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Geomorphological context and formation history of Cloggs Cave: What was the cave like when people inhabited it?

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ABSTRACT

New research undertaken at Cloggs Cave, in the foothills of the Australian Alps, employed an integrated geological-geomorphological-archaeological approach with manifold dating methods and fine resolution LiDAR 3D mapping. Long-standing questions about the site's chronostratigraphy (e.g. the exact relationship between basal megafaunal deposits and archaeological layers), sedimentation processes and geomorphic changes were resolved. The cave's formation history was reconstructed to understand its changing morphology and morphogenic processes, and to clarify how these processes shaped the cave's deposits. Key findings include the identification of: 1) the geomorphological processes that caused the lateral juxtaposition of 52,000 year-old megafaunal and later occupational layers; 2) the existence of one and possibly two (now-buried) palaeo-entrance(s) that enabled now-extinct megafauna and extant large fauna to enter the cave, most likely via a free-roaming passage rather than a pit drop; 3) morphological changes to the cave during the time of the Old People, including the timing of changes to the inclination of palaeo-surfaces; and 4) modifications to stalactites, crushing of calcite formations for the manufacture of powder, construction of a stone arrangement, and movement of large limestone blocks by the Old People. Ultimately, these findings demonstrate that to properly understand what Cloggs Cave was like when the Old People visited the site requires the construction of a narrative that spans some 400 million years and the development of an approach capable of integrating the many scales and processes (e.g. geological, geomorphological, archaeological) that configured to shape the site.

1. Introduction

In 1971–1972, as part of her doctoral thesis, Josephine Flood excavated a large part of Cloggs Cave, a limestone site at the southern foothills of the Australian Alps. Cloggs Cave is arguably the best known, most cited, yet most poorly understood excavated and published

archaeological site in Victoria (southeastern Australia). In 2019–2020, the GunaiKurnai Land and Waters Aboriginal Corporation, representing the Aboriginal Traditional Owners, requested new archaeological excavations to resolve the dating and to provide a better understanding of the cave and its cultural sequence. The original excavation revealed a complex stratigraphy containing megafaunal remains in its deepest

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layers, superimposed by a very rich small vertebrate faunal assemblage consisting largely of owl roost remains and occasional stone artefacts. The uppermost layers consist of a palimpsest of thin ash layers from ancient fireplaces, again with only a very few stone artefacts. The 2.4 m-deep excavated cultural sequence from the 1971–1972 excavations provided the oldest known cultural deposits for the Southern Uplands of southeastern Australia (Flood, 1973a,b, 1974; for more recently excavated, older sequences, see Ossa et al., 1995; Roberts et al., *in press*). However, the deepest cultural layers had somehow been deposited *beside* rather than *on* the older, megafaunal layers, without the mechanisms for this sub-vertical disconformity (separating the megafaunal and habitation layers) being understood. A second problem relates to the small keyhole opening to the cave at ground level, which did not appear sufficiently accessible to allow large megafauna to enter or fall into the cave, while the presence of coprolites of a range of large and medium-sized fauna at depth suggested a free-roaming environment rather than a pit-drop. There were therefore uncertainties about how these faunas entered (and potentially others left) the cave. If megafauna had entered the cave from an alternative entrance that has since disappeared, what did the site look like when people subsequently first entered it, and how did they engage with its internal and external spaces? Last but not least, the angle of the accumulated sediments revealed by the archaeological excavations, and therefore the slope of the palaeo-surfaces, changed around the time that the megafauna ceased to enter the cave, becoming less steep. Why was this so?

To answer these questions, a detailed understanding of the cave's configuration, how it changed through time, the source of its sediments, and their evacuation pathways out of the cave is required. To this end, we have employed detailed geomorphological analyses of the site through high-resolution LiDAR 3D mapping. Our approach combines geomorphological and archaeological examination ("archaeomorphology"; see Delannoy et al., 2017, 2018, *in press*) spanning from before the time of the cave's first occupation by people, through the period of the Old People¹ to the present. This paper addresses these issues by clarifying Cloggs Cave's formation history through a detailed investigation of its structure and contents, adopting a broader landscape perspective that also takes into account the cave's external environment. In this way, Cloggs Cave and its deposits can be set within a grand narrative that encompasses geological and geomorphological scales of time and space to a degree unprecedented in the conventional study of archaeological cave sites, thereby presenting an advanced approach to understanding the formation of sites and their contents. These results will also serve to better understand the origins and history of deposits currently being revealed by ongoing archaeological investigations at the cave.

2. Cloggs Cave's geological and geomorphological context

At its entrance, Cloggs Cave is perched 72.3 m above sea level (a.s.l.). It abuts the southern floodplain of the Buchan River, between the township of Buchan and the Buchan River's confluence with Murrindal Creek, before it joins the Snowy River 4 km further to the southeast (Fig. 1). Across the area the Buchan River intersects a low plateau of c. 200 m altitude, flowing through a weakly boxed (80–120 m) and flat-bottomed meandering valley. Cloggs Cave is found in a vertical escarpment against the convex arc of one of these palaeomeanders. The cave's entrance overlooks the valley floor 17 m below. Slightly upstream, the deeply incised and now-dry valley of an ancient Tara Creek joins the Buchan River valley (see Fig. 2).

Cloggs Cave's perched character, the Buchan River's meandering

palaeo-channels, the dry valleys, and the flat, sub-horizontal ridge-lines among an otherwise undulating terrain each reveals important dimensions of the landscape's, and cave's, formation history. Understanding the geological origins and transformations of this landscape is critical to understanding Cloggs Cave itself, including what it was like during the time of the Old People.

Cloggs Cave formed in Middle Devonian carbonate formations of the Buchan Group (VandenBerg et al., 1996) (Figs. 3 and 4). These formations are characterised by finely bedded dark "blue" limestone overlying more massive dolomites. The Buchan Group sediments were initially deposited in an old, north-south synclinalorium (Buchan Basin) established c. 410–395 million years ago during the Siluro-Devonian transition. Rocks of the Snowy River Volcanics (also Devonian in age) outcrop on both sides of this basin, signalling that it represents an old rift valley. While the physical characteristics of these very different geological formations can today be quite easily read from the surface (rugged, wooded relief of the volcanic landscape; bare plateaux of the carbonate formations), the structure of the ancient geology is less evident from its surface features. Here the topographic relief of both the volcanic and carbonate formations have been slowly eroded for some 350 million years, from the end of the Devonian to the first half of the Cenozoic, to form vast flat ridge-lines ("planation surfaces") (Figs. 2 and 3). During this long geological time-frame, the large, flat planation surfaces were established along the hill and ridge-tops, and the carbonate formations of the Buchan Group witnessed karst dissolution processes ("phantomization", weathering the rock without creating cavities) at varied depths (see Section 4 below). South of the township of Buchan (Fig. 4), the Devonian-era planation surfaces became partially fossilised by later, Oligo-Miocene marine sediments that now superimpose them in angular discordance. This discordance clearly confirms that the large planation surfaces formed prior to the Oligo-Miocene deposits. Their sedimentary facies (sands, conglomerates, calcareous sandstones) suggest the presence of an ancient coastline, into which alluvium from erosion of the mountains around Blue Hill were carried by a palaeo-Buchan River. The subsequent uplift of the whole region led to the gradual withdrawal of the littoral zone to the present coastline further to the south, and to the sinking of watercourses into the ancient planation surfaces.

Descending from the Snowy Mountains (Mount Kosciuszko: 2228 m a.s.l.), today the Snowy River drains a large watershed (15,780 km²). This explains why, over time, it has incised deeply into the landscape to become the major river in the regional landscape. As a result, neighbouring tributaries such as the Murrindal and Buchan Rivers were diverted from their original courses. After descending north-south from the mountains around Blue Hill (1090 m a.s.l.), the Buchan River makes a sharp eastward bend near Buchan, continuing further east to join the Snowy River.

This c. 400 million year-long geological history remains readable in the Cloggs Cave landscape today. The flat-topped hill into which the cave developed corresponds with the formation of pre-Cenozoic planation surfaces (Fig. 2). To the south of the hill that contains Cloggs Cave, the tops (including upper synclinal folds) of other Buchan Group limestone hills and ridges have similarly been bevelled away by erosion (Fig. 3). This planation process is particularly clear at Cloggs Cave where the folds visible in the escarpment have been cut through by erosion across the top of the hill (Fig. 5). On the hill, we also find indurated pebble deposits carried by ancient rivers that once flowed along the plateau's planation surface (Fig. 6); they can be traced all the way to the Miocene coastal formations. The petrographic characteristics of these ancient alluvia (e.g. quartzites, quartzes, siltstones, sandstones, conglomerates) have their origins in the broader Blue Hill area to the north, where ancient non-carbonate deposits of the Yalmy Group, Enano Group and Snowy River Volcanics are exposed (VandenBerg et al., 1996). Their presence along the south bank of the Buchan River indicates that the route of the current valley did not exist then, at least between Buchan and the Snowy River. The nearby presence of these

¹ The respectful term "Old People" is the preferred term used by GunaiKurnai Aboriginal Traditional Owners for the ancestors who lived a long time ago, and whose spirits, according to GunaiKurnai worldviews, continue to dwell in the landscape.

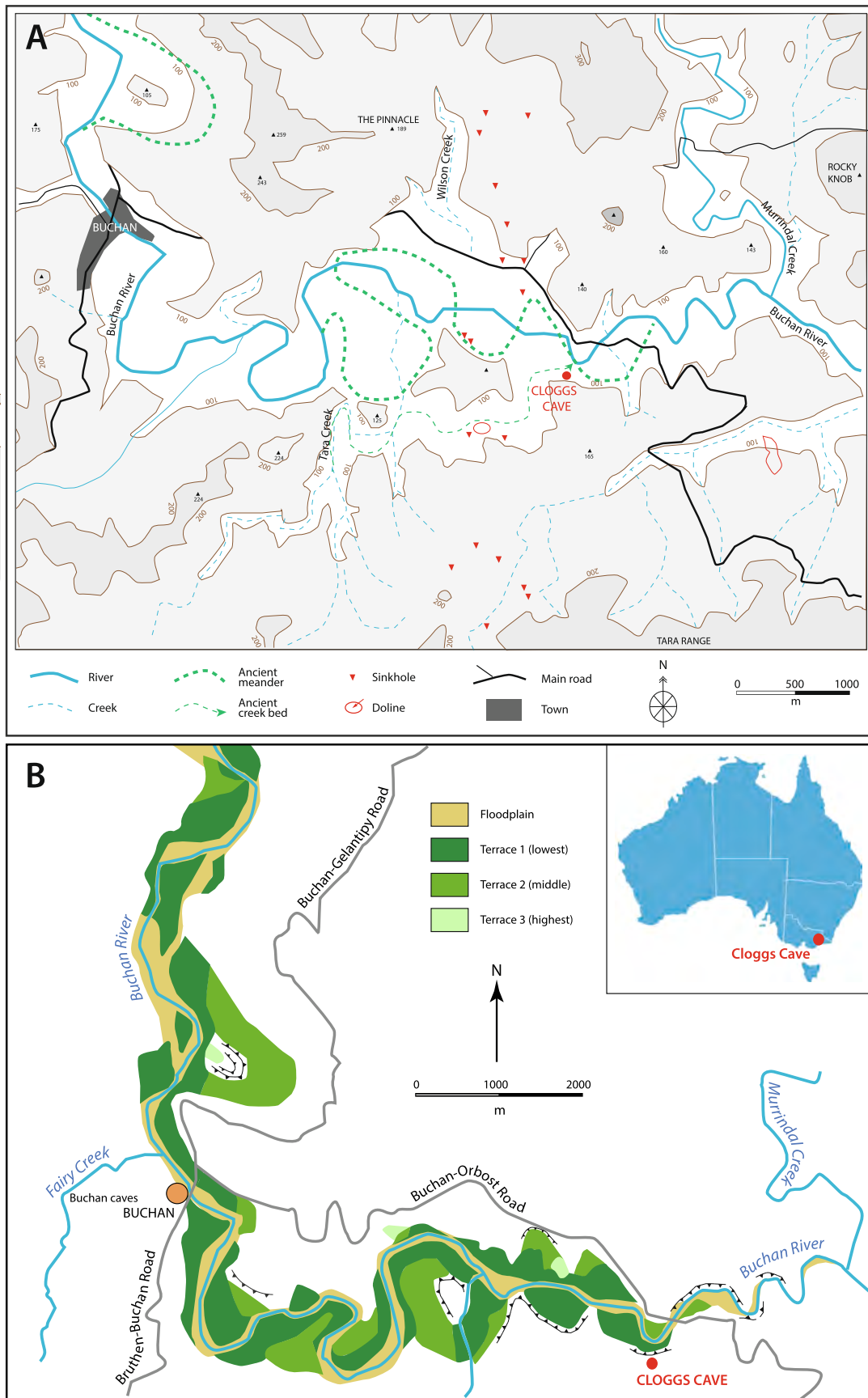


Fig. 1. Location map of study area and stepped terraces of the Buchan River (A by Jean-Jacques Delannoy; B after Webb et al., 1992).

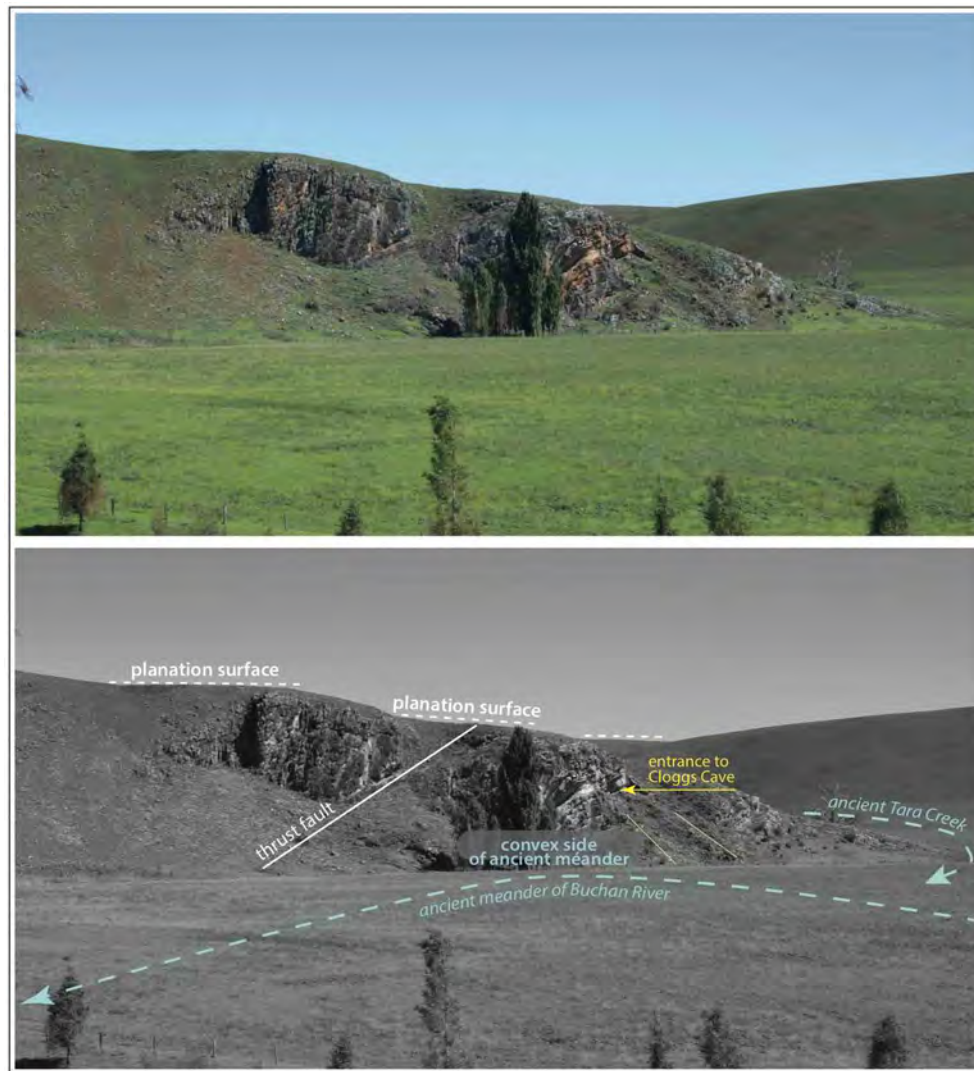


Fig. 2. Cliff-line containing Cloggs Cave and fronting both a palaeo-channel of the Buchan River and its current flood-plain, showing geographical features discussed in-text (photo by Bruno David; annotations by Jean-Jacques Delannoy).

lithologies is also significant for the availability of a broad range of raw materials for the making of stone tools in the local landscape, and for the kinds of sediments that could wash into subterranean cavities (see below).

These observations about Cloggs Cave's external landscape set the scene for the development of the underground karst landscape. For the cave to form, a change of slope in water level was required across the landscape, creating a "hydraulic gradient". In the broader Cloggs Cave region, this was generated by the sinking of the land and its associated bodies of water, or "hydrographic network". This clearly took place after the establishment of the planation surfaces and superposition of Miocene pebbles 10–5 million years ago. It is in post-Miocene (i.e., Quaternary) times, after five million years ago, that the network of underground cavities including Cloggs Cave formed. The underground topography, such as the shape, size and structure of the dissolution cavities, is testament to the sinking of the regional hydrographic network and the change in river courses that took place during the Quaternary (see Section 4 below).

The position of Cloggs Cave above the current level of the bottom ("thalweg") of the Buchan River valley indicates that it originated at a time when the river was higher than it is today, because the phantomized rock began to evacuate as percolating waters drained into the valley floor when it had also reached that level (Figs. 1 and 2).

Similarly, its location against the convex arc of an ancient meander indicates that the cave network, of which Cloggs Cave is a part, must once have extended further north towards the valley. The retreat of the cliff face by the undercutting river gradually dissected the underground network, removing its outer walls and cutting it open to the elements in the process. The presence of old stalagmitic formations in the now-open cavity (the "Porch") immediately outside the entrance to Cloggs Cave testifies to the presence of an ancient northern extension of Cloggs Cave's partially interconnected underground cave network. In this broader geological context, positioning in time the origins and evolution of Cloggs Cave is essential to determining whether in the past animals and people used its current entrance to enter the cave, for it is theoretically possible that other connected cavities penetrate, or previously penetrated, into it. To answer these questions, it is necessary to consider Cloggs Cave itself and the talus slope in front of it.

3. Topographic and morphological characteristics of Cloggs Cave

3.1. Physical context of the cave

The entrance to Cloggs Cave opens half-way down the cliff whose base extends down to the Buchan River's lower terrace (Fig. 7). This alluvial terrace is contemporaneous with the river's palaeo-meanders.



Fig. 3. Geomorphological interpretation of the landscape relief to the south of Cloggs Cave (photo by Jean-Jacques Delannoy).

The cliff rises against one of these meander's point of maximum convexity, and as noted above, is composed of two superimposed and slightly stepped lithologies (limestone and dolomite; Fig. 2). These lithologies are intersected by vertical fractures, one of which runs down the cave's entrance. The entrance Porch to the cave is modelled on this fracture (Fig. 8). Beneath the Porch is a talus slope; the cliffs re-appear on either side. For a few hundred metres to the east of the fracture and of the Porch (on the left in Fig. 2), a succession of tight folds appears (Fig. 5). The entrance to the cave itself is located in a low balcony just above the slope, representing the contact of the two superimposed lithologies of the Buchan Group: 1) the dark blue limestone in which the cave develops (see below); and 2) the more massive dolomitic carbonate base. It is also along the contact zone of these two rock layers that a long ledge runs east from the front to the Porch. To the east a steep, 15 m-high cliff of sub-horizontally bedded dolomite is clearly visible; to the west the limestone outcrops in sub-vertical folds (Fig. 8). The talus under the Porch consists of a mixture of soft sediments and rocks of varied sizes (here the bedrock does not outcrop), some of which were redeposited during Flood's excavations of 1971–1972 (Flood 1973a, 1974, 1980). While these sediments cover a good part of the slope, they cannot alone be responsible for the talus deposit, whose base extends all the way to the alluvial terrace below.

3.2. Cloggs Cave: Description

Although together the cave and its Porch extend 25 m, the cavity penetrates little into the underlying relief, and its furthest point (the terminus in the Upper Passage, see below) is only 18 m from the front of the Porch (Figs. 8 and 9). Nevertheless, it contains a myriad of underground landscapes (Fig. 10). Here we describe the cave's morphology in plan-view succession: from the entrance Porch to the terminus of the cave's Upper Passage.

The entrance area's large vertical Porch (8 m-high) is juxtaposed next to a rockshelter of more modest size (2.9 m-high \times 3.2 m-

wide \times 2.5 m-deep). Many collapsed blocks litter the Rockshelter floor (Fig. 8). The Porch has a keyhole morphology, with its narrower part containing a stalagmitic column whose perched base flanges out. On the Porch's western wall, smaller speleothems adhere to the upper parts of the wall, testimony to the dripping waters that once also fed the eastern stalagmite (Fig. 9). This major phase of speleothem formation corresponds to a period when conditions were favourable for the dissolution and precipitation of carbonates in underground cavities. This could not have happened when the Porch was open to the elements as it is today, but must rather date to a time when the Porch was more enclosed, that is, when the cliff extended further out, prior to retreating to its current position. Furthermore, by being suspended above ground, the base of the stalagmitic column testifies to the palaeo-Porch's ground level having been 1.65 m higher than present. The presence of cemented limestone blocks in the stalagmite's base indicates that the floor was then composed of rocks originating from collapsed sections of the Porch's walls or ceiling. It is difficult to determine the precise thickness of this ancient floor deposit between the base of the stalagmite and the bedrock, especially as the current floor sediments were reworked by the 1971–1972 archaeological excavations (see Flood, 1980). The same applies to the floor of the adjacent Rockshelter.

