deposit, and is the most laterally persistent of the three, occurring almost universally throughout the fan.

Binding flowstones form the basis of the FBU and are a few cm thick, being composed of three or fewer layers of calcium carbonate. Binding flowstones are laterally persistent in the vicinity of major drip sources, but tend to thin out and disappear away from drip sources. Where present, these flowstones are treated as second order sequence boundaries, as they divide the clastic strata into FBU.

Intra-unit flowstones are small, thin flowstones, that are laterally discontinuous and found within a FBU. While they may divide the FBU internally and define an internal stratigraphy, they do not represent large breaks in clastic deposition, and are formed synchronously to or just after clastic sedimentation.

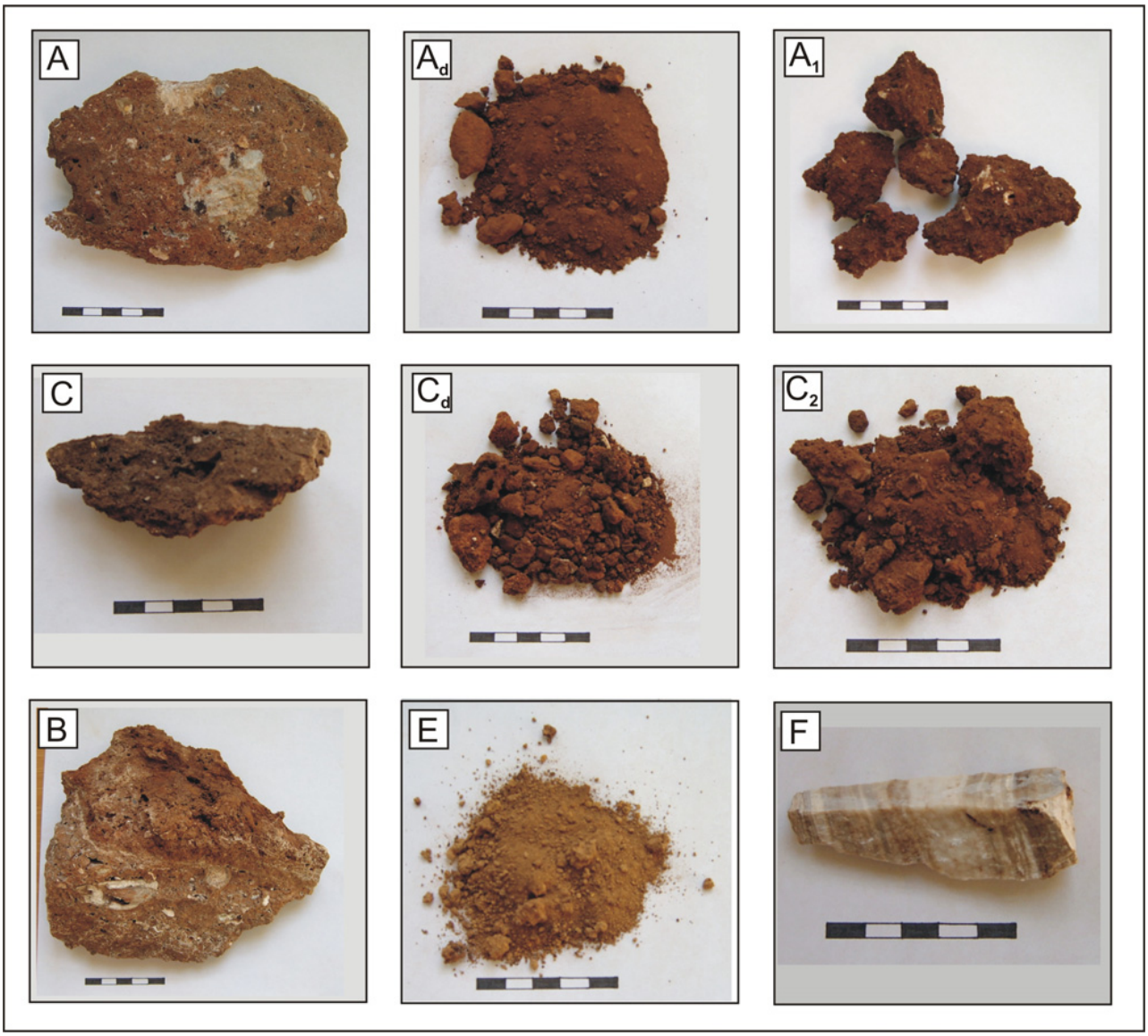


Figure 3.10. Photographs of samples of Gladysvale sedimentary facies: Letter inserts refer to facies name: Photograph A: Facies A. A_d is the decalcified version of Facies A. Photograph A_1: variation A_1 of facies A (note darker colour). Photograph C: Facies C (note dark brown colour and lack of clasts). C_d is the decalcified version of Facies C. C_2 is one of the variations of Facies C. Photograph B: Facies B (note reddish brown colour, presence of fossil bone and thin pervasive flowstones). Photograph E: Facies E, yellowish brown version of Facies E (note powdery texture, decalcified nature and lack of clasts). Photograph F: Facies F, flowstone, this sample is from the basal stalagmite in the Porcupine Pit and is a good example of the layered nature of the Gladysvale flowstones. Scale bar in cm.

3.3.7 Stratigraphic sections

In order to determine the proximal to distal changes and three-dimensional internal structure of the deposit, the exposed faces of the fan were measured up and photographed. Section drawings were produced for the following faces: Eastern Face 1, Southern Face 1, Western Face 1, Hinge, Eastern Face 2, Western Face 2 and the Peabody Chamber (see Figure 2.1). These sections were chosen as they represent proximal to distal changes through the deposit from the east to west lobes of the deposit (Eastern Face 1, Western Face 1, Eastern Face 2 and Western Face 2), as well east-west sections through the deposit in the mid-fan (Southern face 1) and distal (Peabody) regions. The Hinge section is from the proximal regions, where the two lobes split.

A brief note is necessary on the terminology used to describe the relationships between the various units described in the section drawings. A sequence stratigraphic approach is used, where sequences are defined as "stratigraphic units separated by unconformities or correlative conformities" (Mitchum *et al*., 1977). The key to sequence stratigraphy is the identification of unconformities and their role in dividing the sediments into unconformity bounded packages. Mitchum *et al*. (1977) developed the terminology used to describe the relationships between such packages (Figure 3.11) from the study of sub-surface sediments through reflective seismics. However, the resulting terminology and approach has been applied to a wide variety of sedimentological settings, most notably by Miall (1985; 1997; 2000). To the best of my knowledge this is the first use of sequence stratigraphy on cave sediments. The Gladysvale sediments are well suited to sequence stratigraphy, as the clastic units are by definition flowstone bound chronostratigraphic units. These flowstones grow only under specific conditions, one of which is a cessation in clastic input into the cave, making them temporal unconformities. Even if flowstone growth is continuous, the flowstones still mark distinct and substantial breaks in clastic sedimentation. As discussed earlier, flowstones may not be evenly distributed through the cave, and may be limited in lateral extent to areas directly below drip sources. However, units without flowstones are still bound by the correlative non-depositional unconformities or erosional unconformities of the flowstones.

The key terms used in the description of the Gladysvale Cave section drawings are explained in Figure 3.11, which is taken from Mitchum *et* al. (1977). Erosional truncation describes strata that terminate against the upper boundary mainly owing to erosion.

Toplapping strata are initially inclined and terminate against a boundary created mainly as a result of non-deposition. Concordance against the upper or lower boundary occurs when strata do not terminate against either of these boundaries and mirror the topography of the lower boundary. Onlapping strata terminate updip against an inclined surface. Downlapping strata are initially inclined strata, which terminate downdip progressively against an initially horizontal or included surface (Mitchum *et* al., 1977).

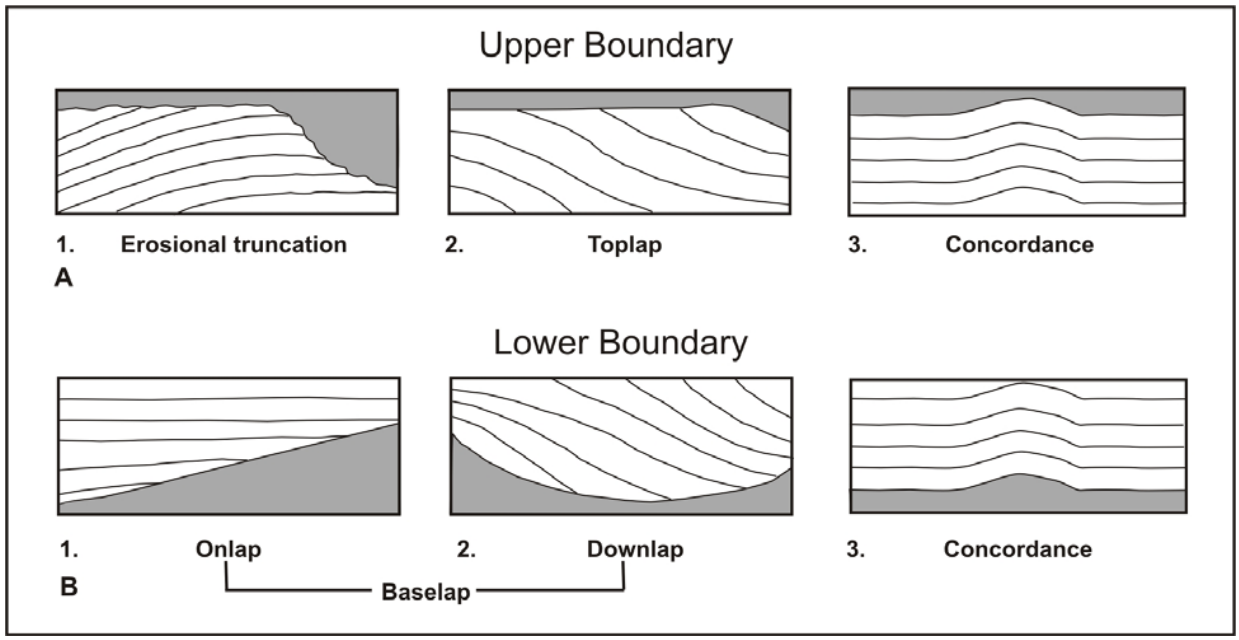


Figure 3.11. Sequence stratigraphic terminologies as used in this study. Relationships of strata to the upper boundary (A) and lower boundary (B) of a depositional sequence (Mitchum *et al*., 1977).

Stratigraphic columns were measured up for all the exposed faces of the deposit (Figure 2.1), using the Flowstone Bounded Unit terminology of Moriarty *et al*. (2000) and the facies described above. Sections were measured at ~1m intervals, so that FBU could be confidently traced across the faces. Stratigraphic columns are presented below, beginning with the Eastern Face 1 and working eastwards through the cave following the exposed faces of the deposit. The stratigraphic columns are drawn to the include grain-size information of the facies, with an expanded width axis to display mud, sand and gravel grain sizes of the matrix. All variations of Facies C and Facies E are considered to be of mud grain size, with all variations of Facies A classed as sand and Facies D as gravel. The flowstone layers are extended out beyond the grain size graduations to mark the breaks in clastic sediments into Flowstone Bounded Units. FBU do not always have well developed binding flowstones, which may be absent altogether if this area is far enough away from a palaeodrip source. Such boundaries are termed erosional (Figure 3.12).

The section drawings of the fan lobe faces are described below, starting with the Eastern Face 1 and working through the rest of the deposit from west to east (see Figure 2.1). The proximal region of the deposit is the southern end of the cave, with the distal region on the northern end.

Eastern Face 1

The Eastern Face 1 (EF 1) is the only lobe face to be exposed both inside the cave and in the deroofed entrance section of the deposit (Figure 3.13). All six major FBU are present throughout the section, and vary in thickness from the proximal to mid-fan region. As with all the section drawings presented here, there is a certain amount of distortion in the photograph and the resulting drawing, and the thicknesses differences between the proximal and mid-fan ends of this section are actually greater than they appear in the drawing. The section varies from 2.4m thick on the southern side to 1.2m thick on the northern. The FBU remain reasonably constant in thickness, with gradual and equal thinning from south to north, as shown in the graph of unit thickness against section number (Figure 3.13 insert). The FBU have filled the cave up to the roof level in the proximal region, while, with progressive thinning of the units across the section, there is a considerable amount of space between the FBU and the roof on the northern side of the section. The angle of repose of the binding flowstones decreases from a high of ~30° in the proximal region, through to ~10° in the middle of the section and to <5° towards the northern most end of the section.

