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DETAILED MORPHOLOGICIAL STUDIES IN NETOPIRJEV ROV, PREDJAMA CAVE: A HYPOGENE SEGMENT OF A SLOVENIAN CAVE

PODROBNA MORFOLOŠKA ŠTUDIJA NETOPIRJEVEGA ROVA V PREDJAMSKEM JAMSKEM SISTEMU: HIPOGENI DEL JAME V SLOVENIJI

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Abstract UDC 911.2:551.4(497.4)

R.A.L. Osborne: Detailed morphologicial studies in Netopirjev rov, Predjama Cave: A hypogene segment of Slovenian Cave.

Netopirjev Rov, part of the upper level of Jana near Predjama Cave, is not a former fluvial cave passage but a complex void made up of coalesced, structurally guided elongate cavities with cupolas and a range of speleogens normally associated with hypogene caves. These cavities were initially separate and later became integrated by the breakdown of their common walls. The main chamber consists of at least two coalesced voids while an apparent bend, a *pseudobend*, towards the northern end of Netopirjev Rov results from the breakdown of the common wall near the ends of two adjacent elongate cavities. It is proposed that this section of cave was excavated by the action of water rising from below (per-ascensum speleogenesis), but the nature and source of this water remains unclear.

Keywords: hypogene, speleogens, cave morphology, structural guidance, Jama near Predjama Cave.

Izvleček UDK 911.2:551.4(497.4)

R.A.L. Osborne: Podrobna morfološka študija Netopirjevega rova v Predjamskem jamskem sistemu: Hipogeni del kame v Sloveniji

Netopirjev rov, ki je sestavni del zgornjega nivoja Predjamskem jamskem sistemu, ne predstavlja predhodni fluvialni jamski kanal, temveč kompleksno votlino, sestavljeno iz prepletajočih se strukturno vodenih podolgovatih votlin s kupolami in naborom speleoloških značilnosti, ki jih običajno povezujemo s hipogenimi jamami. Omenjene votline so bile primarno ločene, kasneje pa so združile s podiranjem njihovih skupnih sten. Glavna dvorana je nastala z združitvijo vsaj dveh votlin, navidezen pregib (psevdopregib) na severnemu koncu Netopirjevega rova pa je nastal kot posledica podiranja skupnih sten v zadnjem delu dveh sosednjih podolgovatih votlin. Menim, da je nastal ta odsek jame z delovanjem dvigajoče se vode od spodaj (per-ascensum speleogeneza), vendar ostajajo lastnosti in izvor te vode nepojasnjeni.

Kjučne besede: hipogeno, speleogen, jamska morfologija, stukturno vodilo, Jama pri Predjama.

INTRODUCTION

It is generally accepted that the vast majority of caves in Slovenia are fluvial systems owing their origin to the action of sinking meteoric water. While this is undoubtedly true of the active parts of the caves, the inactive, often higher zones may have other origins. Large cavities (cupolas) and speleogens that may have a hypogene origin were recognised in Jama near Predjama Cave in October-November 2001, during the author's initial studies of the morphology and natural history of cupolas (Osborne 2004). A number of large cupolas and associated speleogens, particularly rising half-tubes, were recognised in the Cave Behind the Castle section of Jama Cave. Cupolas were noticed when Netopirjev Rov was visited briefly with Dr Tadej Slabe in 2001, so it was considered a high priority area for investigation on my return to Slovenia for an extended stay in 2005.

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JAMA CAVE

Jama Cave (literally the cave) or more correctly Jama pri Predjama (the cave at Predjama) is located one hundred metres from the small village of Predjama, situated to the northwest of Postojna (Fig. 1). Predjama is well known as the location of Predjama Grad, a 16th century rebuild of an older castle that was the home of "robber baron" Erasmus, whose siege and mode of demise in 1484 have become legendary (Habe, 1987). The castle is constructed in front of the limestone bluff containing the cave and partly inside the large cave entrance (Fig. 2).

Fig. 1: Location.

Fig. 2: Predjamski grad (castle) looking north. Lokva stream sink and the lower tourist entrance to the cave are located down and to the left of the image.

Predjama cave is developed on three levels, the lowest level is an active streamway fed by Lokva Stream, which sinks just below the castle.

The geological structure of the area is quite complex with significant thrust faults and strike-slip fault zones intersecting and displacing the limestone near the cave (Čar & Šebela 2001). Šebela & Čar (1991) investigated the relationship between faults and breakdown in Vzhodni rov, part of the second level of the cave (Fig. 3).

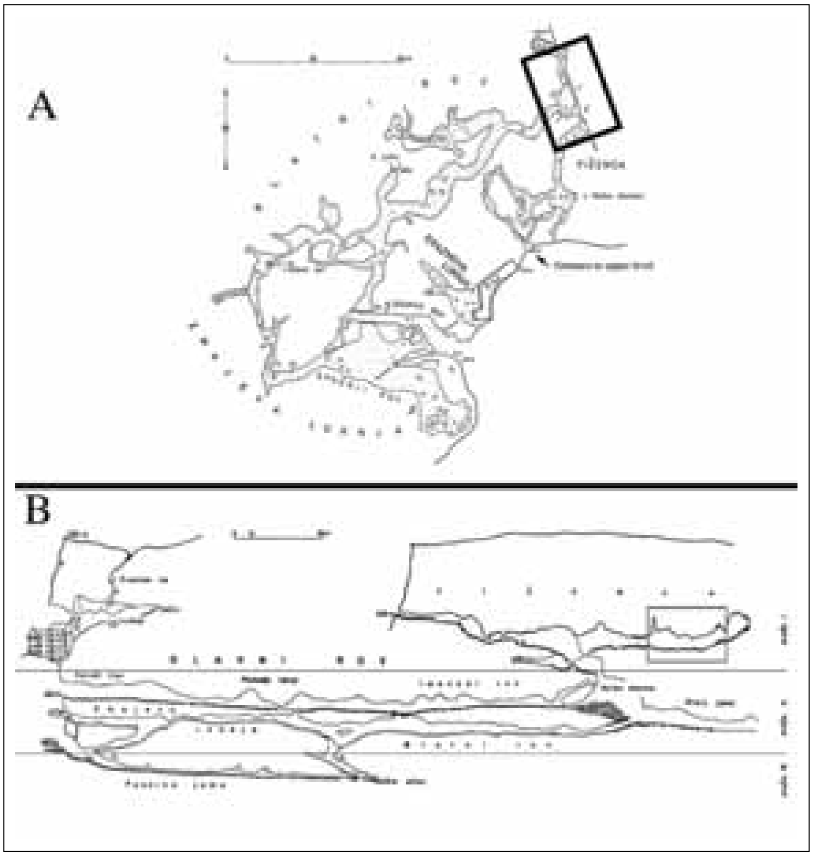

Fig. 3: Jama Cave after Habe (1970). A = plan showing the castle (Grad), middle and upper cave levels, rectangle indicates study area. B = developed long section showing upper, middle and lower levels, rectangle indicates study area.

METHODS

Detailed morphological studies of small sections of cave are relatively uncommon. This type of study, while very time consuming, has the potential to reveal a great deal about the morphology and speleogenesis of complex caves and of enigmatic sections of caves whose origin is subject to controversy. Although this study initially aimed at examining cupolas, which are apparently uncommon in Slovenian caves, it has also revealed some unexpected new information about the general nature and possible evolution of the cave.

Sixty-five metres plan length of cave was examined in five days of fieldwork. Conventional approaches to cave mapping are unsuitable for this type of work, which requires a resolution at least ten times that of most cave maps. Cave plans (more correctly wall contours) were prepared at a scale of 1:100 in the field using a plane table with a laser-ranging alidade. Sections were measured using a laser rangefinder and a digital clinometer mounted on a geared photographic head as described by Osborne (2004) and manually plotted at a scale of 1:100.

Images were taken along the sections at 15-degree intervals of elevation using a still digital camera mounted on a geared tripod head. Vertical stereo photographs were taken at each station and oblique stereo photos were taken to assist in interpretation. The stereo photographs were taken using a *Sputnik* medium format stereo camera and *Fuji Provia* transparency film. Film-plane to subject distance was measured using a laser rangefinder.

Digital images were taken of structures and speleogens. Structural measurements were made using a *Breithaupt Kassel* stratum compass. Where direct measurement was not possible, the orientation of structures was measured indirectly by taking sightings of structural planes using the laser alidade and the plane table.

STUDY AREA

Netopirjev Rov, a dead end passage in the Fižence (upper) section of the cave, extends for some 100 m north northwest from the tourist path at the top of the main ladder leading down to Velika dvorana (Fig. 4). There are no cupolas in the ceiling for the first 25 m of Netopirjev Rov. The first survey station ("1" in Fig. 5) was established adjacent to the first large cupola. Five further main stations and two subsidiary stations were established permitting detailed documentation of approximately 65 m of cave.

Fig. 4: Detail of Netopirjev Rov from Hajna (1996) at original mapping scale.