As one approaches the rear of the Porch, its height decreases rapidly, giving way to an access duct into the cave (the Entrance Passage), a limestone walkway suspended 1.2 m above the current soft sediment floor (Fig. 11). Outside the cave, towards the rear of the Porch, the cavity under the walkway opens up into a small gallery that extends in the direction of the cave. However, the sediment disturbances associated with the 1971–1972 excavations make it difficult to determine the original context and composition of the accumulated deposits. A photograph from Flood's PhD thesis (1973a: plate 15B) of the excavated sediments in this part of the Porch indicates that they were composed of blocks with angular geometries, suggesting that they had fallen from the Porch's walls and/or ceiling.

At the entrance to Cloggs Cave, the Entrance Passage quickly

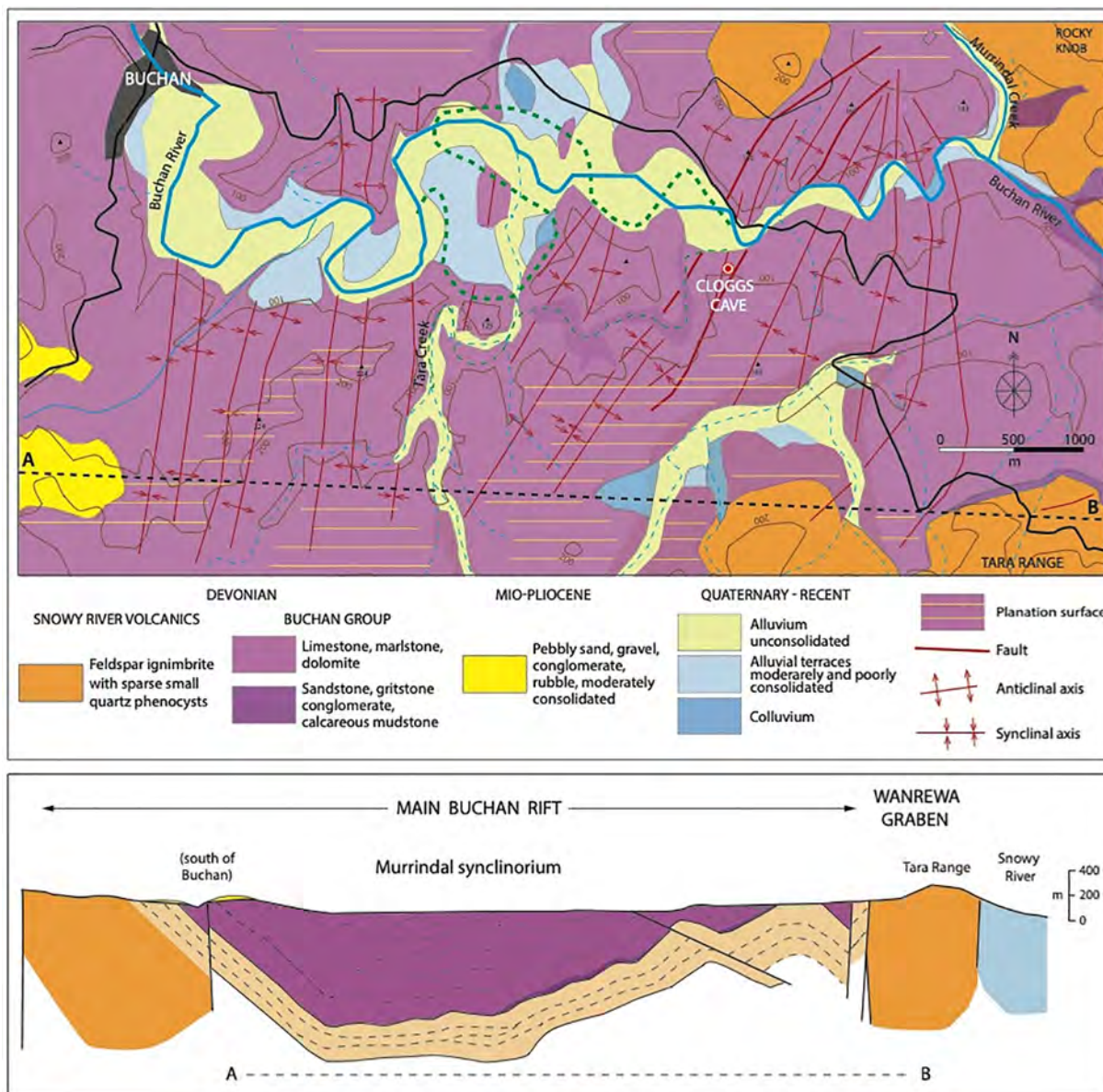


Fig. 4. Geology of study area (after Nowa Nowa map sheet, 8522-4 Zone 55 – 1:50,000 geological map).

narrows to 0.85 m-width × 1.55 m-height. Here, by 1980, a gate was cemented into the wall, to protect the cave from visitors. Past the gate, the Entrance Passage continues for a further 2.5 m. At its southern end, a 1.2 m drop onto a soft sediment floor marks a rapid opening of the cave into a large, 5 m-long × 3.5 m-wide × 5 m-high cavity, the Main Chamber (Section A–B on Fig. 12). This part of the cave is modelled on the arching fold of an anticline, an exceptional geological feature: such cases, revealing the inner heart of an anticline, are rare anywhere in the world and befit UNESCO World Heritage status under Criterion 8 (“outstanding examples representing major stages of earth’s history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features”) (<https://whc.unesco.org/en/criteria/>). The descent from the Entrance Passage, together with the entire Main Chamber, developed along a NNE–SSW orientation, along the axis of the anticline fold. This axis perpendicularly intersects a NNW–SSE fracture along which the length of the cave is modelled. Throughout this paper we refer to the part of the cave modelled in the anticline as the “Main Chamber”, and the long cavity that intersects it along the fracture’s perpendicular axis as the “Gallery”. As the Gallery extends across both

sides of the Main Chamber, it is divided into the “Lower Gallery” and “Upper Gallery” on either side (Figs. 10 and 11).

In the downslope, NNW side of the Main Chamber, the Lower Gallery loses volume and narrows sharply (Section E–F on Fig. 12): here its terminus reaches a non-penetrable crack with two small conduits along the axis of the fracture (Fig. 13C). On the other side of this same fracture, the outer Rockshelter developed. Only the two small conduits along the fracture have the geometry of ancient karst hollows. The rest of the Gallery, including the Main Chamber, formed by successive gravitational collapses of wall and ceiling strata.

This raises an important question: where are the collapsed blocks? Even if numerous blocks were extracted during the archaeological excavations – and many of these were stacked against the northeastern wall of the Lower Gallery during the 1971–1972 excavations – their total volume is well below that of the cavity itself. This deficit will be re-examined in Section 4 below.

The Upper Gallery extends SSE past the 1971–1972 excavation pit. Two slopes have affected its configuration: that of the floor, which rises towards its SSE terminus; and that of the ceiling, which along the fracture line reaches a maximum height of 6 m above the present floor

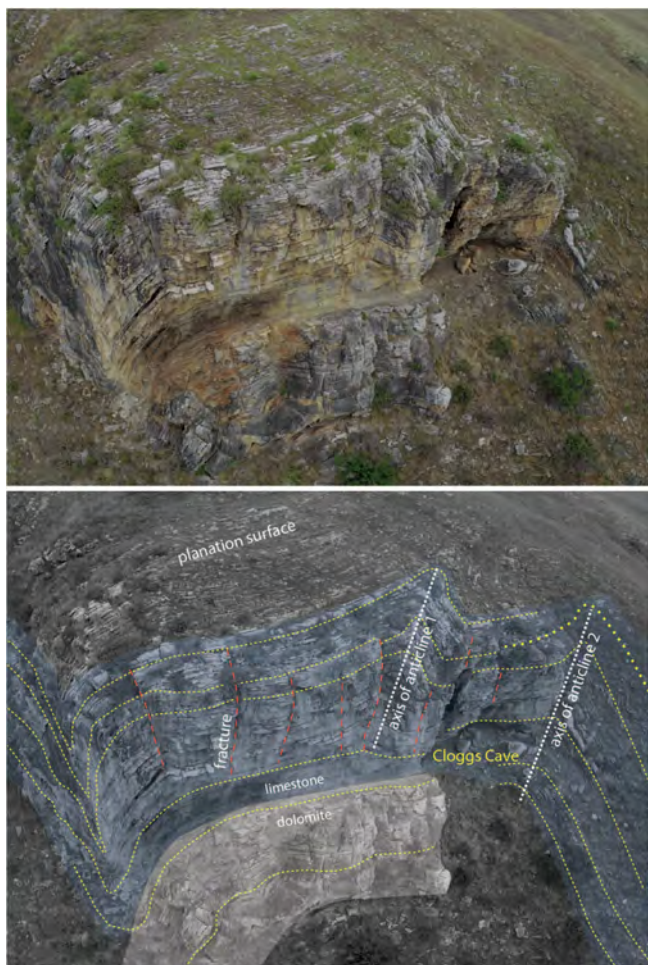


Fig. 5. Geomorphological interpretation of the escarpment and plateau of hill containing Cloggs Cave (drone photo by Johan Berthet; annotations by Jean-Jacques Delannoy).



Fig. 6. Relict alluvium on the hill-top above Cloggs Cave (photo by Jean-Jacques Delannoy).

(Fig. 11; Section G–H–I on Fig. 12). Three factors here require explanation:

1. The low number of blocks on the present floor, in contrast to the large numbers that would have fallen from the walls and ceiling through gravity, until a relatively stable vault was reached (Fig. 13D).

2. The closure of the SSE end of the Upper Gallery as it narrows over a few metres from a wide gallery to an impenetrable crack.
3. The composition of the current brownish sandy-loam floor deposits, upon which sit more or less isolated blocks from “recent” wall collapses. Other, partly buried blocks signal the presence of underlying rock-fall, although their full details are currently obscure.

The Gallery’s floor slopes in two directions: 1) from its SSE end to its junction with the Upper Chamber 3 m to the southwest; and 2) from its junction with the Upper Chamber through the Main Chamber down to its northwestern terminus. The first section is less steep and at much higher elevation than the second, appearing to be suspended above it: the change in slope angle roughly corresponds with the junction of the Upper Gallery and Upper Chamber. Near this intersection, where the floor changes angles, the base of blocks from wall collapses sit flat on or just below the ground. To the northwest, the slope is noticeably steeper, and except for along the eastern edge of the Gallery, it contains fewer blocks on its surface. Here sandy-loam surface sediments again predominate. Drip-holes and dripstone encrustations from mineral-laden drops falling from stalactites overhead can be seen on the ground. They are small and very recent, continuing to grow today.

To the south of the Upper Gallery is the Upper Chamber, with distinctive morphological characteristics both at ground level and on the ceiling. Three of its features are particularly curious:

1. The relative flatness of the floor, essentially composed of fine sediments.
2. The presence of small depressions on the floor.
3. An abundance of speleothems in its northwestern side, on the ground, on the wall and on the ceiling.

As for most other places in the cave, the Upper Chamber’s walls and ceiling formed through the gravitational collapse of rock strata, as here, too, the ceiling is modelled on the geological dip of the rock (Sections C–D and H–I on Fig. 12). The absence of collapsed blocks on the ground indicates that the Upper Chamber’s geometry formed some considerable time ago, prior to the deposition of the current floor’s surface sediments (the timing and provenance of which remain to be determined; see Section 4 below). This relatively ancient age for the Upper Chamber’s geometry is confirmed by the speleothems that cover parts of the wall and ceiling, in particular those on its northwestern side. This preferentially northwestern distribution of speleothems is caused by the dip of the limestone layers, which conduct infiltrating water along their joints (see Fig. 12). We note the presence of several ancient generations of concretions as well as active fistulous stalactites (“soda straws”) and stalagmitic crusts. Here we pay particular attention to the more ancient concretions, for the following two reasons:

1. Many of the stalactites are broken, but their broken distal ends are nowhere to be seen. Only a few recently broken soda straws lie on the ground.
2. The base of the old stalagmitic concretions and flowstones generally lie flat on the ground surface, but in some places are elevated above the current floor by up to 10–20 cm.

The association of the base of the old stalagmitic concretions with the current floor level confirms that the current geometry of the Upper Chamber (including the Alcove, see below) has a considerable age, and that it has remained relatively stable since forming. This observation is noteworthy given that other parts of the cave, in particular the Gallery including the Main Chamber, underwent more pronounced transformations (see Section 4 below). However, why the stalactites on the ceiling broke remains to be determined, and in theory could be due to earthquakes, large fauna, or to accidental or purposeful breakage by people. We address these options in Sections 4 and 5 below.

Towards the southwest corner of the cave, the Upper Chamber gives



Fig. 7. Section across the cave, from the terminus of the Upper Passage through the cave and its Porch, to the Buchan River floodplain (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy).

way to the Upper Passage, a low corridor up to 0.6 m in height and with a loamy floor. Here the cave's morphology changes radically, the narrow, rising corridor now modeled on a NNW–SSE fracture. Although parallel in orientation to the Gallery, the Upper Passage differs in its layout: it follows the dip of the limestone strata (30°), which rise up towards the NNE. The base of the Upper Gallery's terminus is thus at the same elevation as the ceiling of the Main Chamber. About two-thirds along its length, the Upper Passage makes a sharp elbow bend towards the SSW. After the bend, the Upper Passage suddenly stops at an indurated fill capped by a thick flowstone. This fill almost completely clogs the end of the Upper Passage: a gap of about 10 cm between the limestone roof and the flowstone indicates that the conduit continues further towards the SSW. A light draft also signals a connection with other underground karst cavities and ultimately with the surface of the hill. We also find a similar fill at the base of the south wall approximately half-way along the lower arm of the Upper Passage. Here, too, the fill seems to block an ancient duct. We have paid particular attention to the Upper Passage in understanding Cloggs Cave's formation history, because it is the only conduit to have retained its initial karst morphology; everywhere else in the cave, ancient conduits have undergone significant modifications.

From these observations, six points stand out:

1. The layout of the cave is modelled in strongly folded and fractured limestone layers. The cave's Main and Upper Chambers, Gallery and Entrance and Upper Passages are all oriented in a network of NNE–SSW (anticline fold and associated fractures) and NNW–SSE (fractures characteristic of the entire study area) cavities (Fig. 4).
2. The abrupt ends of the Gallery and Upper Passage: while the Upper Passage is short, and the Gallery voluminous, both end abruptly with impenetrable cracks. Only the terminus of the Upper Passage seems to be associated with an ancient fill, the origins and age of which remain to be determined.
3. The large underground cavities were essentially caused by gravitational processes (cliff and overhang retreat near the Porch; widespread collapse of sections of walls and ceilings). The bedding of the limestone and strong dip of the strata are conducive to such collapses due to their weakened mechanical cohesion.
4. The relative paucity of blocks on the floor, in contrast to the much larger volumes of rock that must have collapsed from the walls and ceilings.
5. The nature and genesis of the Main Chamber's low point, towards which the Upper Gallery's talus descends. The stratigraphic layers revealed by Flood's (e.g. 1973a) 1971–1972 and David et al.'s (e.g. David et al., in press, in preparation) 2019–2020 archaeological excavations indicate a complex stratification: the layers are in

angular discordance; the deepest excavated layers have a significantly greater dip than the overlying ones; the deepest (mega-faunal) layers are transected by more recent ones in southern areas of Flood's pit. The processes of sedimentation at Cloggs Cave remain to be defined (see Section 4 below).

6. The presence of a boulder-rich talus slope fronting the Porch, the precise characteristics of which remain to be determined.

It is through these six points of enquiry that the processes and dynamics behind the origins and evolution of the cave are now investigated.

4. Morphogenic reconstitution of Cloggs Cave

Here we investigate how Cloggs Cave changed through time, through morphological features observed both in the cavity and in its external environment, including endokarst formations such as speleothems. We focus in this section on non-human processes; anthropogenic factors that may have contributed to changes in the underground landscape are discussed later (see Section 5 below). We begin with the underground cavities, progressing from the oldest morphogenic events to the most recent. All observations and interpretations relating to the origins and development of the cave (“speleogenesis”) discussed here are plotted on Fig. 14.

4.1. Origins and development of Cloggs Cave

4.1.1. Evidence of a very old phase of limestone weathering

The Upper Passage retains the earliest evidence of the cave's development. Its morphology, unlike that of other cavities in the cave, has resulted entirely from karst dissolution. Of particular interest is the clogging of its terminus with various types of sediment (Fig. 15):

1. A clay formation evident in, and as part of, the limestone matrix. The clay occurs in pockets modelled on the geological dip.
2. A sandy-clay fill rich in quartz and other components foreign to the geology of the Buchan Group (see Section 2 above). This fill is slightly stratified within the duct, a cavity that had already formed. The fill clogs the entire bottom third of the duct, and is also visible in crevices in the ceiling. Its presence in the most elevated hollows of Cloggs Cave indicates that it became entirely clogged up sometime in the past.
3. A thick flowstone covers the sandy-clay fill. The flowstone's laminae formed when water flowed over a soft sediment floor. Speleothems also appear on the walls below the level of the flowstone at the Upper Passage's terminus: they could only have formed after the soft

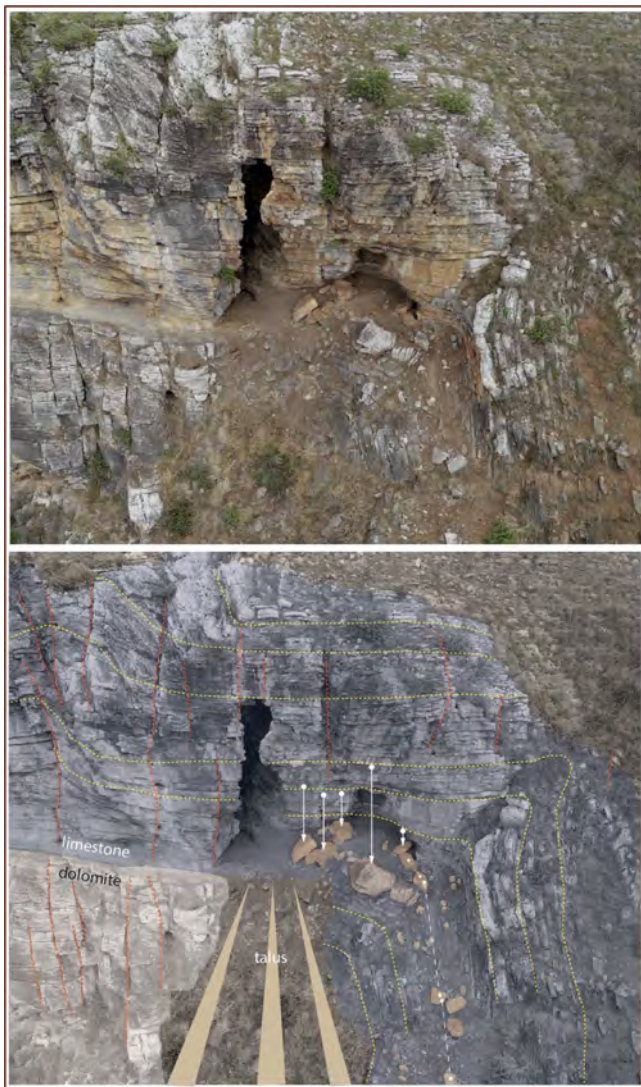


Fig. 8. Entrance to Cloggs Cave. The entrance is located in the contact zone between the folded limestone above and the massive dolomite base below. The fractures associated with the tighter folds of the upper lithology are clearly visible. The Porch is the long vertical cavity to the left, and the Rockshelter is the lower cavity at the right; both are located along fracture planes. Note the sub-vertical folding of the limestone on the right-hand side of the photo (drone photo by Johan Berthet; artwork by Jean-Jacques Delannoy).

sediments below the flowstone had evacuated to form a cavity.

This sequence of events allows us to determine the initial genesis of Cloggs Cave.

The clay formation in the Upper Passage's bedrock relates to an ancient phase of limestone alteration. This phenomenon, known as "phantomization", is characterised by an isovolumetric alteration (i.e., changes that do not alter the volume) of the rock. Here the dissolution of carbonates did not create underground voids, but merely altered the rock (Quinif, 2010; see also Delannoy et al., 2017). This type of alteration occurs in geomorphological contexts of very low gravitational energy, similar to those conducive to the establishment of planation surfaces (see Section 2 above). The chemical alteration of the limestones developed at depth, especially along fracture lines. One of the characteristics of phantomized conduits is their modelling on the network of fractures, and this is the case for the elbow in the Upper Passage. This is why we relate the initial genesis of the Upper Passage to this process of phantomization and to the long and slow erosion process

responsible for the planation surfaces outside; that is, to a time well before the sinking of the regional hydrographic network (here the Buchan River and its tributaries). At Cloggs Cave, pockets of phantomized limestone are also found about half-way along the lower arm of the Upper Passage (Fig. 16B and C).

Following the weathering (phantomization) of the rock along fracture lines deep in the limestone, the sinking of the regional hydrographic network now favored the establishment of a hydraulic gradient and the circulation of groundwater. The areas of altered (softened) rock became conduits for the passing of percolating water, gradually evacuating the softened rock and opening underground conduits such as the Upper Passage. The creation of these voids dates to a post-Miocene phase, sometime after five million years ago. The infiltrating waters brought with them surface-altered sediments and the formations that had been deposited on the planation surfaces (i.e., Oligo-Miocene sandy-gravels; see Section 2 and Fig. 6 above). Their re-deposition into open underground conduits through infiltrating waters contributed to the clogging of the cavities with sandy-clay fills rich in quartz granules and allochthonous materials (i.e., materials transported from elsewhere) ("2" and "3" on Fig. 16B). The nature of the fill in its terminus indicates that the entire Upper Passage cavity was clogged in the process.