The lowermost FBU (LK) follows the topography of the top of the underlying FBI 2, being very thin in the proximal region, and thickening towards the northern end of the section. BM, is more or less concordant with LK in the proximal reaches but increases in thickness distally. SR down-laps into the space left by BM and LK in the proximal section, and then thins significantly across to the section, and is more or less concordant with BM between sections 3 to 1. JS thickness shows an inverse relationship with the thickness of underlying SR, as where SR is thicker, JS is thinner and vice versa (Figure 3.13 insert). Unit JS is therefore filling in the space left by the thinner areas of SR, and is restricted in thickness by the thicker areas of SR. Overlying HL shows a similar relationship with JS, reaching its maximum thickness in areas where JS is at its thinnest. Uppermost FN is considerably thicker than all the other FBU, and remains so across the section. FN is initially concordant with underlying HL, but from sections 3 to 1 displays an inverse thickness relationship.

Between sections 4 and 5 there is a significant increase in most of the FBU thickness. These sections were measured in the area of the section between the internal and external parts of the face (Figure 3.13), and there appears to be some kind of slumping of the whole section at the interface. This may be syntectonically controlled, as the FBU remain intact, within their flowstones, and are not cross cut by the slumping, suggesting that this occurred at the time of deposition of the FBU. Some type of gravitational slumping may also have occurred. Unfortunately this interface area is not exposed in any of the other faces, and cannot, therefore, be further explored.

The EF 1 is dominated by Facies A (Figure 14), in the mid-fan region of the section, with Facies D becoming more prominent in the proximal region, particularly in SR and JS, where Facies D grades into a chert clast rich version of Facies A from sections 6 to 5. JS continues to fine distally, as Facies A grades into Facies C_2 by section 2. LK displays an opposite pattern of coarsening downfan, changing from Facies C in the proximal region through to Facies A in the mid-fan. All facies in the external part of the section are decalcified and display considerable calcareous nodule formation.

Southern Face 1

The Southern Face 1 (SF 1) (Figure 3.15) is a cross section through the Western Lobe of the deposit (Figure 2.1). The face is exposed from the trenching of the lime miners', and the east and west sides of the face are cut-off by trenches made to remove stalagmites, suggesting that these were major drip centres. The presence of better calcified FBU and well developed flowstones on the sides of the section support this. The middle region of the face is mostly decalcified, with poorly developed flowstones. The lower surface of HL is pitted in two places on the eastern side of the section (Figure 3.15). These pits are found along the lower surface where no flowstone is developed and are most likely the product of drip waters from the cave roof, which have dissolved out the underlying sediments instead of producing a flowstone. This phenomenon has been documented in other cave sediments (e.g. Kos, 2001) and is caused by evaporative conditions, which prohibit flowstone development. The middle area is also partially obscured by miners rubble, which could only be removed to an extent, as collapse of the whole middle area of the section was imminent, due to the decalcified nature of the underlying sediments. Once again there is slight distortion in the photograph, and the east and west ends of the actual section are both 1.2m thick. The uniform thickness of the

whole package is born out by the flat nature of the FBU, which do not show major thickness changes across the section. Neither do the angles of repose of the binding flowstones, which are all under 10°.

The changes in FBU thickness across the section are examined more closely in the graph of unit thickness against section number (Figure 3.15 insert). LK, BM and SR are not continuously exposed across the section. From JS upwards, FBU are exposed in their entirety. JS and HL show a concordant relationship across the face, and mirror each other. On the western side of the section BM is also concordant with JS and HL, while SR shows a marked inverse thickness relationship to the underlying BM and overlying JS. FN is, once again, considerably thicker than the other units, and shows a strong inverse thickness relationship with underlying HL. FN also shows the greatest change in thickness from east to west across the section, becoming progressively thicker towards the western side of the section.

The SF1 displays a range of different facies, and is the main exposure of Facies E (Figure 3.16). JS consists of Facies E across the section, as does SR on the western side of the section, which grades into Facies C on the eastern side. LK, HL and FN all fine across the section from east to west, form Facies A in sections 5 and 6, to Facies A_1 to variations of Facies C in section 1. FN is much less calcified from sections 3 to 1 and contains well developed calcareous nodules.

Western Face 1

The Western Face 1 (WF 1) (Figure 3.17) is exposed by a major trench made by the lime miners' to remove the stalagmite growing in the middle part of the upper chamber at Gladysvale, around which the eastern and western lobes of the deposit formed. The face is well preserved, because it is well calcified. The presence of two small stalagmites within the section, as well as the remains of a large basal stalagmite, and the well-developed flowstone, suggest there was a major palaeodrip source above this section, which led to the high level of calcification of the underlying units. There is less distortion in the photograph of this section, with the entire package thinning proximally to distally from 1.7m to 1m (Figure 3.17). The FBU change thinkness across the section in a distinct pattern, with an area of major change in the middle of the section. The repose angles of the binding flowstones follow this pattern,

from angles of 10 -15° in the proximal region, to ~30° in the middle of the section, to angles of under 10° at the southern end.

The variations in thickness of the FBU are shown in the graph of unit thickness versus section number (Figure 3.17 insert). LK and BM are only exposed proximally, with limited exposure of BM in the mid-fan, and are the thinnest units present, and show a slight thinning trend towards the northern side of the section. The rest of the FBU are exposed in full and display complex relationships of concordance and inverse thicknesses between stacked units. SR is initially reasonably thin, and thickens across the face, while overlying JS shows an exactly inverse thickness, and thins across the face. HL mostly mirrors JS, and expands in thickness to fill the space left by the rapid thinning of JS at section 3. FN displays a completely inverse thickness to underlying HL, and thins across the section.

The facies types found in the WF1 are shown in Figure 3.18. As already mentioned, the WF1 is below a major palaeodrip source, ensuring that the FBU are well calcified and well-preserved, with considerable fossil bone also preserved in sections 2 and 3 (Figure 3.18). Away from this palaeodrip source, section 1 is not as well calcified and facies are dominated by Facies type A_1, with abundant calcareous nodules. JS and HL fine across the section, from Facies A in sections 4 and 3, into variations of Facies C in sections 1 and 2. In section 4 of Figure 3.17, SR consists of a three-fold layering of facies, with a layer of well-preserved, *in situ* hyaena coprolites in the middle layer.

Hinge

The Hinge section is between the eastern and western lobes of the deposit (Figure 2.1) and is exposed because of the removal of several major stalagmites by the lime miners (Figure 3.2). The Hinge section is very different to the other sections, in that it documents the splitting of the sediments into two lobes, which dip east and west away from the Hinge (Figure 3.19). The presence of the stalagmites was very important in controlling the accommodation space available for sediments, and while their removal was destructive, it has created a unique exposure of this area of a cave fill fan. The deposit is well preserved and units are partially calcified with well developed binding flowstones. There are also small stalactites extending down from the roof of the cave onto the top flowstone, suggesting that this area was a major palaeodrip source, accounting for the well developed flowstones. The FBU of the Hinge dip

and thin away to the east and west. There is an extent of distortion in the photograph, with the actual measured thickness of the middle of the Hinge at 2m, and the eastern and western extensions thinning to 0.6m and 1m respectively. The binding flowstones record dip angles of ~0-2° in the middle of the Hinge, dipping away to the east and west at between 24° and 36°.

The detailed thicknesses of the FBU are illustrated by the graph of unit thickness against section number (Figure 3.19 insert). An extra basal FBU, MK is present in this section, below LK, and is partially obscured by miners' rubble. However, MK does display a distinctive thickness pattern, which is repeated in subsequent units. MK is at its thickest in the centre of the Hinge, and then thins rapidly away into the eastern and western extensions of the Hinge. MK is not exposed in the far eastern exposures of the eastern extension. LK and BM retain a reasonably constant thickness from the middle of the Hinge into the eastern and western extensions, with a slight inverse thickness relationship on the eastern extension. SR and JS display a concordant relationship with each other and underlying MK, and also reach their maximum thickness in the centre of the Hinge, and thin rapidly away into the eastern and western extensions. HL is only exposed in sections 4 and 5, and shows a limited inverse thickness relationship to underlying JS and SR. FN is not present in the Hinge section.

The Hinge section is dominated by Facies A, with abundant calcareous nodules (Figure 3.20), and a number of large, sub-rounded dolomite boulders. The western extension of the Hinge is made up of more fine grained Facies C, with some fossil bone and snails. The eastern extension of the Hinge consists predominantly of Facies A, with limited Facies C and several sub-rounded dolomite blocks. The southern face of the Hinge section consists predominantly of MK and is exposed directly below the floor of the main Hinge area, and forms the linking area between the WF1 and the EF2. This face consists exclusively of Facies A, with several sub-rounded dolomite boulders and patches of modern flowstone. The cave floor directly in front of this section has a number of small pits, which are filled with cave pearls (Figure 3.20).

Generator section

The Generator section is exposed around the second small cave entrance above the eastern lobe of the deposit (Figure 2.1). The stratigraphic sections of this face are shown in Figure 3.21. Section 1 consists of Facies D which fills in the narrow space between the back

wall of the cave and the cave roof, suggesting that this was a palaeo-entrance to the cave, which was blocked up by incoming coarse-grained sediment. The walls and dolomite blocks are covered by a drapery of rippled flowstone, which would have grown over the sediments after the entrance was blocked off. FBU cannot be clearly identified in rubble choke, due to the massive nature of the sediments and the lack of well developed binding flowstones. In sections 2 and 3, FBU are present, and the top unit is identified as FN by the distinctive rippled nature of the top flowstone, which is present across the whole of the eastern lobe of the deposit. Sections 2 and 3 consist mainly of Facies A, with a few sub-rounded dolomite blocks in section 2 and some of Facies C in section 3. The dip angles of the binding flowstones dip down from steep angles of ~60° in section 1 to very flat angles if under 5° in section 3. The strata in section 3 are also cut off and there is a round pitted area directly in front of the section. The area of the cave roof above this section is a major palaeodrip source (Figure 3.2), and there was most likely a major stalagmite below section 3, against which the incoming sediment backed up. Since the removal of this stalagmite by the lime miners' the cave has continued to drip in the area, as the small ~4cm new stalactites growing down from the broken off stalactites suggest, and formed the pitted surface below from the drip waters.

Eastern Face 2

The Eastern Face 2 (EF 2) is on the eastern side of the major trench running through the deposit, and is exposed as a result of the removal of the major stalagmite which would have been situated between the eastern and western lobes of the deposit (Figure 3.2). The face is well preserved, especially in the southern, proximal region, with flowstones present in between all the units. The middle and distal section of the face is obscured by miners' rubble (Figure 3.22). Attempts were made to remove the rubble, but the deposit beneath it has been damaged and it was therefore left in place. There is some distortion in the photograph, but the face does thin dramatically from south to north, with measured thickness from 2m, to 1.5m in the middle and 0.8m at the northern end. The FBU vary in thickness hugely across the section, and dip distally. The angles of repose of the binding flowstones vary from ~10° in the proximal part of the section, dipping rapidly down to ~30°, then flattening out to ~10° and reaching final angles of under 5° at the northern end of the section. This western lobe of the deposit does not appear to have more distal equivalents towards the back wall of the cave, and the northern end of this section is therefore the most distal of the western lobe, where sediments downlap and terminate.

The thickness variations of the FBU of the EF 2 are illustrated in the graph of unit thickness against section number (Figure 3.22 insert). The extra FBU MK is also present in the proximal regions of this section, and is initially very thick, but thins rapidly in section 3 and is not present in section 2. LK and BM show a clear inverse thickness relationship, and alternately thicken and thin, depending on the thickness of the other unit. SR displays concordance with BM, and thickens towards the middle of the section, with distinct thinning towards the northern, distal region. JS is weakly concordant with SR, and shows the least variation in thickness across the face. HL and FN are only present in the middle of the section, where they downlap into the saddle created by the thinning of JS and SR.

Figure 3.22 shows the stratigraphic columns and facies types identified for the EF2. FBU BM, SR and JS coarsen across the face, from Facies C in section 1 to Facies A in sections 3 and 4, with abundant fossil bone preserved in sections 3 and 4. FBU LK becomes finer grained across the face, from Facies A in section 1 to variations of Facies C in sections 3 and 4. FBU MK is found only in the proximal section 1, and consists of Facies A, with patches of modern flowstone and some drip pits on the floor in front of the section. The base of section 2 is dominated by sub-angular to sub-rounded dolomite blocks and a block of stalactitic material, which appears to have fallen off the cave roof before LK was deposited above it. HL and FN are found only in section 3 and consist of fine grained variations of Facies C.

Western Face 2

The Western Face 2 (WF2) forms the eastern-most exposed face of the eastern lobe (Figure 2.1), and is exposed as a result of the removal of a large stalagmitic boss, which also exposed the Porcupine Pit (Figure 3.2). There is little to no exposure between this section and the preceding EF2. As already discussed, this lobe of the deposit appears to have no distal equivalents against the back wall of the cave, and the distal sediments are therefore exposed in the northern-most areas of the EF1 and this section. This section is not very well preserved, with well developed flowstones present only in the more distal areas (Figure 3.23). The more proximal areas are highly decalcified, display considerable surface weathering, and are partially obscured by miners' rubble. The section continues back from the southern edge of the photograph, but is poorly preserved and difficult to interpret. There is some distortion in the photograph, with measured thickness varying from over 2.6m in the proximal southern

region to ~1m at the distal end. FBU show much less variation in thickness compared to the last section, the EF2, and all gradually thin towards the distal side of the section. Flowstone repose angles vary from ~20° to under 10° across the section.