GEOLOGY AND STRUCTURE

The bedrock in the study area is massive grey limestone. Bedding was not recognised in the study area, but many other structural planes were visible. Despite clear evidence of structural guidance in this section of cave, it proved difficult to find sites for measuring the dip and strike of the structures. Most surfaces that appeared planar from the distance or at mapping scale were found at close inspection to be significantly modified by solution, usually with a "wavelength" greater than the base of the measuring instrument.

The dominant structural planes in the study area strike NNW-SSE and dip steeply to the NE (Table 1).

These are most likely shear planes parallel to the major fault zone located immediately to the northeast (Fig. 4). The strike and dip of these planes varies considerably. They are often irregularly folded on a small scale, with variable amplitude up to 200-300 mm producing a wavy surface. The irregularity of the dominant structures means that the axes of both large and small-scale solution features are rarely symmetrical.

From a speleogenetic point of view the second most important structure is an almost vertical joint set striking NNE (020). Four sets of structures have been identified that strike generally E-W. Only one of these, a southerly-dipping joint that guides the development of sloping blind pipes and low angle wall pockets is of any speleogenetic significance.

Table 1: Structural planes in the study area.
Bearings are magnetic.

Directly measured in field			
DIP	***DIP direction***	***strike***	***comment***
60°	045°	135°	Dominant NNW-SSE striking structures. Both strike and dip are variable. Many planes have wavy surfaces. Guides vaults, eastern wall and vertical pockets. (Average strike 151° and dip 66°)
70°	066°	156°	
79°	074°	164°	
85°	184°	094°	No clear speleogenetic role
70°	210°	120°	No clear speleogenetic role
65°	340°	070°	No clear speleogenetic role
50°	192°	102°	Pair of conjugate joints. South-dipping joint guides sloping blind pipes and low angle wall pockets.
50°	016°	106°	
Measured from plans			
? 80+	Almost vertical ? steeply SE (110)	020°	Guides many short wall surfaces and vertical pockets.

CAVE MORPHOLOGY

GROSS MORPHOLOGY

Netopirjev Rov begins as a high, broad passage about 5 m wide. After about 20 m it turns to the NE and then sharply to the NNW and narrows to about 1 m. After five metres it broadens into a rectangular chamber 15 m long x 10 m wide and then narrows to about 3 m for another 15 m where it makes a distinct turn to the NW. The passage continues for another 20 m before terminating (Fig. 4).

The study area in Netopirjev Rov consists of four distinct larger sections, a broad Southern Section, a Narrow Section, a Chamber and a Northern Section and three smaller sections; the Northwest Passage, the high-level Fossil Tube and the Eastern Tube.

Southern Section

The southern part of the study area is the northern end of a NNE-SSW trending passage that takes a distinct bend to the NE (Fig. 5) just south of the study area. As it turns to the NE, the passage widens to approximately 10 m and the ceiling lowers. From Station 1, the passage begins to narrow and turn to the north as it joins the Narrow Section.

At Station 1, the passage has narrowed to 7 m with a high cupola forming a 2 m semicircular projection on its eastern side (Figures 5, 6A & 6B). The western half of the passage ceiling near Station 1 is relatively flat, approximately 5 m high with irregular stalagmites projecting down approximately 1.5 m (Figures 6A & 7A). A conical cupola dominates the eastern half of the ceiling (Fig. 5). This cupola extends for 16 metres above the general level of the ceiling (Figures 6A & 6B). The floor is relatively flat with numerous small pustular stalagmites up to 1.3 m high.

Narrow Section

This section is approximately 7 m long and ranges in width between 2 and 2.5 m. For the first 4 m it trends north and then makes a distinct turn to the NW. It has the form of a narrow rift (Figures 6C & 8A) that widens to a maximum of 4 m between 2-8 m above the floor and then narrows upwards. Above 8 m, the ceiling is divided into a series of cupolas and is crossed by a channel (Fig. 6D). Rock blades and flowstone pendants separate the hollows in the ceiling.

The floor is composed of rubble and accumulations of organic silt. To the north the floor drops approximately 2 m from the level southern section to the floor

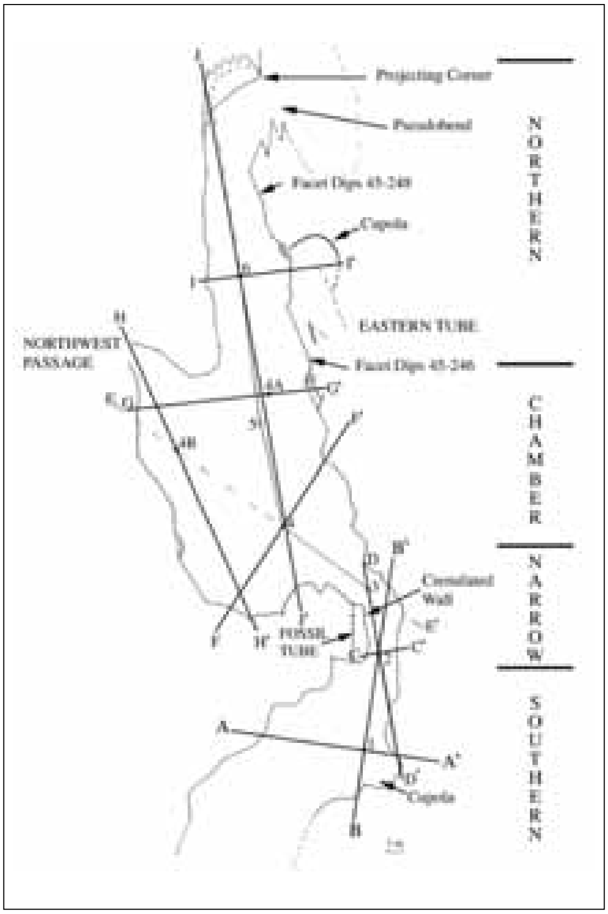

Fig. 5: Composite map of the study area based on wall contours plotted on a plane table at six stations at an original scale of 1:100.

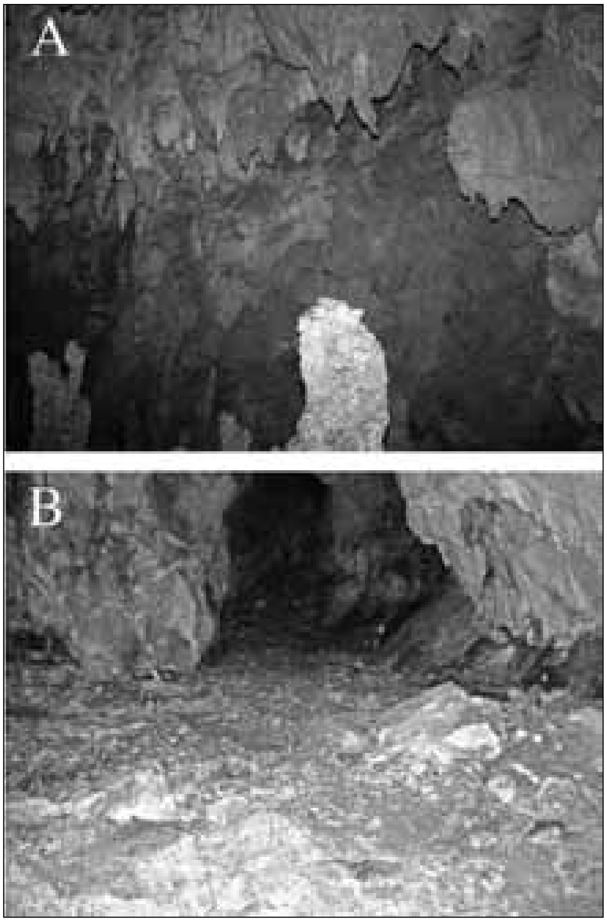

Fig. 7: A - Looking west from Station 1.

B - Chamber, looking north from Station 4. Note breakdown pile and the composition of the floor. Note also the fall in floor level to the south followed by rise in floor level towards Northwest Passage to the left and Northern Section to the right.

of the Chamber. A facet is developed in the western wall between 1 and 3 m above the floor. A similar structure probably occurs in the eastern wall, but is obscured by flowstone.

Chamber

The Narrow Section obliquely joins the southeastern corner of a spacious roughly rectangular chamber with a floor area of approximately 150 m^2. The Northern Section extends directly from the northern end of the Chamber while the Northwest Passage, a narrow rift, extends from the northwestern corner.

The eastern wall slopes to the east and is partly overhanging (Fig. 8C). It extends as a series of long sections trending NNW separated by shorter sections oriented NNE (Fig. 5). This allows the Chamber wall and its extension in the Northern Section to have an overall northerly trend, while being primarily guided by the NNW-SSE trending structure.

The western wall is more vertical than the eastern and has less steps. Towards its northern end the western wall swings to the east and continues as the western wall of the Northwest Passage.

The northern wall is quite small because the opening between the Chamber and the Northern Section is 6 m wide. It runs directly west-east for only about 2.5 m before turning north to form the western wall of the Northern Section. For about 6 m the wall then runs perpendicularly or obliquely the dominant NNW-SSE structural planes.

