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Observations on the geology and geomorphology of a large doline in dolostone at Forest Hills, Tasmanian Wilderness World Heritage Area

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Abstract

The Forest Hills is a remote karst area in the Tasmanian Wilderness World Heritage Area. The principal evidence for karst at this location is the Forest Hills Depression – a large (80 ha) doline and associated stream sink cave. The depression is formed in dolomitic strata, probably a correlate of the Weld River Dolomite (Calver 1989). This paper provides an updated geological map of the Forest Hills and upper New River Gorge plus the first descriptions of the associated karst features, including the large Forest Hills Cave. The Forest Hills Depression is a significant example of an enclosed depression that is noteworthy for its undisturbed condition and remote wilderness setting. Compared to other large karst depressions in Tasmania, several of which are derived from glacio-karstic interactions, the Forest Hills Depression stands out as a genetically less complex example formed chiefly by conventional solution-driven karstification.

Keywords: karst, caves, dolostone, Tasmanian Wilderness World Heritage Area, Forest Hills

Introduction

The Proterozoic rocks of western Tasmania include fractured, folded and variably silicified dolomitic strata, within the Togari, Weld River and Clarke Groups (Calver 1989, Calver and others 2014). The surface expressions of these strata exhibit diverse styles of karstification (Kiernan 1995), including rugged alpine karst at Mt Anne, Mt Weld and Mt Ronald Cross, steep-sided cavernous residual hills in valley floor settings at Maxwell River and Lightning Plains, highly decorated caves in hill flank karst at Hastings, spectacular riverine gorges and natural arches at Jane River and Weld River, polje-like depressions and spring mounds at Smithton and Dismal Swamp, probable hydrothermal karst at Mt Weld, and karren-rich coastal karst at Birthday Bay and Point Hibbs. The extent and variety of karstification of dolomitic strata in western Tasmania challenges the conventional view that dolostone (often referred to simply as ‘dolomite’, the dominant mineral in dolostone rock) is less susceptible to karstification than typical limestones, due to the lesser solubility of the mineral dolomite compared to calcite (Rauch & White 1970).

The Forest Hills are located within the catchment of the New River, which rises on the Eastern Arthur Range at Lake Geeves and then flows in a broadly south-easterly direction to New River Lagoon on Tasmania’s south coast. The closest vehicular access is 25 and 28 km east of the Forest Hills at Hartz Mountains and Hastings Caves respectively, and the closest walking track is 23 km away at the mouth of the New River Lagoon on the South Coast (Figure 1). The difficulty of access is compounded by gorges and deeply dissected fluvial terrain mantled by a dense and almost unbroken forest cover (Figures 2 and 5). Consequently, Forest Hills remains one of the least explored and minimally documented karst areas in Tasmania.

The possible presence of karst at the Forest Hills came to attention in the early 1970s following publication of the 1:100,000 scale Tasmap Huon sheet. Depression contours on the map (based on aerial photogrammetry) suggested the existence of a large, fully enclosed perched basin overlooking the New River Gorge between the Forest Hills to the south and the Crest Range to the north. We refer to

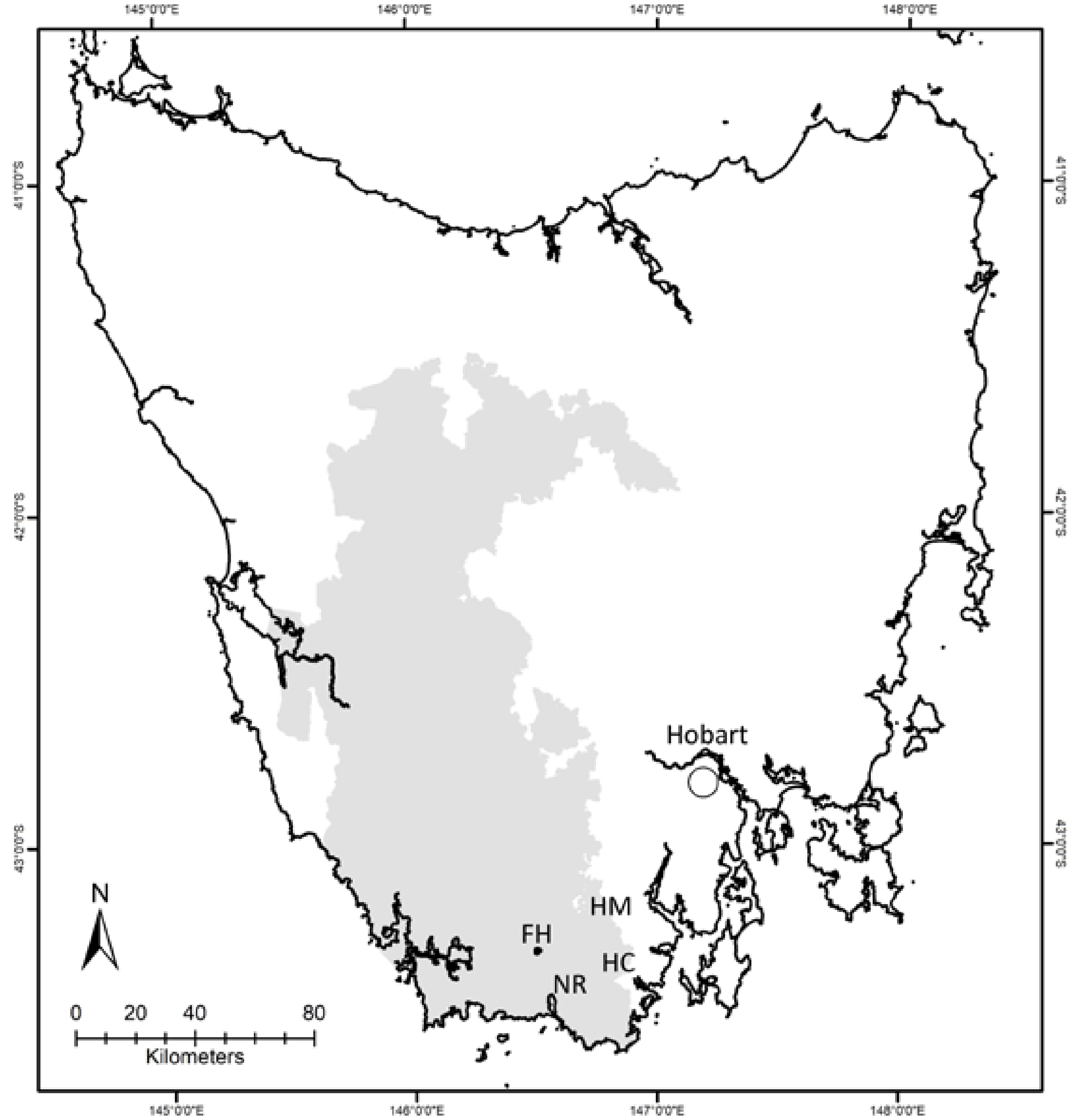

Figure 1. Tasmania showing the locations of the Forest Hills (FH), Hartz Mountains (HM), Hastings Caves (HC), New River Lagoon (NR) and the Tasmanian Wilderness World Heritage Area (shaded). The map co-ordinates are geographical (degrees latitude and longitude) based on the WGS84 datum.

this feature as the Forest Hills Depression[1] (Figures 2 and 3). Members of the Tasmanian Caverneering Club (TCC) initiated an aerial reconnaissance of the Forest Hills in 1972 (Shaw 1973), sighting a large cave entrance within the depression (see Figure 4). Two members of the club – Attila Vrana and Jeanette Collin – subsequently mounted a ground-based expedition to explore the cave. They left no published account of this but in conversation with one of us (RE) in 2013, Collin confirmed that she and Vrana had successfully navigated to the depression and explored the cave seen previously from the air. Her recollection of the cave was vague but suggested that it terminated at a sump or log blockage not far underground.

There appears to have been no further interest in the Forest Hills karst until 1985 when one of us (CS) and Grant Dixon made geological observations during a rafting trip through the New River Gorge. The depression itself was not explored but dolomitic rock was noted cropping out close by on the New River, leading the authors to infer the presence of similar strata within the Forest Hills Depression (Dixon & Sharples 1986). This prediction was confirmed by us during fieldwork at Forest Hills by the (then) Department of Primary Industries, Parks, Water and Environment in February 2012, part of a broader survey of the karst systems of the

1. We adopt the term 'depression' for the purpose of naming the Forest Hills feature, because this avoids the regionally derived morpho-genetic connotations of more specific words often applied to large, enclosed karst basins (e.g. uvala, polje). In doing so, we note that the Forest Hills Depression conforms to the accepted definition for a doline or sinkhole (Field 2002).