The variation in thickness of the FBU is shown in more detail in the inserted graph of unit thickness against section number in the inserted graph in Figure 3.23. MK and lowermost LK are not present in this section. BM is only present in the more proximal part of the section and thins rapidly such that it is not present in section 2. SR and JS show a concordant relationship and mirror each other's thicknesses across the section, both thinning towards the distal side of the section. HL and FN have a concordant relationship with each other, but show a strong inverse thickness relationship with the underlying JS and SR. FN is considerably thinner in this section than in other sections.

The measured stratigraphic sections and observed facies for the WF 2 are shown in Figure 3.24. The WF2 is dominated by Facies A, with Facies D found in the lower FBU in the more proximal sections, and some Facies C found in the upper FBU and capping Facies A in FBU JS and HL in sections 3 and 2 (Figure 3.24).

Porcupine Pit and Eastern Face 3

The Porcupine Pit and the Eastern Face 3 (EF3) are found in the second trench through the deposit, on the far eastern side of the cave (Figure 2.1), and are poorly exposed and poorly preserved. The Porcupine Pit section is one of the thickest stratigraphic sections measured and is dominated by the large stalagmite at the base of the section and by Facies D, with a capping of Facies A in uppermost FN (Figure 3.25). The section drawn up for the EF3 is a representative section of the whole face, which was difficult to access and dangerous as the face sloped down steeply into the underground levels of the cave (Figure 3.25). FBU FN to SR were identified, on the basis of the distinctive rippled flowstone which caps FN in this section and in the WF2 and can be traced around. The section is dominated by Facies A and D, with limited Facies C cappings in FBU JS and HL, as well as the entire FN.

Peabody Chamber

The section exposed in the Peabody Chamber and Peabody Extension is the most distal section of the internal deposit at Gladysvale Cave, with sediments backed up against the back wall of the cave (Figure 2.1). These sections were initially exposed via the removal of stalagmites by the lime miners (Figure 3.2). However, the actual concave Peabody Chamber was excavated further by the removal of blocks of breccia by Frank Peabody in 1948 (F.E. Peabody, unpublished field notes, 1948). The Peabody extension section is situated to the eastern side of and is continuous with the main section (Figure 3.26). The entire Peabody section shows varying levels of preservation, with both the eastern and western ends of the sections being calcified, with well-developed flowstone units, especially in section 4 of the extension section. The presence of a number of small stalagmites and stalactites within the extension section suggests that this area was a major palaeodrip point, explaining the high levels of calcification in this area. The western most part of the section (the original Peabody Chamber) is well-calcified, with abundant visible bone present, but few binding flowstones developed. The middle area of the entire section is poorly preserved, with little to no flowstones present, and is partially obscured by miners' rubble. There is little distortion of the photograph, and the sediments reach a maximum thickness of 1.8m just to the east of the Peabody Chamber, thin out to 1 m in the middle of the section and thicken out again to 1.3m to the eastern extent of the section. The FBU show little variation in thickness from the Peabody Chamber into the extension part of the section, with sudden thickness changes in the far eastern part of the extension. The binding flowstones show similar patterns in their repose angles, with flat angles of under 10° for the Peabody Chamber and beginning of the extension, with flowstones dipping down to the east at angles of between 25° and 30° in the far eastern part of the extension section.

The variations in FBU thickness are illustrated in more detail in the inserted graph of unit thickness against section number in Figure 3.26. LK and BM are only present in sections 1, 3 and 4, and thin towards the eastern side of the extension part of the section concordantly. The overlying FBU, SR and JS, are of similar thickness and show a very slightly inverse thickness relationship to each other. SR thins dramatically towards the eastern side of the extension section, and ends in a distinct toe of sediment. JS fills into this space created by the termination of SR, and downlaps onto the underlying unit. JS is limited from any further lateral expansion by the presence of the stalagmitic cave wall (Figure 3.26), and as a result the

unit thickens towards the side wall of the cave. HL displays a concordant relationship with JS, and mirrors the thickness variation of the underlying unit. FN shows the greatest variation in thickness and shows a strong inverse thickness relationship with all the other units (Figure 3.26). FN fills the Peabody Chamber to the roof, unlike in the rest of the cave, where there is a significant space between the top of FN and the cave roof.

Figure 3.27 shows the stratigraphic columns and Facies identified for the Peabody Chamber and the Peabody extension. Section 1 is dominated by Facies A in the upper FBU and by Facies B in the lower FBU. Facies B is restricted to the Peabody Chamber, and is the dominant facies found across the face; it has abundant fossil bone preserved where it is better calcified in sections 3 and 4. There are limited occurrences of Facies C directly above and below the binding flowstones in sections 1 and 4. The base of JS in section 4 consists of Facies C.

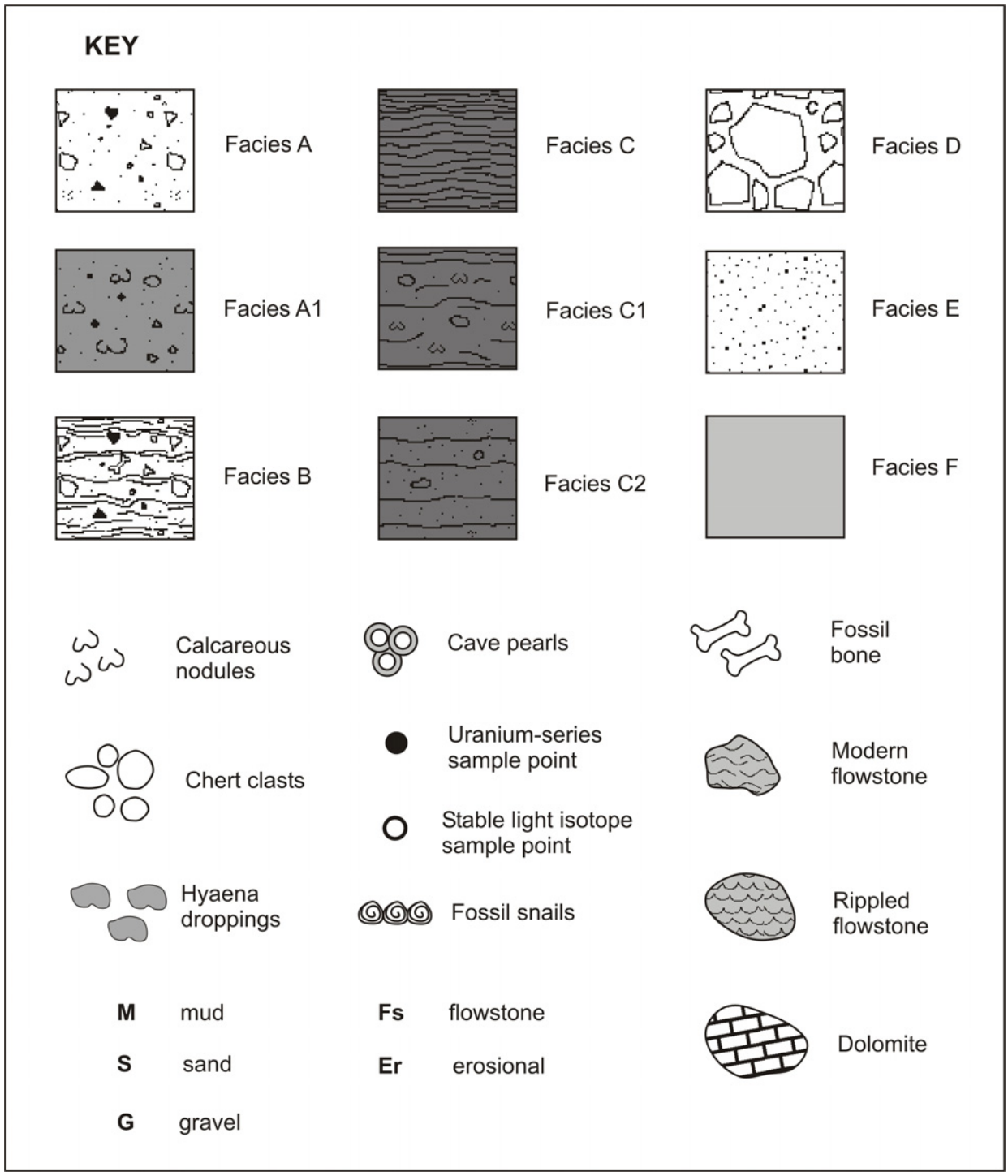


Figure 3.12. Key for facies and sedimentary structures recorded in the Gladysvale stratigraphic columns.

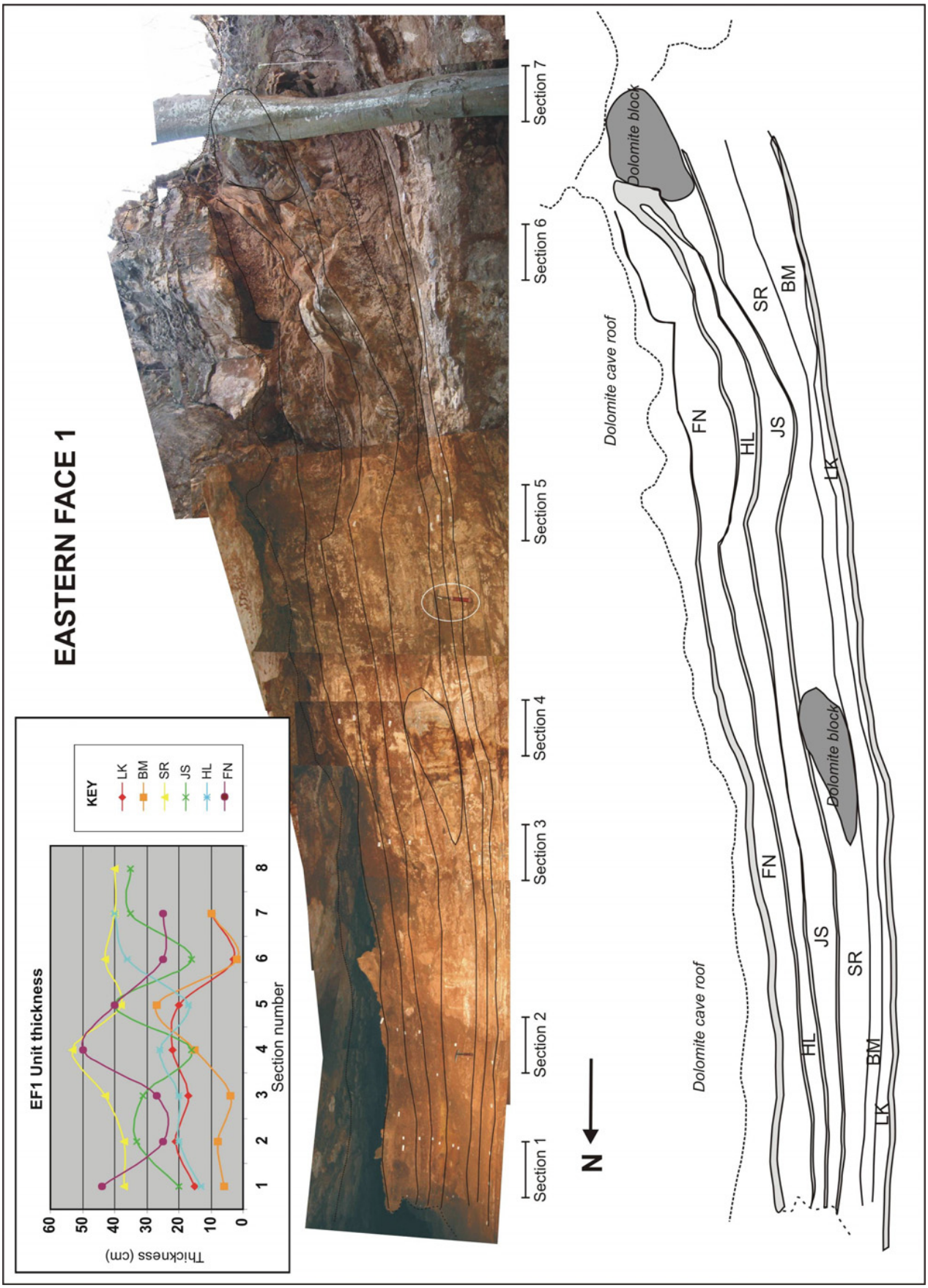


Figure 3.13. Eastern Face 1 section: annotated photograph (top) and line drawing (bottom), with graph of unit thickness (insert), geopick (circled in white) for scale (30cm).