The ceiling of the Chamber is quite complex. Its principal features are two ceiling vaults separated by a projecting divider (“C” in Fig. 9A). The Eastern Vault continues into the Northern Section. This vault is generally 7 m high with cupolas extending to almost 30 m. An incomplete central divider separates the two main vaults, projecting down to 3 m off the floor at its lowest point. The larger Western Vault extends to a height of 11 m of the floor. There are also two smaller, irregular vaults, and

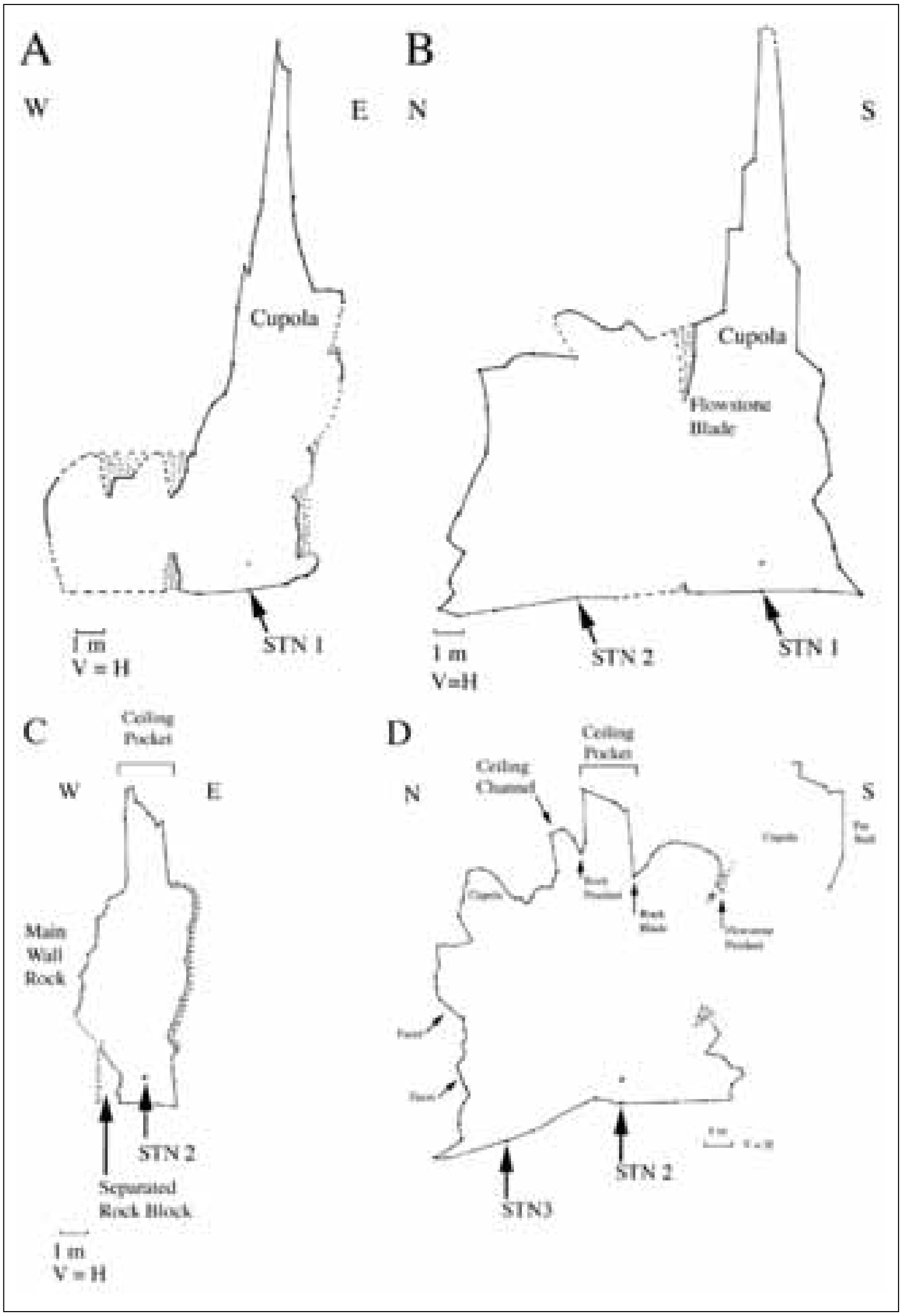

Fig. 6:

A - W-E Section at Station 1, A-A' in Fig. 5.

B - N-S Section at Station 1, B-B' in Fig. 5.

C - W-E Section at Station 2, C-C' in Fig. 5.

D - N-S Section at Station 2, D-D' in Fig. 5.

a series of smaller parallel structures in the western part of the ceiling (Fig. 9C).

The floor of the Chamber is generally flat, with a slight slope down to the north. Towards the northern end of the Chamber, the floor rises up into the Northwest Passage (Fig. 10A). Where it is not covered by flowstone and stalagmite, the Chamber floor consists of angular bedrock cobbles and some small piles of larger breakdown fragments (Fig. 7B).

High-Level Fossil Tube

The remnant of a high-level tube extends to the south from the southern end of the Chamber (Fig. 10B). This tube has a roughly circular profile, is approximately 2 m in diameter. It runs parallel and slightly to the west of the Narrow Section (Fig. 5).

Northwest Passage

Like its Artic namesake, the Northwest Passage goes nowhere. It is a high, narrow, blind, rift extending from

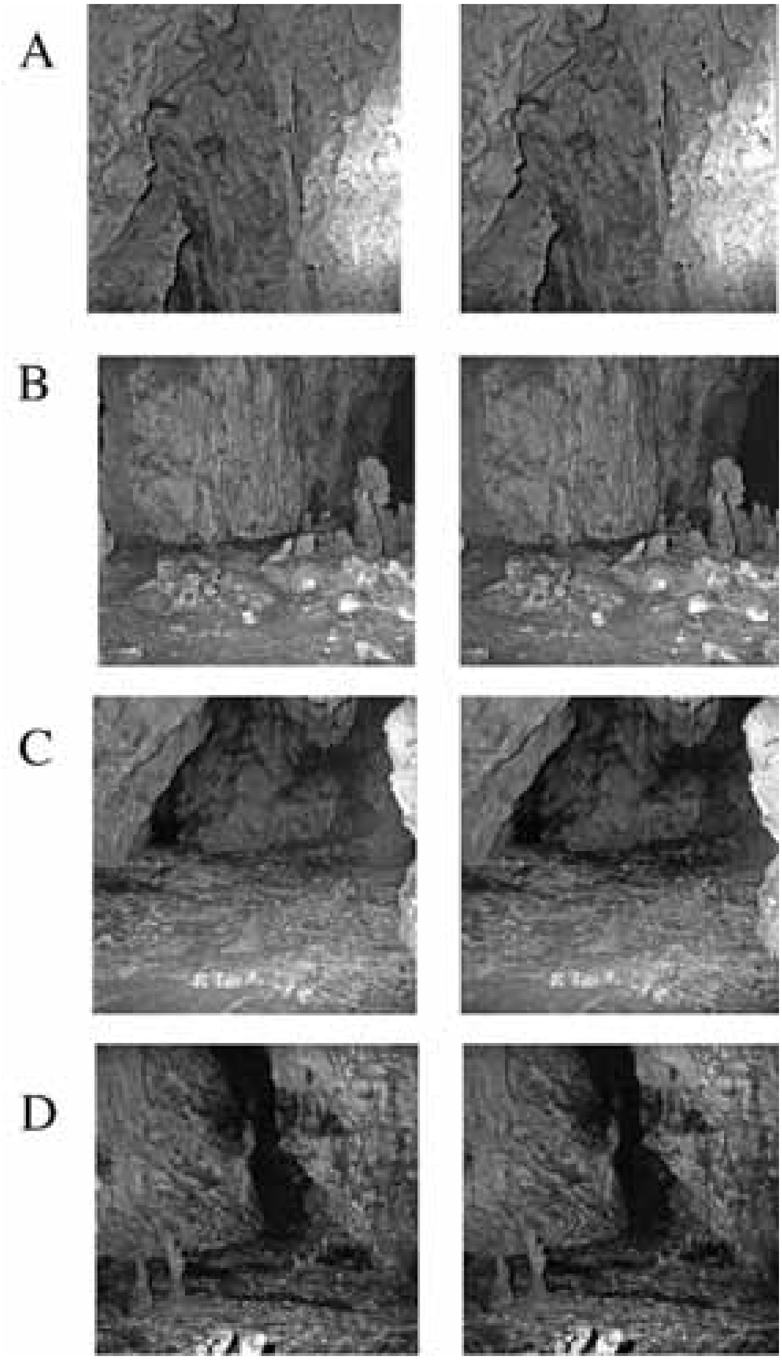

Fig. 8: Stereo Plate # 1

A - Looking north into Narrow Section from Station 1. Note south dipping notches in western (LHS) wall and elliptical pockets in end (northern) wall.