However, this blockage was subsequently completely cleared along the Upper Passage, and partially so at its terminus. The trigger for this de-clogging may have been a wetter phase causing greater water-flow, or an accentuation of the gravity gradient caused by the sinking of the external hydrographic network, or both. In either case, the de-clogging slowly progressed over a long period of time whose duration was determined by the efficiency of the waters running through the cavity.

The flowstone ("Flowstone A" in Table 1) began to develop on the fill in the Upper Passage's terminus c. 285,600 ± 4200 years ago² (as determined by a U-series age at the base of the flowstone; see "6" and "7" on Fig. 15; Table 1), indicating that the earlier de-clogging of the top of the Upper Passage had been completed before then. For at least 50,000 years (as determined by the difference between the age of the top and bottom of the flowstone), the Upper Passage was traversed by very low velocity encrusting water flows: the flowstone's laminae of regular growths suggest very slow or stagnant waters. This allows us to conclude that during the growth of the flowstone, the lower half of the Upper Passage was still largely or entirely filled with sediment. The percolating water at the terminus of the Upper Passage was responsible for the induration of its sandy-clay fill. In the non-indurated areas, the fill has since evacuated (the small, decimetric duct at the base of the terminus) (see "8" on Fig. 15).

We can now apply these first stages of cave formation, observed from the Upper Passage, to the entire cave. Although traces of these early stages can no longer be seen in the Upper Chamber, Main Chamber and Gallery, their modelling along the network of fractures, together with the geometry of the cave's terminals – the rapid passage from open cavities to closed fractures – are indications of their forming along a network of phantomized conduits.

4.1.2. The opening of underground cavities by gravitational collapse

Apart from the Upper Passage, the NNW terminus of the Gallery (Fig. 13C) and the Entrance Passage, the other cavities of Cloggs Cave do not have visible morphologies directly linked to the work of dissolution. While solution voids probably existed in the past, they have been completely erased by subsequent rock collapse caused by gravitational processes. This opening up of underground cavities by the

² Throughout this paper, "BP" refers to uncalibrated ¹⁴C ages, "cal BP" to calibrated ¹⁴C ages. All uncalibrated ¹⁴C, and OSL ages, are reported with 1 sigma probability, and all calibrated ¹⁴C ages are reported at 95.4% probability using Calib 7.10 with the IntCal13 curve selection (Reimer et al. 2013; Stuiver et al. 2020). All U-series ages are reported with 2 sigma probability.

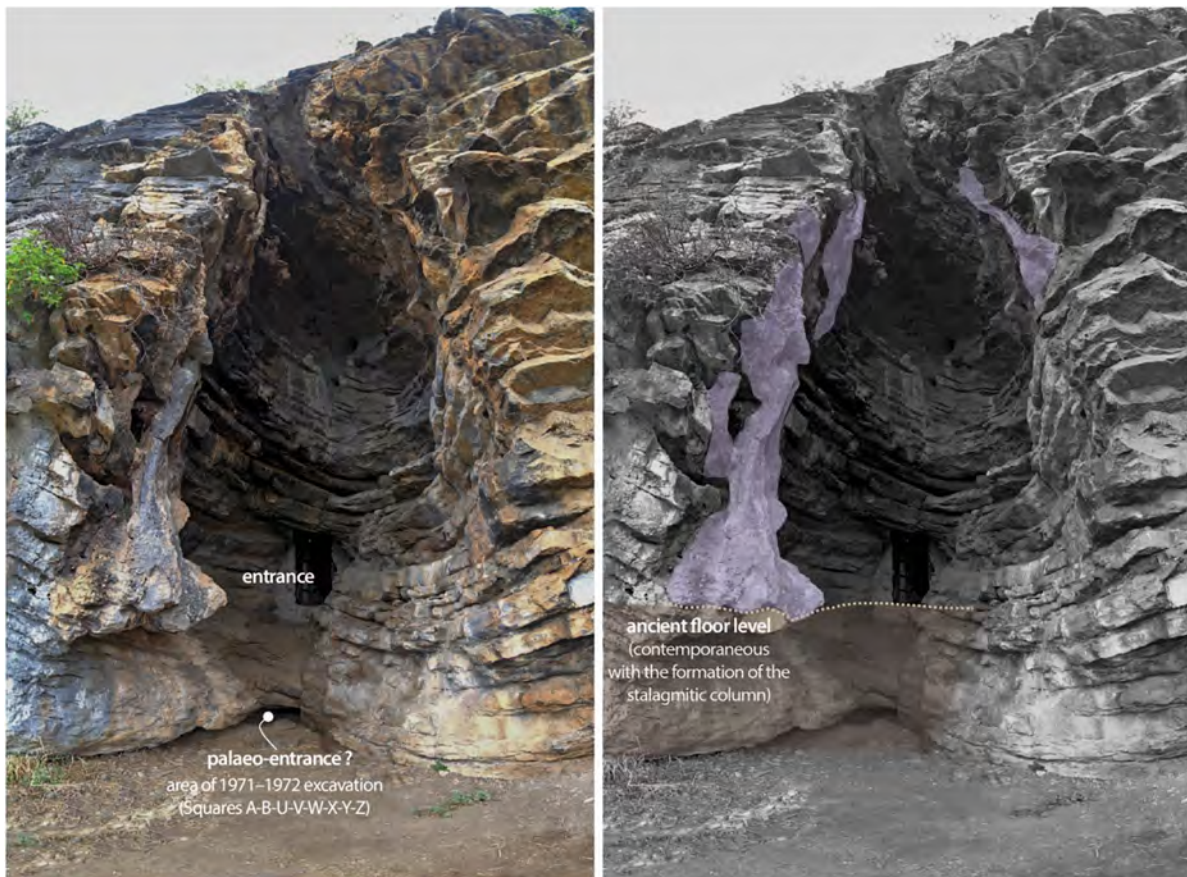


Fig. 9. Cloggs Cave's entrance Porch. The mauve colouring denotes speleothem deposits (photo by Jean-Jacques Delannoy).

successive collapse of sections of walls and ceilings is relatively old, as indicated by the paucity of blocks on the ground. There are, in addition, numerous instructive clues on the extant rock surfaces of the Main Chamber (Fig. 17). The talus from the Upper Chamber down to the bottom of the Main Chamber has few collapsed blocks, both on its surface and at depth, at least in the area revealed by the archaeological excavations downslope (e.g. Squares S, SS, T and TT of Flood (1973a), and P34, P35 and R31 of David et al. (e.g. in press)). This means that the cave had already largely formed before the talus deposit had built up. The presence and orientation of some large blocks in the archaeological excavations remain to be investigated in detail (see Section 5 below).

The current slope of the talus from the northern edge of the Upper Chamber down to the bottom end of the Main Chamber indicates that it has changed over time (Figs. 17 and 18). Today it is steeper than it was in the past. Old surface speleothem flows against the west wall fed flowstone formations at its base ("3" on Fig. 17D and "1" on Fig. 18). These flowstones capped an old surface that was less steep than the current slope. A U-series age on the flowstone ("Flowstone B" in Table 1) indicates that it began to develop $109,800 \pm 12,000$ years ago. Stalactites have also been dated to that time in the Upper Chamber and its Alcove, indicating favorable conditions for speleothem formation c. 110,000 years ago.

The age of this former surface means that the volume and general geometry of the Main Chamber had already long been established by then, and that the floor of the Main Chamber was already filled with a thick deposit emanating from the Upper Chamber. This means that the low point of the Main Chamber and accompanying gradient acted to draw down sediments. This process of subsidence continued thereafter, as evident by the steeper slope of the current floor and the internal structure of the deposit as revealed by the southeastern sections of

excavation Squares S, SS, P34 and P35 (see Fig. 27A). It is interesting to compare this dynamic of subsidence in the Main Chamber with the relative stability of the almost horizontal floor of the Upper Chamber. Apart from the slight compaction of localised subsidence depressions, the level of the Upper Chamber's floor has changed little since c. 110,000 years ago. Between the level of the floor marked by the base of the flowstone dated to $109,800 \pm 12,000$ years ago and currently growing small stalagmites on essentially the same slope, two old generations of speleothems are present, for each of which the base also corresponds approximately to the current floor. This ancient floor level matches those of both the Entrance Passage and the base of the large stalagmitic column in the entry Porch (Figs. 9 and 17D). As the current talus slope has not changed significantly for the past 110,000 years, it was also probably the floor level that connected with the current floor of the Upper Passage.

From this evidence, we can determine that the underground cavities, formed by successive wall and ceiling collapses, were created early in the cave's formation, but after the weathering and evacuation of the rock in the phantomized conduits of the Upper Passage (see below). The evacuation of the weathered rock took place with the establishment of the hydraulic gradient associated with the down-cutting of the Buchan River valley, that only started with the uplift of the relief and the southward withdrawal of the Miocene sea. The sinking of the hydrographic network occurred through the course of the Quaternary (Webb et al., 1992; see Section 2 above).

4.1.3. Development of Cloggs Cave's Porch and its immediate surroundings

As noted above, the entrance Porch of Cloggs Cave is perched above the thalweg of the current Buchan River (Figs. 1, 2 and 7). At least two factors may have come into play in the forming of the entrance:

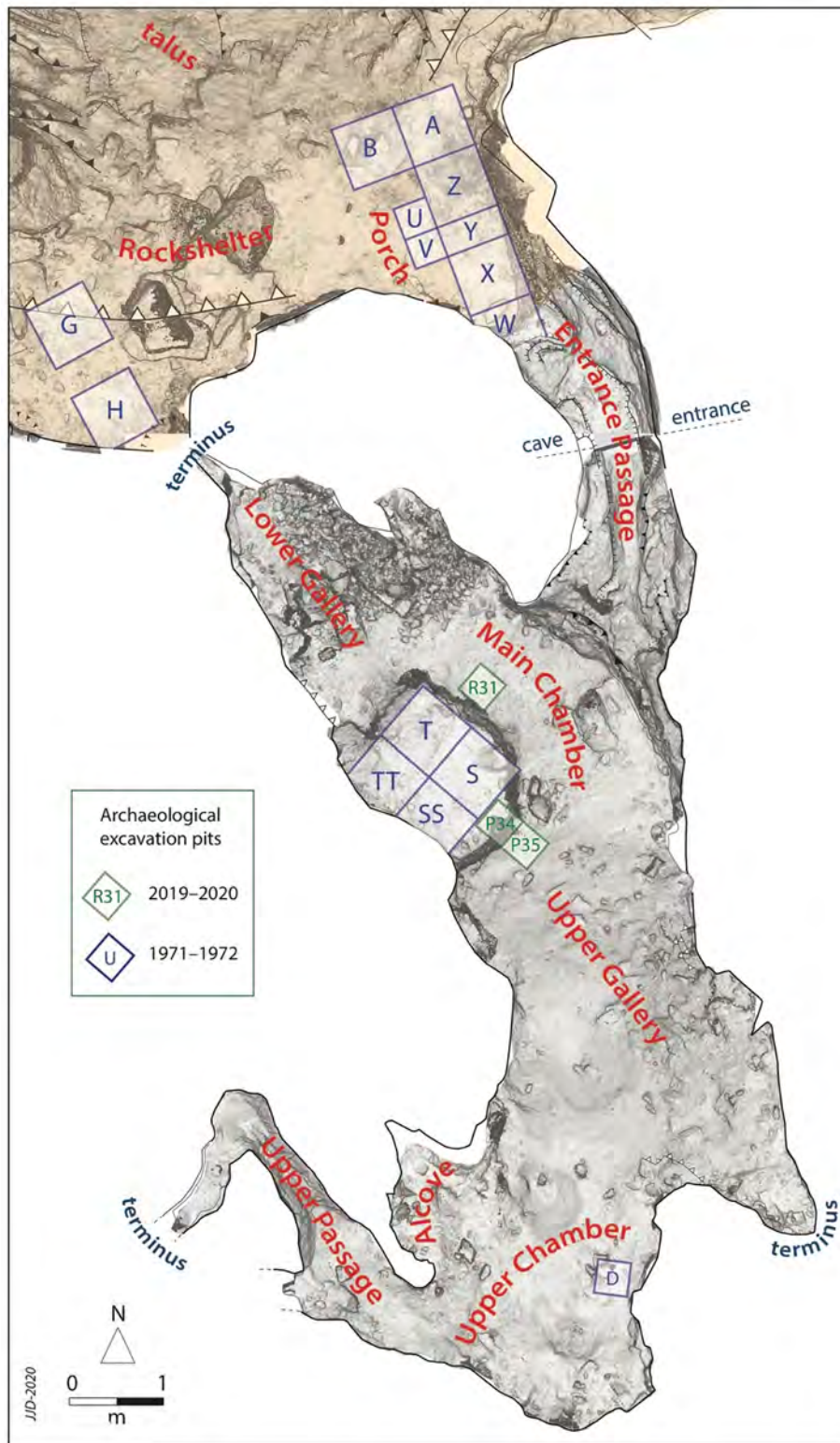


Fig. 10. Plan of Cloggs Cave, from the 3D laser model (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy and Bruno David).

1. The lithological contact between the dark blue limestone (in which the cave developed) and the underlying dolomite (see Section 2 above and Fig. 8) influenced the shaping of the entrance through karst processes. In this scenario, the more compact and slightly less permeable dolomite preferentially retained surface moisture along its contact zone with the overlying limestone, causing undercutting

and phreatic duct formation through weathering of the base of the limestone.

2. An ancient phase of karst weathering, the commencement of which was then controlled by the sinking of the palaeo-Buchan River to lower altitudes (i.e. karst networks developed in step with changing regional river levels). In the nearby caves of Buchan,

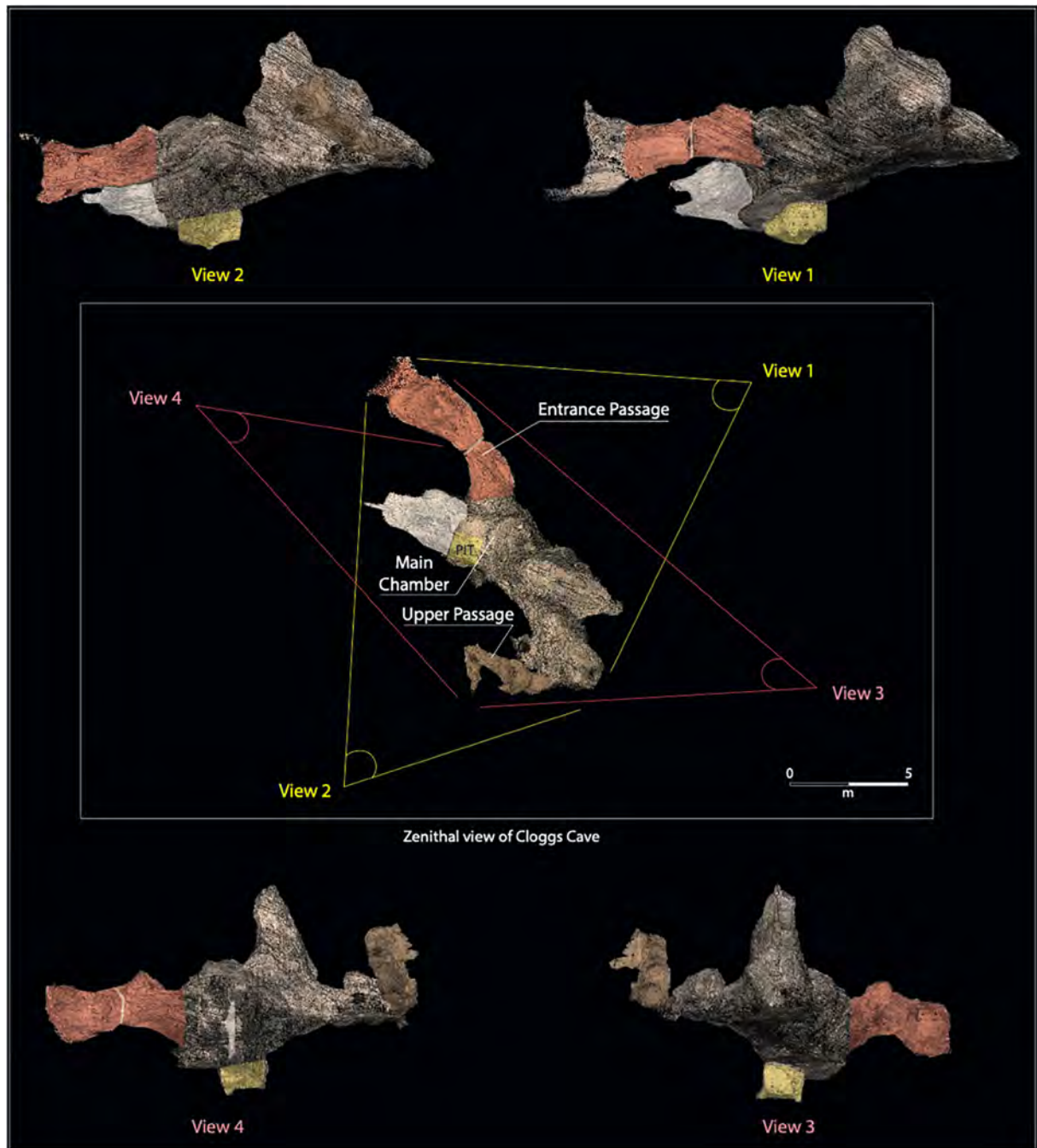


Fig. 11. Three-dimensional views of Cloggs Cave, from a range of angles (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy).

topographically staggered karst networks may relate to different stages of the sinking of the Buchan River, some dating to the second half of the Tertiary (see Section 2 above; Webb et al., 1992).

These two causes, individually or combined, could explain the perched nature of Cloggs Cave and the external extension of its Porch and Rockshelter above the Buchan River floodplain. However, the origin of the Main Chamber's lowest point, which lies deeper than the current Porch and Entrance Passage, remains enigmatic at this stage of investigation (but see below), especially considering that the 1971–1972 archaeological excavations (Flood, 1973a, 1980) were topographically lower than the limestone/dolomite contact zone (Figs. 7 and 8). This low point of the Main Chamber suggests the existence of an underlying network of cavities that would cause subsidence by drawing

the Main Chamber's accumulated sediments down. However, there is no hint of ducts or of an underground network under Cloggs Cave in the dolomite cliff-line exposed just to the east below the entrance Porch, nor in the blue limestone substrate exposed beneath the adjacent Rockshelter, nor in the talus slope below the Porch (Fig. 8). Analysis of the geometry of the talus slope and its constituent blocks would determine the origins of the scree, but these are now largely hidden from view by redeposited sediments, including from the 1971–1972 excavations (thermal and geophysical imagery, not undertaken here, could resolve this issue). Only the largest blocks could be studied, and these have fallen from the upper escarpment and entrance Porch. The angle of the slope onto which the collapsed blocks sit is relatively old. This can be deduced from the following observations:

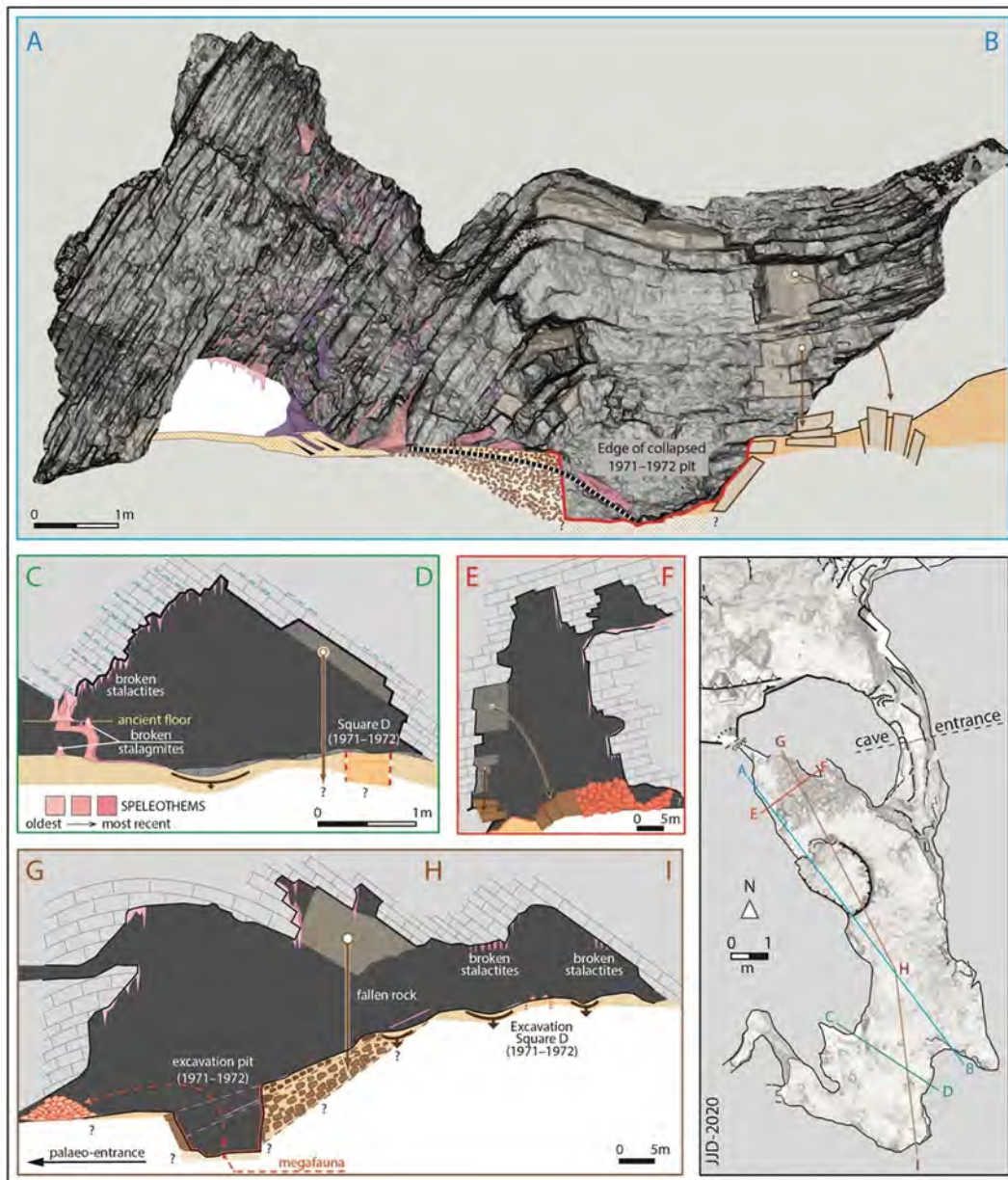


Fig. 12. Synoptic views across key sections of Cloggs Cave, as generated from the 3D model (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy).