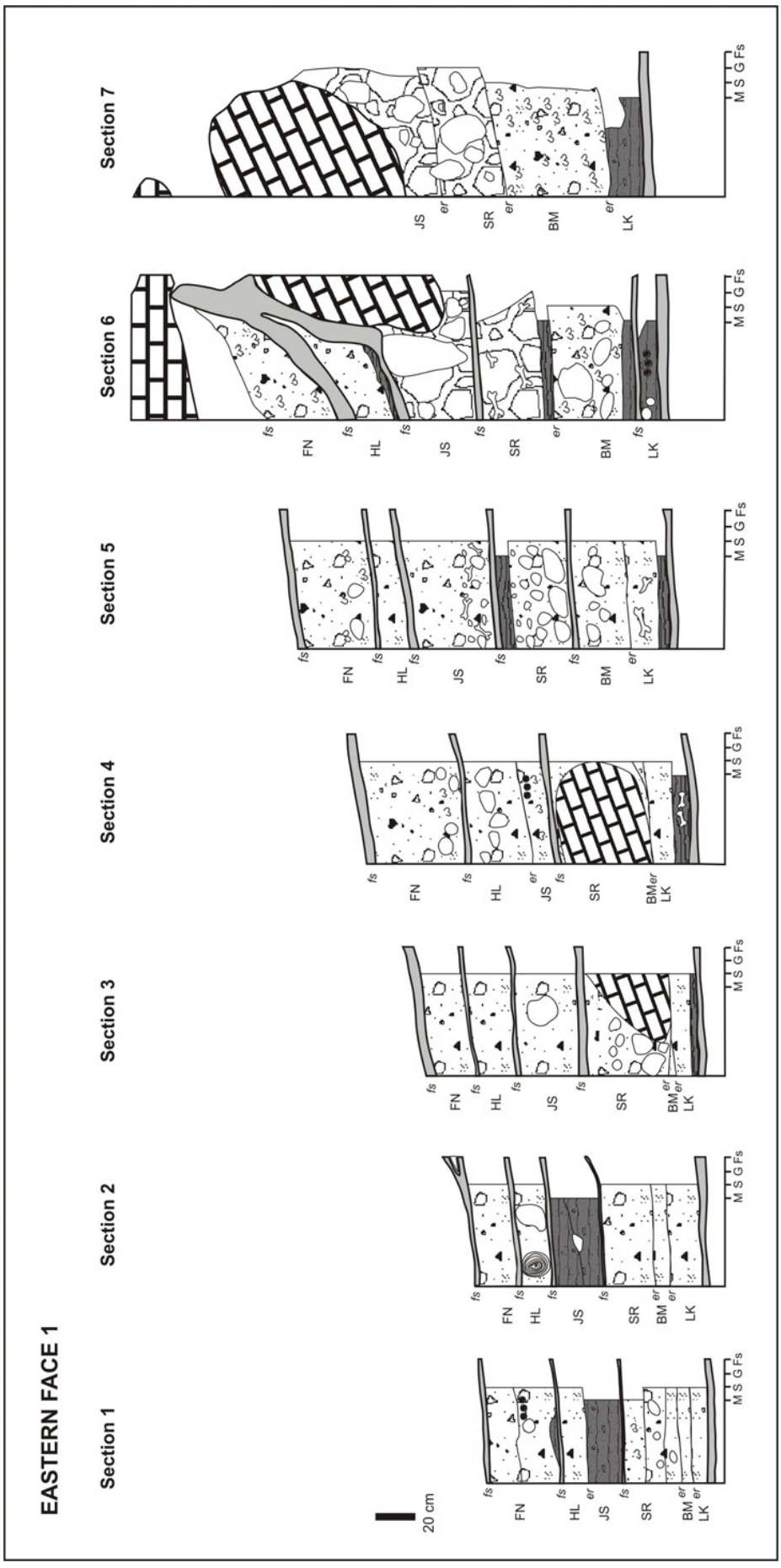


Figure 3.14. Stratigraphic columns for the Eastern Face 1.

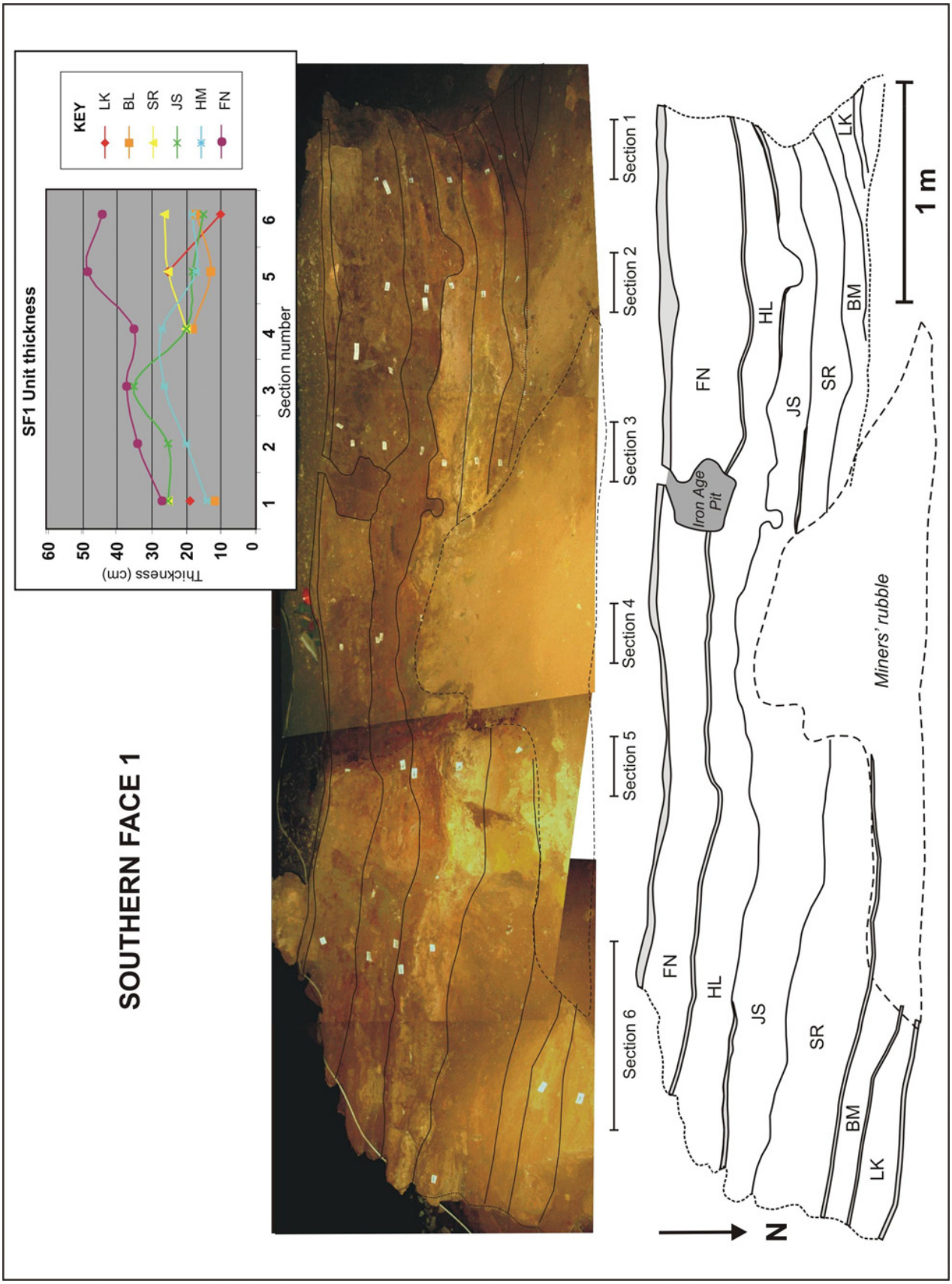


Figure 3.15. Southern Face 1 section: annotated photograph (top) and line drawing (bottom) and graph of unit thickness (insert), 1m scale bar.

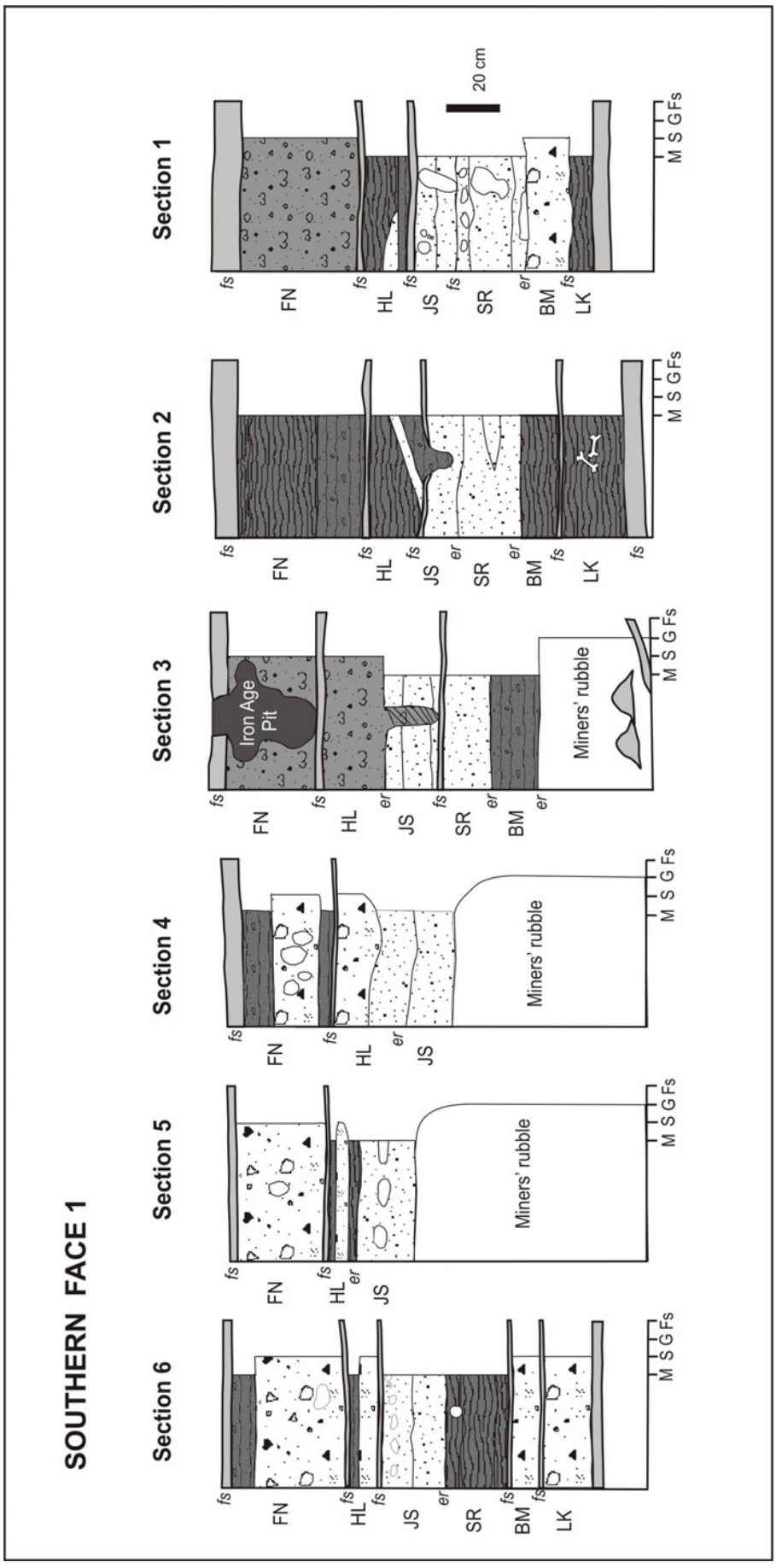


Figure 3.16. Stratigraphic columns for the Southern Face 1.