B - Looking into Chamber from Station 2, northern wall below ceiling divider is in centre field. Opening to Northwest Passage is on left and opening to Northern Section is on right. Note breakdown pile and near vertical structural planes in northern wall.

C - Chamber, view looking south from Station 6 along axis of eastern ceiling vault. Note opening of narrow section on LHS (E), hanging eastern wall with notch, and projecting divider between E & W ceiling vaults.

D - Looking NW from Station 4B into Northwest Passage.

the northwestern corner of the Chamber as a continuation of the western ceiling void (Fig. 5, 10A). Where it leaves the Chamber the passage is 3 m wide and 8 m high and after 3 metres narrows to just less than 1 m wide. In cross-section, the outer part of the passage is widest at its base, with a triangular profile and then narrows into a slot with roughly parallel sides (Fig. 8D). The bottom half of the Passage is filled with flowstone, while the upper half narrows into a blind rift in bedrock.

An inner profile of the passage is shown in Fig. 11D. Externally it has the form of two ellipses with the same vertical axis stacked one on top of the other. The lower ellipse widens to the east (right in Fig. 11D) while the upper ellipse widens to the west (left in Fig. 11D). The western wall (just below the "D" in Fig. 11D) has a complex texture consisting of small, vertically oriented elliptical hollows separated by ridges.

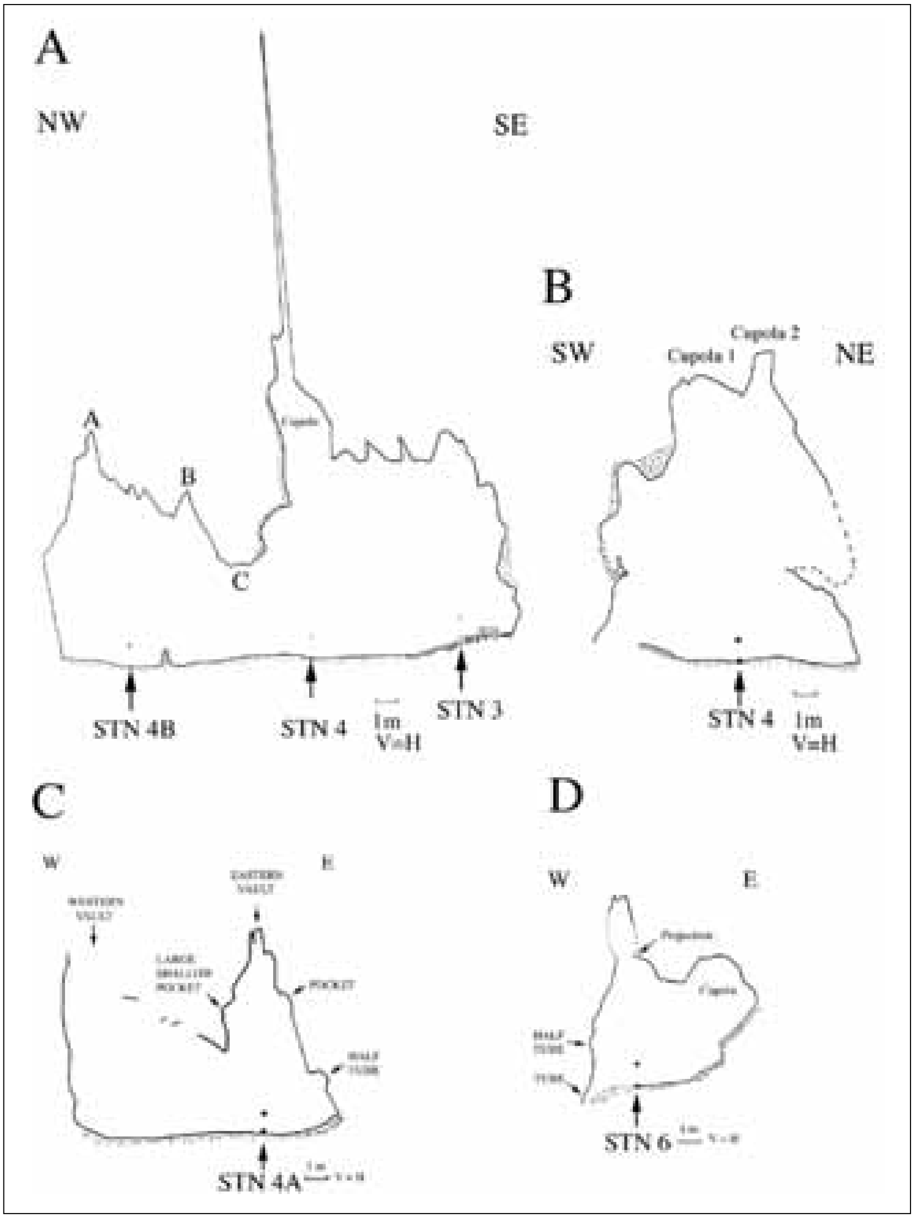

Fig. 9:

A - NW-SE Section at Station 4, E-E' in Fig. 5.

B - SW-NE Section at Station 4, F-F' in Fig. 5.

C - W-E Section at Station 4A, G-G' in Fig. 5.

D - W-E Section at Station 6, I-I' in Fig. 5.

Northern Section

The Northern Section consists of twenty metres of north-south trending tunnel. It is about 6 m wide at its southern junction with the Chamber and tapers to 3 m wide at its northern end. The lower part of the western wall is generally vertical with a distinct notch developed about 6 m from the floor (Fig. 11B). The eastern wall is more complex with distinct facets developed at two levels in addition to the upper notch (Fig. 5, 15 A & D). Near Station 6, the Eastern Tube and a small hemispherical cupola are developed in an alcove in the eastern wall (Fig. 9D. Above Station 6 projections from the bottoms of the upper notches extend into the tunnel from both walls, coming closer than 1 m together (Fig. 9D).

The floor starts out approximately level with that of the Chamber. After Station 6 the floor rises approximately 3 m to the north as a talus slope (Fig. 10B & 11B). The slope contains angular blocks that stack up against the western wall and the northern end of the section (Fig. 10B).

The ceiling of the Northern Section is a direct continuation of the Eastern Vault of the Chamber. The average ceiling height, ignoring pockets and cupolas rises to the north from about 5.5 m at the edge of the chamber to 6.5 m at the northern end (Fig. 10B). Without the rubble slope the average ceiling height at the northern end would be at least 8.5 m.

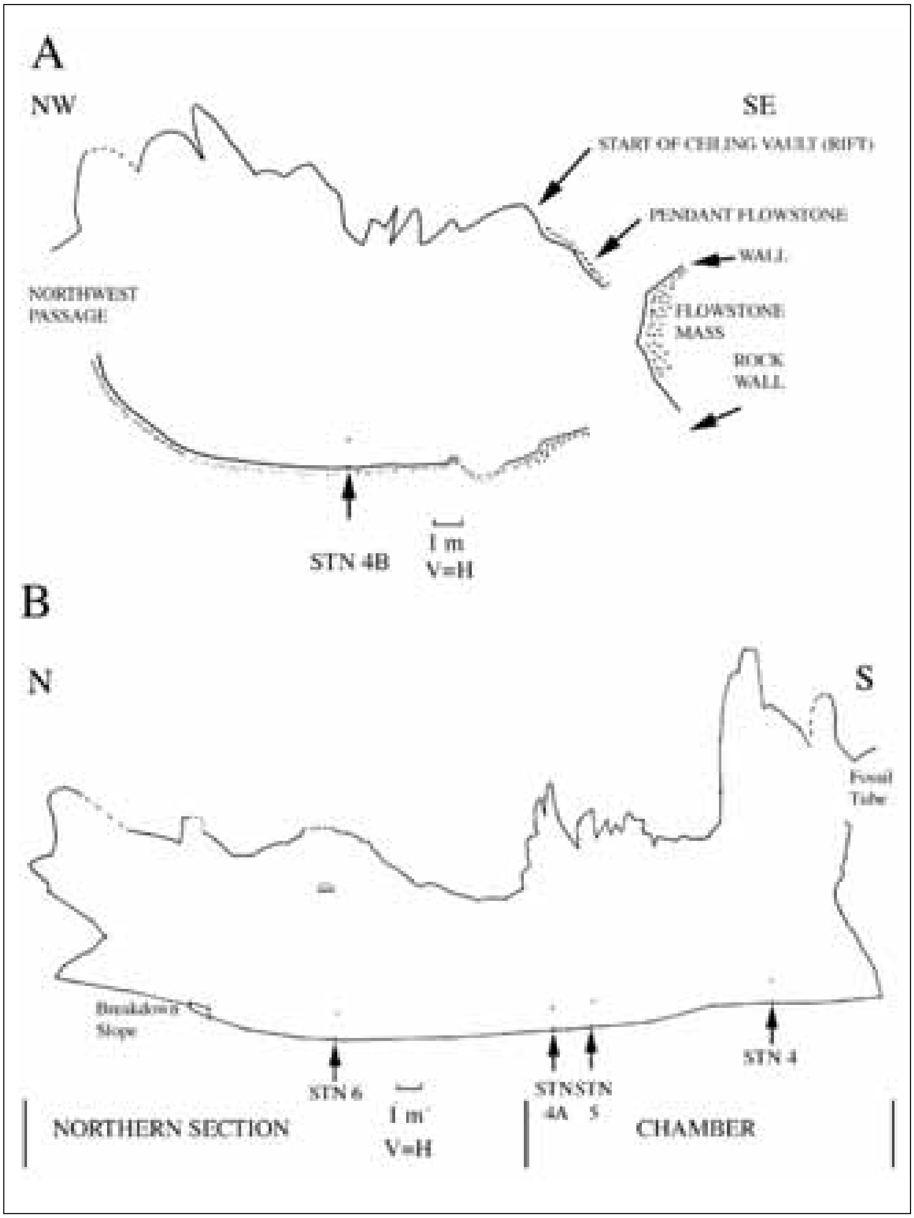

Fig. 10:

A - NW-SE Section at Station 4B, H-H' in Fig. 5.