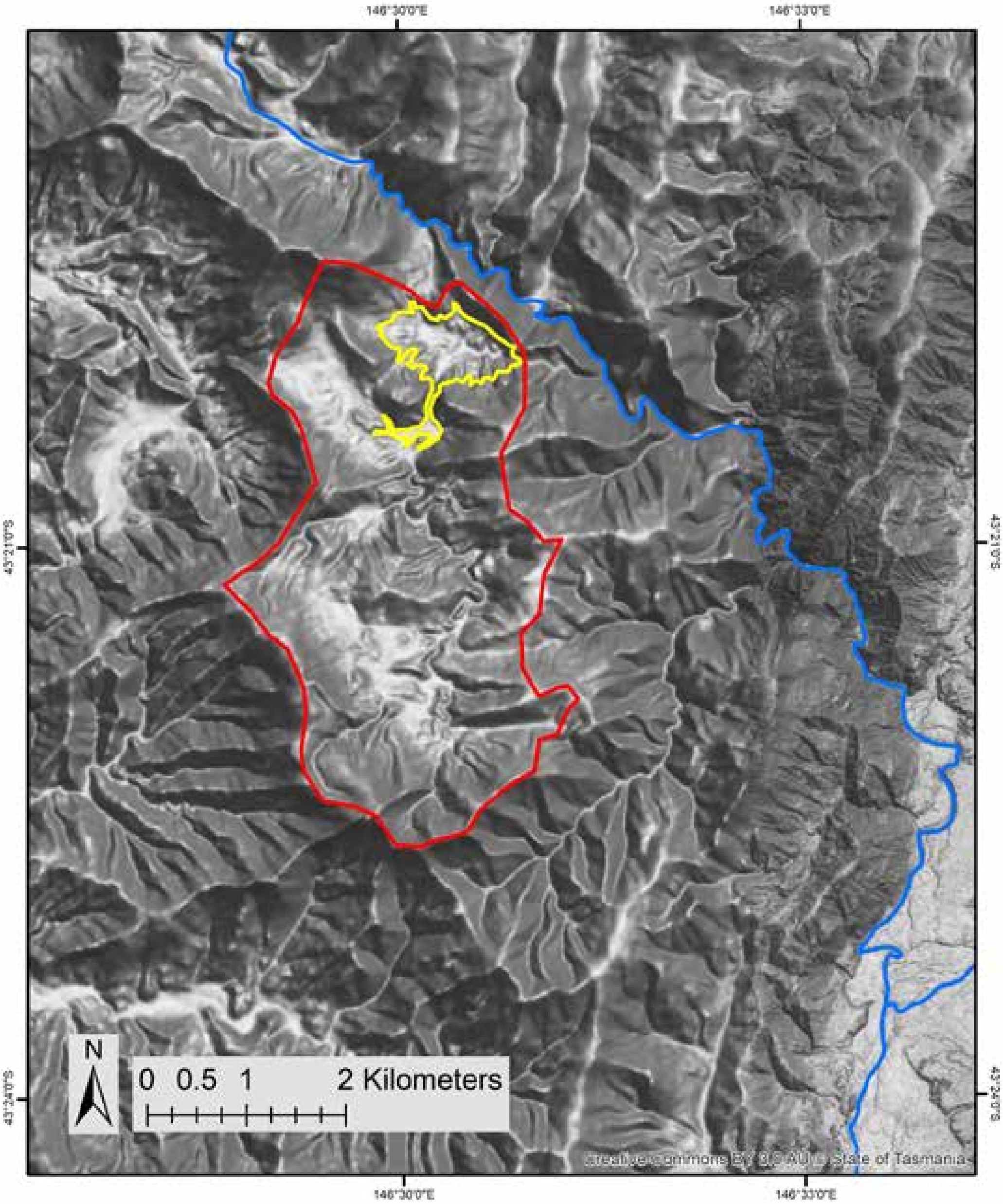

Figure 2. Digital elevation model of the Forest Hills identifying the Forest Hills Depression (yellow polygon), its catchment area (red polygon) and the New River (blue line). Basemap: hill shade (source: Land Information System Tasmania LISTmap). The map co-ordinates are geographical (degrees latitude and longitude) based on the WGS84 datum.

Tasmanian Wilderness World Heritage Area. In this paper we present the results of the Forest Hills component of that survey.

Methods

Access

We gained access to the Forest Hills from the Crest Range by descending from a point near Satellite Lake to the New River at the upstream end of the New River Gorge (Figures 5 & 6). After bivouacking on a mid-stream shingle bar in the river, we traversed a narrow ridge extending between the upstream end of the New River Gorge and the Forest Hills Depression, entering it from the north (Figure 6).

Map co-ordinate system and grid references

Location data in this paper is based on hand-held GPS waypoints collected in the field. The results are shown on the map figures as geographical (latitude-longitude) co-ordinates based on the WGS84 datum, but waypoint locations are recorded in Appendix 1 as both geographical co-ordinates and as Map Grid of Australia (MGA) Zone 55 eastings and northings based on the Geodetic Datum of Australia (GDA94) and the Universal Transverse Mercator (UTM) projection.

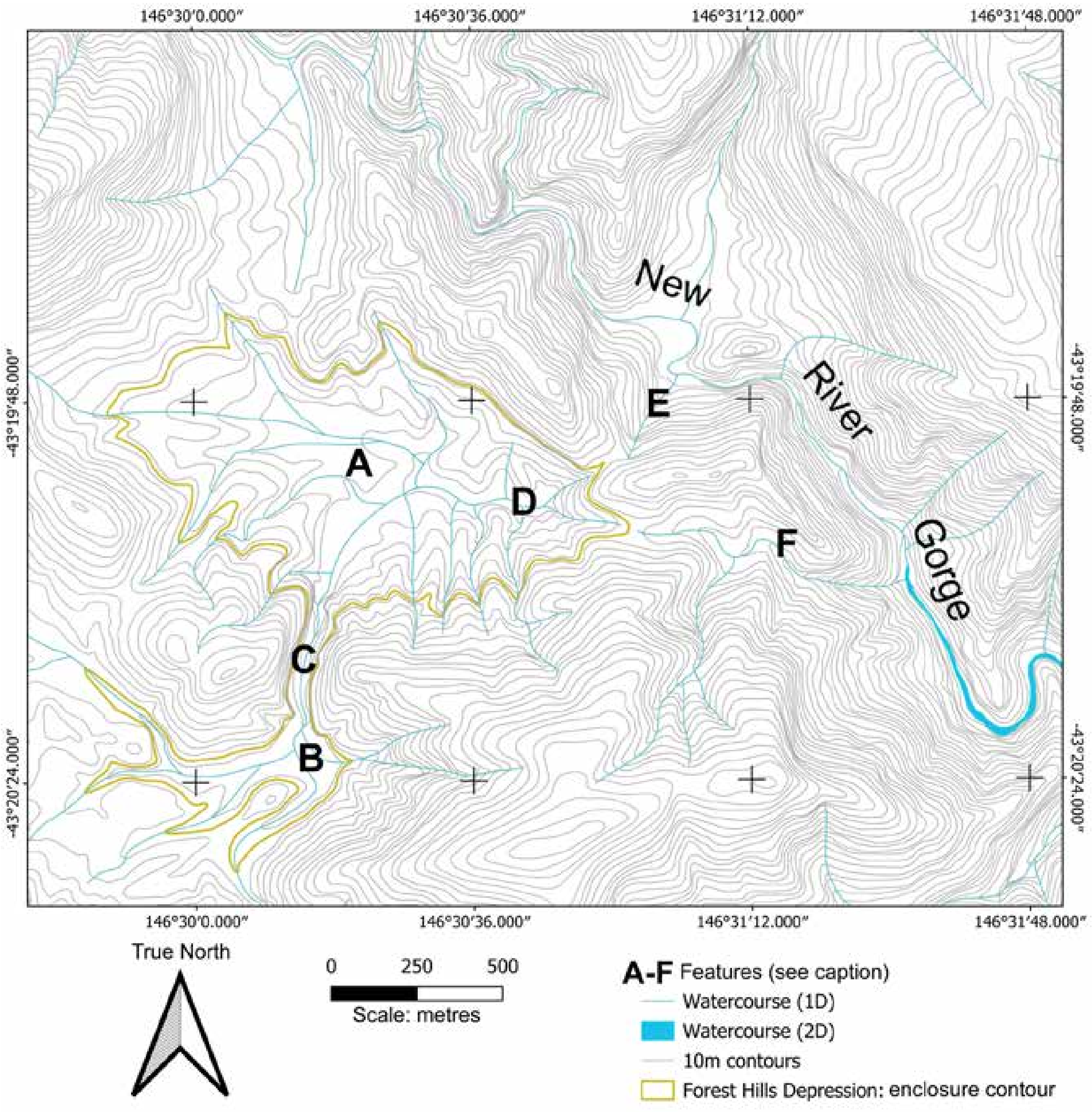

Figure 3. Contour map of the Forest Hills Depression showing: the northern (A) and southern (B) lobes of the depression, connected by a breach (C) in the intervening ridge (item 4 on Figure 5). Water sinking underground at Forest Hills Cave (D) probably discharges from one of two candidate tributaries (E, F) feeding the New River (see geomorphology text for discussion). Map Source: 10 m contours and watercourses from Land Information System Tasmania (LISTmap). The map co-ordinates are geographical (degrees latitude and longitude) based on the WGS84 datum.