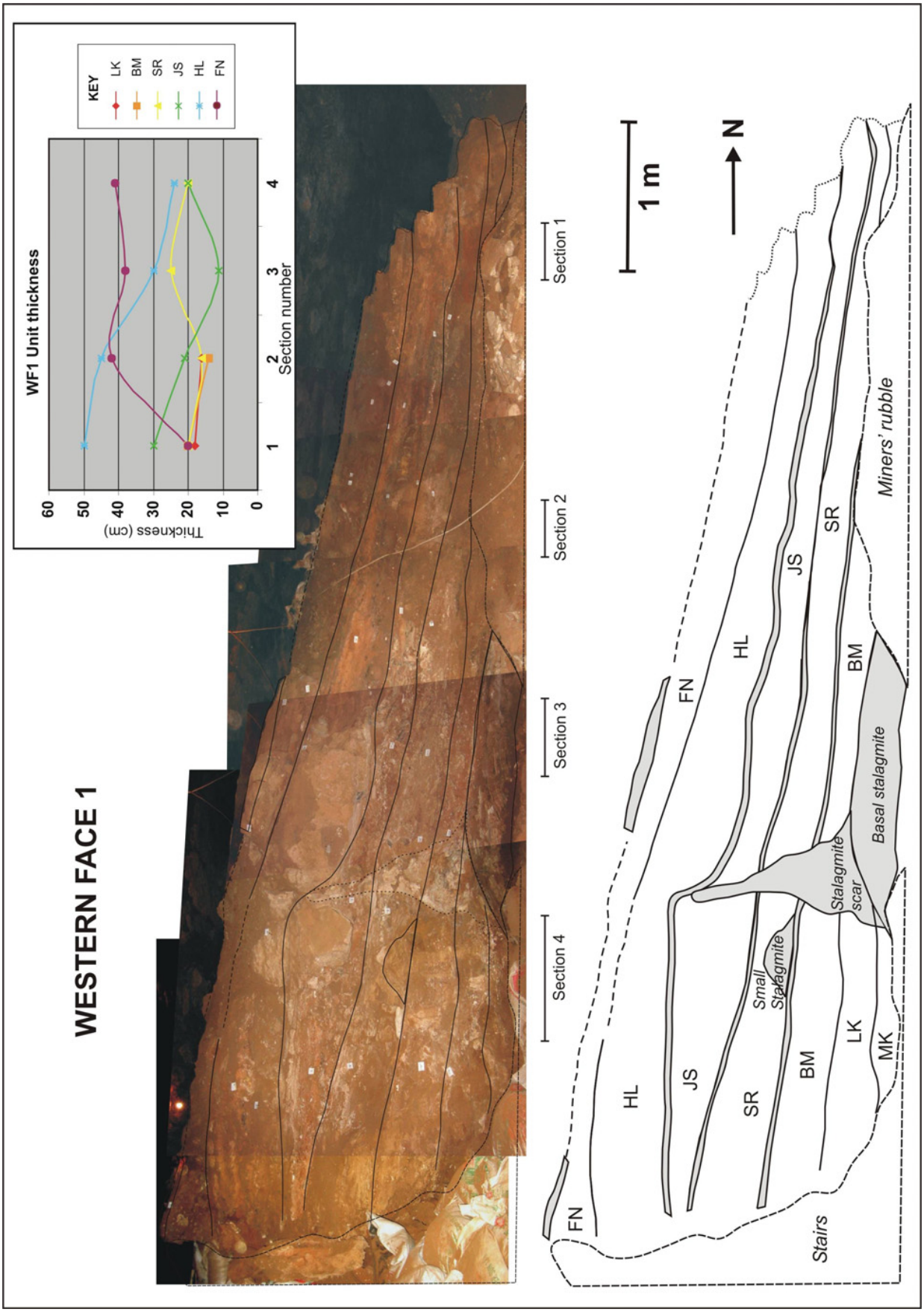


Figure 3.17. Western Face 1 section: annotated photograph (top), line drawing (bottom) and graph of unit thickness (insert), 1m scale bar.

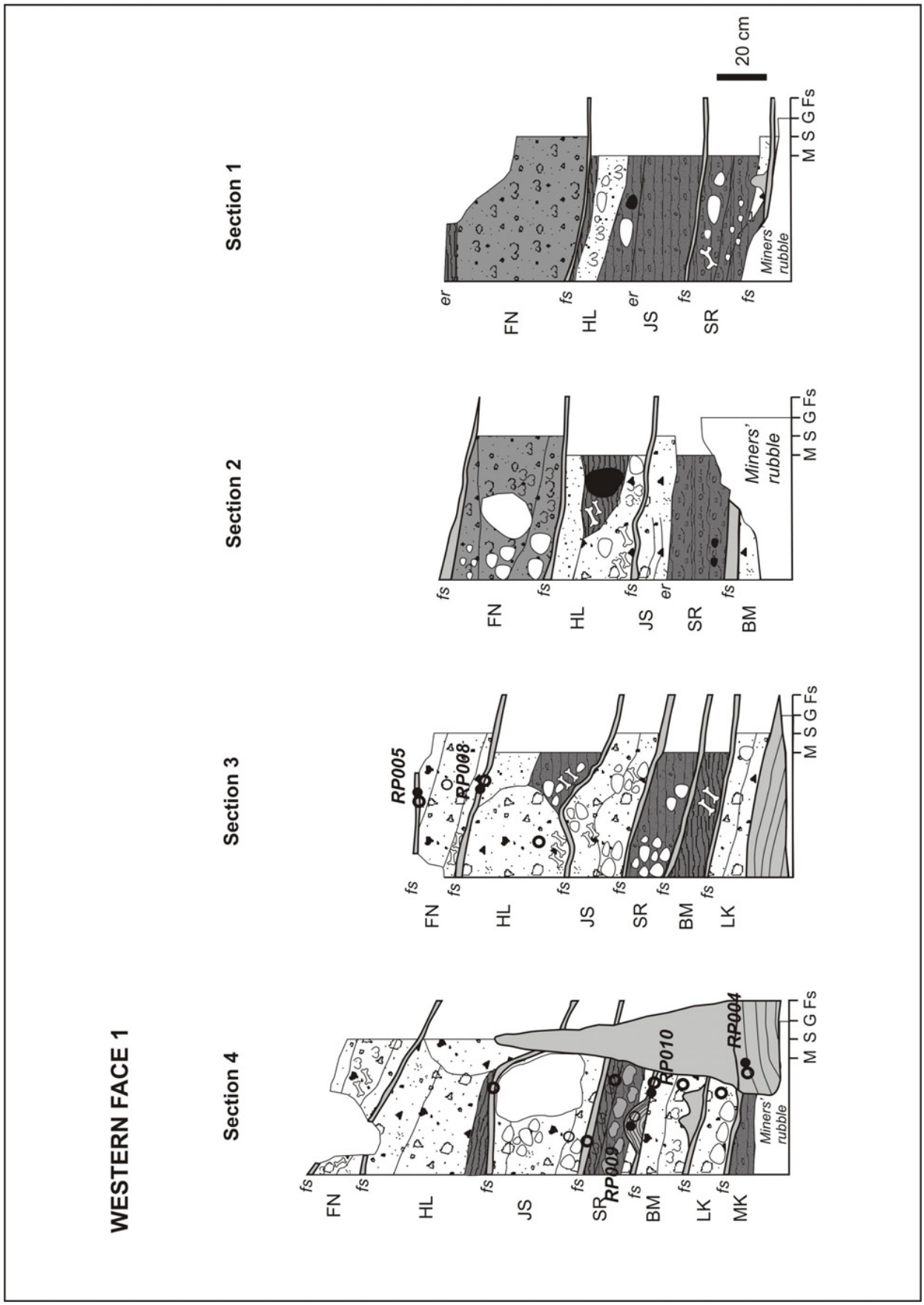


Figure 3.18. Stratigraphic columns for the Western Face 1.

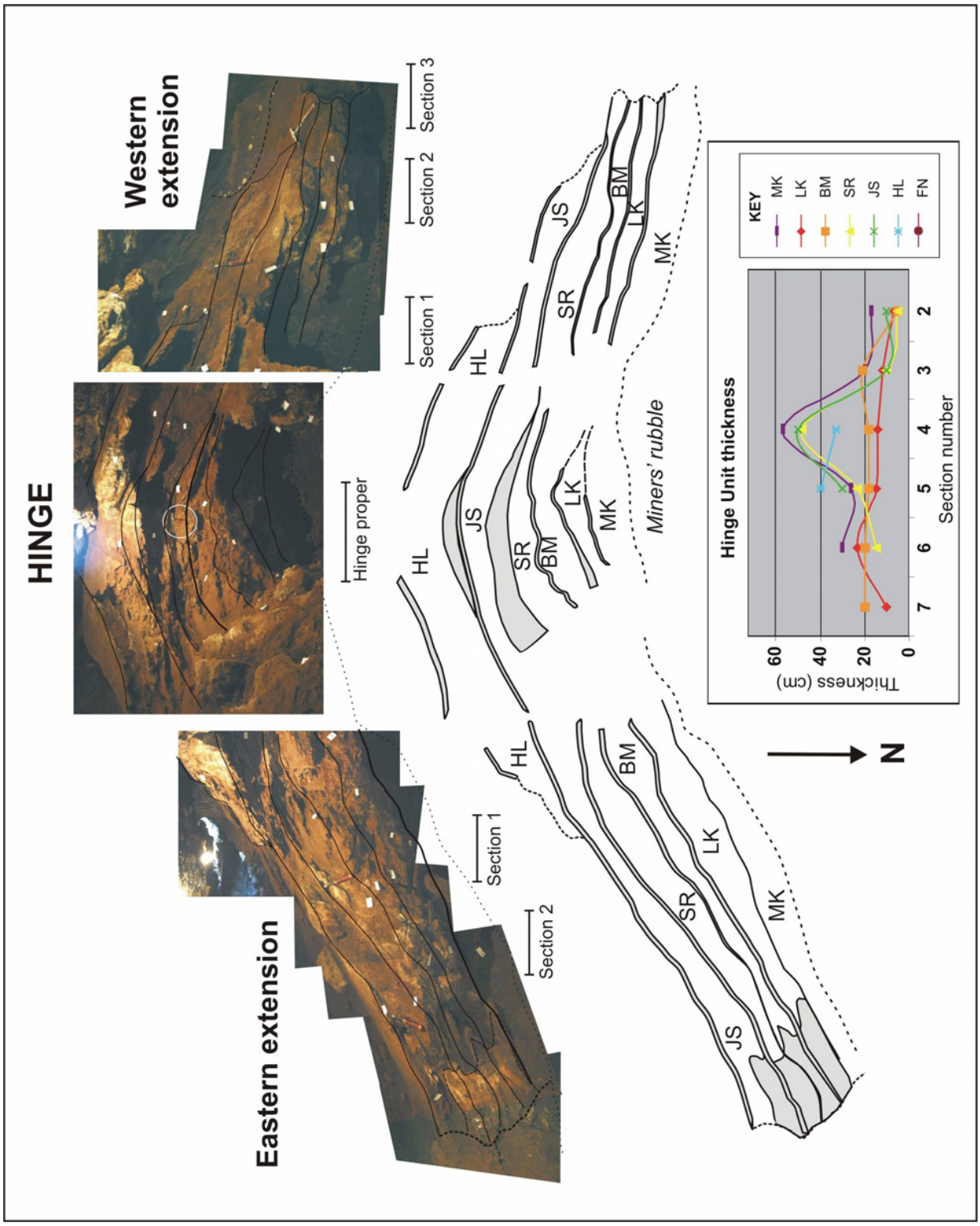


Figure 3.19. Hinge section: annotated photograph (top), line drawing (middle) and graph of unit thickness (bottom), geopick (circled in white) for scale (30cm).

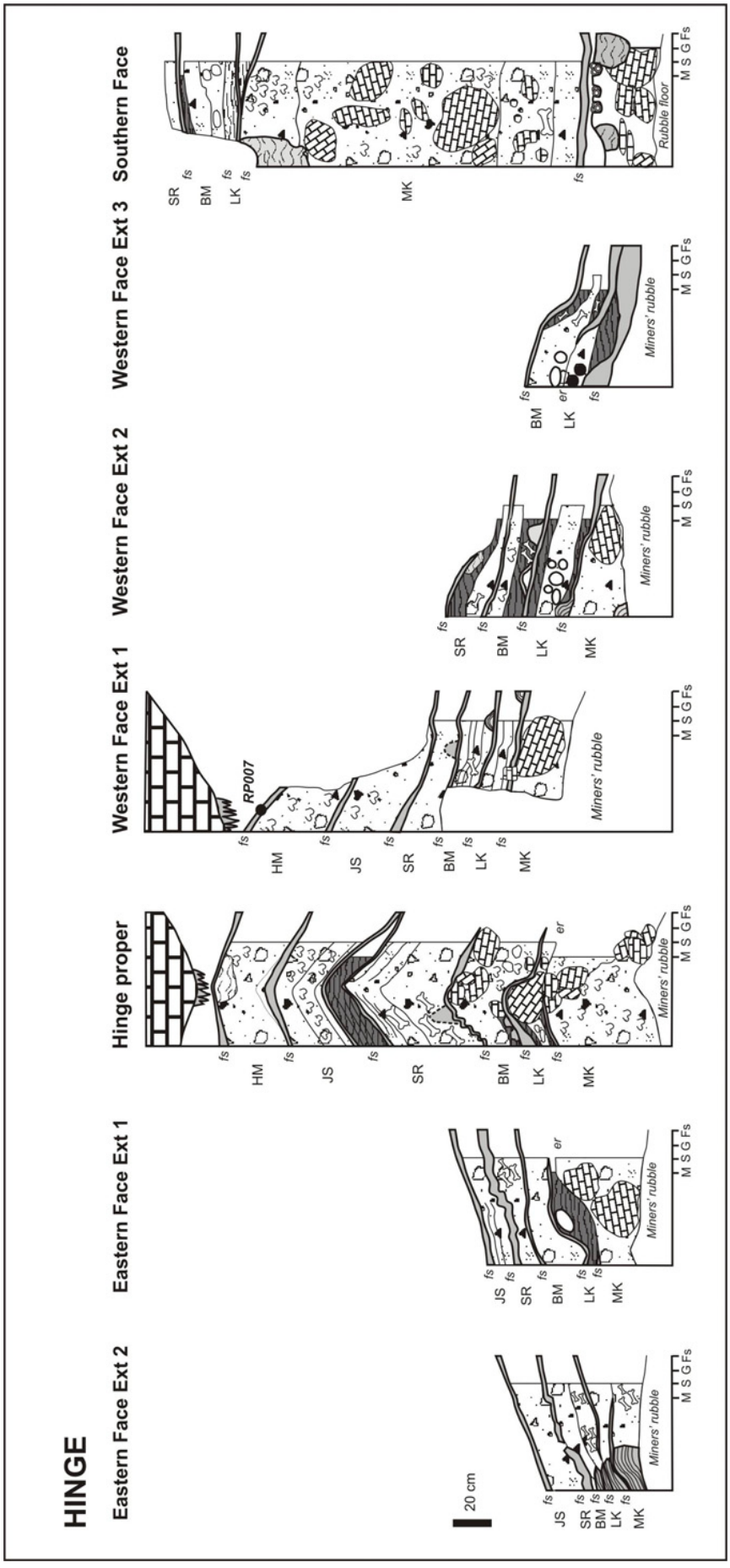


Figure 3.20. Stratigraphic columns for the Hinge sections.