B - Composite N-S long section between Stations 4, 5 & 6, J-J' in Fig. 5.

This section follows the axis of the Eastern Vault.

The grain size of fragments in the cave floor increases northwards and the cave floor rises 2.5 m to the wall at the northern termination up a rubble slope and approximately another metre to the floor of the adjacent tunnel to the east around the pseudobend (Fig. 5).

Eastern Tube

The Eastern Tube extends to the SE from the eastern wall adjacent to Station 6 (Fig. 5 & 11A). The tube begins with a roughly circular outline, becoming slightly elliptical towards the floor. The walls of the circular section are not smooth, but modified by angular bedrock projections roughly aligned along the NNW-SSE structural trend. A notch on the northern side of the tube opening is aligned along a southerly-dipping joint, whose trace is visible in the tube's walls (Fig. 11A). The tube was not explored, but images suggest that it connects to a small maze with smooth walls.

Pseudobend

Detailed examination of the relationships at the northern end of the study area indicated that there has been a conflict between perception and reality. The apparent bend to the northwest ("A" in Fig. 4) is not real, but an artefact of mapping. The Northern Section does not turn to the NW, as it appears, but actually terminates at its northern end (Fig. 5, 11C & 12C). The connection to the next section of the cave is not a bend in a single passage, but rather

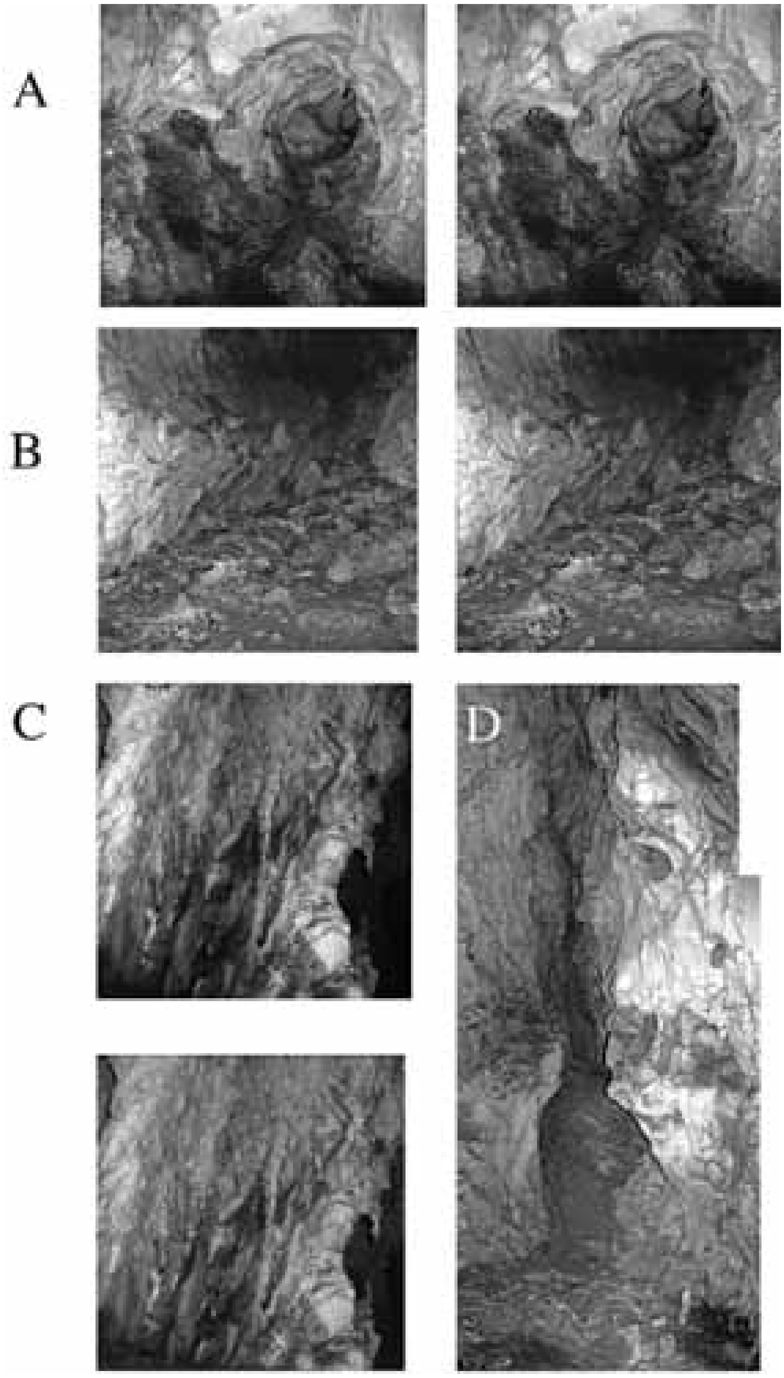

Fig. 11: Stereo Plate # 2

A - Looking SE from Station 6 into the Eastern Tube, hemispherical cupola is up to left. Note morphology of tube and tiny vadose incision in floor of tube.

B - Looking north from Station 6 showing breakdown & wall notch in W wall.

C - To view this image in stereo, align the viewer vertically on the page.
Pseudobend at northern end of Northern Section. Note projecting corner on right and elliptical pockets with a vertical axis.

D - Stitched image showing a profile of the Northwest Passage. Vertical field of view is approximately 8 m.

the result of breakdown of the dividing wall between two adjacent cavities (a breakdown portal of Osborne 2005). The northern side of the portal is a thin blade of bedrock and flowstone (Fig. 5 & 12A), forming a projecting corner (Osborne 2007).

This breakdown close to the termination of two adjacent, apparently blind cavities has produced a previously undescribed type of feature, that I have called here a pseudobend (Fig. 5).

Steps in the formation of a pseudobend are shown in Fig. 12B. Two ovoid, blind solution cavities form on parallel guiding structures with their ends overlapping ("1" in Fig. 12B). The wall between the adjacent cavities weakens ("2" in Fig. 12B) and eventually fails due to breakdown producing a pseudobend ("3" in Fig. 12B).

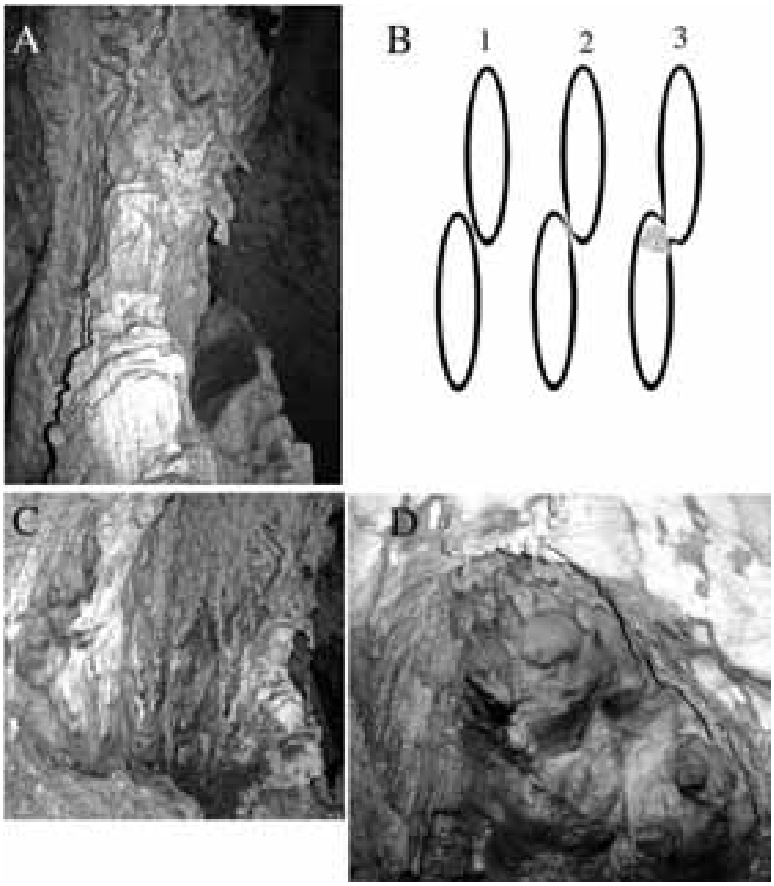

Fig. 12:

A - Projecting corner on northern side of pseudobend, view looking NE.