1. The junction of the slope to the alluvial terrace at its base is contemporaneous with the convex palaeo-meander that abutted the Cloggs Cave escarpment.
2. The entrance Porch owes most of its morphology to wall and ceiling collapses. Its configuration was at several points “fossilized” by adhering stalagmitic growths (Figs. 9 and 19). The base of the stalagmite dates to $79,900 \pm 6200$ years ago, so the wall on which it is cemented and much of the Porch’s associated morphology must pre-date that age, as do the rocks that fell from the Porch prior to the stalagmite’s growth and that now lie in the talus.

It is important to note that across the regional landscape, karst processes are still active. In the dry valley of the paleo-Tara Creek (see Section 2 above; Figs. 1–4), temporary water flows withdraw and are lost in the underground karst and joint conduits that connect with the thalweg and/or lower terrace of the Buchan River. Recognition of this karst drainage indicates the presence of underground conduits below the level of Cloggs Cave.

4.2. Cloggs Cave’s formation history

Cloggs Cave’s development did not take place in isolation, but rather as part of a broader, interconnected landscape. In the previous pages we have investigated the clues of its genesis and development sector by sector, and process by process. We now assemble this evidence to reconstruct the cave’s evolution through time (Fig. 20). The history of human occupation and use follows in Section 5.

1. The oldest morphogenic events observed are the establishment of planation surfaces across the landscape and the phantomization of the substrate at depth. Both of these processes entailed the alteration of carbonates in a very low gravitational energy environment, and over a very long geological time-frame lasting several tens to hundreds of millions of years. These landscape formation processes continued until the Miocene. Vestiges of alluvial formations previously present on the planation surfaces (Fig. 6) indicate that the hydrographic network was not boxed in, at least in the study region.

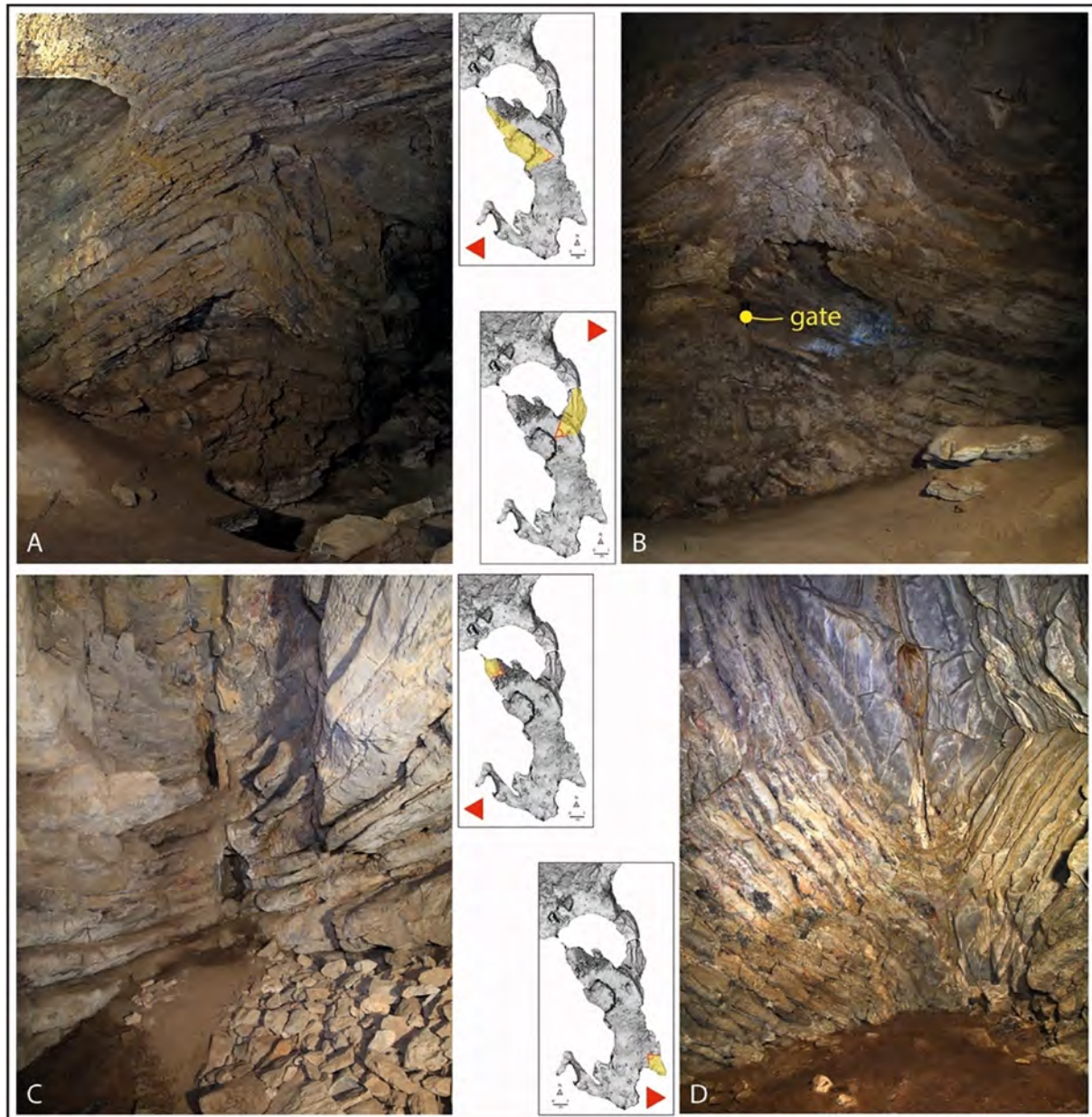


Fig. 13. A: The Main Chamber formed in the arching fold of an anticline. The ceiling is modelled along the arch of the fold. The wall just above the excavation pit contains collapsed niches, signalling the chamber's evolution through gravitational collapse. B: Descent from the Entrance Passage into the Main Chamber. From the access gate (at rear of photo), the Entrance Passage extends along the axis of the anticline fold in which the Main Chamber also formed. Blocks originating from the Entrance Passage lie flat on the Main Chamber floor. Their un-natural position and orientation on the slope, away from their source areas, indicates that they were placed there by people. C: NNW terminus of the Lower Gallery. This part of the cave is modelled along a sub-vertical fracture that cuts through the anticline fold of the Main Chamber. Two small conduits developed through karst dissolution processes along this fracture. The rocks at the bottom right-hand side of the photo were piled up during the 1971–1972 archaeological excavations. D: SSE terminus of the Upper Gallery. Like the rest of the Gallery, it is modelled along a fracture line (visible along the wall and ceiling). The Gallery grew through successive wall and ceiling collapses. The few blocks emerging from the floor testify to the history of these collapses (photos by Jean-Jacques Delannoy).

The Oligo-Miocene formations south of Buchan indicate that the coast was fairly close.

The Miocene formations across the region uplifted to more than 200 m above sea level, with an uplift rate of up to 76 ± 7 m/million years maintained over the past 3.5 million years (Engel et al., in press). The slight deformation of the surfaces indicates that this process was slow. It also resulted in the sinking of the hydrographic network, and in the process the Buchan River was redirected to flow into the Snowy River, rather than directly to the coast as it previously did. Three river terrace levels have been identified along the Buchan River valley (Fig. 1). The oldest (T3) is located c. 30 m

above the current river's thalweg. The second (T2) developed c. 10 m above the current course of the river. The last (T1) is less than 3 m above the current watercourse. These stepped terraces are thinly capped by a maximum 1.5–3 m of alluvium. This thin capping means that they are more the result of phases of sinking of the hydrographic network than of alluvial sedimentation. The ensuing hydrographic network, including the establishment of a more pronounced hydraulic gradient, initiated karstification: the circulation of underground waters began to invade the phantomized rock, evacuating the altered rock to create a network of underground cavities, some of which had surface openings. As each of these

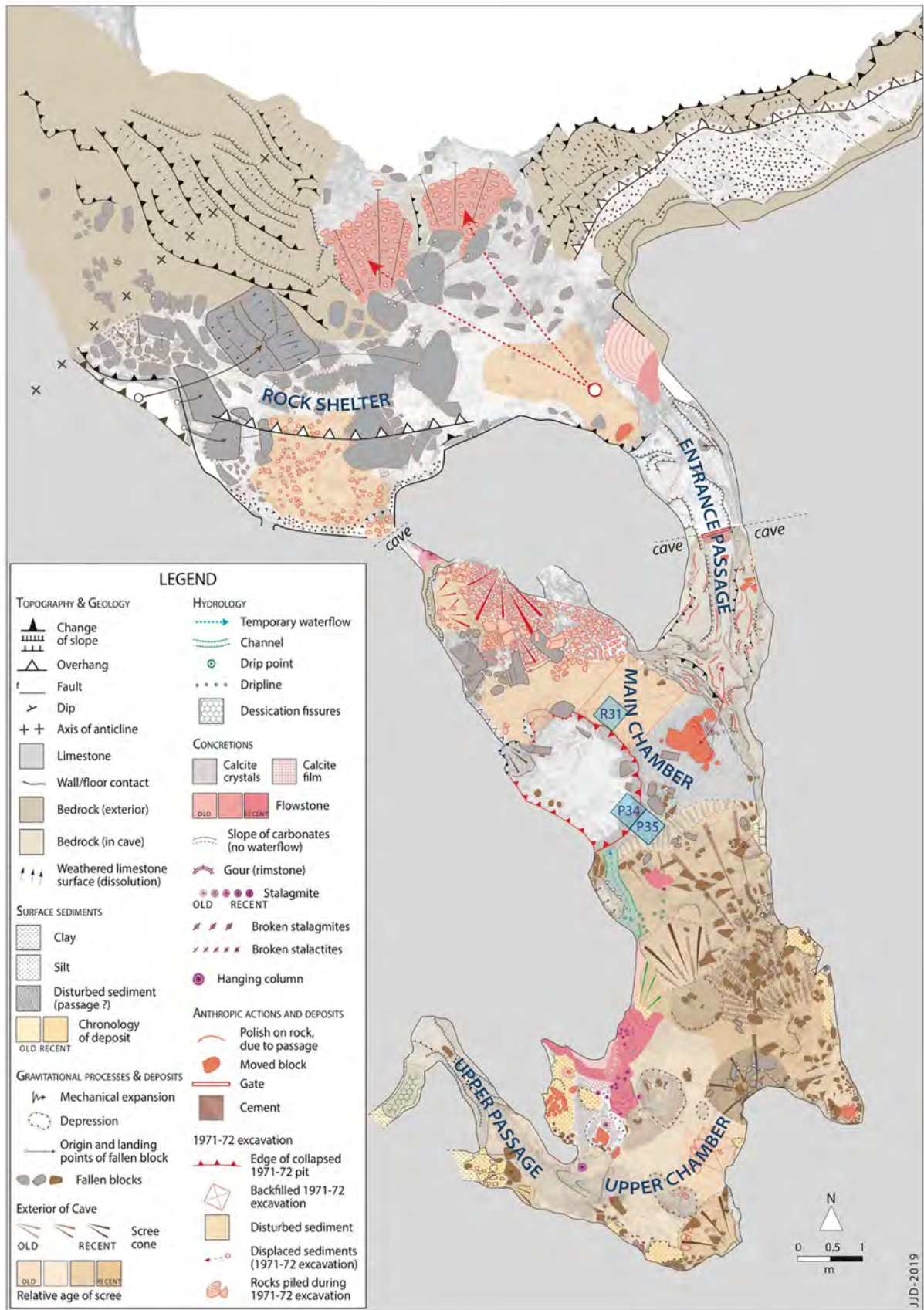


Fig. 14. Archaeomorphological map of Cloggs Cave (cartography by Jean-Jacques Delannoy).

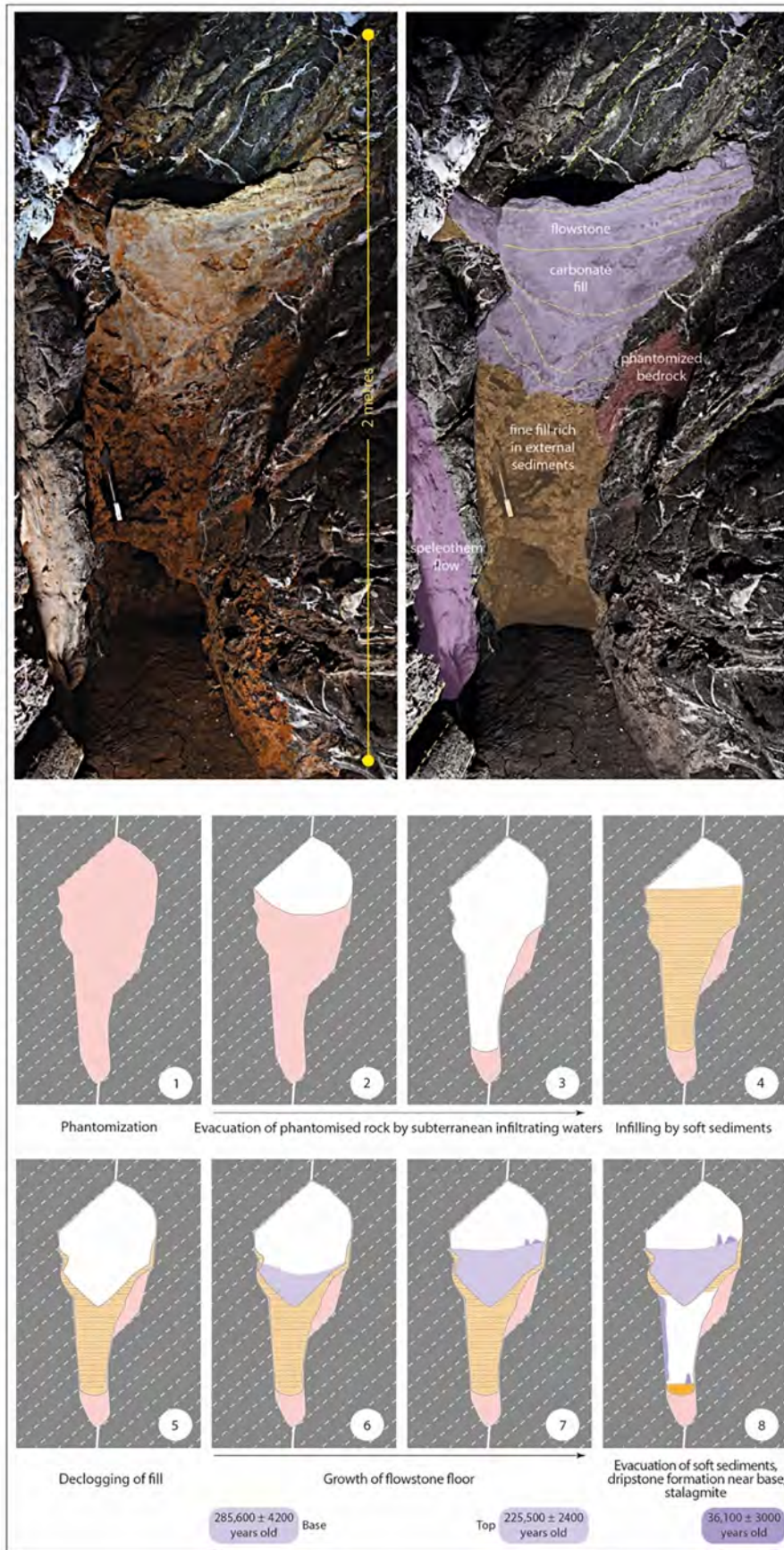


Fig. 15. Diagrammatic interpretation of the geomorphological history of the terminus of the Upper Passage (photo and artwork by Jean-Jacques Delannoy).

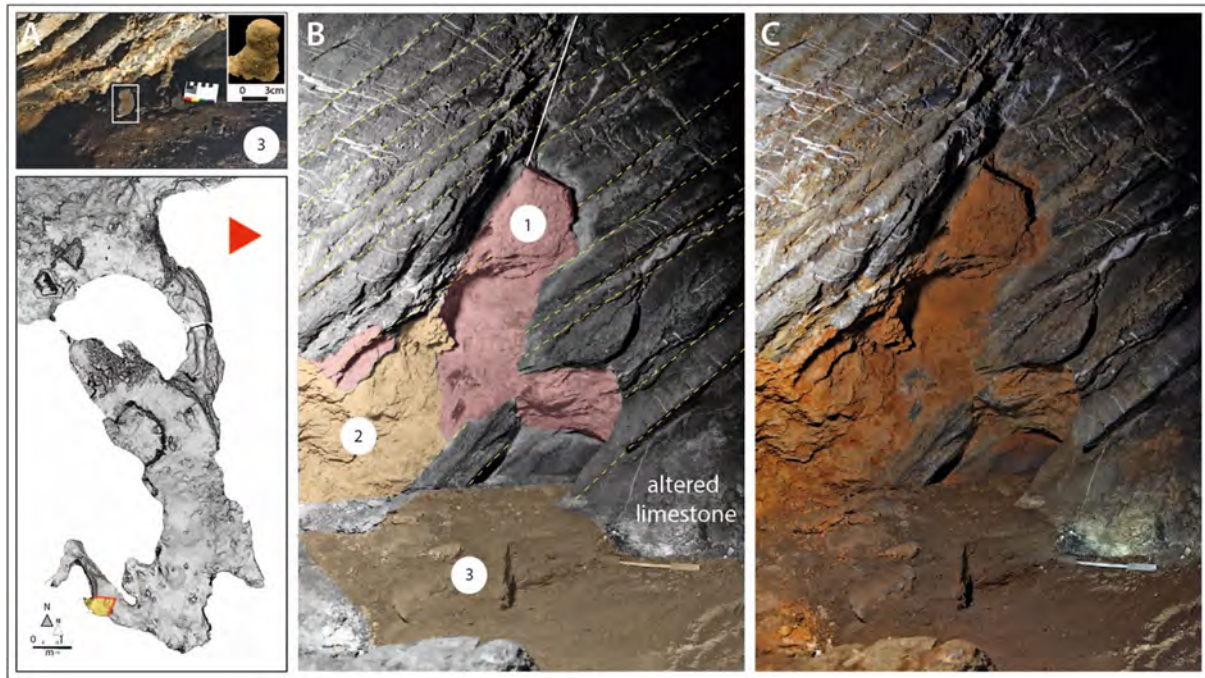


Fig. 16. Speleogenic reconstitution of the infilled pockets of the Upper Passage. 1: “Phantom rock” formation. 2: Sandy-clay fill. 3: Laminated sandy-silts. U-series ages indicate that the small stalagmite (A) began to grow $36,100 \pm 3000$ years ago, and stopped growing $20,100 \pm 1970$ years ago (see Table 1) (photos by Jean-Jacques Delannoy).

phases of water penetration reached a different topographic depth, karst weathering processes and cavity formation became topographically staggered through time (Webb et al., 1992). Because of its perched character above the current thalweg of the Buchan River, the initial hollowing out of Cloggs Cave is contemporaneous with the highest terrace (T3).

2. The weathering and enlargement of the underground voids through karst processes was followed by rock fall from walls and ceilings. It is then that the large cavity of the Gallery including the Main Chamber formed. The paucity of collapsed blocks on the ground and in the underground fill, as revealed by the archaeological excavations, can be attributed to their dissolution by underground flows over long geological time. This also applies to the entrance area, where few of the Porch and Rockshelter’s blocks remain. Those found by Flood in the exterior excavations of 1971–1972 relate to later rock falls, and their volumes are much smaller than those of the Porch and shelter.
3. The steepening of the hydraulic gradient with the sinking of the Buchan River that followed the development of T3 resulted in the installation of a new, deeper karst drainage system, the conduits of which must be located under Cloggs Cave. As a result of the lower drainage, Cloggs Cave’s pre-existing and more elevated ducts became traversed by lower-energy waters carrying altered sediments from the ancient planation surface overhead, causing their progressive clogging (e.g. the sandy-clay fill in the Upper Passage) (Fig. 15). It is likely that all of the existing underground cavities of Cloggs Cave were then filled with incoming sediments before the ducts clogged up. The topographic correspondence between the current floor of the Upper Chamber, the level of the Entrance Passage and the base of the perched stalagmitic column in the entrance Porch may be contemporaneous with this speleogenic stage, but further dating is needed to confirm this.
4. The accentuation of the hydraulic gradient (linked to the T2 terrace) caused deeper voids to develop than previously existed, drawing down through subsidence the Main Chamber’s accumulated sediments. This resulted in the formation of a talus between the Upper Chamber (whose accumulated sediments remained more or less

intact) and the now largely evacuated Main Chamber, remobilizing the clay-silt fill through a combination of down-slope erosion and ongoing drawing down of sediments through the deep Main Chamber voids. Rock fall from the walls and ceilings are a constituent part of this initial talus between the Upper and Main Chambers. It dates back to at least c. 110,000 years ago, the age of the stalagmitic floor that developed on the ancient talus slope.