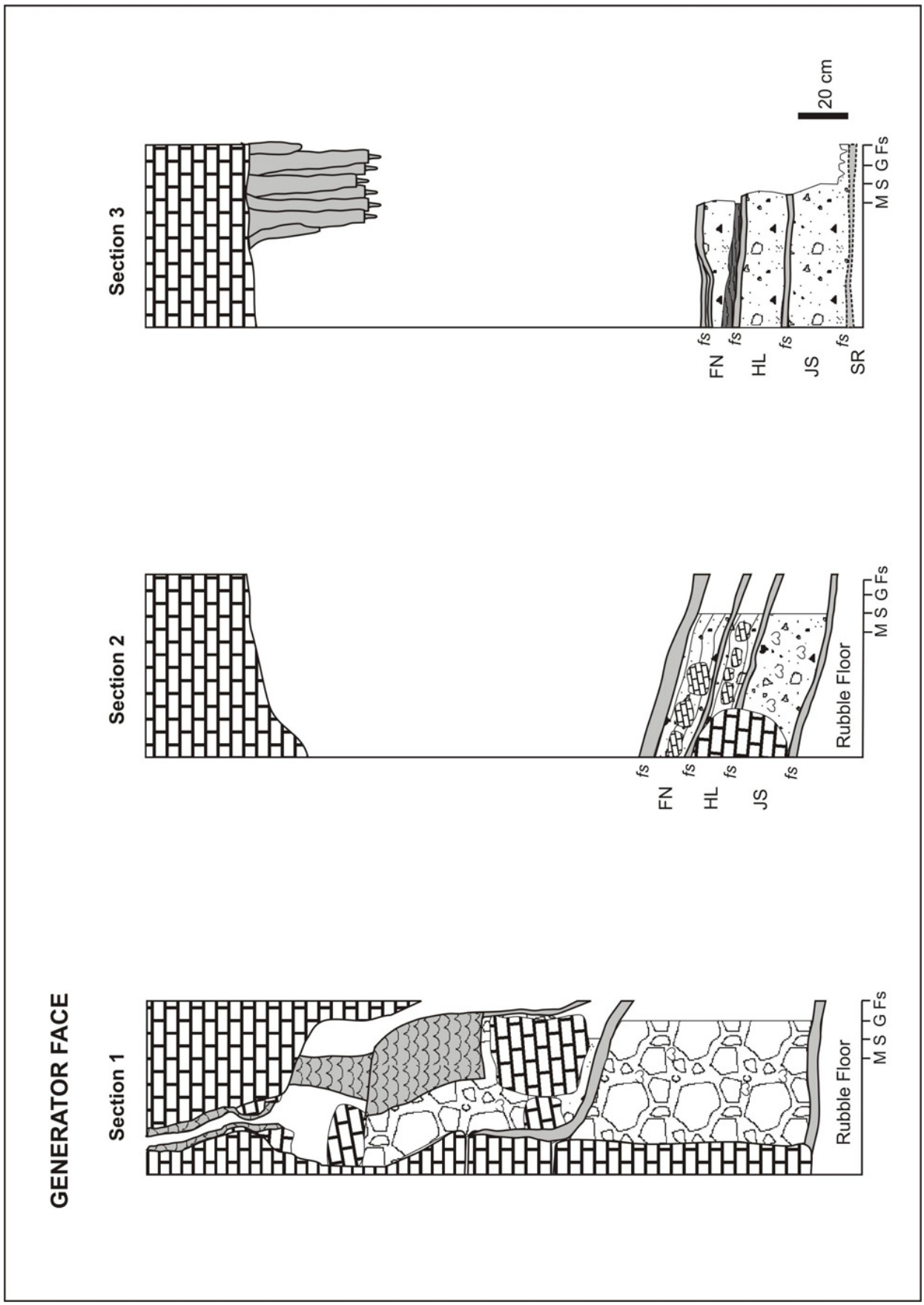


Figure 3.21. Stratigraphic columns for the Generator section.

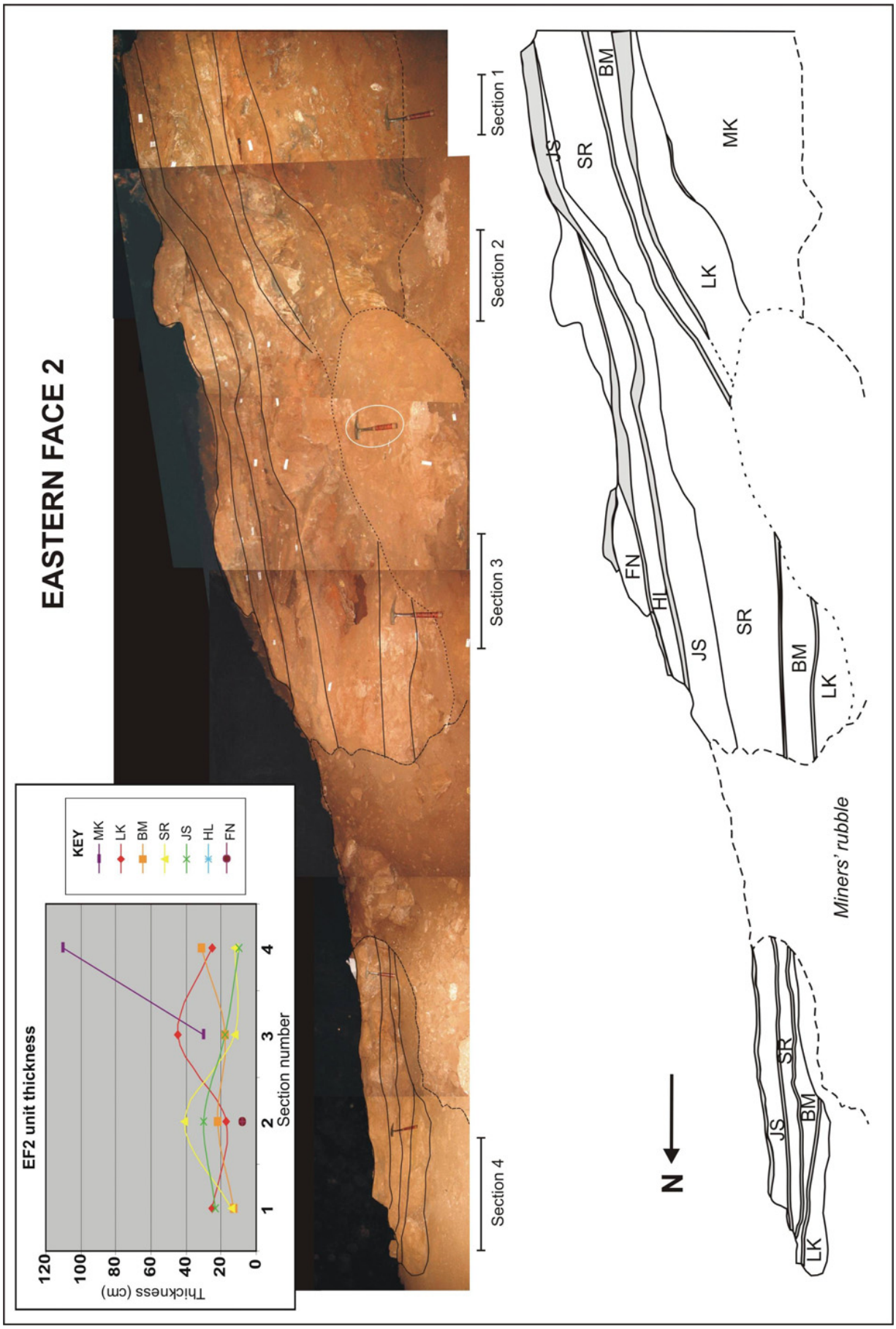


Figure 3.22. Eastern Face 2 section: annotated photograph (top), line drawing (bottom) and graph of unit thicknesses (insert), geopick (circled in white) for scale (30cm).

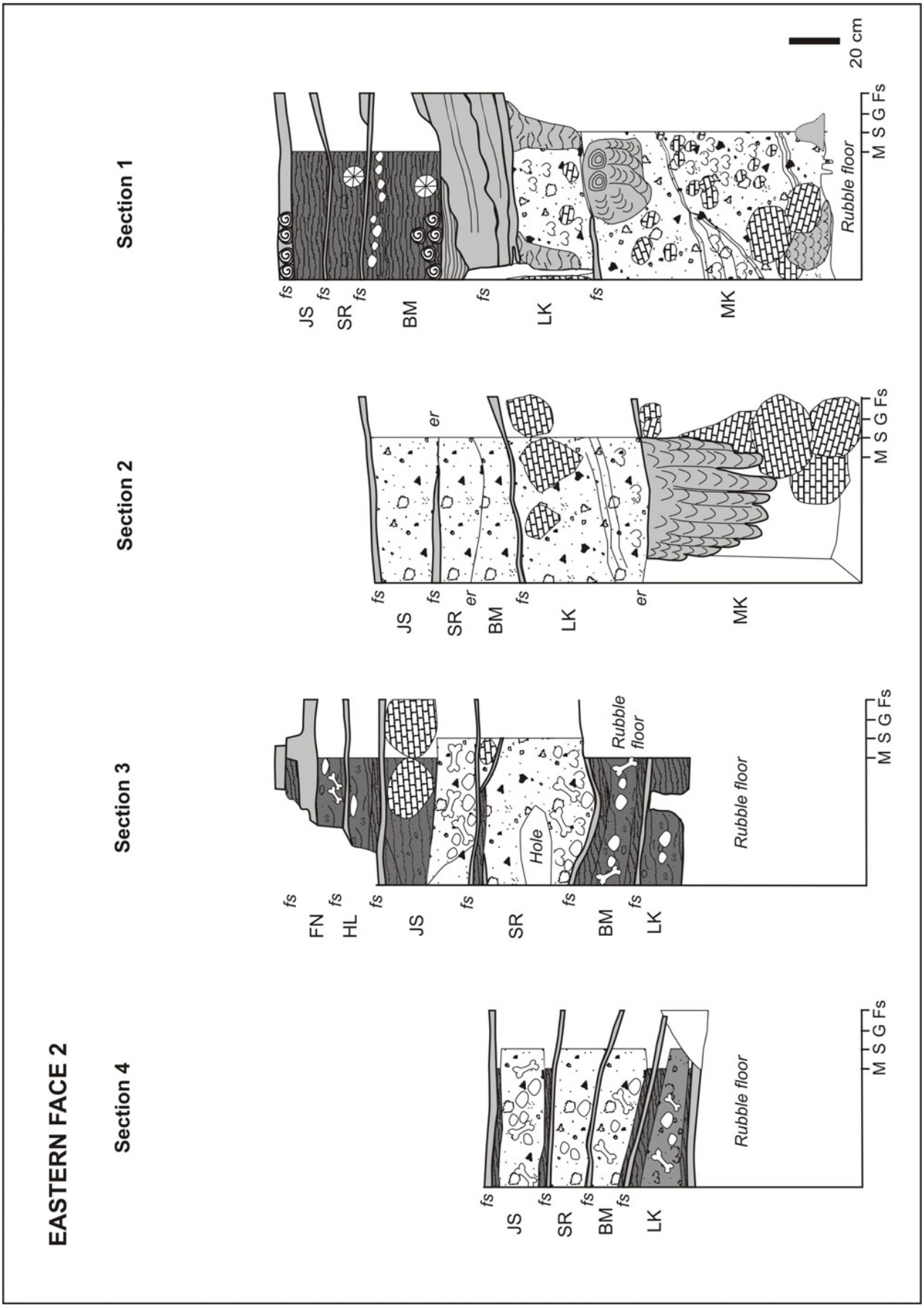


Figure 3.23. Stratigraphic sections for the Eastern Face 2.