Geological bedding dip and strike measurements

Bedding dip and strike measurements were measured in the field as inclinations in conventional degrees and as magnetic compass directions. Compass readings are reported 'as read', noting that the 2012 magnetic north (MN) was 15.05° east of true north for this location.

Cave maps

Cave maps presented here (Figures 16 and 18) are based on conventional point to point survey traverses using Suunto compass and clinometer (±0.5°) and handheld laser rangefinder (±0.05 m). The standard conforms to ASF Mapping Grade 54 or better.

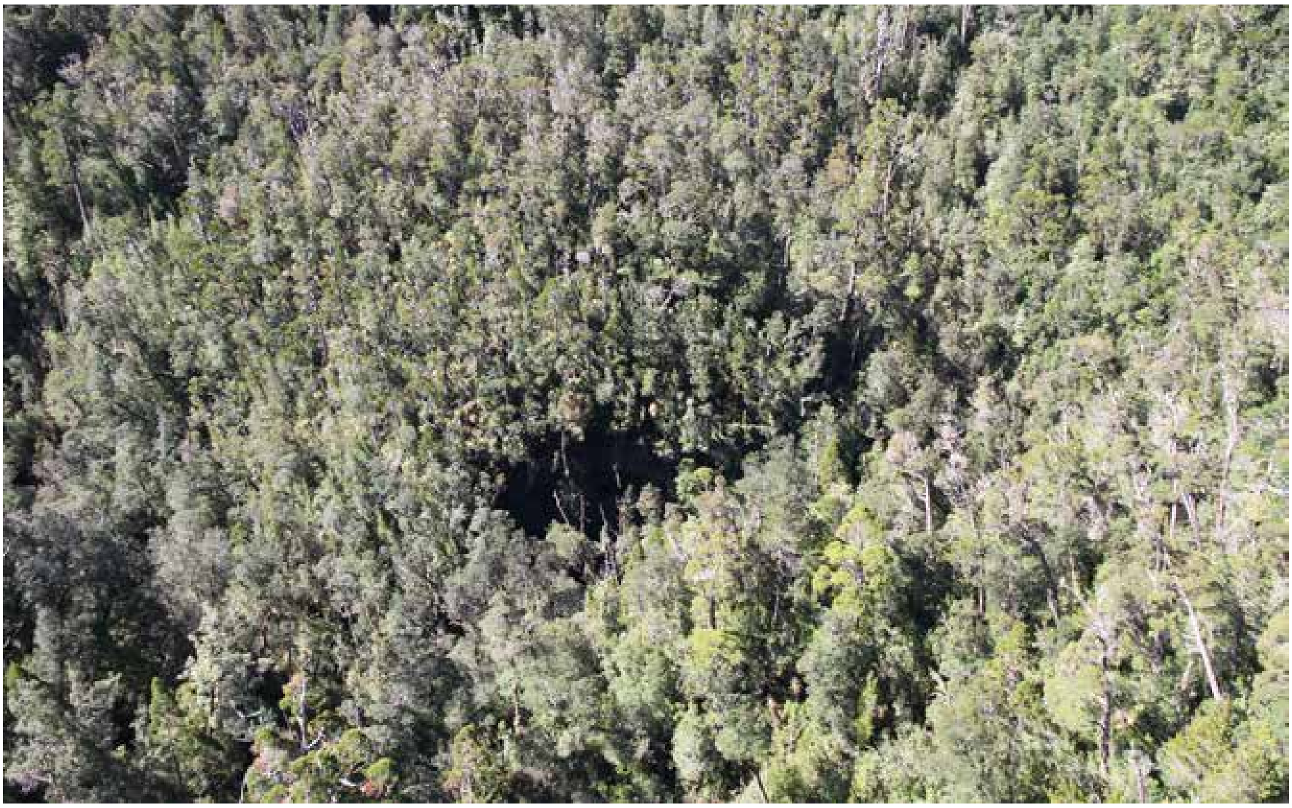

Figure 4. Aerial view of the deepest point of the Forest Hills Depression. The apparent cavity at the centre of the image is a 20 m high overhanging cliff directly above Forest Hills Cave (see Figure 15). In this image the point of entry to the cave is concealed by vegetation (Photo by Rolan Eberhard).

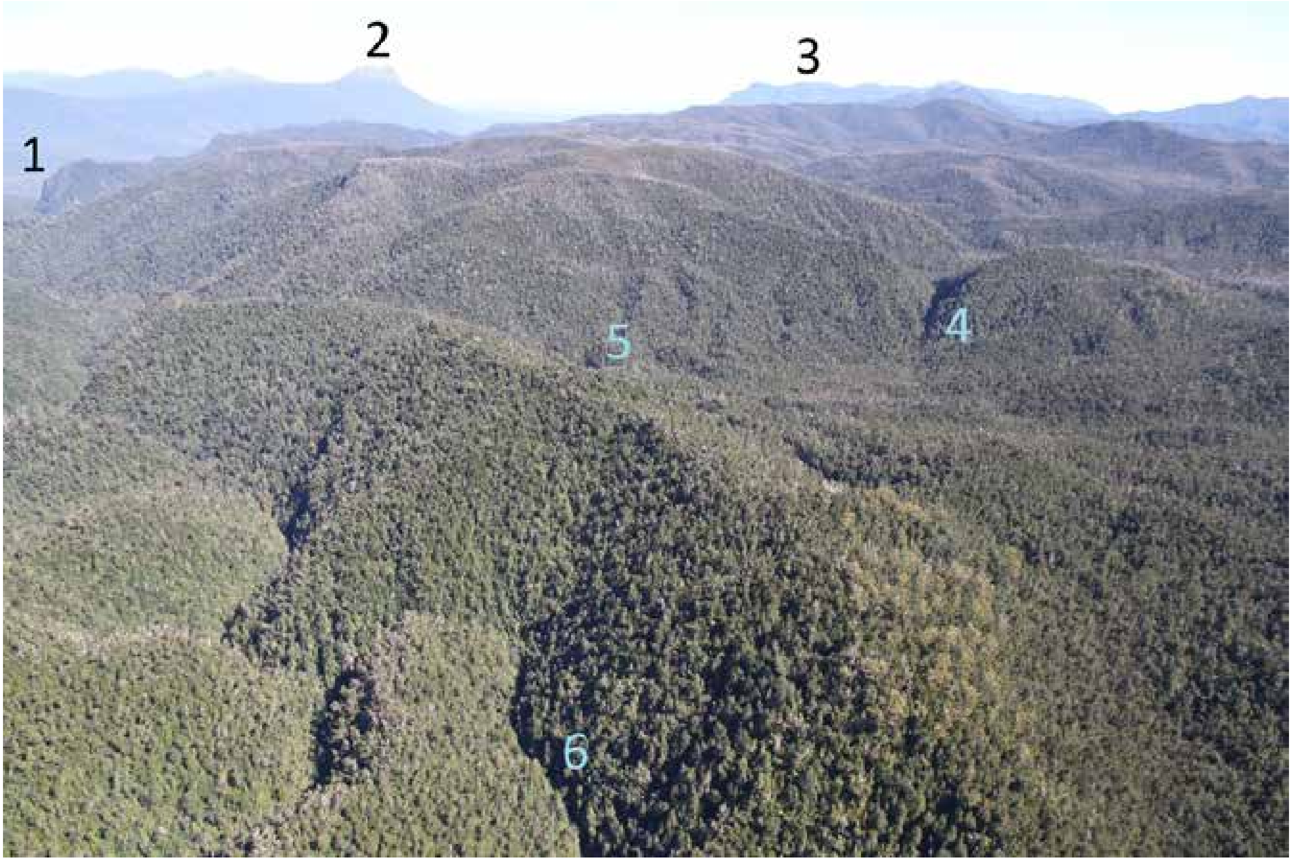

Figure 5. Oblique aerial view of the Forest Hills looking south from the Crest Range. 1: Gibraltar (bluff on the New River, see Figure 13); 2: Precipitous Bluff; 3: Ironbound Range; 4: gorge connecting northern and southern lobes of the Forest Hills Depression (breaching a presumed strike ridge in siliclastic rock); 5: Forest Hills Cave (deepest point in the Forest Hills Depression); 6: upstream end of New River Gorge (Photo by Rolan Eberhard).

Results

1. Geology

This section provides a summary of the bedrock geology observed in the upper sections of the New River Gorge and in the Forest Hills Depression. An updated interpretation of the local geological structure is also provided. Geological observations at some individual waypoints are tabulated at Appendix 1.

New River Gorge Section

The following observations refer to bedrock exposures in the upper New River Gorge, 1 km north of the Forest Hills Depression. Rock units are described from upstream to downstream, referencing GPS waypoints shown at Figure 6. The most downstream observation aligns with, and corroborates, the most upstream observation on the New River by Dixon and Sharples (1986).