5. After this first talus, renewed subsidence affected the base of the Main Chamber, evacuating a large part of the fill and probably clearing conduits under the Entrance Passage and Rockshelter.
6. Following this evacuation of sediments, the steeply dipping sediments containing the megafauna remains revealed at the base of the 1971–1972 excavations (Flood, 1980) were deposited c. 52,000 years ago, as determined by single-grain optically stimulated luminescence (OSL) of sedimentary quartz (see below) (David et al., in preparation; Flood, 1980).
7. A new, more localised episode of subsidence created new cavities along the talus slope and remobilized adjacent sediments, including old concretions and rock fall. U-series ages on an in-fallen broken stalagmite deep in a subsidence crater’s fill, and radiocarbon (from here-on, ^{14}C) ages on individual pieces of charcoal from the fill, date this in-filling to 6090 ± 1140 years ago, the age of the tip of the stalagmite (Table 1) (David et al., in press). The angle of the current talus slope from the Upper Chamber to the Main Chamber belongs to this stage. The longevity of the current slope angle means that the voids under the Entrance Passage were then clogged up.
8. After the clogging up of the underground conduits, the talus slope stabilised. Some rock has since fallen onto the floor, mainly from the east wall of the Gallery: the slope of the base of the blocks is parallel to that of the talus slope on or in which they sit.

It was during the last two stages that the cave was visited by people. The evidence of their presence is now explored in Section 5.

5. The Old People at Cloggs Cave: The agency of people

Archaeological excavations undertaken by Flood in 1971–1972 and

Table 1
Details of U-series ages, Cloggs Cave.

Sample ID	Lab number	Mass/g	238 ng/g	230/238A	2SE	234/238A	2SE	Age (Uncorrected) Ka	95% err
Small Stalagmite A (Top)	UME190411-537	0.2000	64	0.3880	0.0030	1.6100	0.0035	29.538	0.267
Small Stalagmite A (Base)	UME190411-611	0.2070	110	0.5695	0.0029	1.5088	0.0028	50.199	0.341
Flowstone A (Top)	UME190411-373	0.1710	536	1.6337	0.0033	1.6719	0.0021	233.954	1.633
Flowstone A (Base)	UME190411-381	0.1820	214	1.5437	0.0048	1.5037	0.0022	291.191	4.001
Flowstone B (Base)	UME190411-524	0.2110	1683	0.7885	0.0048	1.0283	0.0028	156.841	2.378
Alcove Stalactite	UME190411-408	0.4920	553	0.9900	0.0029	1.5077	0.0020	107.572	0.552
Porch Stalagmite Base-1	UMF200320-212	0.0960	400	0.7602	0.0015	1.1922	0.0009	106.576	0.378
Porch Stalagmite Base-2	UMF200320-209	0.1720	758	0.6361	0.0015	1.2025	0.0010	79.959	0.289
Excavated Straw (BSEW)	UME190411-503	0.5810	188	0.1774	0.0010	1.4135	0.0022	14.532	0.094
CC1-Top	UME190411-236	0.3110	116	0.1006	0.0006	1.2875	0.0018	8.842	0.053
CC1-11	UMF200320-352	0.1200	86	0.1865	0.0018	1.2869	0.0026	16.975	0.180
CC1-10	UME190411-255	0.3000	102	0.1253	0.0007	1.3009	0.0018	11.004	0.064
CC1-9	UMF200320-355	0.1740	109	0.2190	0.0012	1.2842	0.0013	20.250	0.123
CC1-8	UME190411-258	0.3620	103	0.1222	0.0007	1.3248	0.0019	10.511	0.061
CC1-7	UME190411-290	0.3140	139	0.1153	0.0006	1.3092	0.0018	10.015	0.054
CC1-6	UMF200320-415	0.1340	179	0.1773	0.0010	1.3281	0.0017	15.536	0.096
CC1-5	UMF200320-418	0.1040	122	0.1176	0.0017	1.3187	0.0014	10.151	0.155
CC1-4	UME190411-298	0.5820	157	0.2902	0.0008	1.3514	0.0017	26.085	0.087
CC1-3	UMF200320-438	0.1010	95	0.1322	0.0017	1.2978	0.0015	11.668	0.157
CC1-2	UMF200320-520	0.2280	139	0.1321	0.0010	1.3288	0.0016	11.371	0.092
CC1-Base	UME190411-372	0.2820	129	0.1203	0.0007	1.3450	0.0020	10.177	0.063
Straw 1	UME190411-441	0.7410	64	0.0039	0.0001	1.3896	0.0020	0.303	0.007
Straw 3	UME190411-419	0.5770	104	0.0763	0.0005	1.3026	0.0019	6.569	0.042
Straw 4	UME190411-389	0.7890	142	0.2089	0.0008	1.3592	0.0018	18.067	0.076
Straw 5	UME190411-436	0.3390	287	0.0131	0.0002	1.3717	0.0019	1.043	0.013
Straw 6	UME190411-444	0.4400	227	0.2922	0.0010	1.4267	0.0019	24.710	0.102
Straw 7	UMF200320-613	0.1750	223	0.2495	0.0011	1.5350	0.0012	19.147	0.093
Straw 8	UMF200320-555	0.1100	92	0.1019	0.0016	1.4092	0.0016	8.156	0.132
Straw 9	UMF200320-342	0.1320	134	0.0144	0.0005	1.4130	0.0020	1.117	0.039
Straw 10B (Lower)	UMF200320-614	0.1610	238	0.1238	0.0010	1.3820	0.0018	10.192	0.087
Straw 10 A (Upper)	UMF200320-307	0.1690	157	0.0307	0.0012	1.4090	0.0016	2.399	0.095

Sample ID	232/238A	2SE	230/232i	2SD	230/232A	Age (Corrected) Ka	95%err	Age (ka Before AD 1950)	± 95%
Small Stalagmite A (Top)	0.067392	0.001348	2.02	0.40	5.8	20.156	1.974	20.10	1.97
Small Stalagmite A (Base)	0.093785	0.001876	2.02	0.40	6.1	36.201	2.990	36.10	3.0
Flowstone A (Top)	0.083804	0.001676	2.02	0.40	19.5	225.544	2.392	225.50	2.4
Flowstone A (Base)	0.051852	0.001037	2.02	0.40	29.8	285.643	4.266	285.60	4.2
Flowstone B (Base)	0.180512	0.003610	2.02	0.40	4.4	109.684	11.962	109.80	12.0
Alcove Stalactite	0.002928	0.000059	2.02	0.40	338.1	107.184	0.569	107.11	0.57
Porch Stalagmite Base-1	0.134021	0.001427	2.02	0.40	5.7	79.891	6.143	79.90	6.2
Porch Stalagmite Base-2	0.196814	0.001561	2.02	0.40	3.2	37.718	10.458	37.70	+9.7/-11.1
Excavated Straw (BSEW)	0.002428	0.000049	2.02	0.40	73.1	14.158	0.116	14.09	0.12
CC1-Top	0.014506	0.000290	2.02	0.40	6.9	6.349	0.259	6.28	0.26
CC1-11	0.060606	0.000619	2.02	0.20	3.1	6.164	1.129	6.09	1.14
CC1-10	0.026881	0.000538	2.02	0.20	4.7	6.381	0.482	6.32	0.48
CC1-9	0.082877	0.001010	2.02	0.20	2.6	5.161	1.631	5.08	1.64
CC1-8	0.023160	0.000463	2.02	0.20	5.3	6.614	0.406	6.55	0.41
CC1-7	0.021002	0.000420	2.02	0.20	5.5	6.450	0.374	6.38	0.37
CC1-6	0.050792	0.000474	2.02	0.20	3.5	6.843	0.901	6.78	0.91
CC1-5	0.018531	0.000319	2.02	0.20	6.3	7.027	0.353	6.96	0.36
CC1-4	0.103935	0.002079	2.02	0.20	2.8	7.924	2.009	7.9	2.0
CC1-3	0.027275	0.000376	2.02	0.20	4.8	6.967	0.508	6.91	0.50

(continued on next page)

Table 1 (continued)

Sample ID	232/238A	2SE	230/232i	2SD	230/232A	Age (Corrected) Ka	95%err	Age (Ka Before AD 1950)	± 95%
CC1-2	0.024584	0.000358	2.02	0.20	5.4	7.246	0.433	7.18	0.43
CC1-Base	0.016522	0.000330	2.02	0.20	7.3	7.453	0.284	7.39	0.29
Straw 1	0.000756	0.000015	2.02	0.40	5.1	0.187	0.025	0.12	0.03
Straw 3	0.007321	0.000146	2.02	0.40	10.4	5.327	0.254	5.26	0.25
Straw 4	0.009323	0.000186	2.02	0.40	22.4	16.563	0.312	16.50	0.32
Straw 5	0.004116	0.000082	2.02	0.40	3.2	0.384	0.133	0.32	0.13
Straw 6	0.009260	0.000185	2.02	0.40	31.6	23.298	0.298	23.23	0.30
Straw 7	0.014809	0.000186	2.02	0.40	16.8	17.041	0.436	16.98	0.43
Straw 8	0.011759	0.000218	2.02	0.40	8.7	6.311	0.392	6.24	0.40
Straw 9	0.003532	0.000063	2.02	0.40	4.1	0.565	0.117	0.50	0.116
Straw 10B (Lower)	0.008285	0.000132	2.02	0.40	14.9	8.874	0.276	8.81	0.27
Straw 10 A (Upper)	0.004142	0.000132	2.02	0.40	7.4	1.751	0.161	1.69	0.161

ongoing research (2019–2020) by David et al. (in press; Stephenson et al., in preparation), including evidence of the anthropic breaking of stalactites (see below), indicate that the cave was first frequented by people by c. 23,000 years ago (with the proviso that unexcavated parts of the cave and eDNA analyses of older excavated sediments (in progress) may still reveal older occupation). Sub-surface archaeological evidence of the Old People has been found both at depth and close to the surface in the Main Chamber, including stone artefacts, in situ hearths and a buried standing stone (e.g. David et al., in press; Flood, 1980).

There are also surficial signs of the Old People in the cave, in addition to those uncovered by the excavations, despite the impacts of limited numbers of recent visitors walking through the cave, and thus disturbing and obscuring the surface evidence in places (including during the 1971–1972 fieldwork). One relatively unscathed area is particularly noteworthy: the small Alcove at the northwestern corner of the Upper Chamber. The Alcove is of low height (0.8 m), and has undoubtedly been protected from recent foot traffic by this limited height and thus awkward reach for passing visitors.

The archaeomorphological mapping (Fig. 21) of the Alcove revealed the following striking elements:

1. It formed through rock collapse in the same way as the rest of the Upper Chamber, Main Chamber and Gallery. The ceiling faithfully follows the geological dip of the rock (Fig. 22), and its southern end is marked by a narrow wall-“pillar” that separates the Alcove from the entrance to the Upper Passage. A number of isolated and clustered blocks lie on or very slightly embedded into the ground.
2. There is a succession of very slight depressions in the floor, aligned in the direction of a small subsidence hollow 40 cm in diameter. A rounded stone has been placed in the subsidence hollow (Fig. 23). Its round morphology is unlike that of any of the collapsed blocks in the cave, and its presence in the hollow is curious: it cannot be associated with either the fill that is exclusively composed of fine sediments, or with wall or ceiling collapses. This round stone is an artefact purposefully brought into the Alcove. It may not have been intentionally positioned at the bottom of the hollow given the latter’s freshness, and may have rolled down from an adjacent placement. Irrespective of its original position, the stone must have been introduced into the Alcove by someone.
3. The same interpretation applies to the eight blocks on the Alcove’s floor (Figs. 21–23). While their individual shapes are consistent with collapsed blocks, their arrangement is not. The adjacent wall and ceiling show no signs of recent collapse. Furthermore, numerous stalactites, some of which date back some 107,110 ± 570 years (Table 1), have formed on the ceiling overhead, reflecting their age and stability. Rather, the blocks were intentionally brought in and arranged in a rough circle and wedged with small rocks around their bases by the Old People. The provenance of these blocks was initially sought within the Alcove, without success. But their size and thickness match those of the lower wall’s rock strata at the eastern edge of the Upper Chamber, just opposite the Alcove some 3.8 m away (Fig. 24). We note the presence of a small scree apron of matching blocks at the base of the wall; this apron is geometrically consistent with the collapse of blocks from adjacent sections of the wall, resulting in a small overhang in the lower parts of the wall, but the fallen blocks are missing from the floor (Fig. 24). This scree area is probably the source of supply for the Alcove’s stone arrangement. Given this intentional displacement, one wonders if the small number of other blocks positioned flat on the ground between the scree apron and the Alcove were also placed there by the Old People (e.g. see blocks on soft sediment floor on Fig. 24). Their morphologies and sizes are similar to those of both the scree apron and of the stone arrangement.
4. Next to the stone arrangement, the ground is covered by a whitish calcite powder that is too fine and homogeneous in texture to have

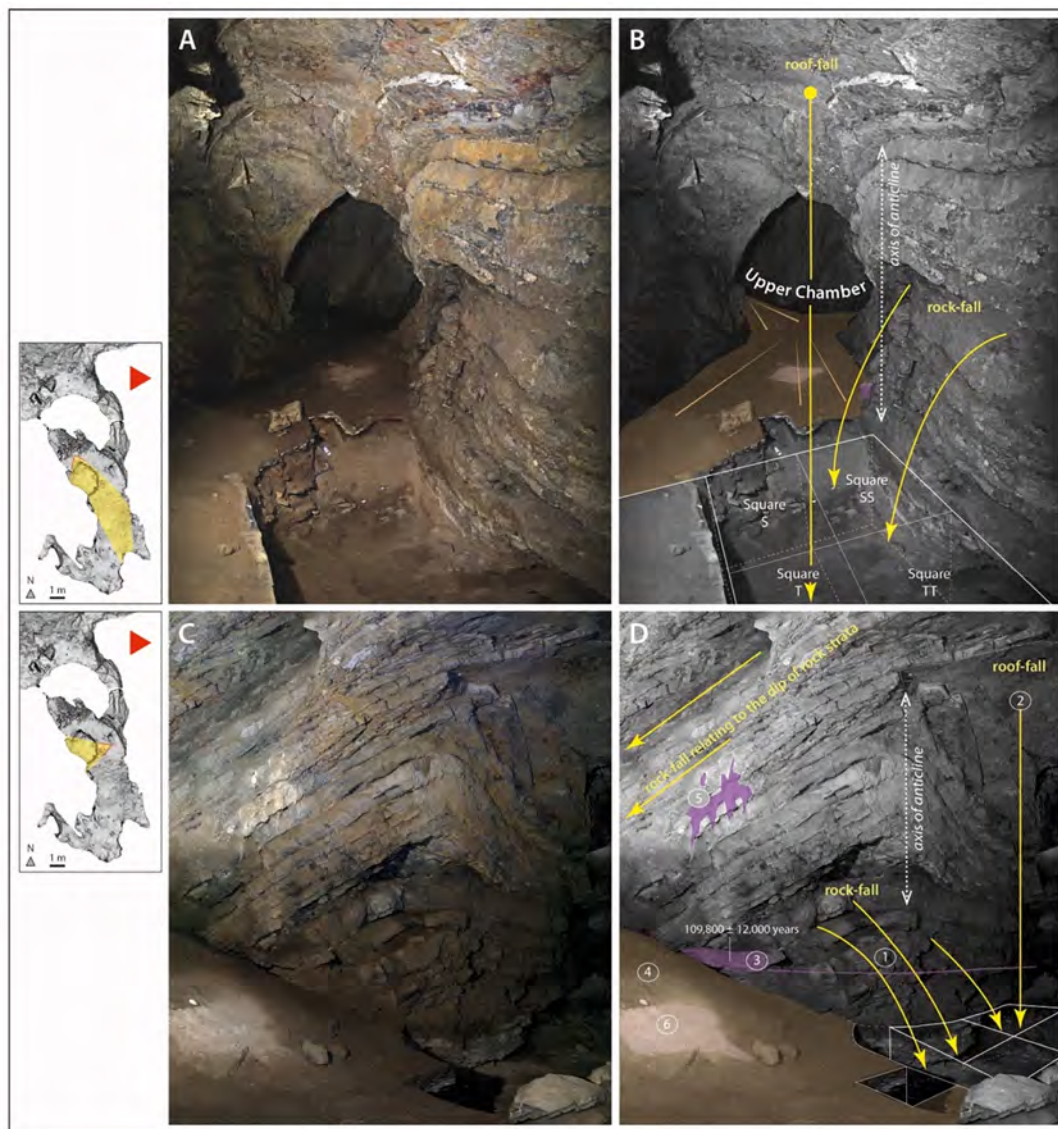


Fig. 17. Speleogenic interpretation of: A & B: The cavity from the Main Chamber to the Upper Chamber. C & D: The cavity in the Main Chamber. The numbers represent some of the cave-formation steps that have left physical marks in the cave. Steps 1 and 2 concern rock-falls responsible for the outward expansion of the cavity. Stage 3 signals the presence of flowstone on an old talus slope. Step 4 represents the current slope, upon which small stalagmites and thin flowstone grow (6). Step 5 represents currently active speleothem flows on the wall (photos by Johan Berthet; artwork by Jean-Jacques Delannoy and Bruno David).

resulted from the unintentional trampling of calcite encrustations. Furthermore, the texture, colour and position of the powdered calcite differs from that of the fine calcite deposits currently or recently growing on the Alcove's floor (Figs. 23 and 24). The powdered calcite near the stone arrangement appears to have been crushed and ground into powder. It may be relevant to note that many stalactites in and near the Alcove have been broken (Fig. 25), and a small grindstone partially covered with crushed calcite-like crystalline mineral (analysis is ongoing) was recovered from the excavations in the Main Chamber 8 m downslope from the Alcove (Stephenson et al., in preparation). While we do not know whether the breaking of stalactites, the crushing of calcite-like mineral on a grindstone, and the crushed calcite powder on the Alcove floor (next to a stone arrangement) are connected, the intentional collection and processing of crystalline calcite within the cave is not in question.

It is difficult to determine with certainty the antiquity of these events. U-series dating on soda straw stalactite re-growths (some of which are

still active) on the broken surfaces of larger stalactites within the Alcove, indicates that the oldest dated re-growths (soda straws) started forming $23,230 \pm 300$ years ago (Fig. 25; Table 1), so the original stalactites must have first been broken before this age. However, this does not mean that this is when the original stalactites were broken, as the start of re-growth is conditioned by the physical pathways and chemistry of infiltrating waters, and therefore by external bio-climatic conditions. This means that not all stalactites will necessarily begin to re-grow at the same time, especially if they are spread apart on the ceiling. Many of the dated soda straws began to grow more recently, so some of the original stalactites could also have been broken more recently (Table 1). The excavated grindstone with crushed calcite-like crystalline residue has been ^{14}C -dated by stratigraphic association to between c. 1600 cal BP and c. 2100 cal BP (for details, see Stephenson et al., in preparation).

The above observations lead us to conclude that the Old People actively engaged with, and modified, Cloggs Cave's spaces and materiality as far back as c. 23,000 years ago, and possibly earlier (e.g. breaking of stalactites, displacement of blocks, construction of a stone circle), including the processing of crystalline calcite. As a result of its

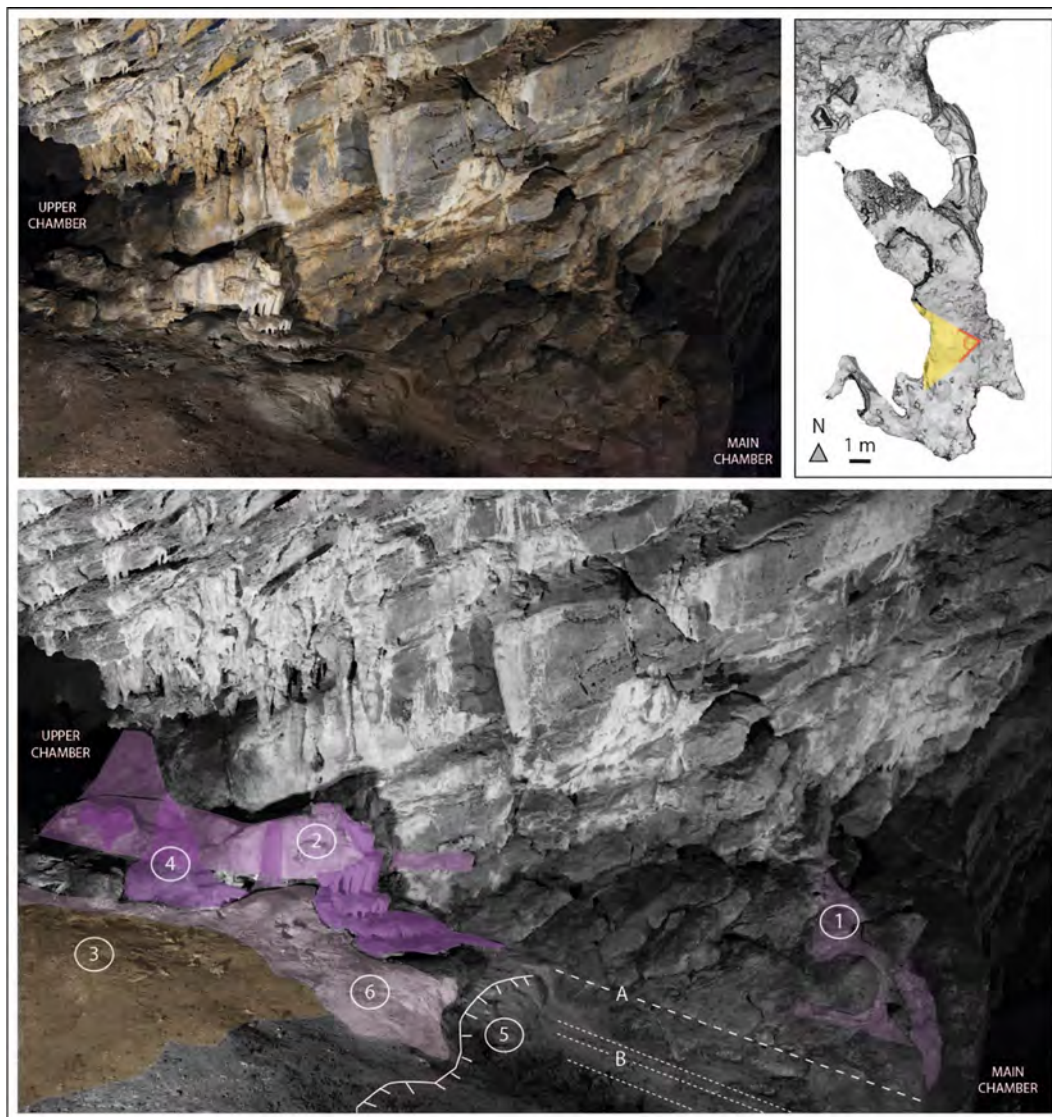


Fig. 18. Speleogenic interpretation of the Upper Gallery's talus as it emanates from the Upper Chamber. The numbers represent some of the cave-formation steps that have left physical marks in the cave. "1" represents an old concretion that formed with the (currently suspended) flowstone below it (see "3" in Fig. 17D). "2" represents more recent generations of slightly suspended concretions above the long-duration and current talus of "3". "4" and "6" represent recent and current concretions. "5" marks a sudden, down-stepping in the angle of the slope between the Upper Chamber and the Upper Gallery. "A" and "B" are thin breccias of the old fill adhering to the wall (photo and artwork by Jean-Jacques Delannoy).

low ceiling height, the small Alcove in the Upper Chamber was a privileged place for the exploitation of calcite: the stalactites are easily accessible, which is not the case for the rest of the cave where the ceiling is unreachable (Upper and Main Chambers, Gallery). The Upper Passage also had stalactites on its low ceiling, but these were not broken, adding further support for the anthropic nature of the breaks in and next to the Alcove: other than people, large animals capable of breaking the stalactites did not enter the cave after the time of the megafauna, and the breakage pattern is unlike that caused by earthquakes. Here the stalactites are broken near their bases and at a regular height, whereas those broken by earthquakes tend to undulate with the seismic waves and to break about midway along their lengths (e.g. Becker et al., 2006; Lacave et al., 2004). The geography of the cave induced a geography of activities by the Old People.