B - Stages in the formation of a pseudobend
1 - Two adjacent blind cavities form along parallel or roughly-parallel structures
2 - Boundary wall between cavities is thinned by solution.
3 - Boundary wall fails by breakdown, producing a pseudobend with a breakdown pile from the wall failure.

C - Looking NE towards northern termination of Northern Section. Projecting corner is at right of frame. Note elliptical pockets.

D - Hemispherical cupola east of Station 6.

Ceiling Vaults (Cathedrals)

The most dramatic structures in the Chamber ceiling are the vaults. These are narrow, elongate hollows in the cave ceiling with a roughly triangular cross-section (Fig. 9C). There are three main vaults in the chamber, two in the western side and one in the east. The larger, Eastern Vault is 3 m wide at its base and generally penetrates 5.5 m above the average height of the cave ceiling. Cupolas, bellholes and related forms, frequently modify the vaults but these are by no means restricted to the vaults.

The NNW-SSE structures guide the vaults but the vaults are not straight-line features due to: -

- irregularities in the strike and dip of the guiding structures
- the dip of the guiding structures
- the effects of intersections with other structures
- the ability of speleogenetic processes to overcome structural guidance

The Eastern Vault continues to the north as the ceiling of the Northern Section (Fig. 9C & 10B) and the far western vault continues as the ceiling of the Northwest Passage (Fig. 9C & 10A).

The Western Vault consists of two roughly parallel sub-vaults (“A” and “B” in Fig. 9A) with the more western being the larger of the two. The western vaults are separated from the Eastern Vault by the central divider, a bedrock blade modified by breakdown (“C” in Fig. 9A). Fig. 13A shows the triangular profile of the western sub-vault and its abrupt termination at the southern end of the Chamber. The apex of the vault is not a straight-line feature and is modified by cusps and pockets. The walls of the vault have a complex morphology (Fig. 13B), similar to that seen in the walls of the Northwest Passage.

The Eastern Vault (Fig. 9C & 13C) has a triangular profile similar to that of the western vaults, but its walls and apex are smoother, because larger-scale solution features have modified them (Fig. 13C & 16C).

Vaults as Cathedrals

The eastern wall of the Chamber is contiguous with the eastern wall of the Eastern Vault and the western wall of the chamber is contiguous with the western wall of the far western vault. So rather than being features of the cave ceiling, the vaults are the upper sections of the principal cavities that have joined to make the Chamber.

Before its eastern dividing wall failed, the Eastern Vault would have been a cavity with an elliptical plan and a triangular cross-section some 5 m wide at floor level by

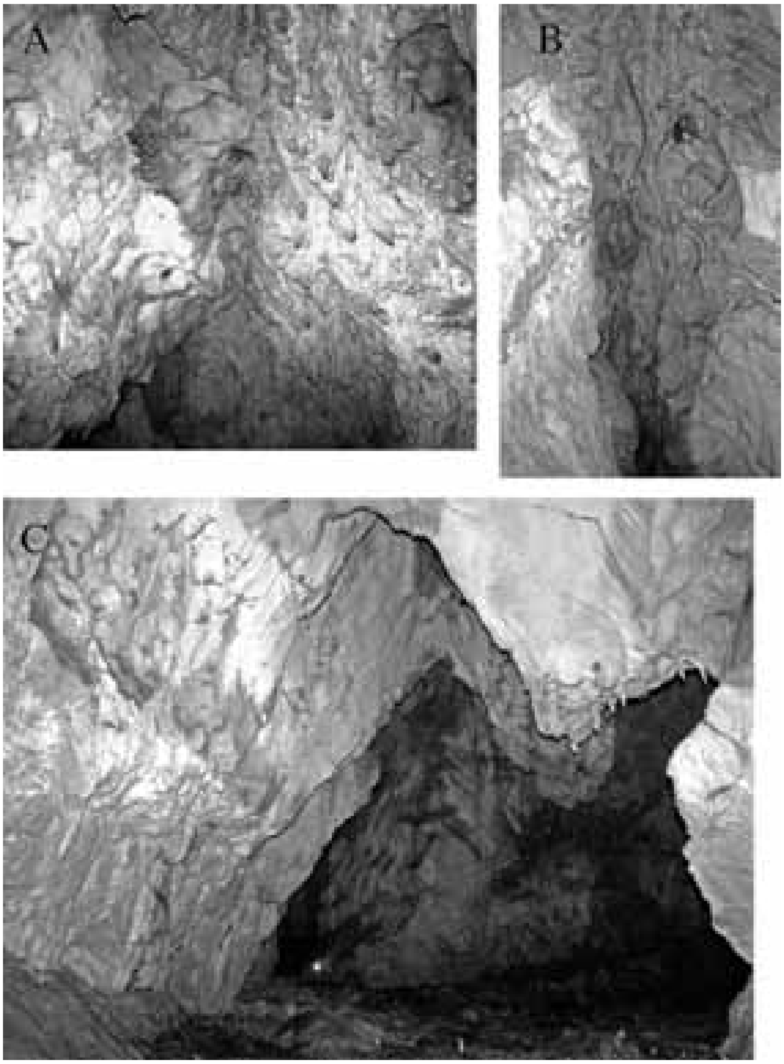

Fig. 13: Ceiling Vaults

A - Looking south along axis of Western Vault, note triangular profile.

B - Looking up into apex of Western Vault, note pockets and cusps in walls and along axis.

C - Looking south along axis of Eastern Vault from Station 6, note overhanging eastern wall and irregular, broken bottom of central divider.

28 m long and 4 m high at its lowest point (Fig. 9C). This is similar to the elliptical cupolas with longer horizontal than vertical axes called cathedrals by Osborne (2004). Before the failure of the lower parts of the dividing walls, the Chamber would have consisted of three adjacent cathedrals developed on roughly parallel axes separated by thin bedrock walls.

Cupolas

Most cupolas occur in the ceilings of the main cavities, however two, the high conical cupola near Station 1 and the hemispherical cupola near Station 6, are located to the side of the main cavities.

Conical Cupolas

The two tallest cupolas, one above Station 1 and the other above Station 4 have a conical profile (Fig. 6A, 6B & 9A). The stereo view looking up the cupola at Station 1 shows it to have an elliptical cross-section along a N-S axis (Fig. 14A), although this does not show up on the cross-section. The stereo image also shows that the opening to the highest point of the cupola is through a flowstone blockage.

The conical cupola above Station 4 begins as a 2 m wide opening in the ceiling. After 4 m above the general level of the ceiling, the cupola contracts to 1 m wide for another two metres. A chance shot by the laser rangefinder showed that it then extends upwards for a further 14 m as a narrow shaft less than 0.3 m wide, giving it a maximum reach above the floor level of some 30 m (Fig. 9A).

Elliptical Cupolas

While the cross-sections (Fig. 9A & B) suggest that the morphology of the ceiling above Station 4 is relatively simple, photography shows it to be much more complex, consisting of a complex NNW-SSE trending cavi-