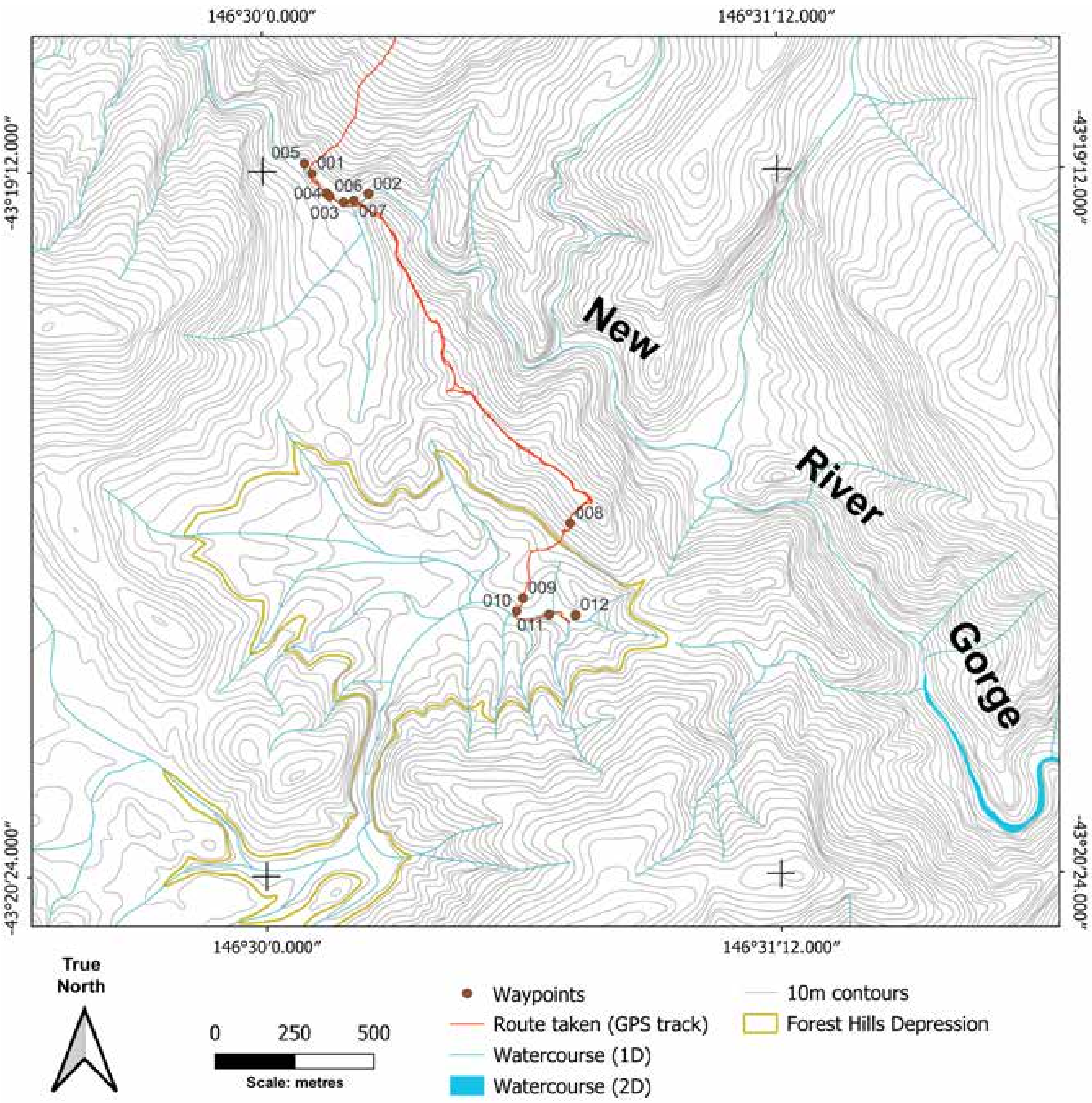

Figure 6. Map of the part of the upper New River Gorge and Forest Hills Depression visited during 2012, showing numbered waypoints and tracks as recorded by GPS. Map Source: 10 m contours and watercourses from Land Information System Tasmania (LISTmap) The map co-ordinates are geographical (degrees latitude and longitude) based on the WGS84 datum.

Quartzite (upstream exposures)

Well-bedded hard grey fine-grained quartzite with planar beds and finer planar laminations crops out at Waypoint 005 and at least 100 m upstream of this point. The bedding dips at 50° towards 340° MN (striking ~70° MN). Bed facing is unknown. No outcrop was detected for about 100 m downstream of Waypoint 005.

Reddish-brown slates

Fine-grained reddish-brown slate crops out along this stretch of the river from Waypoint 004 to 003, including Waypoint 006. At Waypoint 006 the bedding dips 70° towards 25° MN (striking ~295° MN). A strong cleavage dipping 35° towards 265° MN was noted. Bed facing is unknown. Planar vertical joint fractures spaced 30-40 cm apart were observed in an outcrop at Waypoint 004. A dominant joint set strikes ~300° MN, and a secondary vertical set strikes roughly normal to this.

Quartzite (downstream exposures)

Well-bedded hard fine-grained grey quartzite with generally planar to finely laminated bedding crops out between Waypoints 003 and 002, including Waypoint 007. At Waypoint 007 the beds dip 80° towards 30° MN (strike ~300° MN). Bed facing is unknown. Tight isoclinal folds with roughly 0.5 metre wavelengths were observed in several places.

Dolomitic siltstones and interbedded quartzite

Fine-grained grey-to-pale-brownish well-bedded laminated dolomitic siltstone crops out at Waypoint 002. A specimen from this site was previously confirmed in stained thin section to be dolomitic siltstone (Dixon & Sharples 1986). A fine-grained planar-bedded quartzite bed which crops out immediately downstream of the dolomitic siltstone is interpreted as an interbed within the broader dolostone sequence of the New River Gorge. This sequence extends for several kilometres downstream of Waypoint 002 and includes siliceous conglomerate interbeds, as mapped by Dixon & Sharples (1986).

The dolomitic siltstone at Waypoint 002 dips steeply at 80° towards 30° MN (strike ~300° MN), suggesting it is conformable with the quartzites and slates upstream.

The outcrops show fine slightly undulous laminations (possibly algal laminations) and some breaks in the laminations are suggestive of mud cracks, consistent with deposition in a low-energy intertidal to supratidal environment. Considerable variation in dolomite content is apparent, with sporadic small lenses of relatively pure pale brown dolostone 10-20 mm thick and 100-150 mm long being present, and some more dolomitic brown siltstone interbeds showing recessive weathering surfaces compared to less dolomitic grey beds standing proud adjacent.

A tight isoclinal fold axis striking approximately 350° MN is visible in the quartzite beds immediately downstream of the dolomitic siltstones at Waypoint 002; folding along this axis may explain the strong cleavage observed in the reddish-brown slates upstream (see above). A weak cleavage is also visible in the dolomitic siltstones at Waypoint 002, dipping about 45° towards the north and striking roughly east-west, although this cleavage is not explained by the aforementioned folding.

Siliceous conglomerate boulders

Sporadic allochthonous boulders of hard siliceous conglomerate with coarse well-rounded siliceous clasts were observed in the New River Gorge between Waypoints 001 and 002. These may be derived from upslope outcrops of the conglomerate beds reported downstream of Waypoint 006 by Dixon & Sharples (1986).

Forest Hills Depression

The following observations are presented in the order they were made when entering the depression from the north, via a high-relief and south-east trending ridge rising from the south side of the New River Gorge (Figure 6). This ridge is roughly aligned with quartzite bedding strikes observed in the New River bed directly below its northwest end between Waypoints 003 and 002 (Figure 6) and is therefore inferred to be a mainly clastic bedrock strike ridge. No outcrop was observed on the densely vegetated ridge-top; however, clastic rocks were noted at waypoints 008 and 009 on the south-western flanks of the ridge as described below. The route taken joins the main watercourse draining across the base of the depression to sink at the Forest Hills Cave (Waypoint 012). Approaching the sinking point of the stream at Forest Hills Cave, the channel narrows to a small ravine with plunge pools and a high-level cave (Canyon Cave). These features provide clear exposures of bedrock within the eastern portion of the depression.

Siliceous cleaved pink siltstone (slate)

Angular lag fragments of moderately hard, very fine-grained, well-sorted, siliceous, orange-pink (Munsell 10 R 7/4) to brownish-pink laminated siltstones were observed high on the strike ridge forming the north-eastern slope of the Forest Hills Depression at Waypoint 008. No in situ bedding orientation was apparent. The rock shows a distinct cleavage indicative of low-grade regional metamorphism and is inferred to be an extension of the reddish-brown slate unit observed in the New River Gorge.

Siltstones with secondary carbonate

Laminated siltstone bedrock crops out low on the strike ridge forming the north-eastern slope of the Forest Hills Depression at Waypoint 009. The beds dip at 80° towards 20° MN (strike ~290° MN). Patches of chalky surficial deposits suggestive of tufa were observed at the base of the siltstone outcrop, implying a local carbonate source. This outcrop is almost certainly a siltstone interbed within dolostone strata that crop out a short distance downslope (see below). Angular lag fragments of similar siltstone were also noted upslope at Waypoint 008.