5.1. Evidence of Cloggs Cave's formation history from the archaeological excavations

Cloggs Cave is known to palaeontologists (e.g. Wroe et al., 2013) and archaeologists (e.g. Ossa et al., 1995) through Flood's (e.g. 1973a, 1973b, 1974, 1980) doctoral findings from the early 1970s. Its major points of interest have since then been the insinuation of late-surviving megafaunal remains, thought to date to c. 22,980 ± 2000 BP (ANU-1220), superimposed by artefactual layers beginning ≥ 17,720 ± 840 BP (ANU-1044) (e.g. Flood, 1973b, 1974, 1980: 260). While at Cloggs Cave the megafaunal layers are deeper and older than the oldest stone artefacts, in a broader Australian context the timing of the two indicated a long overlap of at least 25,000 years between megafauna and people, leading to major debates on the nature of megafauna-people interactions across the continent (e.g. Brook et al., 2013; Field et al., 2008; Johnson, 2006; Wroe et al., 2013). Taking these debates into

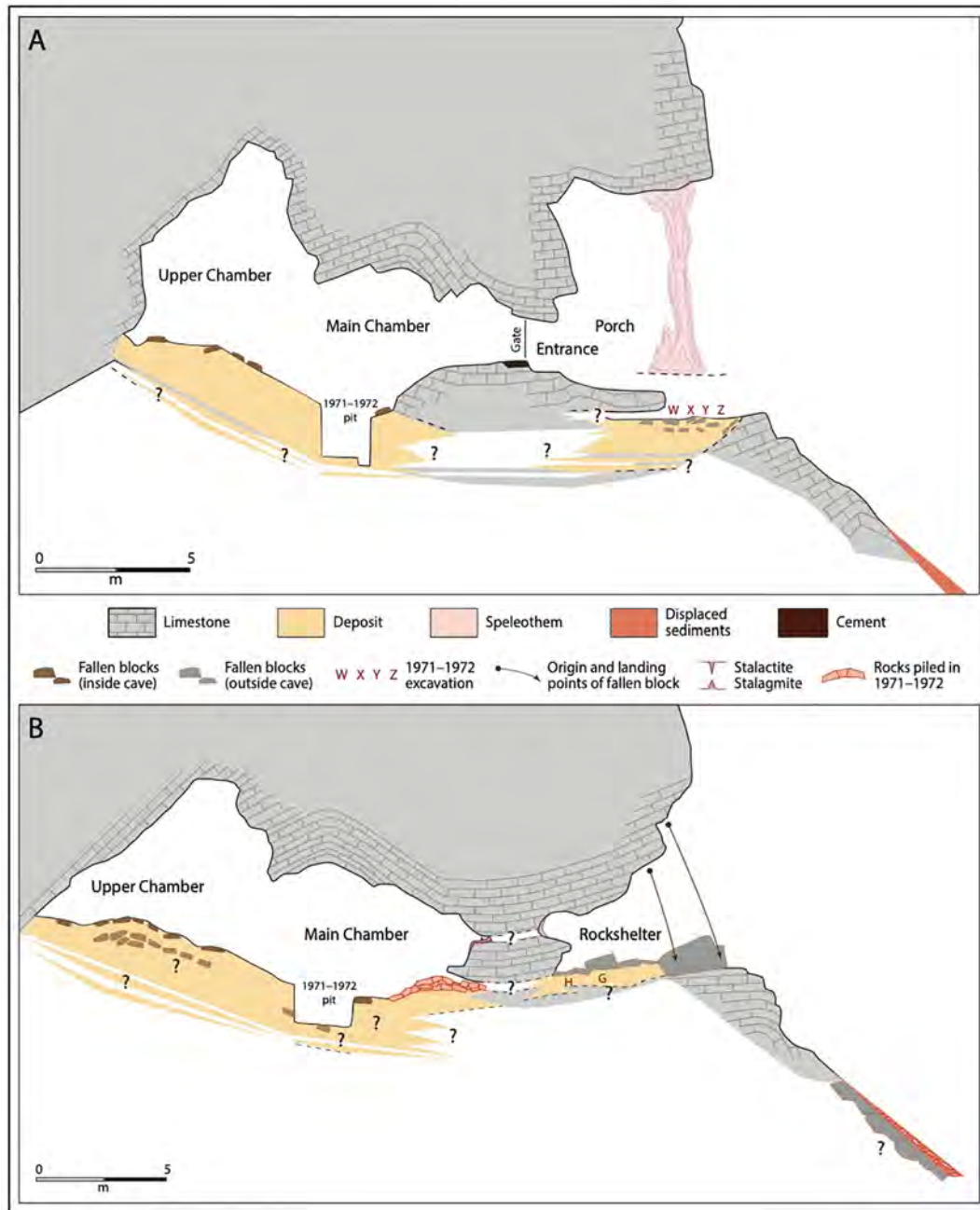


Fig. 19. Sections through Cloggs Cave, based on the 3D laser model. A: Across the cave and entrance Porch. B: SSE-NNW section through the cave and Rockshelter outside (artwork by Jean-Jacques Delannoy).

account, and the influence that Cloggs Cave has had on them, interrogating the original findings with new eyes has become more important than ever. Here we present our results through a combination of new methods, new small-scale excavations geared at better determining the chronostratigraphy of the area of the original excavations, and new AMS ^{14}C , OSL and U-series dating. Full details of the dating methodologies and results are provided in David et al. (in preparation b), with the following sections providing a synthesis of key chronological findings. The new excavations undertaken against the southeastern (Squares P34 and P35) and northeastern (Square R31) walls of the 1971-1972 open pit have enabled both a detailed documentation of the complex stratigraphy (already well recorded by Flood (1973a) and her colleagues), and its clarification (not previously understood) (Figs. 26 and 27).

Understanding the positioning and depositional history of each

layer is fundamental to clarifying: 1) how the palaeontological and archaeological finds were deposited; 2) how they may or may not have been related to deposition; and 3) their antiquity (^{14}C , OSL and U-series ages). Furthermore, a critical question has been the nature and location of the cave's entrance in the past, both to determine how the megafauna entered the cave, and the lie of the land during the time of the Old People: has it always been much like it is today, through a single entrance, the Entrance Passage; or has it changed through time? And if the entrance into the cave was once different, what was its size and shape, where was it, and when did it close up? Investigations on the geological and geomorphological history of the cave (see above), working closely with the archaeological evidence (see below) and using high-resolution 3D laser mapping and the very detailed dating of speleothems and excavated sediments, are all critical to addressing these questions.

The stratigraphy revealed by the southeastern and northeastern

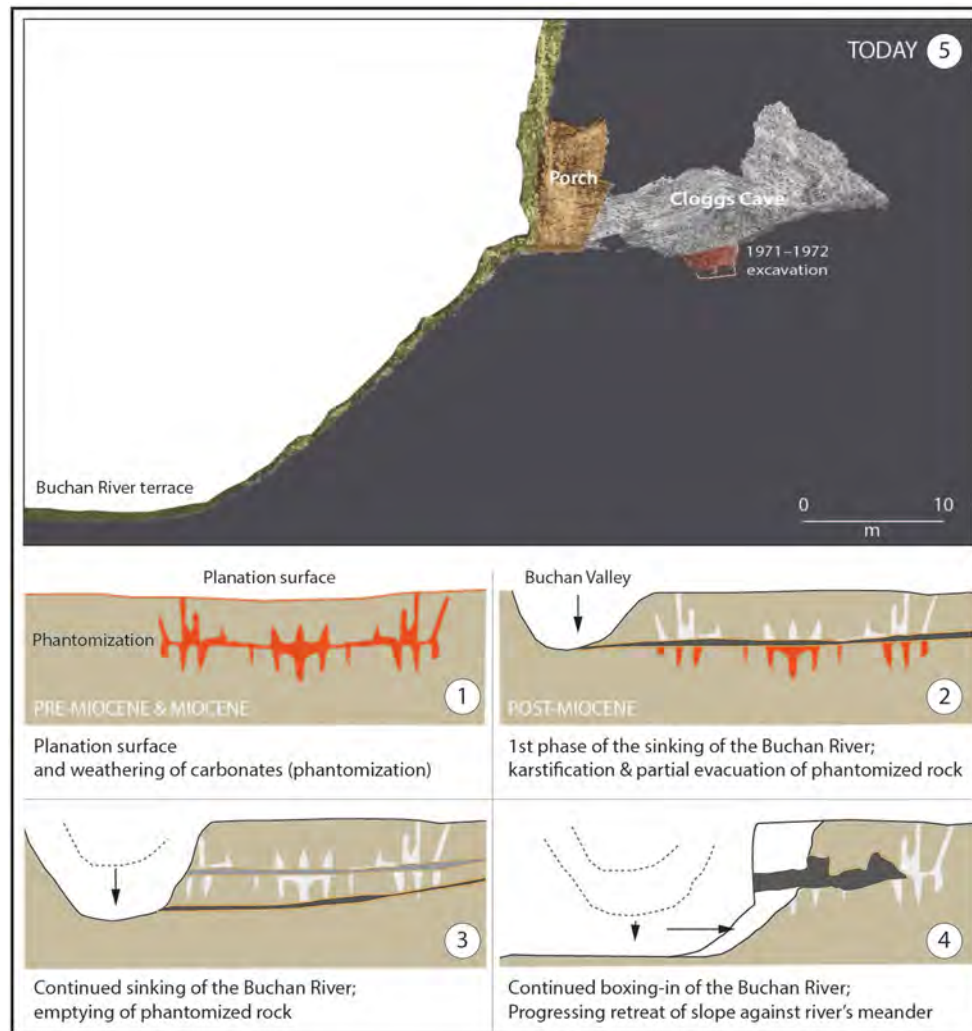


Fig. 20. Synthesis of the major morphogenic stages, based of surface and subterranean geomorphological indicators (artwork by Jean-Jacques Delannoy).

walls of the 1971–1972 and 2019–2020 archaeological excavations, along with the orientation and composition of the layers, have enabled us to differentiate 10 Geomorphological Phases (GPs) for the Main Chamber's deposits (Fig. 28). These Geomorphological Phases (GP) were identified to distinguish the formation processes from Flood's (1980) and David et al.'s (in press) sediment layers. The oldest phase, GP1, is the deepest and can be seen at the base of the excavations. The most recent, GP10, corresponds with the uppermost stratigraphic level up to the present ground surface.

The Geomorphological Phases enable further details of the cave's evolution to be determined (Figs. 29 and 30). Three major sets of Geomorphological Phases (represented by the yellow, red and blue GP colour codes on Fig. 28), each altering the shape of the floor, can be identified:

1. A period of slow sedimentation of fine-grained sediments in a low-energy depositional environment (GP1–GP6). Based largely on the animal bones from Squares P34–P35 (the 2019 excavation) and Square S (the only part of the 1971–1972 excavation to have been analysed in detail), the oldest visible deposit (corresponding with GP1) is that which contains the megafaunal remains (*Sthenurus orientalis* (now recognised as *Simosthenurus occidentalis*; see Prideaux 2004), *Macropus titan*) as well as those of almost all the extant medium-size to large fauna (*Macropus* spp., *Vombatus ursinus*). A few bones or teeth of the extinct Tasmanian tiger (*Thylacinus* sp.), regionally extinct Tasmanian devil (*Sarcophilus* sp.), and extant swamp wallaby

(*Wallabia bicolor*) also occur either exclusively in the megafauna layers or from deep, mixed assemblages whose excavation "spits" had cut across the stratigraphic interface with the megafauna layers. Fauna whose remains are more frequent in the cave deposit, including its upper levels, such as the cave-inhabiting rock wallaby (*Petrogale penincillata*), brushtail possum (*Trichosurus vulpecula*, whose coprolites are extremely abundant through most of the excavated deposit), and many other small fauna, could easily have entered the cave from the current entrance, either as live animals or through predators and scavengers (Hope, 1973; the authors, unpublished data). The OSL ages, and the ^{14}C ages from the upper parts of the megafaunal layers, indicate that GP1 began sometime before $51,830 \pm 5510$ and continued to $46,930 \pm 4150$ years ago (OSL ages).

GP1's soft sediments are well stratified and slope steeply down towards the north. A secondary slope towards the southwest is also apparent on the southeastern face of Flood's excavation pit. This double-sided slope suggests that as GP1's thin layers of parallel-sided fine sediments built up, they were also being carried down the steep slopes towards their exit point out of the cave: the low point towards which the sediments are inclined signals a conduit to a lower cavity and/or to an underlying palaeo-exit point. Although we cannot determine precisely when the steep down-slope erosion of sediments took place, it must have been sometime after 110,000 years ago, given that they did so as exposed surface deposits, and that flowstone had sealed a higher talus slope c.

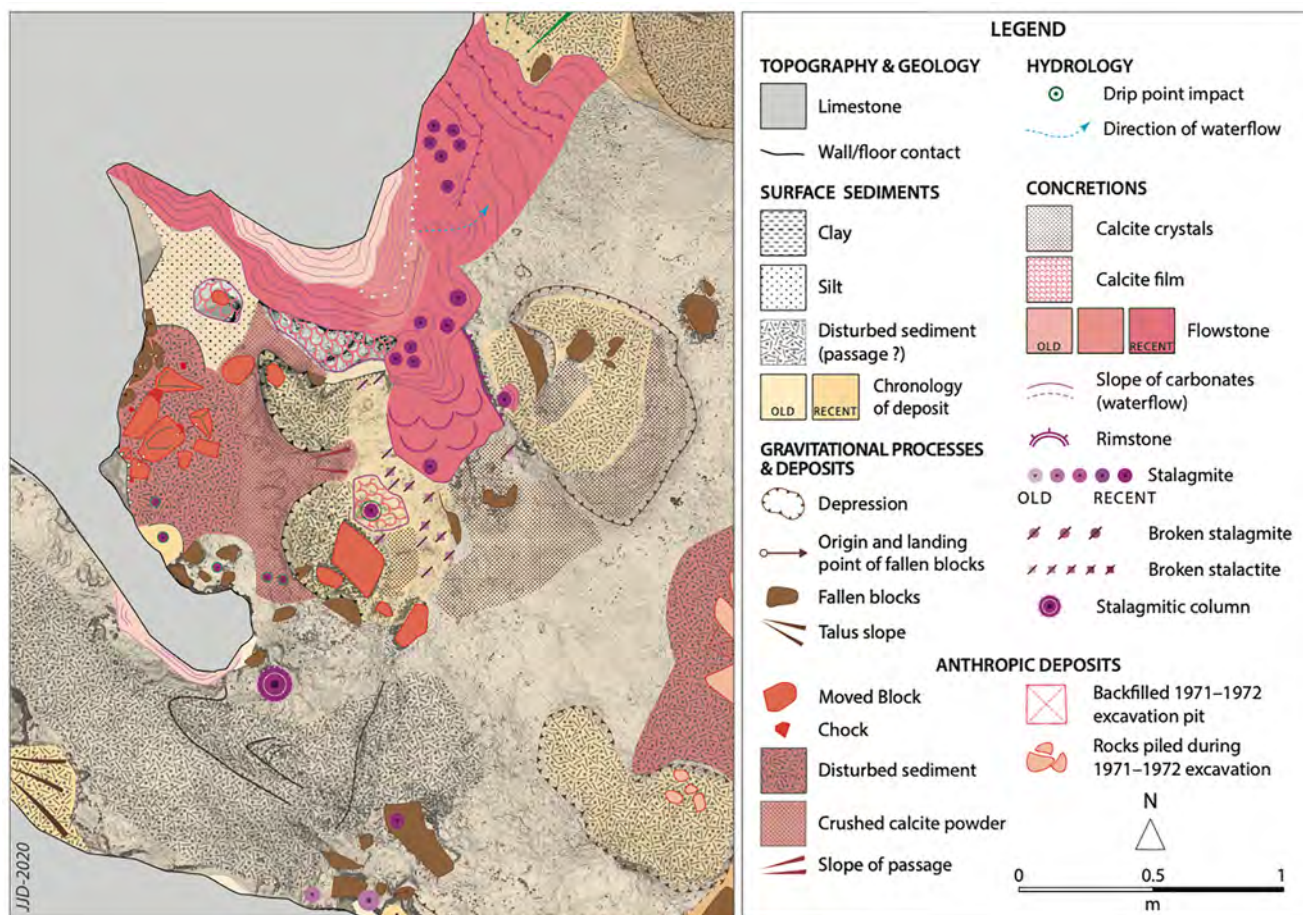


Fig. 21. Archaeomorphological map of the Alcove at the northwestern corner of the Upper Chamber (cartography by Jean-Jacques Delannoy).

110,000 years ago (see Section 4 above; Fig. 17). Taking into account the height and slope of this ancient floor, the deeper GP1 sediments could only have been carried down their steeply inclined slope after the capping flowstone had already formed (and after the flowstone’s underlying deposit had already evacuated), i.e. after 110,000 years ago (Fig. 30).

The texture and bedding of GP1’s fine sediments indicate that they were deposited in a very low-energy, humid environment. Sedimentation was slow, in the order of 1 cm/100 years (Fig. 29).

This slow deposition under low-energy conditions continued through 1) a gradual attenuation of the dip of sediment layers (possibly caused by a clogging and/or lower efficiency of sediment evacuation), and 2) the accumulation of numerous limestone blocks from roof-fall, with their bases parallel to the slope of their containing layers (GP2). The thickness of the blocks indicates that a maximum of two rock strata fell from the ceiling.

From GP3 to GP6, beginning c. 45,000 cal BP until c. 6000 cal BP, sedimentation continued with the increased and more regular supply of fine elements interspersed by occasional ceiling and wall collapses, as indicated by the slightly faster rate of sedimentation of 1 cm/400 years (Fig. 29). We note that while layers continue to dip, their inclination diminished as sedimentation progressed. This accumulation of sediments (gradual infilling of the cave), accompanied by the attenuation of layer angles, indicates that sediments now ceased to be evacuated. Signs of people in the form of stone artefacts first appear in the deposits between 19,330–19,730 cal BP (17,002 ± 53 BP, Wk-51058) and 20,590–23,530 cal BP (20,145 ± 64, Wk-51060) in XU37 of Square R31, midway through this long period’s deposits (at the start of GP5).

2. A catastrophic event: deep floor collapse and rapid lateral infilling

(GP7–GP8). After c. 39,000 years of fine sediment accumulation in a low-energy environment during the previous phases, between GP6 and GP7 Cloggs Cave experienced a rapid, “catastrophic” event that profoundly changed the Main Chamber’s floor. A sudden collapse of the floor along the southwestern side of the area of the 1971–1972 excavation pit created a deep crater that cut through the layers of the previous phases (GP1–GP6). Its localized character (two-thirds of the southeastern wall of Squares S and SS, possibly also parts of Squares T and TT – this information is not available from the 1971–1972 excavation report – and all of Squares P34 and P35) indicates a sudden, very high energy event related to a partial re-opening of the cave’s evacuation points (see below). This collapse carried with it all of the GP1–GP6 sediments that had previously accumulated in the zone of collapse, along with adjacent material cascading in from upslope. The composition and structure of the mixed deposit that subsequently filled the subsidence crater – fine sediments and blocks – suggests a high-energy infilling from the steep higher slope and a significant supply of water.