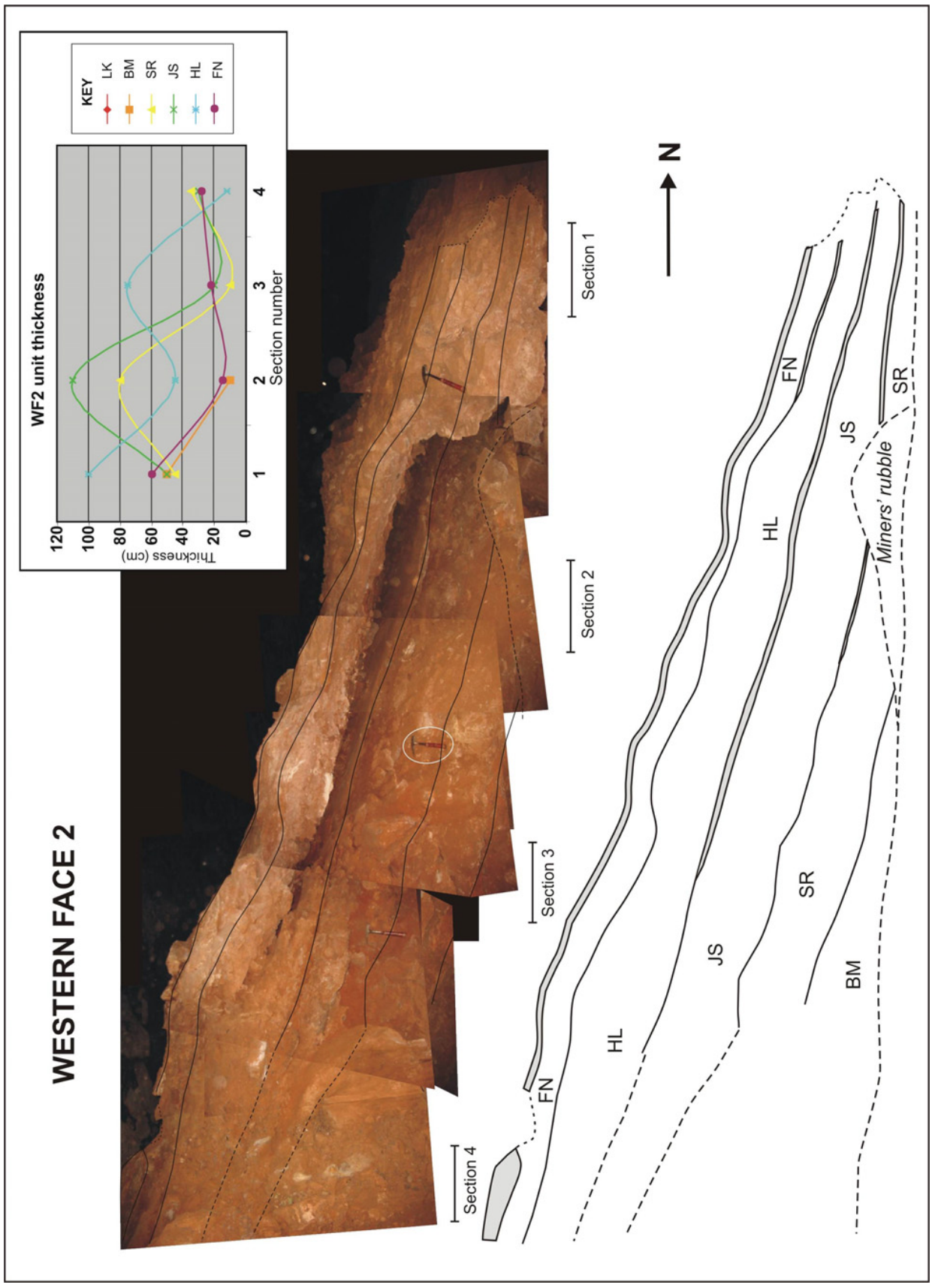


Figure 3.24. Western Face 2 section: annotated photograph (top), line drawing (bottom) and thickness of units against section number graph (insert), geopick (circled in white) for scale (30cm).

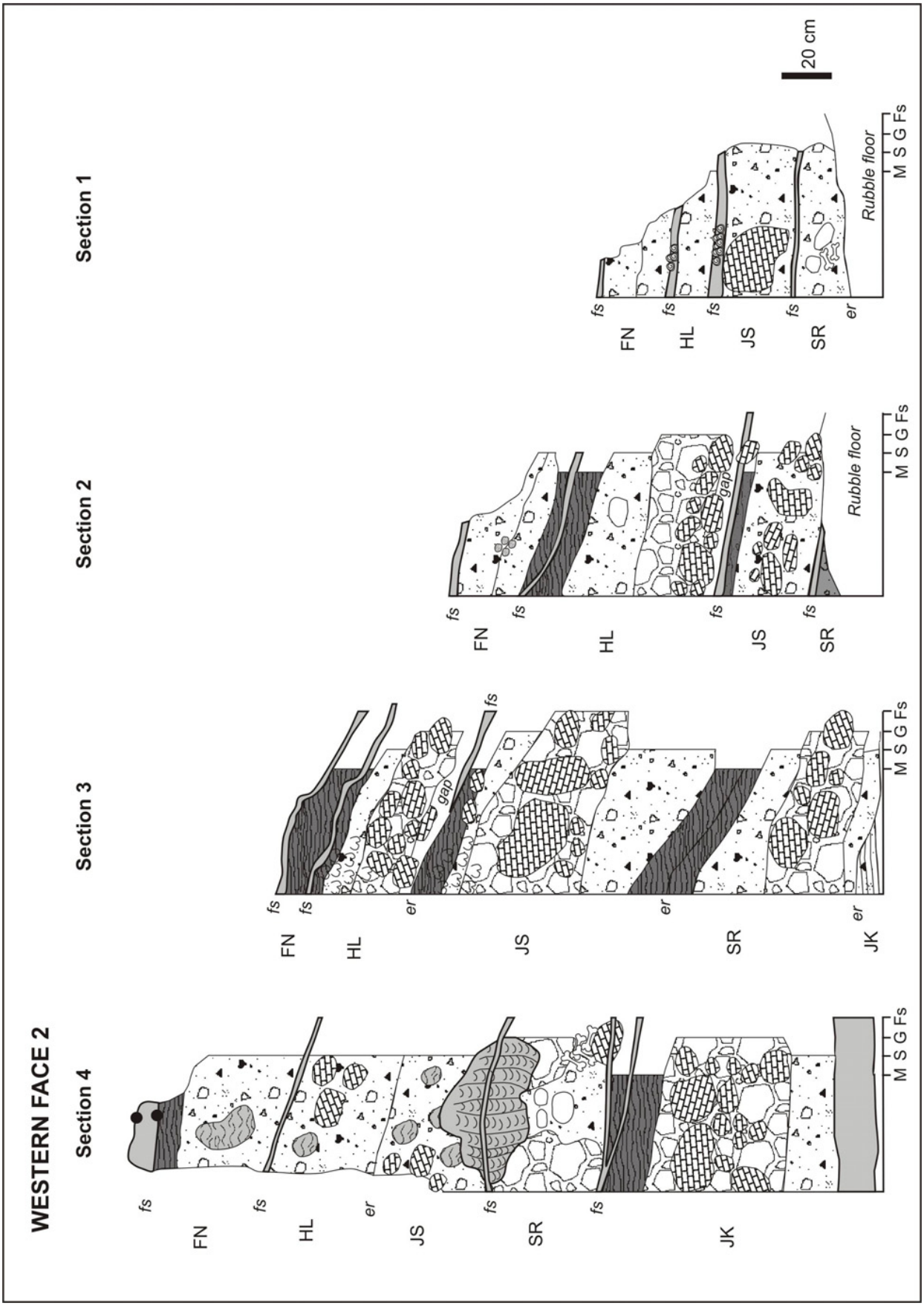


Figure 3.25. Stratigraphic columns for the Western Face 2.

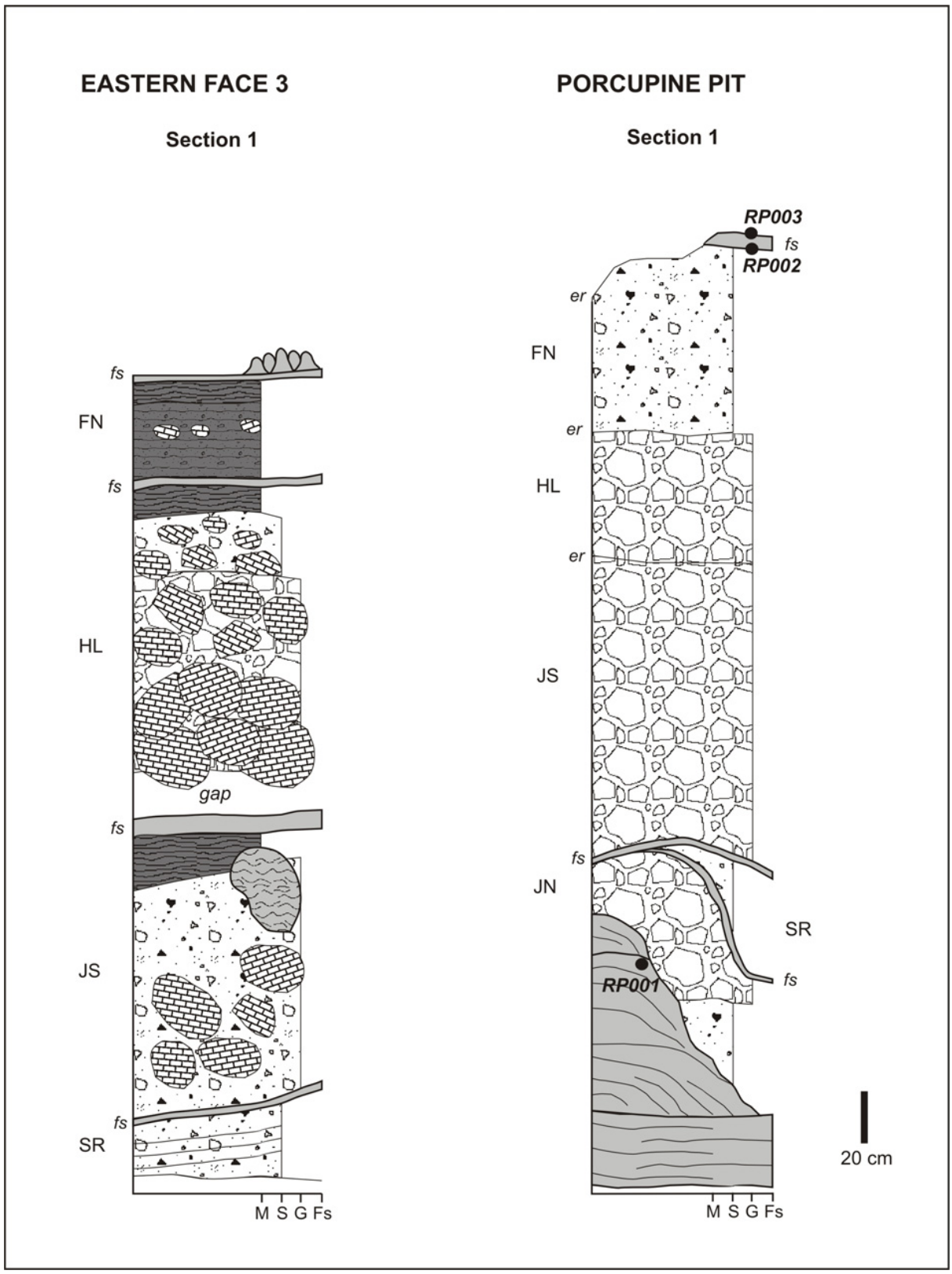


Figure 3.26. Stratigraphic columns for the Eastern Face 3 (left) and the Porcupine Pit (right).