Dolostone with minor phyllitic siltstone interbeds

No outcrop was observed between Waypoints 009 and 011. However, numerous outcrops of dolostone bedrock were observed on the watercourse between Waypoints 011 and 012 and inside Canyon Cave and Forest Hills Cave, as described below.

Figure 7. Apparent small-scale folding of interbedded dolostone and dark silty (carbonaceous?) beds or laminae exposed at Canyon Cave (Waypoint 011). These may be tectonic folds, soft-sediment deformation features, or stromatolitic algal mat fossils (Photo by Chris Sharples).

Figure 8. Thin silica boxwork veins standing proud of the dolostone matrix in Canyon Cave (Waypoint 011) (Photo by Chris Sharples).

Canyon Cave

Waypoint 011 marks the location of Canyon Cave, an upper-level conduit in the side of the ravine draining to Forest Hills Cave. Canyon Cave is formed in a hard, relatively pure, creamy-white to creamy-pale brown coloured fine-grained rock with generally thin to laminated planar bedding. In places, purer dolostone is interbedded with fine-grained, dark brown, laminated silty layers 0.5-20 mm thick. The latter may be clastic and/or carbonaceous layers, and a silty algal mat origin is possible. The bedding is mostly planar but distinctly 'wavy' bedforms (with wavelengths of ~100 mm) are evident in some sections. These may be fine tectonic or soft-sediment deformation folds or stromatolitic algal mat growth forms (Figure 7). Thin silica veins are also present, commonly in several cross-cutting parallel sets. Differential weathering of these features has produced minor silica boxworks within the cave (Figure 8). Some of the dolomite beds are offset by small faults.

Planar-laminated dolostone bedding orientation was measured at two points in the cave. At the back end of the cave the dolostone bedding dips at 70° towards 30° MN (strike ~ 300° MN), and at the cave entrance the dolostone bedding dips very steeply (close to vertical) towards 25° MN and strikes about 295° MN. Bed facing is unknown.

Forest Hills Cave

Similar dolostone occurs within Forest Hills Cave near Waypoint 012. Here, the rock is a hard, crystalline and fine-grained, varying in colour from white (Munsell N9) on fresh surfaces to creamy-yellow (Munsell very pale orange 10 YR 8/2) on weathered surfaces. Multiple cross-cutting sets of parallel thin linear silica veins 0.5-10 mm thick have weathered to form boxworks within the cave. Bedding generally appears massive but fine planar laminae are visible in some exposures and thin planar beds in others. Bedding dip at two points was measured at 50° towards 35° MN (strike ~305° MN) and 55° towards 30° MN (strike ~300° MN). Bed facing is unknown.

Large displaced dolostone boulders at the cave entrance exhibit sub-ordinate foliated fine-grained clastic sedimentary interbeds generally 50-100 mm thick but up to 1.0 metre thick at one point. In hand specimen this is a fine-grained siliceous siltstone. The colour is pale greenish (Munsell light olive grey 5 Y 6/1) on fresh surfaces but weathered to brown on weathered surfaces. The rock is distinctly foliated with a micaceous sheen on slightly undulose broken cleavage planes and may be best described as a phyllite or phyllitic siltstone indicative of low-grade regional metamorphism.

A clast of the dolostone collected outside Forest Hills Cave was submitted for analysis at the Mineral Resources Tasmania laboratory, Rosny (MRT collection No. G403296). Images of the hand specimen and thin sections are provided at Figures 9 to 11. The report (Bottrill & Woolley 2015) describes the rock as a banded, veined and brecciated carbonate rock, with a mostly white colour and brown/fawn coloured carbonate veins and discontinuous bands to a few millimetres in width. Based on acid tests, the presence of dolomite as the main carbonate is inferred. In thin section the rock is described as a brecciated, veined dolostone, with micritic to finely sparry dolomite (neomorphic pseudospar?) cut by discontinuous bands and veins of chert and macroquartz. The specimen shows good indications of early banding resembling cryptalgal or stromatolitic laminations, partly altered by layer-parallel diagenetic formation of sparry dolomite. Also, coarser carbonates and quartz clots appear to have formed in tectonic veins and fractures, along with moderate primary foliation (sedimentary banding), some conjugate veining due to brittle deformation, and strong indications of the introduction of silica as chert

Figure 9. Hand sample of dolostone from the Forest Hills Depression, collected just outside Canyon Cave at Waypoint 011 (Mineral Resources Tasmania collection No. G403296). Banded and stock worked quartz-dolostone rock with probable sedimentary layers (sub-vertical, brown), variably silicified and cut by a network of brown quartz-carbonate veinlets in a white dolostone matrix (Bottrill and Woolley 2015). Field of view: 100 mm.

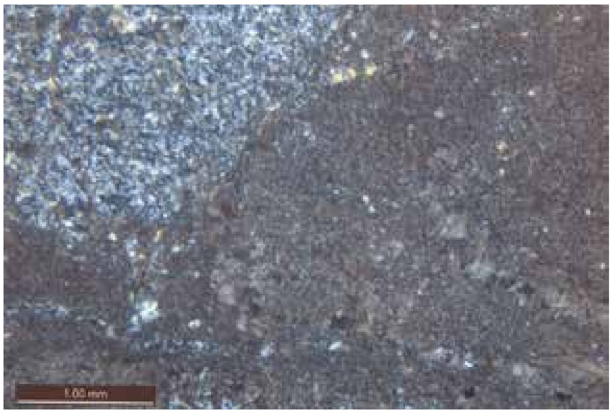

Figure 10. Thin section of sample G403296, collected just outside Canyon Cave at Waypoint 011. Brecciated quartz-dolostone rock, showing a block of quartz dolomite (white-pale grey-yellow) in the top left, in a micritic to finely sparry dolomite (brownish grey) matrix, with some dolomite (Bottrill and Woolley 2015)

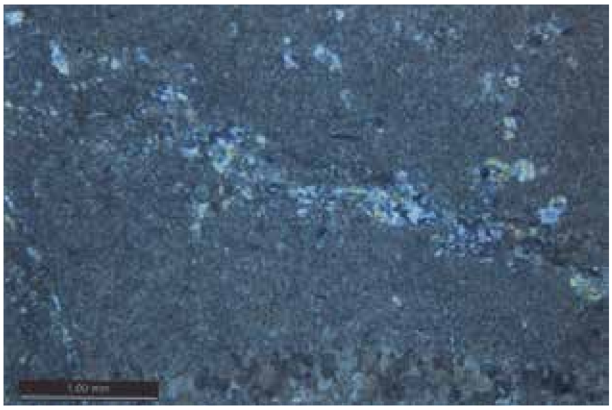

Figure 11. Thin section of sample G403296, collected just outside Canyon Cave at Waypoint 011. Brecciated quartz-dolostone rock, showing disseminated (detrital or authigenic) quartz dolomite (white-pale grey-yellow) grains in a micritic to finely sparry dolomite (brownish grey) matrix, with some dolomite veins and cherty quartz veins (Bottrill and Woolley 2015).

replacing sedimentary bands during the brecciation and veining. The textures are interpreted as the products of diagenesis and deformation, with no indications of hydrothermal alteration, sulphides or other mineralisation.

Geological Interpretation and Synthesis

Figure 12 presents an interpretive geological map of the Forest Hills Depression. Figure 13 is a larger scale map integrating our observations with those of Dixon & Sharples (1986) on the New River between the Forest Hills Depression and the prominent quartzite strike ridge, "Gibraltar", to the east. We infer that dolostone within the Forest Hills Depression is part of a conformable sequence of dolostones, low-grade metamorphic cleaved reddish slates, quartzites and interbedded dolomitic siltstones and siliceous conglomerates dipping steeply towards the northeast, between the Forest Hills Depression and the upper part of the New River Gorge. This sequence is truncated by *en echelon* faults trending broadly north-south. The most westerly of these faults accounts for significant differences in observed bedding directions at Waypoints 004 and 005 on the New River. The east-facing slope of the large hill immediately southwest of the waypoints is interpreted as a fault-line escarpment associated with this fault. The cleaved reddish-brown or pinkish slates (siliceous siltstones) observed at Waypoints 003 to 004 on the New River, and as lag fragments within the Forest Hills Depression at Waypoint 008, are interpreted as along-strike expressions of the same stratigraphic unit.