For heuristic purposes, in Figs. 29 and 30 we have distinguished the creation of the subsidence crater (“between GP6 & GP7”) from its rapid infilling (“GP7”), although in practice the two occurred concomitantly. The northern side of the infilled crater is marked on the southeastern wall of the 1971–1972 excavation pit by a sub-vertical disconformity that separates the transected well-stratified GP1–GP6 sediments to the north and the crater’s more chaotic GP7 fill to the south (Fig. 28). The GP7 fill has now been extensively dated, with the 29 AMS ¹⁴C, six OSL and 13 U-series ages spanning the entire c. 1.7 m depth of Squares P34–P35’s infilled crater deposit (Fig. 27B). The chronostratigraphically indistinguishable and mixed ages are characteristic of a sudden infilling event. The transection of GP6’s



Fig. 22. The Alcove, featuring traces of the Old People's activities. The numbers represent physical traces of the Alcove's development, in chronological order from oldest to most recent. 1: Ancient stalactites, some of which were broken by people (red lines). 2: Ancient flowstone. 3: Concretion that seals the Alcove and Upper Chamber's soft sediment floor. 4: Currently growing concretion. 5: Thin film of calcite (start of flowstone on floor) (photos and artwork by Jean-Jacques Delannoy).

layers by GP7 indicates that the catastrophic collapse and concomitant infilling of the crater took place after 6090 ± 1140 years ago (as determined by the age of the in-fallen stalagmite deep in the fill) but before c. 6000 cal BP (as determined by the age of the base of the stratified sediments that cap the fill); this is consistent with the total absence of younger dates in the fill. The deglugging of underground cavities that caused the rapid collapse of the crater thus took place during the wettest period of the Early Holocene.

In Australia, following increased aridity at the Pleistocene–Holocene boundary, the period spanning c.9000 to 5000 years ago is frequently documented as recording a relatively rapid change from arid to humid conditions with increases in climatic instability and effective precipitation (Quigley et al., 2010; Xia et al., 2001). Multiple Australia-wide records indicate an abrupt transition into much wetter and warmer conditions associated with the Middle Holocene “climatic optimum”, centred at c. 7000 years ago (Gingele et al., 2007; Quigley et al., 2010; Stanley and De Deckker, 2002; Xia et al., 2001) and potentially related to peak sea levels and modern-day temperatures by 8000 years ago (Lewis et al., 2013; Reeves et al., 2013). Southeastern Australia also records a warmer, wetter and more homogenous climate than at present during the Early to Middle Holocene (Gouramanis et al., 2013; D’Costa et al., 1989; McCarthy and Head, 2001; McCarthy et al., 1996) in paleoclimatic archives that include speleothems collected at Royal Cave in Buchan, 5 km west of Cloggs Cave (Green et al., 2013).

Following the collapse and rapid infilling during this peak wet phase, sedimentation of what was then a shallow depression continued more slowly, as indicated by the less chaotic structure of the upper fill (GP8). Here the GP8 deposits accumulated in a localized depression, as indicated by their failure to spread more widely. The OSL and ^{14}C ages from GP8 (SU3A) have generally good chronostratigraphic resolution, indicating this phase took place between c. 6000 cal BP and c. 4400 cal BP (Fig. 27B). This upper part of the now-infilled crater lies in angular disconformity with the GP6 layers

to the north in excavation Square S (Fig. 28).

3. A new phase of low-energy sedimentation and increased human presence (GP9–GP10). GP9 sediments continued to fill the top of what was then a low depression until it became flush with the surrounding sediments, and then continued to cap the entire Main Chamber's floor (including the GP6 and GP8 deposits). It is probably at this time that the Porch's current shallow opening under the Entrance Passage became sealed from the cave by accumulating surface sediments (see “GP9” on Fig. 30). The previous underpass had probably remained too shallow for use as an entrance passage into the cave by animals since c. 47,000 years ago, as there are no signs of natural deaths of medium-sized to large animals in the excavated deposits since then.

The excavations have revealed much archaeological evidence of human activity during GP9 (beginning c. 4400 cal BP), including the repeated building of hearths across all excavation squares (e.g. David et al., in press; Flood, 1980) and a standing stone in Square P35 (David et al., in press) dating to between 2100 cal BP and 1600 cal BP. We also associate with this phase the removal of two large blocks from the floor of the Entrance Passage (where their extraction footprints can be seen) to the floor of the Main Chamber (Fig. 31). These two blocks could not have landed in their current positions by themselves; they must have been repositioned by people, at the point of jump-down into the cave from the Entrance Passage.

When the Old People repeatedly returned to Cloggs Cave to make the fireplaces and standing stone, c. 2100–1600 cal BP, the cave would have looked much like it does today. Sedimentation increased markedly to 1 cm/20 years and became finely stratified as a result of the fires built by people. Minor wall collapses caused a few scattered blocks to accumulate on the ground, notably along the eastern edge of the Gallery; such minor falls continue today (GP10). Currently, the main agents of change in the cave are people, in particular along the talus

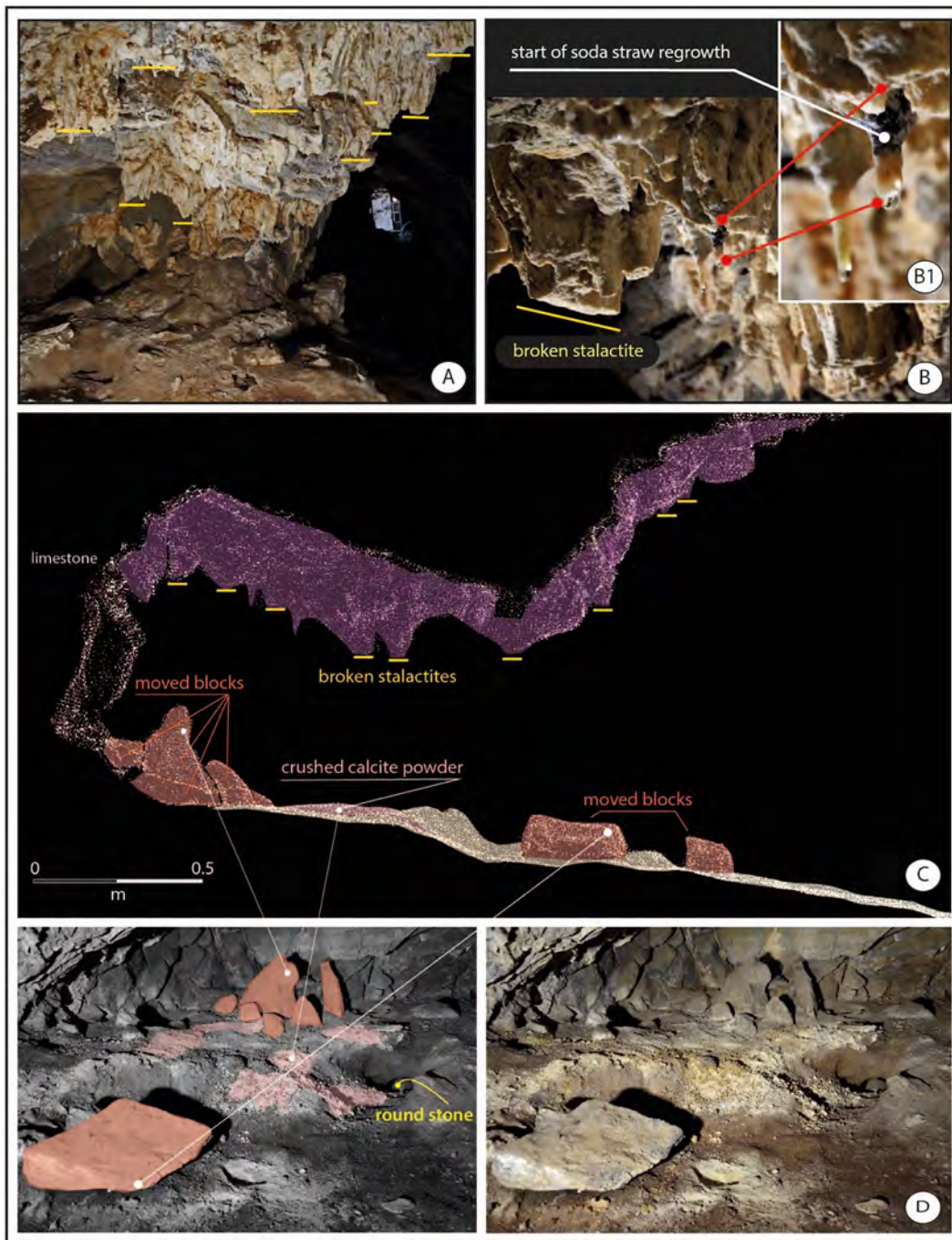


Fig. 23. Section across the Alcove at the northwestern corner of the Upper Chamber, showing details of the stone arrangement and other placed blocks, calcite powder on the floor, and round stone artefact (3D acquisition by Johan Berthet; photos and artwork by Jean-Jacques Delannoy).

slope that rises from the Main Chamber to the Upper Chamber, where blocks have clearly been recently moved and fine sediments disturbed.

We have already noted the presence of a talus slope below Cloggs Cave’s entrance Porch (see Section 3 above; Fig. 8). While some of its surficial sediments came from the sieve refuse of the 1971–1972 excavations, most of the blocks came from the retreat of the escarpment, including the Porch and Rockshelter as voids that weakened the mechanical cohesion of the rock. This is a classic geological phenomenon that has often been shown to have contributed to the closure of cave entrances, such as at Chauvet Cave in France (Delannoy et al., 2010; Sadier et al., 2012). At Cloggs Cave the mass of collapsed blocks in the talus slope that fronts the Porch is poorly visible. The deposit is, however, inset in the bedrock that outcrops on either side (Fig. 8). This is

precisely where one would expect the talus apron to bulge out, if the bedrock had been continuous underneath. This anomalous geometry indicates a depressed sub-surface bedrock, as one would expect of an ancient opening. This is consistent with the vertical extension of the current Porch’s wide opening downwards, both along the long fracture line and along the axis of the narrow opening that can today be seen beneath the start of the Entrance Passage. The presence of an ancient entrance below the current Porch (and Rockshelter?) would also explain the whereabouts of the missing blocks from the collapsed entrance Porch and its overlying escarpment. This likely scenario nevertheless awaits confirmation from sub-surface investigations. Given the cave Gallery’s c. 110,000 year-old floor level (as marked by remnant flow-stone), and the catastrophic collapse of thick sediment deposits on at

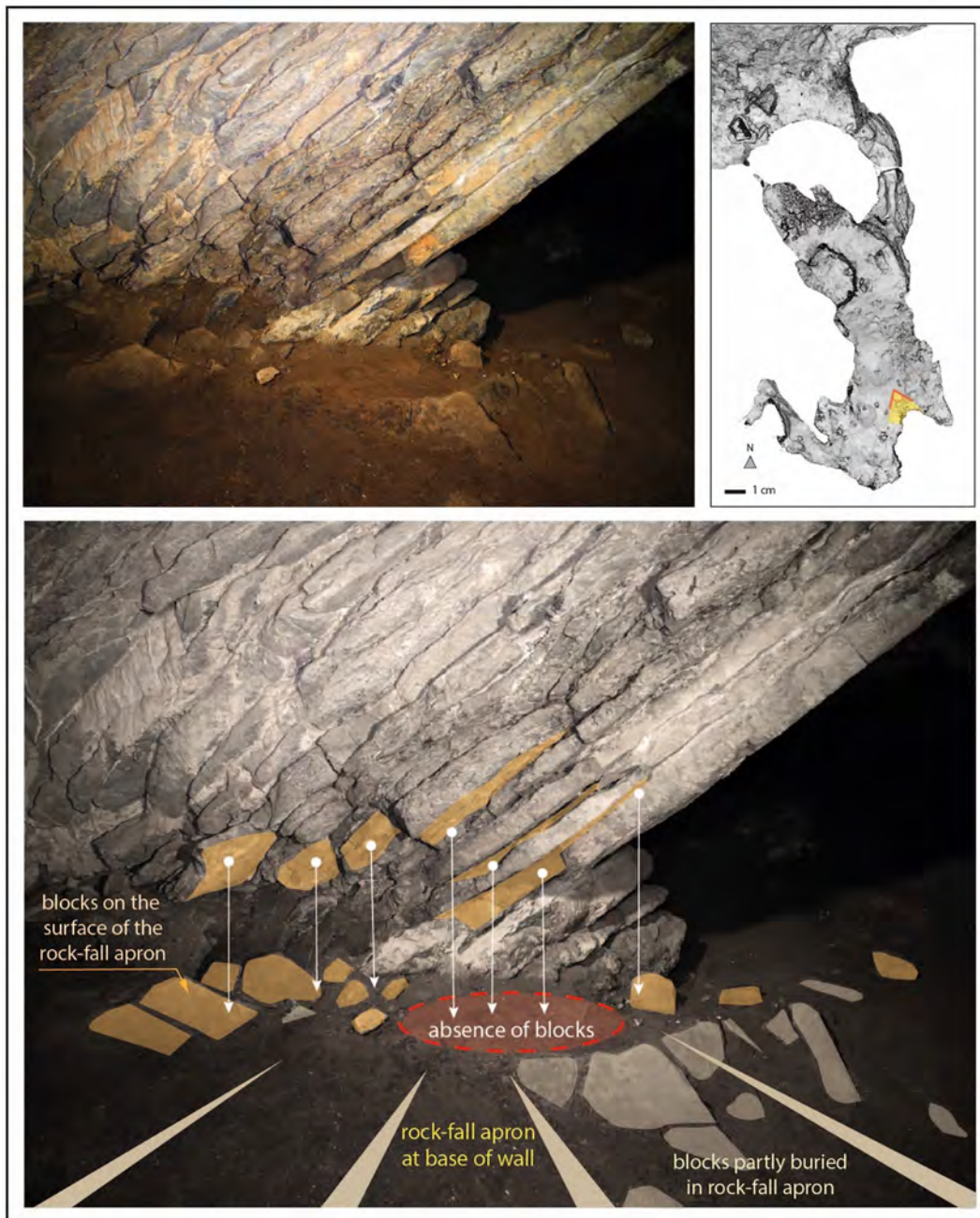


Fig. 24. Archaeomorphological interpretation of the source area for the stone arrangement in the Alcove. Note the rock scree apron at the base of the wall (photo and artwork by Jean-Jacques Delannoy).

least two occasions (post-110,000 and again c. 6000 years ago), we conclude that only part of Cloggs Cave’s underground network of cavities is today exposed at surface level. This is consistent with Flood’s observations during the 1971–1972 excavations in the Porch and Rockshelter, which went down c. 60–100 cm before reaching rocky layers that gave way to or contained large cavities (Flood 1973, 1980: 259). By excavating Squares A–W against the start of the Entrance Passage, Flood exposed deeper levels than are currently visible, and in the process observed that: “the undercutting below the entrance passage extends inwards ... for more than 5 m” (Flood, 1973a: XV6–7). She further wrote (Flood, 1973a: XV5):

The deposit in the rock-shelter was unstable, not because of its dryness, but because much of it was a jumble of large fallen blocks, with holes and gaps in between. I was able to push a rod down one

of these holes for 3 m without touching anything. On another occasion the floor of a pit (W [beneath the start of the Entrance Passage]) gave way under the excavator. Fortunately he was unhurt, but thereafter the excavators of the entrance zone in the rock-shelter were belayed with a rope whilst they dug.

6. Conclusion

Since the early 1970s, Cloggs Cave has featured prominently in Australian megafaunal debates, and in discussions on the antiquity of human occupation at the foothills of the nation’s highest mountains, the Australian Alps. Yet, and with only four problematic ¹⁴C ages and a lack of clarity of sedimentation processes to go by, until now the antiquity of the cave’s deposits, and the depositional relationship between the

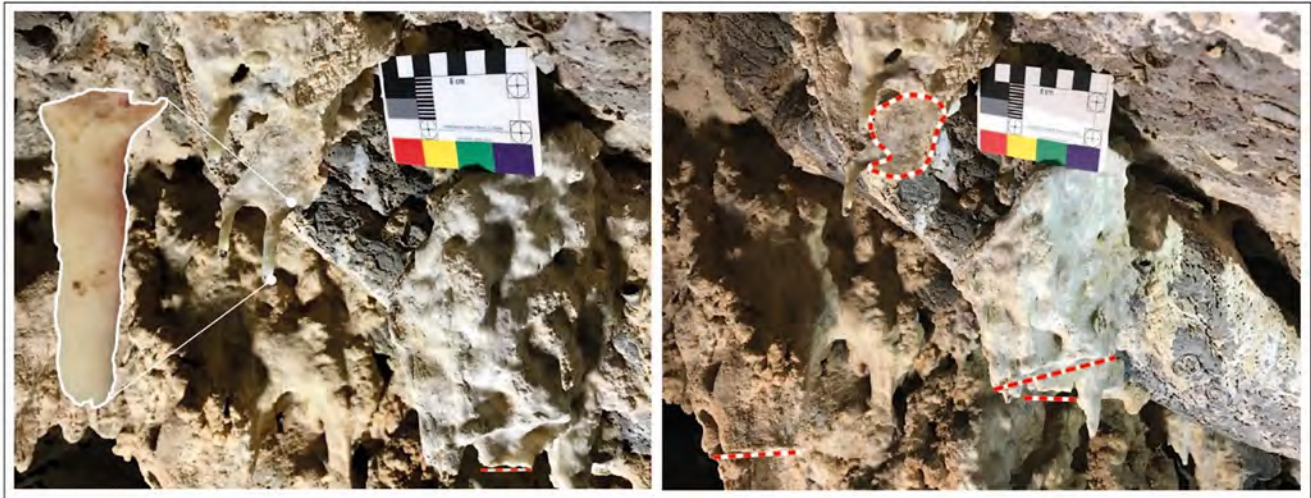


Fig. 25. Examples of broken stalactites and soda straw re-growths on the ceiling of the northwestern corner of the Upper Chamber, including the Alcove. The top of the sampled straw shown here (inset) has a U-series age of $23,230 \pm 300$ years, indicating when it started growing over the broken stalactite (photos by Helen Green).

mega-faunal and occupational layers had not been well understood, oscillating between statements of contemporaneity and significant temporal separation. Nor were the processes of sediment accumulation and evacuation clear; how mega-fauna, and people, had entered the site in the past; and what the cave looked like at the time of the Old People. The details revealed by taking a longer-term, inter-connected or trans-

disciplinary geological, geomorphological and archaeological approach to the cave's formation history have been critical to understanding its changing morphology and morphogenic processes, including how sediments entered and left the cave before, during and after the time of the Old People. Such a broader geographical and temporal perspective of a site's landscape history is almost never undertaken in archaeology,

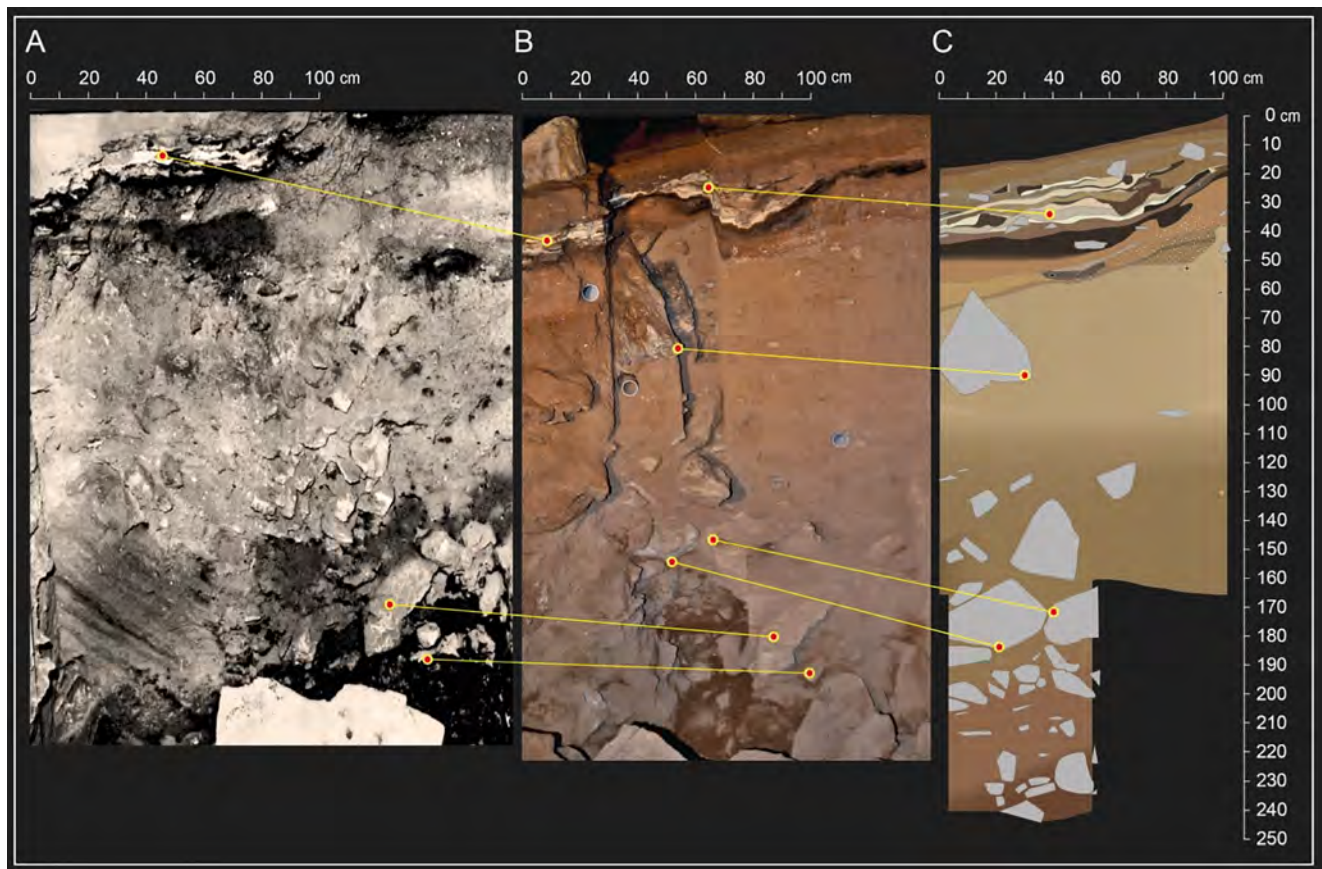


Fig. 26. Comparison of A: the southeastern wall of Squares S and SS from Flood's 1971–1972 excavations (after Flood 1980: 264). B: Squares P34 and P35 (after completion of David et al.'s (e.g. in press) excavation in 2019) against the southeastern wall of the 1971–1972 pit. C: section drawing of the northwestern wall of David et al.'s Square P35 (as drawn prior to excavation from the southeastern wall of the 1971–1972 pit) and contiguous southeastern wall of Square P34 (artwork by Jean-Jacques Delannoy and Bruno David).