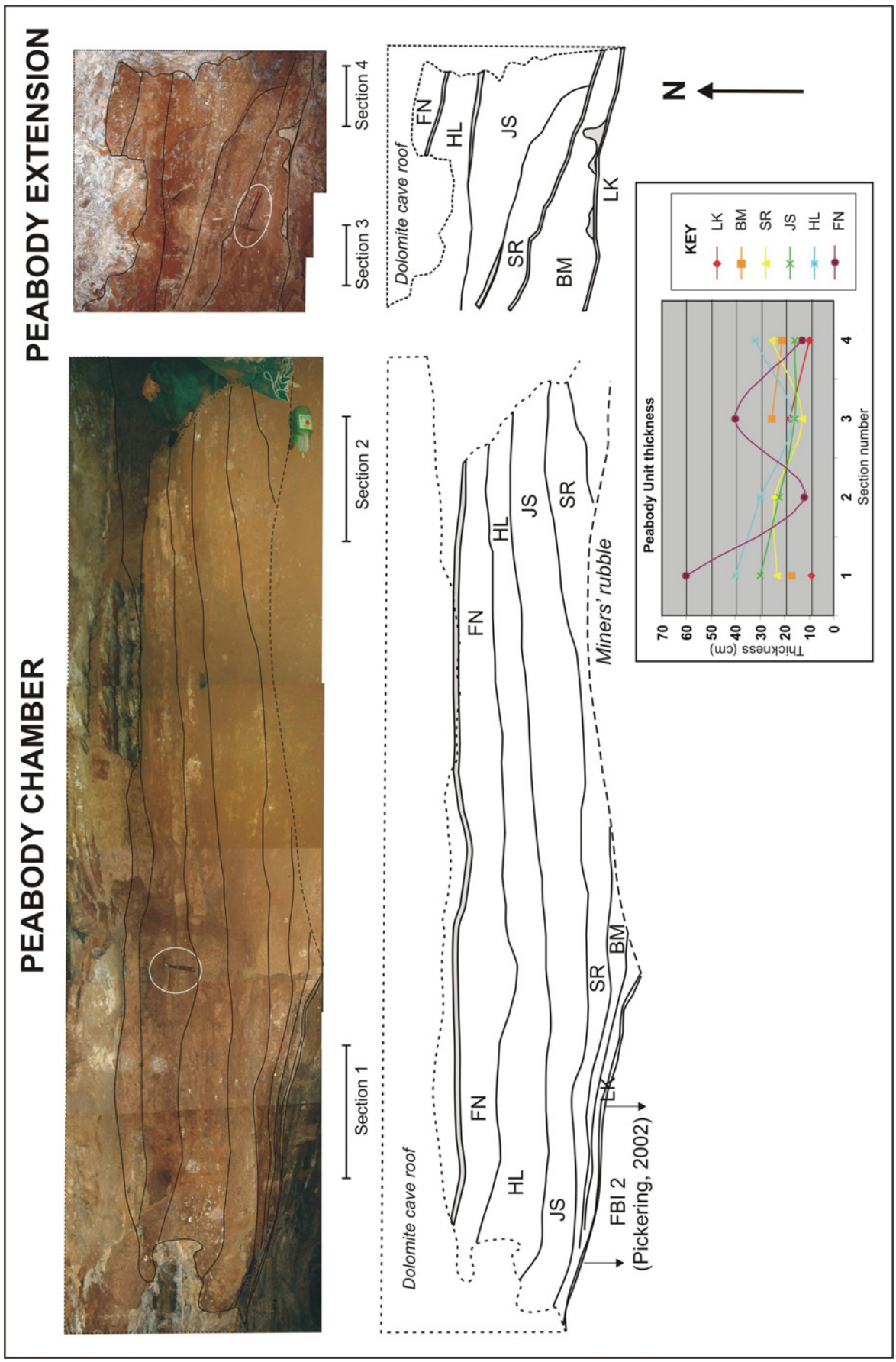


Figure 3.27. Peabody Chamber and Peabody extension sections, annotated photographs (top) , line drawings (bottom) and graph of unit thickness against section number for both the Peabody Chamber and Peabody Extension, geopicks (circled in white) for scale (30cm).

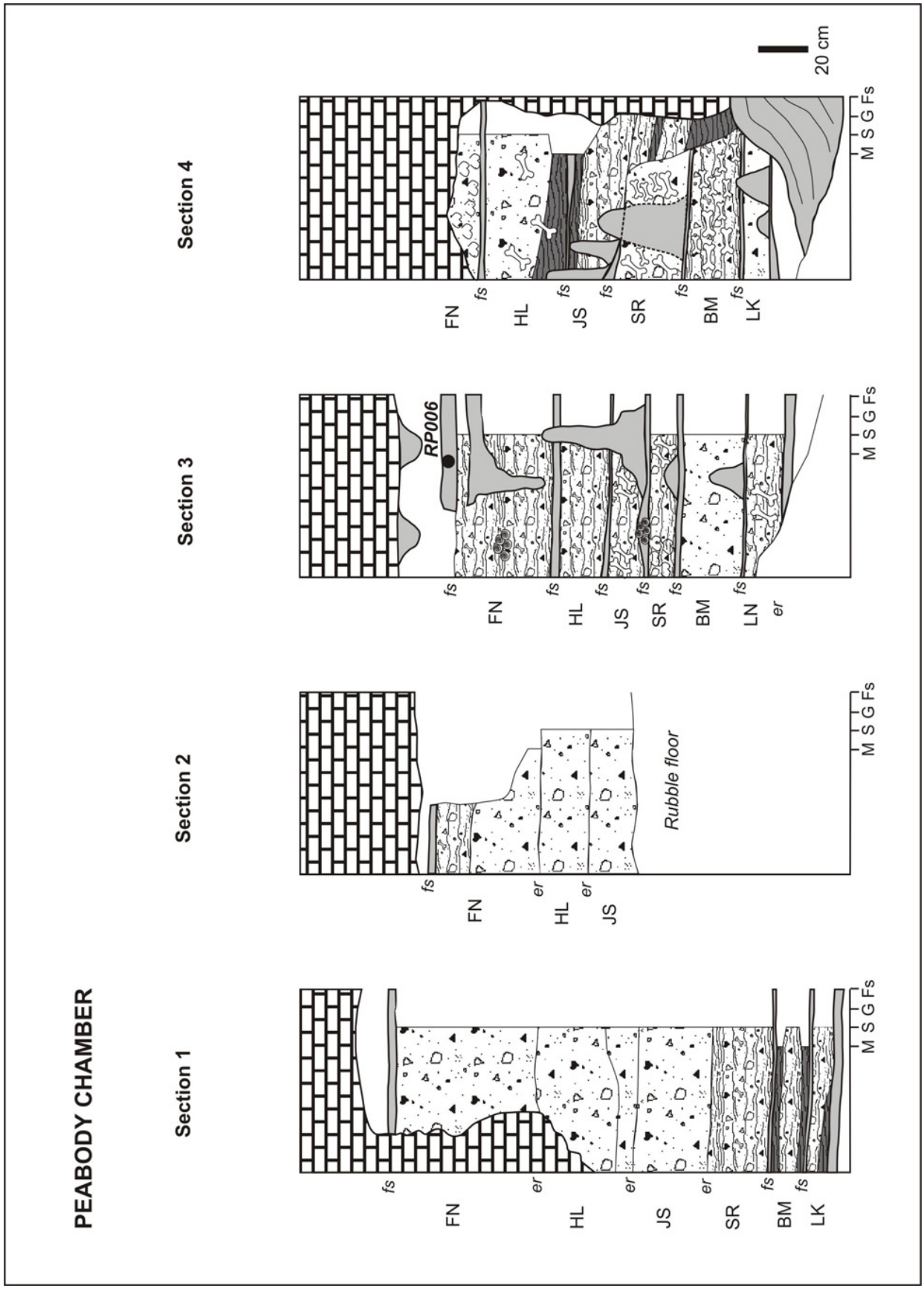


Figure 3.28. Stratigraphic columns for the Peabody Chamber and the Peabody extension.

3.4 Hydrological interpretation of facies

The ultimate objective of a facies approach is to make environmental interpretations of the facies, as the facies associations represent different depositional environments and conditions (Boggs, 2001); hence the following hydrological and environmental interpretations are made of the Gladysvale facies.

Facies A

Facies A is the dominant facies observed within the FBU in the upper chamber at Gladysvale, and is found from the proximal to distal reaches of the deposit. The thin section analysis of a number of samples of this facies from the WF1 (Figure 3.4, 3.5) indicate that microscopically the sediments consist of micropeds, which are microscopic soil structures (Retallack, 1990) set in a clay rich matrix, suggesting that these sediments found inside the cave represent soil horizons from the hillslope outside the cave which have been brought into the cave. Similar structures are found in the sediments in the Naracoorte Cave (Moriarty *et al*., 2000), and these sediments are also interpreted as soils washed into the caves. The lack of clear bedding, coupled to the massive nature of this facies and large amount of matrix, could therefore suggest that this facies is produced when soil profiles from outside the cave are catastrophically and suddenly washed down the slope and into the cave. The angularity of the clasts suggests a short transport distance.

Facies A_1

Facies A_1 is a decalcified version of facies A and most likely was deposited in a similar fashion, but was not subjected to the same degree of post-depositional calcification, resulting in non-calcified sediments, with calcification present only in the form of calcareous nodules.

Facies B

Facies B is similar to facies A, but occurs almost exclusively in the distal reaches of the deposit, and is mutually exclusive from Facies A. The thin sections from the Peabody Chamber (Figure 3.6) indicate that this facies is far better calcified, with pervasive calcite on a thin section scale. The presence of thin, laterally persistent flowstones within the facies and

well developed binding flowstones are also indicative of a high degree of calcification. The facies displays poorly to well developed internal layering, and relatively flat dip angles, and subangular to angular clasts. These factors suggest that this facies was also washed into the cave, but in a less chaotic way than Facies A. The distal position of this facies and its similarities to Facies A in terms of composition, suggests that Facies B is a distal equivalent of Facies A, which was washed into the back of the cave by more gentle water flow, leading to the layering of the sediments. At the back of the cave a number of palaeodrip sources were active and several stalagmites blocked the passage of the sediments (Figure 3.2), leading to the sediments backing up against these stalagmitic bosses and then being well calcified by the drip waters.

Facies C

Facies C consists of fine grained, dark brown, muddy sediments, which are unambiguously horizontally laminated and are invariably found in close association with the binding flowstones, either above or below them. This facies is interpreted as the product of very gentle water-borne sedimentation, where fine-grained muddy sediment from outside the cave was gently washed into the cave by small volumes of water, and the fine layers were built up over time. The close association of this facies with the binding flowstones supports this interpretation, as flowstones are known to grow during periods of increased precipitation (Ayliffe *et al*., 1998; Moriarty *et al*., 2000; Richards & Dorale, 2003), and Moriarty *et al*. (2000) argue that for significant flowstone growth to take place, a cave must be closed to clastic sediment input form outside the cave. Thus, the periods directly preceding and following flowstone growth would also have been relatively wet, with the cave only slightly open, through which only minor sediment could enter and form the muddy layers on either side of the flowstones.

Facies C_1

Facies C_1 is a decalcified version of Facies C and most likely formed in much the same way, but was further away from drip centres and was therefore not well calcified and the binding flowstones were also poorly developed.

Facies C_2

Facies C_2 is also a variation of Facies C, but has less well developed microstratigraphy and more clasts. This facies is concentrated in the proximal and mid-fan regions of the deposit and is interpreted as a proximal version of Facies C, where the coarser grained component of the sediment was dumped near the cave entrance by slightly faster flowing water, which, therefore, did not allow for the development of microstratigraphy. The rest of the sediment was then carried further into the cave under lower energy conditions and deposited as the finely layered Facies C.

Facies D

Facies D is the coarsest grained facies recorded at Gladysvale and consists of large (over 15cm) subrounded blocks of roof dolomite, which are randomly orientated and chaotically stacked upon each other with little to no matrix and no other clasts - particularly no bone - present. This facies is found exclusively in the proximal regions of the deposit, in close proximity to the cave's palaeo-entrances and is interpreted as a gravity collapse of roof material and boulders lying outside the cave, which fell into the cave as the entrance re-opened during episodes of valley erosion and cut back.

Facies E

Facies E is difficult to interpret because of its enigmatic appearance, limited extent and highly decalcified nature. The facies occurs as entire units in the SF1 and northern portion of the WF1 and may be a highly decalcified, altered version of Facies A. The lack of any sedimentary structures in the sediments may suggest that these sediments were *not* washed into the cave and instead are the *in situ* products of animals living in the cave, such as bats, and may represent an accumulation of bat guano. This has been documented in other caves (Gillieson, 1996).

Facies F

Facies F describes all the speleothem material found in the cave, predominantly as the binding flowstones of the FBU, but also as stalagmites. This facies is thus a chemical

sediment which has precipitated inside the cave from calcium carbonate-rich drip waters. Flowstones need specific conditions in order to grow and are associated with periods of increased effective precipitation (Ayliffe *et al*., 1998; Moriarty *et al*., 2000; Richards & Dorale, 2003; Holmgren *et al*., 2003).