The alignment of a prominent north-south gorge draining into the Forest Hills Depression from the south (C on Figure 3) can be interpreted as a structural effect associated with a second fault to the east of the first fault. The upstanding form of the ridge cut by the gorge suggests a strike ridge in siliclastic rock. A third fault further east again is consistent with the abrupt termination of the large passage in Forest Hills Cave, interpreted as evidence of a major structural deflection of underground drainage at a fault contact. It is inferred that a band of dolostone extends east of the cave through the topographic saddle between it and the New River Gorge. Within this block, the strike of the dolostone bedding potentially swings from north-west to west, in accordance with the orientation of the probable strike ridge immediately north of the saddle. This interpretation allows for the transmission of water from the Forest Hills Depression to the New River via sub-surface conduits in dolostone, to an inferred spring resurging in the New River Gorge (E or F on Figure 3), outside the Forest Hills Depression. Without such a connection the Forest Hills Depression would be a permanent lake.

Aspects of the broader structural setting of the Forest Hills Depression remain uncertain. Whereas the dolostone is probably truncated to the west against northwards-dipping quartzites along an inferred north-south fault, to the south-east and east the dolostone abuts a thick north-south striking metamorphosed phyllite sequence. The latter rocks crop out for several kilometres downstream of the depression and include at least two thick north-south striking quartzite units near its eastern end, including the prominent ridge of "Gibraltar" (see Figure 13). The dolostone sequence and the phyllite sequence are probably in faulted contact. The suggestion by Dixon & Sharples (1986, Figure 1) that the dolostone outcrop extends for some distance south of the Forest Hills Depression is unconfirmed. The broad upstanding strike ridge which bounds the southern side of the depression is suggestive of siliclastic or meta-siliclastic rocks. The geology of a flat-floored basin immediately south of this ridge and connected to the Forest Hills Depression via a gorge has not been verified and is not interpreted on Figures 12 and 13. However, on present evidence, we cannot exclude the possibility that the basin is underlain by dolostone. This question is considered later in the paper.

Based on lithological similarity, we consider it likely that the Forest Hills Dolostone is a correlate of dolomitic rocks within the Weld River Group, potentially the massive dolostones and intercalated mixtite, mudstones and sandstones of the Cotcase Creek Formation (Calver 1989). The Forest Hills Dolostone is dissimilar to the Precambrian dolostones of the Clark Group, which comprise thinner, less pure dolomite beds (Clive Calver pers. comm. 2012).

2. Geomorphology

The Forest Hills is the central portion of a larger region of hills and ridges bounded by the valleys of the New, Old and Solly Rivers. The terrain is strongly dissected with several hundred metres of relief and a high density of low order dendritic surface channels. The Forest Hills Depression is a closed basin at the termination of an un-named watercourse draining northwards from the Forest Hills towards the New River (Figures 2, 3 & 5).

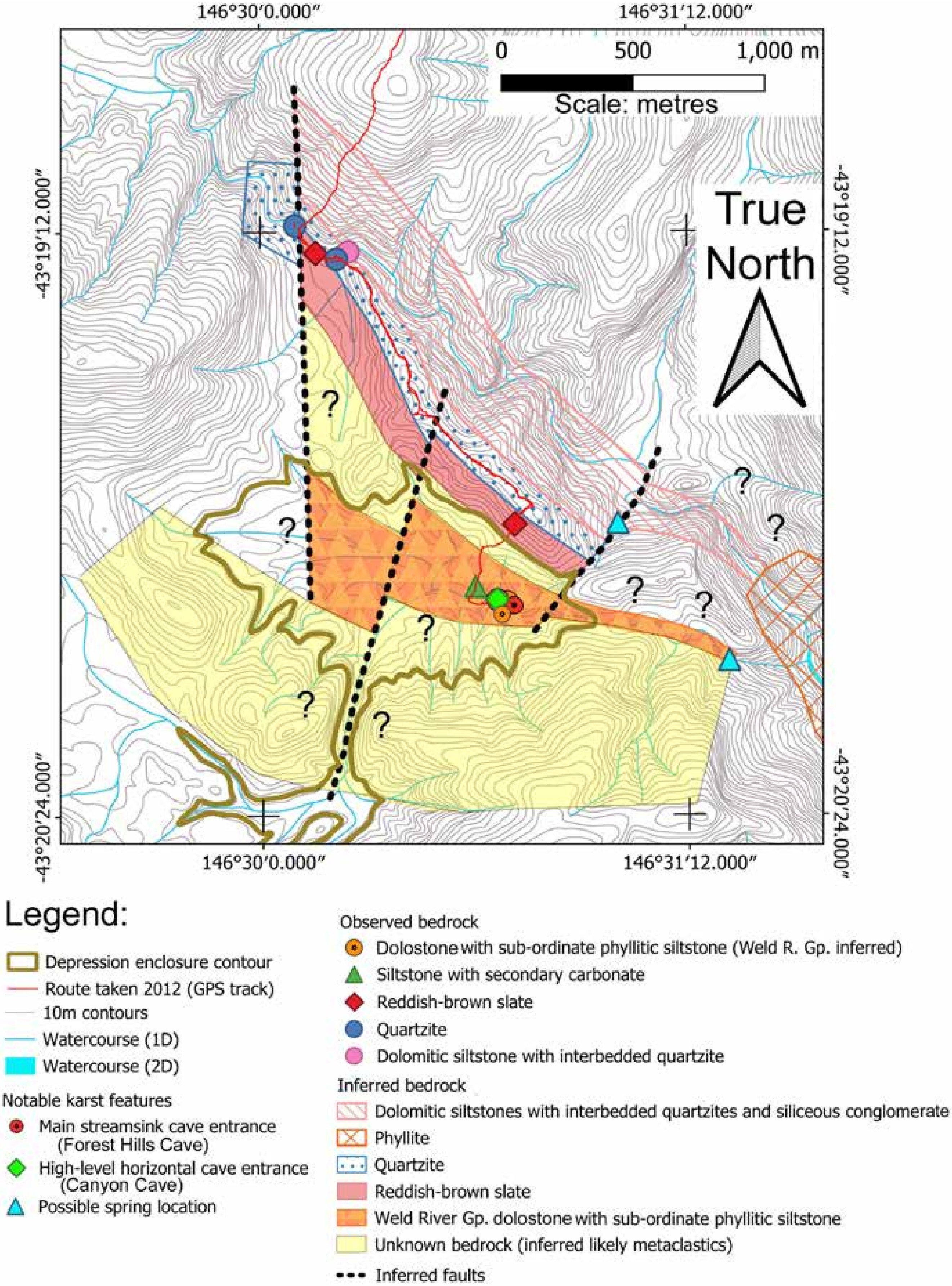

Figure 12. Geological map of the upper New River Gorge and Forest Hills Depression area showing observed features and interpreted Precambrian geology based on integrating geological observations from the 2012 field trip with those of Dixon & Sharples (1986). Areas of uncertainty that require more field data to resolve are indicated thus: '?' Base map source: 10 m contours and watercourses from Land Information System Tasmania (LISTmap). The map co-ordinates are geographical (degrees latitude and longitude) based on the WGS84 datum.