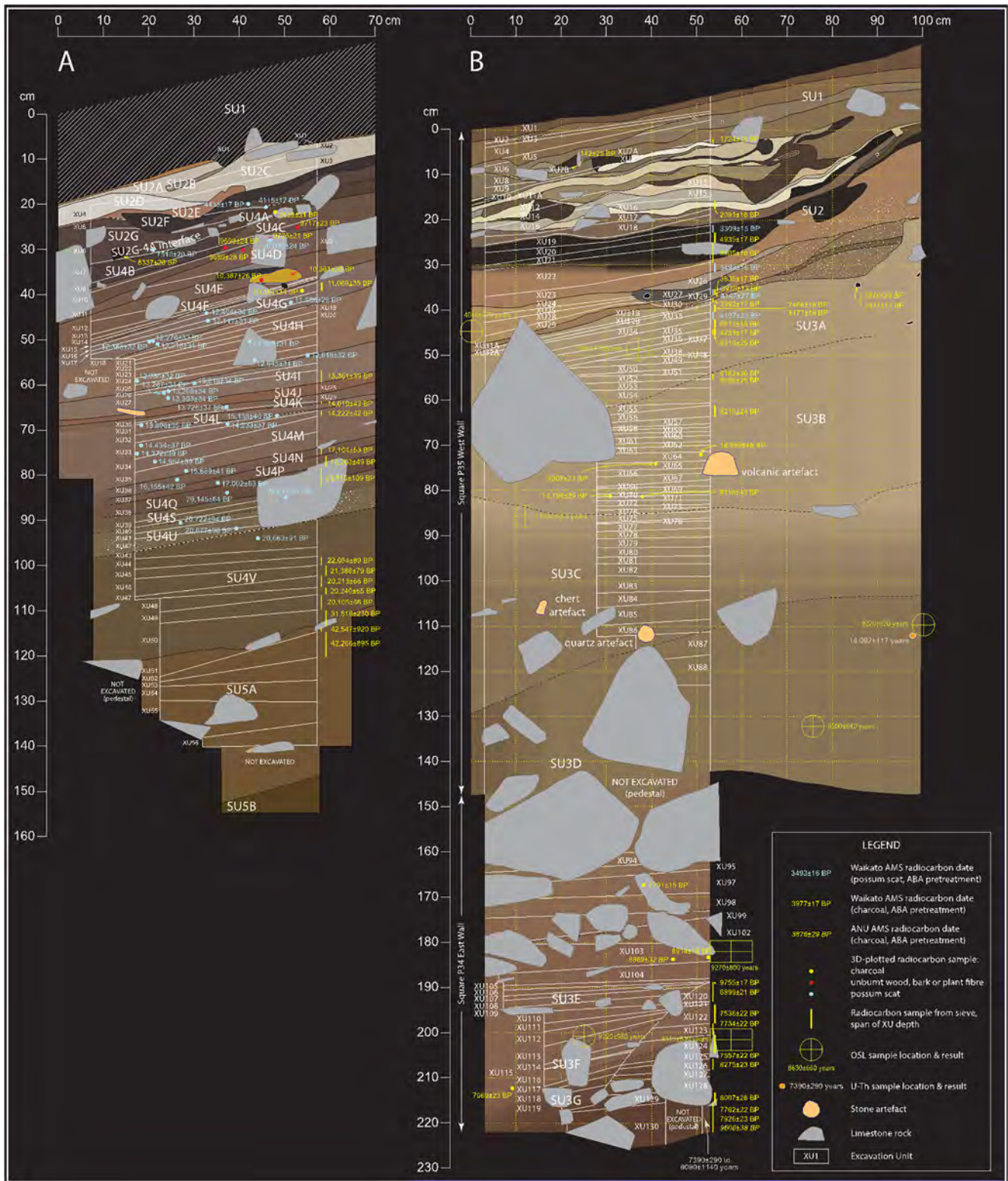


Fig. 27. Section drawings: A: Southwestern wall of Square R31 (as drawn from the northeastern wall of the exposed 1971–1972 pit). B. Contiguous Squares P34 (southeastern wall) and P35 (northwest wall, as drawn from the exposed 1971–1972 pit) stratigraphic sequence. SU40, SU4R and SU4T do not appear on the southwestern wall of Square R31, as they are localised layers in other parts of the square. The SU1 layers correspond to GP10, SU2 to GP9, SU3 to GP7–GP8, SU4 to GP3–GP6, and SU5 to GP1–GP2 (artwork by Bruno David).

limiting what can be said about its deposits, including how it relates to the period of human occupation.

For Cloggs Cave we can now conclude with the following answers to the questions posed at the start of this paper:

1. *Why are the stone artefact-bearing sediments located on the opposite side of a disconformity that contains the layers with megafaunal remains?*
Answer: Because c. 6090 ± 1140 years ago, a sudden collapse of the accumulated sediments in the southwestern parts of the

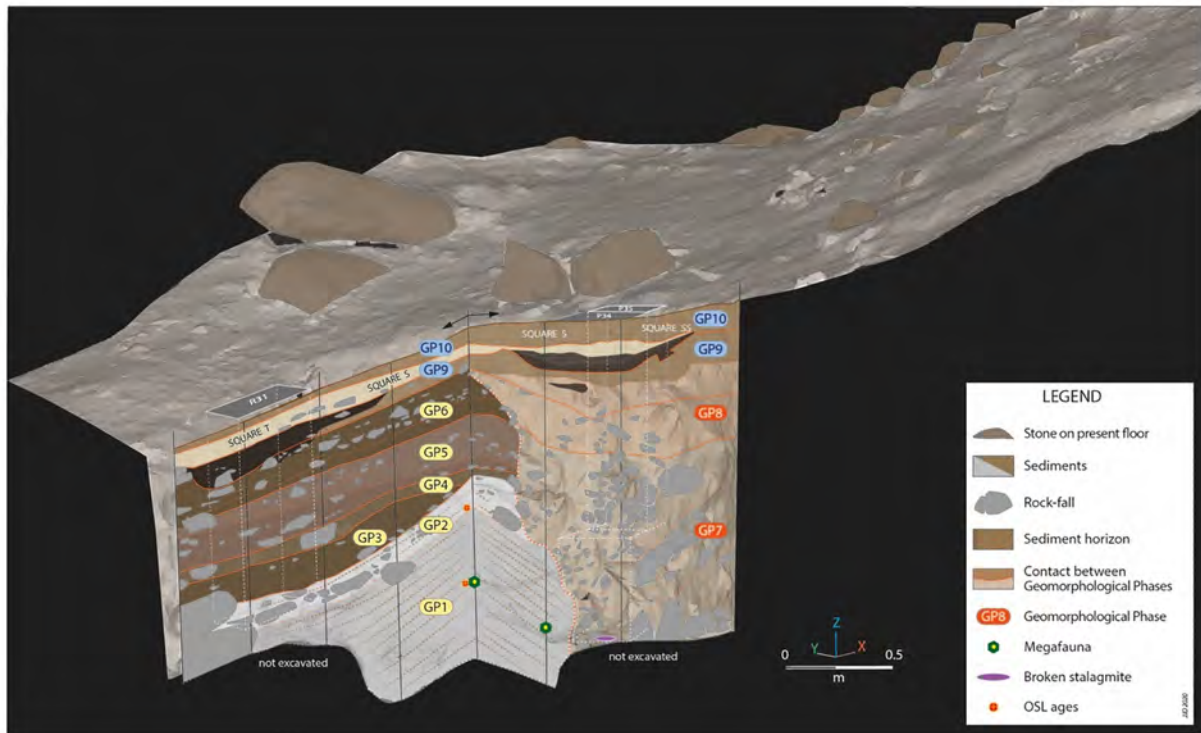


Fig. 28. Graphic synthesis of the Geomorphological Phases (GPs), as seen from the northeastern and southeastern walls of the 1971–1972 excavation pit (incorporating the results of the 2019–2020 excavations). This isometric view of the northeastern and southeastern sections is precisely spatially calibrated to the 3D laser scan of the open pit and adjacent slope (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy from concept by Jean-Jacques Delannoy and Bruno David).

1971–1972 archaeological pit area, in the Main Chamber, had cut through stratified deposits, creating a crater that was almost immediately filled by sediments eroding from the adjacent slopes. Those infilling sediments carried with them blocks, soft sediments and stone artefacts from neighbouring areas. Around 6000 cal BP, a shallow depression at the top of the largely-filled crater continued to accumulate sediments, until the floor of this part of the Main Chamber became flush with surrounding areas. Late Holocene sediments associated with repeated uses of the cave by the Old People then capped the entire deposit with cultural deposits, including multiple thin, ashy layers from hearths.

2. *How did the megafauna and other medium-size to large extant terrestrial fauna, also evident from the megafauna layers, enter the cave?* **Answer:** During the time of the megafauna, another entrance existed immediately below the current one. The existence of one, and possibly two, significant but now-buried entrance cavities below the Entrance Passage and Rockshelter is indicated by: the shape of the Porch; size and shape of the underground cavity, whose top is currently exposed under the Entrance Passage; evidence obtained during the 1971–1972 excavations about the presence of deeper cavities beneath the Porch and Rockshelter excavation pits; depressed talus slope below the Porch, with outcropping bedrock on either side; and the changing slope of the accumulated deposits at the base of the Main Chamber. The large numbers of ^{14}C and OSL ages obtained from the 2019–2020 excavations indicate that 52,000 years ago megafauna could have accessed the cave through the palaeo-entrance. This entrance, today sealed under the Entrance Passage but with a remnant cavity at its very top (and probably also under the Rockshelter where it would be completely sealed), was largely open during GP1 and GP2 on Fig. 30. The presence of a topographically lower palaeo-entrance than today's also means that fauna could then enter (and leave) the cave from lower down the talus slope, i.e. from closer to the floodplain below, although

precisely from how much lower remains unknown (today the cave entrance is perched 17 m above the floodplain; the floor of the palaeo-entrance at the time of the megafauna was at least 3.6 m deeper than it is today based on the cavity under the Rockshelter, but could have been lower still). The palaeo-entrance suggests a free-roaming passage rather than a pit-drop, consistent with the paucity of medium-size and large fauna bones and coprolites in the megafauna layers. Accumulating sediments inside the Main Chamber caused the floor level to rise, blocking off the palaeo-entrance from the inside. We do not know whether this blockage began with wall and ceiling collapse inside or outside the cave.

3. *What were the entrance and cave morphologies like when the Old People entered the cave, and how did they engage with its internal spaces?* **Answer:** From the onset, people entered the cave through its present entrance, as the palaeo-entrance had already long been buried by the time of their first archaeologically known visits. The earliest stone artefact dates to sometime between 19,330 and 23,530 cal BP, a time when the walls and ceilings of the cave were much like they are today. However, the floor of the Main Chamber was then c. 85 cm lower than it is today, although the angle of its slope was similar. While it is worth noting that the sudden floor collapse c. 6000 years ago took place during a period when the Old People used the cave, the collapse can be related to the action of percolating waters during the wettest phase of the past 30,000 years (e.g. Petherick et al., 2013).

It is of interest to note that the Old People had repeatedly broken stalactites in and near the small Alcove on the edge of the Upper Chamber, crushed up calcite formations to make powder, and created a stone arrangement in the Alcove. A number of other blocks were also moved around inside the cave, including two blocks that were removed from the bedrock floor of the Entrance Passage and repositioned at the bottom of the jump-down (the access point) into the Main Entrance.

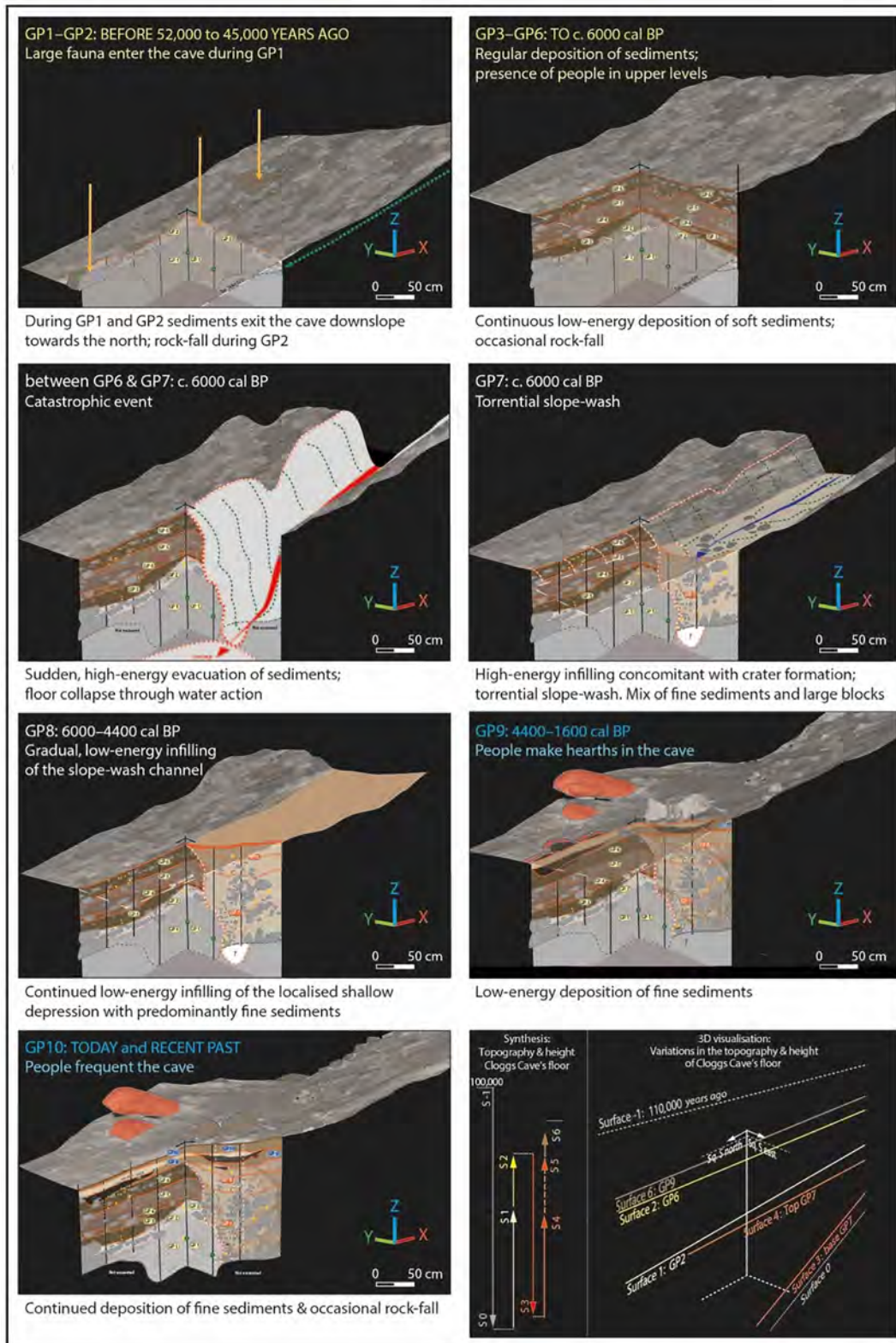


Fig. 29. Morphogenic history of the Main Chamber, based on the Geomorphological Phases. The figure reads from left to right and from top to bottom. The diagram at bottom right summarizes changes in the slope (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy).

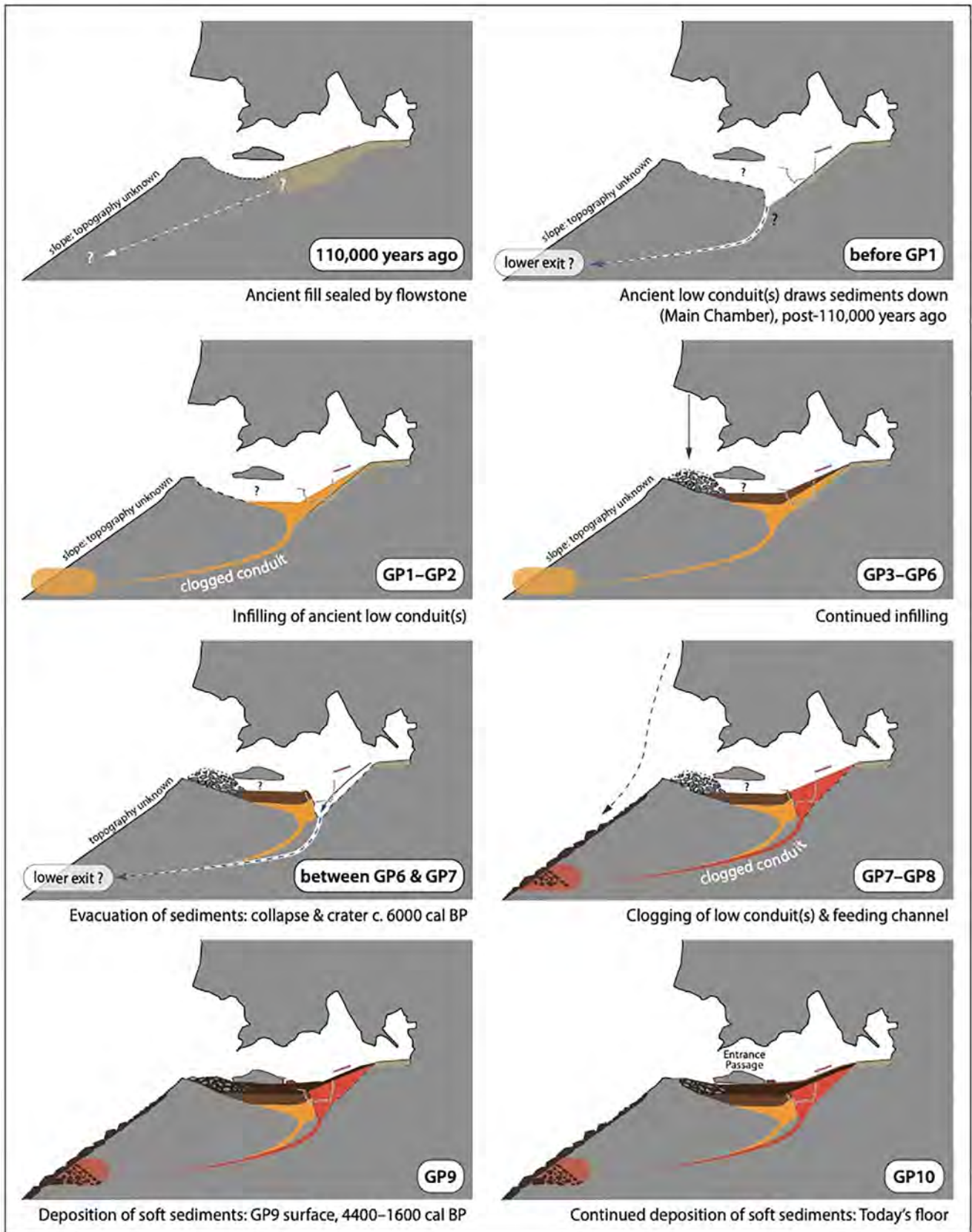


Fig. 30. Reconstruction of Cloggs Cave through time (3D acquisition by Johan Berthet; artwork by Jean-Jacques Delannoy).

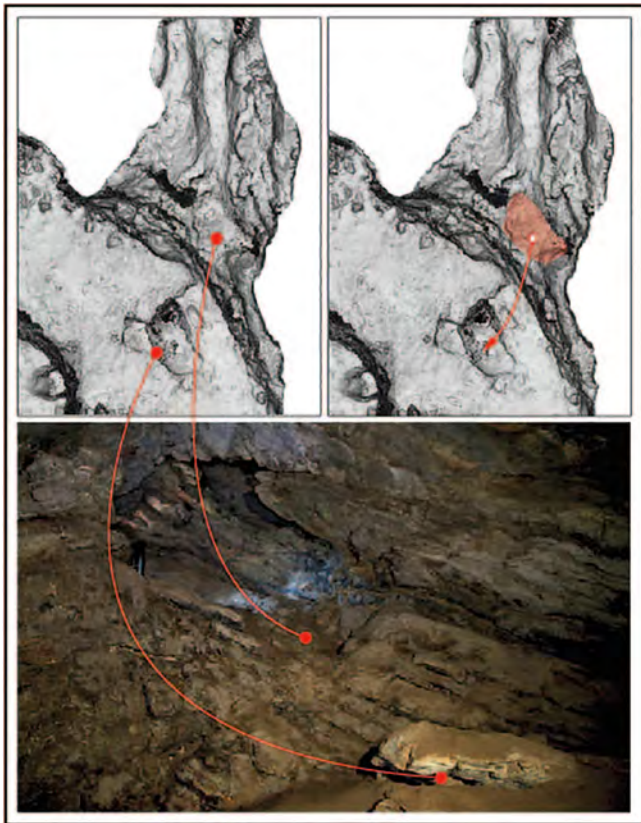


Fig. 31. The 315 kg limestone block on the floor of the Main Chamber at the jump-down from the end of the Entrance Passage. The originating footprint can be seen in the bedrock floor of the Entrance Passage. The block can only have attained its present position on the floor of the Main Chamber, slightly up-slope of the Entrance Passage's axis and separated from its originating footprint by the Entrance Passage's rising bedrock, through human action. It was placed flat in its current location 1.5 m from its originating footprint and 60 cm SSW of the edge of the Entrance Passage (3D acquisition by Johan Berthet; photo and artwork by Jean-Jacques Delannoy).

The largest of these repositioned blocks weighed 315 kg. Precisely when these activities took place remains to be determined, but soda straw re-growths on broken stalactite stumps indicate that some must have been broken as far back as $23,230 \pm 300$ years ago or more.

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