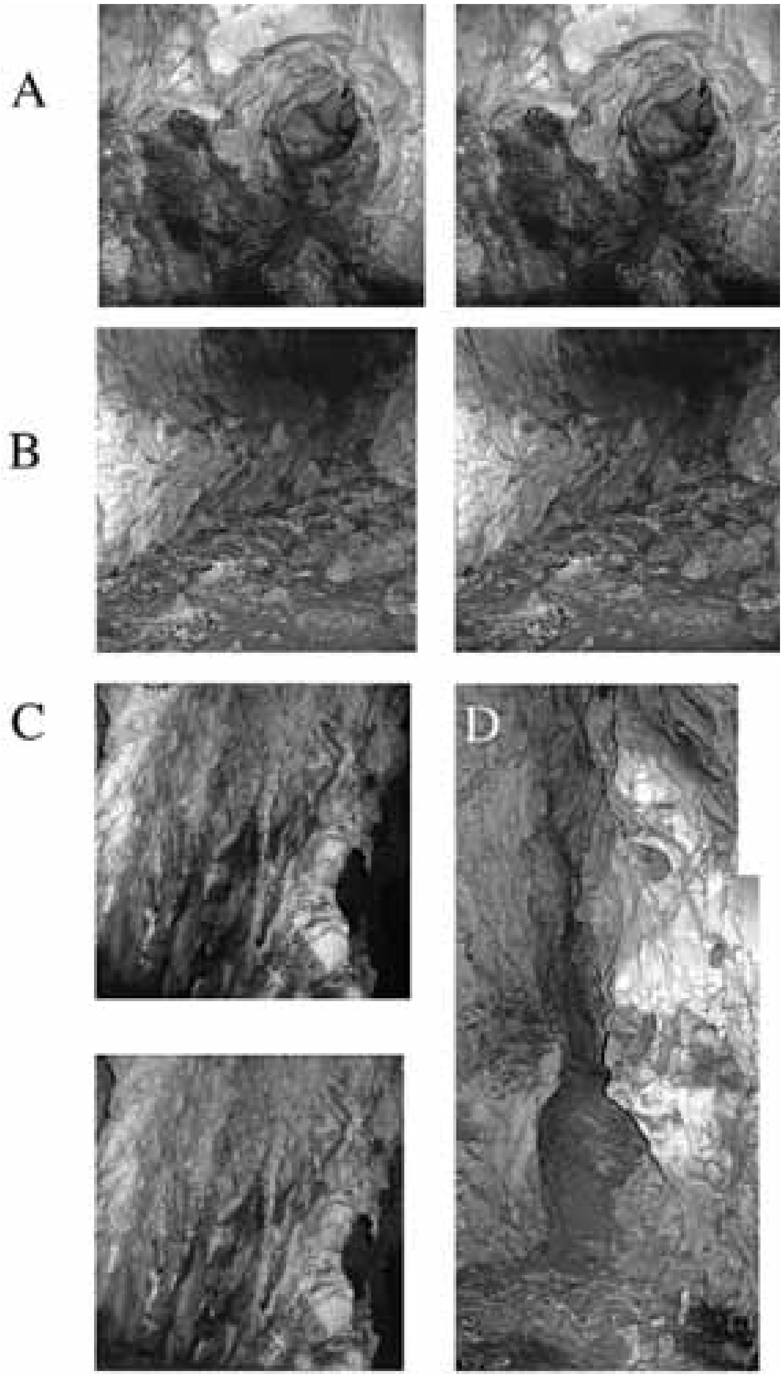

Fig. 14: Stereo Plate 3

- *A - Looking vertically up into the cupola above Station 1, note central dark section and flat ceiling corresponding to "step" in Fig. 6A.*
- *B - Looking vertically up into the ceiling above Station 4, note complex of solution pockets aligned along structural trend running obliquely across photograph.*
- *C - Looking north towards northern end of Narrow Section note inclined elliptical pockets dipping steeply to the east (right) and the blade-like dividers between them.*
- *D - Crenulated wall at southern end of Chamber, looking southwest. Scale is 1 m folding rule.*

ties modified by smaller elliptical hollows and cusps (Fig. 14B).

Hemispherical Cupolas

Hemispherical cupolas are uncommon in the study area. The best example is off the main cavity to the east of Station 6 (Fig. 9D & 12D). The dome of this cupola is approximately 3 m wide and penetrates up 1.5 m above the divider between it and the vault of the Northern Section.

SPELEOGENS

Notches

Distinct notches occur in both walls of the Northern Section to the north of Station 6 (Figures 9D, 11B, 15A & 15D). The lower part of the notch in the western wall near Station 6 is rounded (Figure 11B), while the lower notches in the eastern wall have planar facets at their base (Figures 15A & 15D). The remnant of a notch (or pseu-

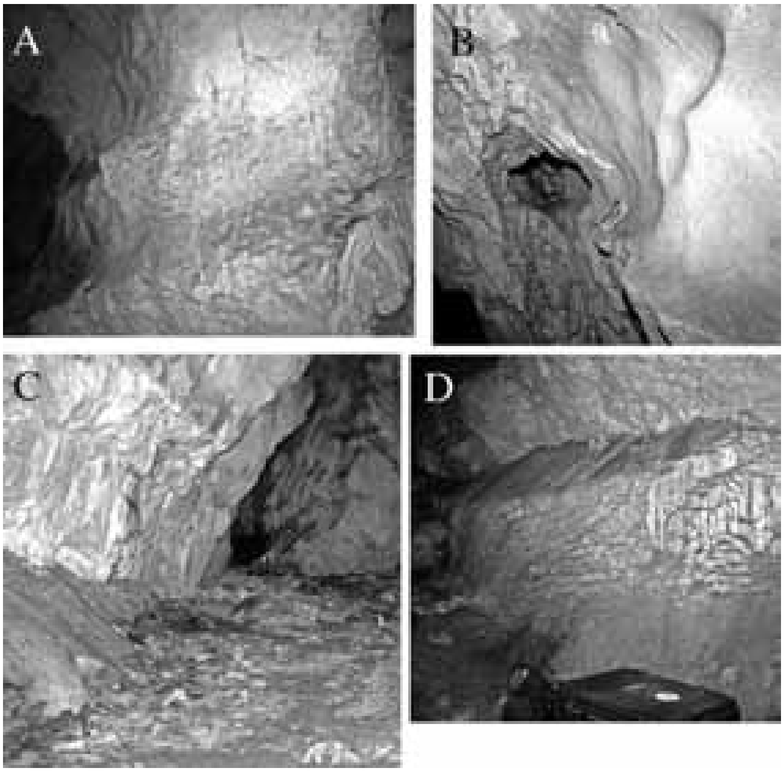

Fig. 15:

A - Facets and notches in eastern wall north of Station 6, note apparent scallops developed on surface of facet at lower right of image.

B - Pseudonotch/half tube extending into blind tube in eastern wall adjacent to Station 4A (see Fig. 9C). Note easterly-dipping structure guiding blind tube. Also note large shallow pockets. Colour blocks on scale are 10 mm.

C - View looking south along eastern wall of the chamber showing well-developed facet at the base of the wall. Note also eastward slope of Narrow Section wall next to Fig. in red caving suit.

D - Well-developed facet in lower part of eastern wall north of Station 6. Black instrument case is 600 mm long.

donotch) occurs high the eastern wall of the Chamber (Fig. 8C &13C).

Facets

Facets occur at two levels in the eastern wall of the Northern Section, north of Station 6 (Fig. 15A & 15D). The lower facet here dips at 45˚ towards 248˚ magnetic. A single facet occurs close to floor level in the eastern wall between Station 5 and Station 6 (Fig. 15C). This facet dips at 45˚ towards 246˚ magnetic. Facets also occur at the northern end of the Narrow Section (Fig. 6D).

Pseudonotches, Half Tubes, Tubes and Blind Pipes

Remnants of a system of small-diameter tubes and blind pipes are intersected by the cave walls to form pseudonotches and half-tubes. A sub-horizontal pseudonotch that ends as a blind pipe, is developed in the eastern wall of the Chamber opposite Station 4A (Fig. 9C & 15B). A vertical tube, partly exposed as a half tube, rises up the western wall from floor level opposite Station 6 (Fig. 9D & 16A).

Blades

Sharp, elongated narrowing projections of bedrock extend from the cave ceiling. These differ from conventional pendants by being elongate and by having a sharp, narrowing edge. Osborne (2007) described this type of speleogen as a blade. In Netopirjev Rov blades run parallel to the principal axes of the cavities.

? Scallops

Large scallop-like depressions occur in small section the eastern wall adjacent to Station 6. This is the only occurrence of this type of speleogen in the study area. These depressions occur on the upper and lower (concave) surfaces of a notch and suggest slow upwards flow towards an opening in the upper wall (Fig. 15A).

Cusps

Cusps are small elliptical hollows in cave walls and ceilings, they frequently occur as modifications to the surfaces of cupolas. There are many cusps in the ceiling above Station 4 (Fig. 16B) where they occur in the surfaces of larger elliptical features.

Large Shallow Pockets

Large shallow pockets occur occasionally in the upper parts of cave walls, most frequently, but not always, within the ceiling vaults or cupolas. These are shallow depressions with a circular outline, approximately 400 mm in diameter and 300 mm deep. A good example is found in the east wall of the Eastern Vault (Fig. 9C & 16C)

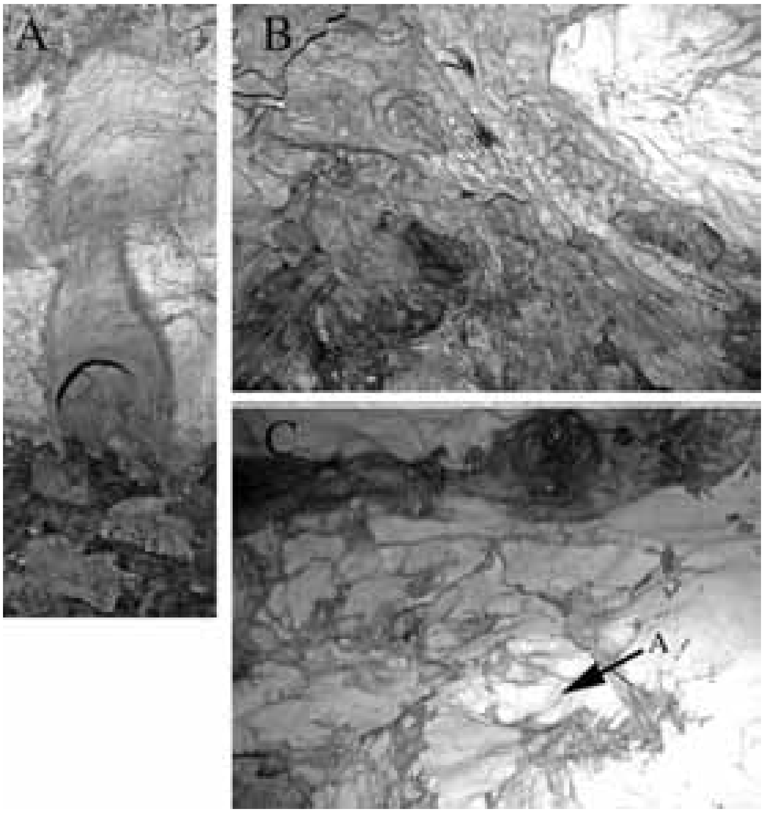

Fig. 16:

A - Vertical tube exposed as half tube at base of western wall opposite Station 6 (see Fig. 9D).