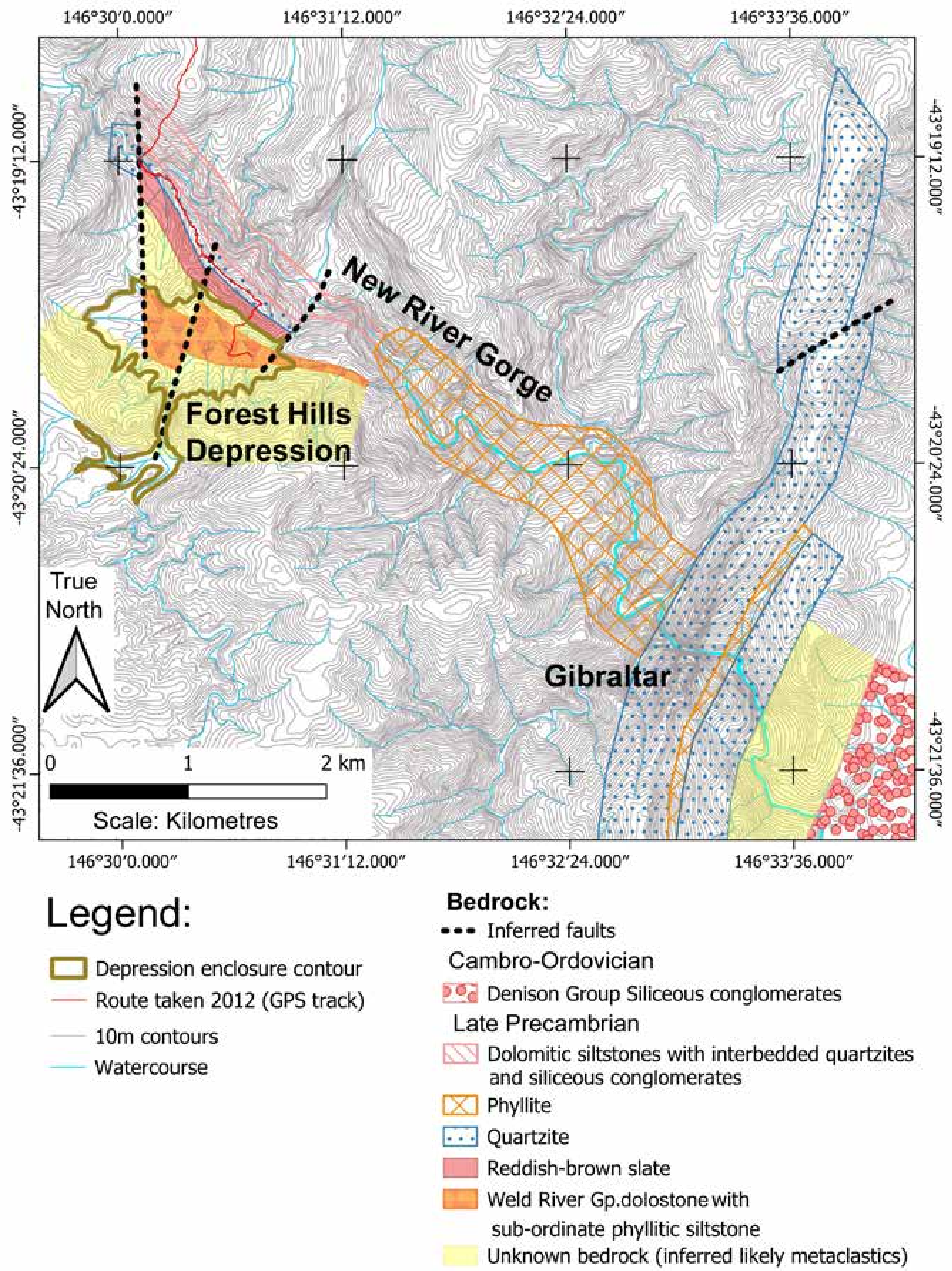

Figure 13. Interpretive geological map of the broader New River Gorge area integrating geological observations from the 2012 field trip with those of Dixon & Sharples (1986). Base map source: 10 m contours and watercourses from Land Information System Tasmania (LISTmap). The map co-ordinates are geographical (degrees latitude and longitude) based on the WGS84 datum.

The principal tributary to the depression has cut a deep, narrow breach in an inferred strike ridge which separates the main northern portion of the depression from a secondary lobe that extends south for several hundred metres. At other points the internal flanks of the basin are incised by multiple, mostly shallow surface channels. The difference between the highest (390 m ASL) and lowest (340 m ASL) depression contours, as mapped by Land Information System Tasmania (LIST), indicates that the depression is at least 50 m deep. The feature is thickly vegetated with locally dense thickets of horizontal scrub *(Anodopetalum biglandulosum)* and occasional large King Billy Pines *(Athrotaxis selaginoides).*

Tributary surface streams draining into the depression coalesce within a 10 m deep V-shaped canyon in dolostone bedrock (Figure 14), commencing near Waypoint 011 about 100 m above the sink point. A short distance above the sink the gradient of the channel steepens, with minor cascades and plunge pools, and swings from a dominantly easterly alignment to a northerly one. The surface channel terminates in a jumble of massive dolostone boulders at the deepest point of the depression (Forest Hills Cave, near Waypoint 12; see Appendix 1), which is enclosed by steep slopes and cliffs more than 20 m high. A smaller tributary joins from the south at this point, while another small stream from the east joins the cave stream amongst boulders a few metres inside the cave entrance. The cliff above the cave is steeply overhanging with a dripline up to 15 m from its base, creating a sheltered south-east facing bench on silty sediment vegetated by ferns (Figure 15).

Forest Hills Cave (Figure 16) is accessed via holes between boulders that partially fill what appears to be a formerly spacious canyon or conduit in bedrock. About 50 m into the cave the zone of collapse gives way to a tunnel up to 15 m wide and 5 m high. This feature cuts obliquely across the strike of steeply dipping dolostone beds, suggesting that its alignment is controlled by fractures or faults. The base of the passage is formed in pebbly gravels locally cemented by a dark amorphous matrix encountered in many Tasmanian caves which entrain tannin-stained water. Banks of pale, silty sediments have been deposited above the gravel base in places. The open passage extends for about 60 m and then abruptly terminates at a froth-covered pond (sump) (Figure 17). Coarse woody debris and traces of frothy scum were noted high on the walls

Figure 14. V-shaped canyon in dolostone at the point where the stream enters rockfall at the entrance to Forest Hills Cave, which is directly in front of the figure in the image (Photo by Rolan Eberhard).

Figure 15. Bivvy site below overhanging cliff at Forest Hills Cave (approximately Waypoint 012). The point of entry to the cave is a few tens of metres to the rear and left of the tent at the lower left in the image. Whitish frothy scum from earlier flooding partly coats the vegetation and overhanging rock wall here (Photo by Rolan Eberhard)

and ceiling at various points in the cave. Similar evidence was also observed outside the cave (Figure 15), indicating that water backs up in the base of the depression during flood events, fully submerging the cave under a temporary lake.

A second cave, Canyon Cave (Figure 18; Waypoint 011), is located on the south side of the stream canyon and about 10 m above the base of the active watercourse. The cave comprises a simple horizontal tunnel about 50 metres long, which for most of its length is developed along the strike of the dolostone beds, which dip steeply in a northerly direction. The passage is generally 4-5 m wide and 2-3 m high (Figure 19) but becomes lower approaching the back end of the cave. At this point the passage trends upwards for a short distance before terminating at an apparently slumped blockage of silt. Canyon Cave lacks a perennial stream and appears to be a fossil feature related to a phase of cave development pre-dating downcutting by the stream and the initiation of Forest Hills Cave. However, fragments of leaf litter deposited on the cave walls indicate that Canyon Cave remains subject to at least occasional inundation by back-flooding within the Forest Hills Depression.

Neither of the two recorded caves show significant speleothem development, which is limited to minor stalactites and botryoidal deposits in Canyon Cave. In keeping with many other caves in silicified dolostone in Tasmania, both Canyon Cave and Forest Hills Cave contain well-developed silica boxwork standing proud of the dolostone matrix (Figure 8).

Discussion

Confirmation that the Forest Hills Depression is formed in dolostone rock, likely a correlate of the Weld River Group, corroborates earlier inferences (Dixon & Sharples 1986) regarding the geology of the upper New River and the Forest Hills. Our updated geological map (Figures 12 and 13) interprets the Forest Hills Dolostone outcrop as relatively small (37 ha) and formed by three contiguous fault-bounded blocks that do not extend far beyond their surface expression as a karst landform, i.e. the Forest Hills Depression. The ridges that enclose the depression, and portions of the depression itself, are underlain by non-karstic siliclastic rocks, within a conformable but fault-disrupted sequence of low-grade metamorphic