B - Elliptical cusps developed on surfaces of small elliptical cupolas in cave ceiling.

C - Large shallow pocket, looking up to the west from Station 4A, Axis of Eastern Vault is visible in top of frame. The location of the large shallow pocket is indicated by "A" (see also Fig. 9C).

Vertical and Inclined, Structurally-Guided Pockets

These are elliptical hollows frequently 1 m high x 100-200 mm wide and up to 1 m deep. They are developed along structural planes in the cave walls. Vertical pockets form where the cave walls are perpendicular to the NNW-SSE and the NNE-SSW structures. Outstanding examples of vertical structurally-guided pockets occur at the end of the Northern Section (east of J' in Fig. 5, Fig. 11C).

Inclined structurally-guided pockets are well developed in the north wall of the Narrow Section opposite Station 3 (near D' in Fig. 5, Fig. 14C).

WALL MORPHOLOGY

Wall morphology in the study area results from a complex interplay between geological structure and cave forming processes.

Where cave walls are oblique or perpendicular to the principal structural planes complex morphologies develop, while walls parallel to the principal north-northwest to south-southeast trending structure tend to be planar. The hanging wall tends to overhang at between 62-72 degrees, close to the average angle of dip of the guiding structure (66^o), while the footwall is much closer to vertical, dipping to the east at approximately 80 degrees.

Crenulated Walls

This type of wall surface is produced by the interaction of solution with two structural planes in the wall. Rather than producing the deep structurally-guided pockets described above, the wall surface in this case is crenulated into a series of ribs composed of triangular points and hollows, each surface roughly following a structural plane.

A good example of this morphology occurs in the SW wall at the junction of the Chamber and the Narrow Section of the cave (Figure 5). Here the wall has a crenulated, almost corrugated surface resulting from a combination of almost vertical flutes and ribs (Figu. 14D).

BREAKDOWN

While much of the cave floor is composed of relatively small breakdown blocks, there is little evidence for recent breakdown in the study area. The principal masses of breakdown debris are located in the floor of the Narrow Section and as a fan at the northern end of the study area. The fan is debris from the failure of the cave wall that created the pseudobend but the origin of the breakdown debris in the Narrow Section is unclear. The breakdown mounds in the Chamber are probably derived from the failure of the lower section of the divider between the ceiling voids (i.e. the common wall between the two originally separate voids).

MORPHOSTRATIGRAPHY

A morphostratigraphy for the study area can be constructed by examining the cross cutting relationships between different types of large cave voids and speleogens. This suggests the following stages of cavity development:

1 Development of the Fossil Tube and other phreatic tubes, now represented by pseudonotches (1 in Fig. 17)
2 Development of rising tubes and cupolas (2 in Fig. 17)
3 Development of cathedrals, now forming ceiling voids (3 in Fig. 17)
4 Integration by breakdown of walls between cathedrals (4 in Fig. 17)

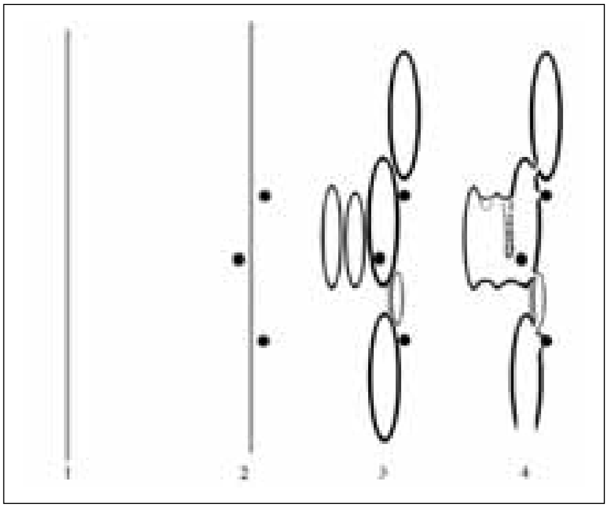

Fig. 17: Evolution of Netopirjev Rov

1 - Fossil phreatic tube forms.

2 - Cupolas and rising tubes form in first phase of hypogenic speleogenesis.

3 - Cathedrals form, intersecting the cupolas and rising tubes in second phase of hypogenic speleogenesis. The cathedrals are laterally disconnected.

4 - Cathedrals become integrated largely by breakdown (failure) of their adjoining walls.

INTEGRATION

After the third stage of development Netopirjev Rov would have not been a "passage", but rather a series of isolated adjoining cavities (3 in Fig. 17). The present condition of the cave results from the integration of these cavities. This was probably a result of solution thinning the walls between adjacent cavities, followed by the more obvious breakdown failure of the walls.

DISCUSSION

Neither the general form of Netopirjev Rov, nor the suite of speleogens found there, are typical of those of conventional fluvial caves. There is nothing to indicate that water flowed horizontally from south to north (or from north to south) during the last two phases of cave development. The only scallops present are large and indicate slow upwards flow. Most of the major cavities and speleogens are guided to a significant degree, if not controlled by, geological structures, principally joints and shear planes. Bedding and lithology appear to play no role in cave development in the study area. There are no level or planed ceilings suggesting epiphreatic or paragenetic development and no relict fluvial or paragenetic sediments.

Rising water could have entered this section of cave as a result of flooding or due to sedimentation and paragenesis at a lower level. They simplest mechanism for this would be for water to rise up through the existing connection to Velika dvorana (prior to the breakdown), flow laterally northwards to the study area and then rise through open joints in the cave ceiling excavating the cupolas and ceiling vaults etc (see Fig. 3B). The problem with this mechanism is that prior to breakdown of the party wall the western vault of the chamber was blind along strike and could not have received lateral flow form the south. The same applies to the section of cave north of the study area. Prior to breakdown producing the projecting corner, the northern segment of the cave was also blind (see "4" in Fig. 17).

Another possibility is that flood or paragenetic water rose from below directly into the blind cavities. This would require feeder connections from the lower section of the cave directly below the main chambers and the cupolas. As the cave floor is composed largely of gravel to cobble sized breakdown fragments it is impossible to determine the shape of the cavities below floor level, but it does not seem likely that there are filled vertical connections below the floor to the lower cave levels.

Cavities and speleogens similar to those in Netopirjev Rov occur in hypogene caves of both thermal and artesian origin as described by Klimchouk (2007). While tube feeders do occur in these caves, the dissolving fluids were often directed through rifts developed directly up the structural planes (propagation planes) along which both large and small-scale cavities are excavated. These "fissure and rift-like feeders" (see Plate 5, p 45 of Klimchouk 2007) take the form of slots opening down the guiding structural plane in the cave floor. Such structures could easily be blocked and covered beneath breakdown below the cave floor.

CONCLUSIONS

The gross cave morphology and the speleogens in the study area are inconsistent with a single-phase fluvial origin for this section of cave. The gross cave morphology and the speleogens suggest that following an initial phreatic phase; two later phases of major cave excavation in Netopirjev Rov resulted from solution by rising groundwater. It seems likely that the dissolving groundwater was directed upwards through structural planes in the limestone, rather than laterally along cave passages or up a "feeder" tube from a lower level. Netopirjev Rov is thus a multiphase non-fluvial, per-ascensum (i.e. Hypogene sensu Klimchouk 2007) segment of cave with later modification by breakdown.

There is as yet no indication of the source, chemistry or temperature of the waters involved in the hypogene excavation of this section of cave. Its close association with a fault and fault-related shear planes suggests that waters travelling at depth along the fault plane may have been involved.

IMPLICATIONS

While hypogene caves have been reported from neighbouring countries such as Hungary and Italy, I am unaware of published reports of hypogene caves or hypogene sections of caves from Slovenia. Audra (pers comm. 2008) reports three thermal caves in Slovenia while I am personally aware of several other suspect hypogene caves and sections of caves in Slovenia. The presence of hypogene features in the upper section of Predjama Cave and their close association with a fault suggest that similar features might exist elsewhere in Slovenia either as relicts in old sections of large complex caves or in individual hypogene caves directly adjacent to faults.

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NOTE ON STEREO FIGURES

The stereo images in Fig. 8, 11 and 14 are laid out for viewing with a pocket lens stereoscope. In all but Fig. 11C the viewing axis is horizontal. To view Fig. 11C the axis of the stereoscope needs to be vertical to the page.

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