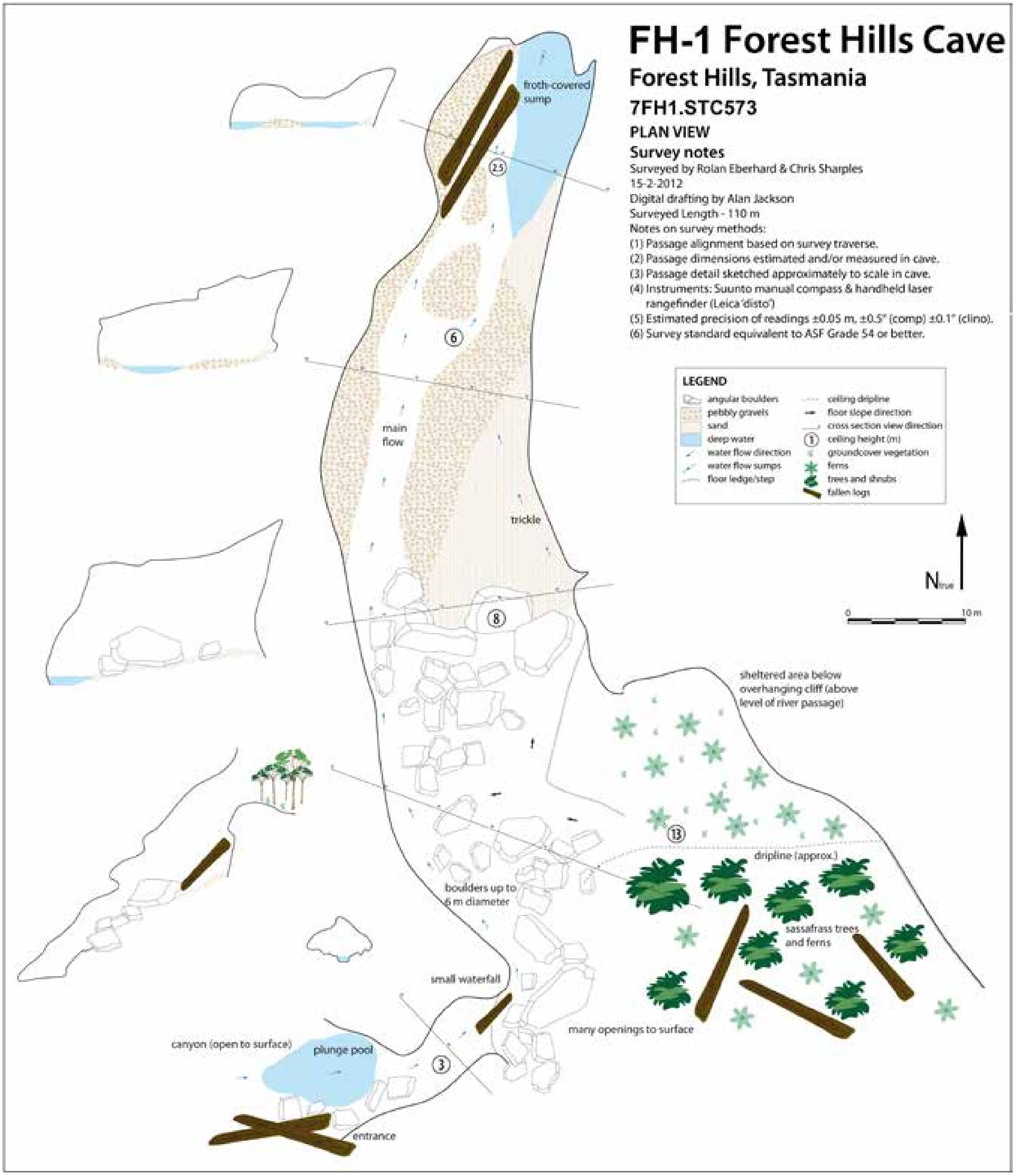

Figure 16. Map of Forest Hills Cave, FH-1.

strata. Beyond these two main findings, other elements of the geology remain speculative. For example, we infer the southern lobe of the Forest Hills Depression (upstream of a straight narrow gorge through an inferred siliclastic strike ridge) to be underlain by siliclastic rocks, based on the conclusion that the upstanding ridge that separates the depression into northern and southern lobes is not a karst landform and that it delineates the southern limit of the dolostone (Figure 12). On the other hand, the structural complexity of the geology raises the possibility of additional, presently un-mapped fault-bounded blocks of dolostone. The presence of such a block to the south of the upstanding ridge could account for the lack of relief within the southern lobe of the depression. However, we have taken a conservative approach and not mapped the southern lobe as dolostone.

Figure 17. Termination of large passage in Forest Hills Cave. The figure in the image stands at the edge of a thick bank of stream froth. Traces of froth can also be seen attached to the ceiling above the figure; also, a log of wood can be seen to the left of the figure (Photo by Rolan Eberhard).

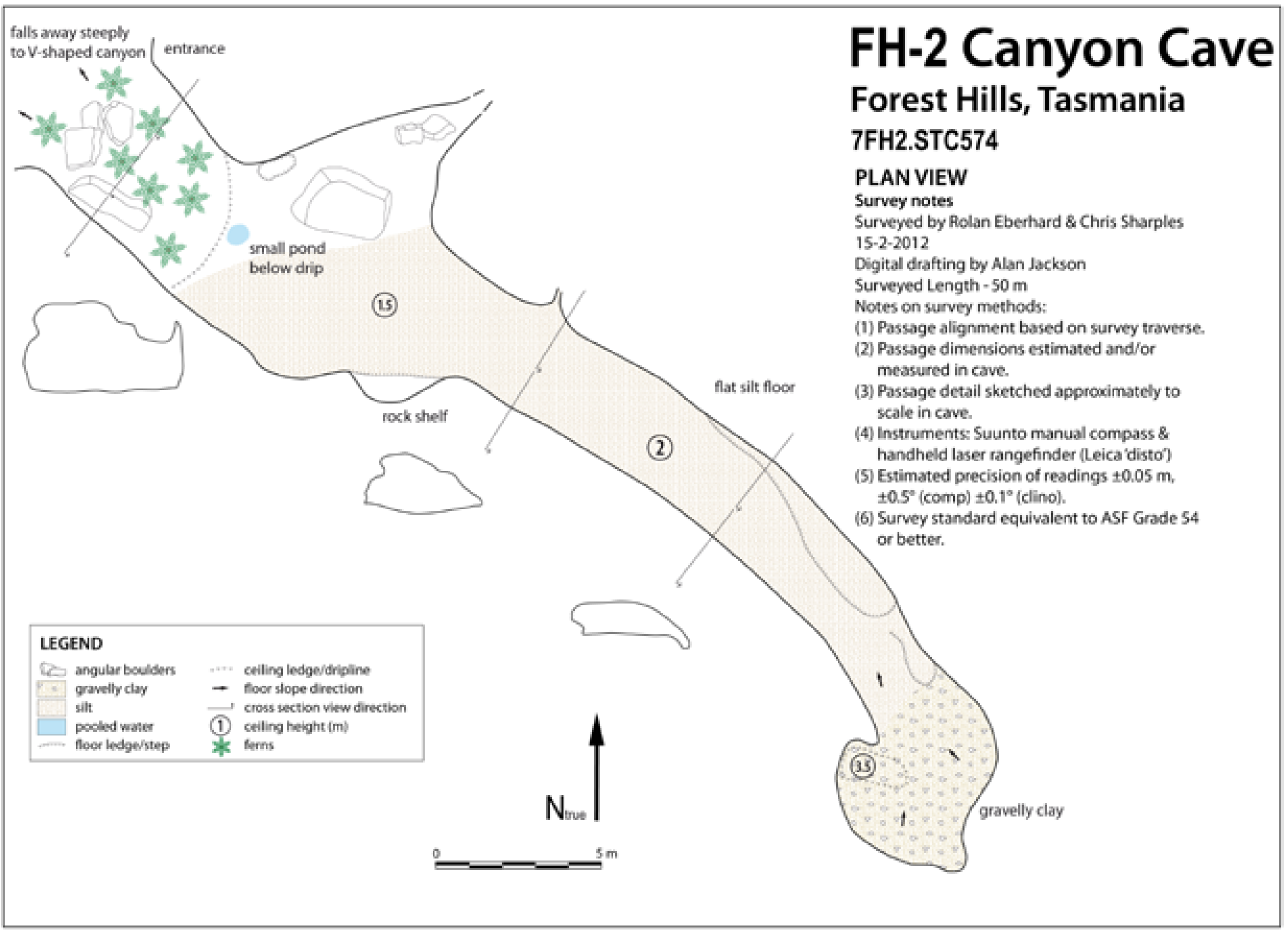

Figure 18. Map of Canyon Cave, FH-2.

Figure 19. View towards the entrance from inside Canyon Cave, showing small drip-water pool. The spacious horizontal form of the passage and its silty base are typical of most of the cave (Photo by Rolan Eberhard).

Our geological model incorporates a putative narrow eastern extension of the dolostone that likewise has not been directly verified but, in this case, is supported by the abrupt termination of Forest Hills Cave at an inferred fault. The immediate cause of the termination appears to be a blockage of fluvial sediment; however, we suspect that the ultimate cause is a structural effect related to the juxtaposition of dolostone and siliclastic strata by faulting. This would have the effect of deflecting the alignment of the passage, trapping woody debris and sediment at that point. The deflection implies the existence of a pathway for underground drainage, which we infer is eastwards via a third fault-bounded block of dolostone.

This geological interpretation constrains the location of potential resurgence points for water sinking underground within the Forest Hills Depression. Based on proximity and hydraulic gradient, candidate discharge points include two minor tributary valleys which join the New River north and east of the Forest Hills Depression respectively (Figures 3 and 12). An outlet at E implies a fall of ~60 m over ~0.6 km; an outlet at F implies a fall of ~90 m over ~1.1 km. Whilst the steeper hydraulic gradient favours the former as the resurgence point, the inferred fault at the termination of Forest Hills Cave suggests that underground drainage towards E is impeded by a block of siliclastic strata. This would cause underground drainage from the Forest Hills Depression to be directed eastwards towards a discharge point near F, beyond a broad W-E elongated saddle that we have inferred on topographic and structural grounds to be underlain by an eastern extension of the faulted dolostone (Figures 12 and 13).

As observed under baseflow conditions in February 2012 and when visited by TCC in 1972 (Shaw 1973), the Forest Hills Depression was free draining. However, it is apparent that this condition does not apply during high stage flows, based on our observation of fresh deposits of silt, vegetable debris and frothy scum coating surfaces several metres above the level of the entrance to Forest Hills Cave (Figure 15) and within Canyon Cave. Both caves had evidently been fully submerged by water backing up at the sink not long prior to our visit. An event of this type would also submerge portions of the forested low point of the depression, creating an ephemeral body of ponded water, possibly some hundreds of metres in diameter during major floods. The frequency of such events is unknown, but the large catchment and heavy seasonal precipitation experienced by Tasmania's south-west suggest that flooding of the depression may be a semi-regular occurrence. In any case, the frequency and duration of flooding is not sufficient to inhibit the rainforest which colonises the base of the depression.

A further consideration in characterising the hydrology of the depression is the possibility that some surface runoff is lost to underground flow above the cave. We suspect this because the discharge of the stream at the entrance to Forest Hills Cave (see Figure 14) is subjectively less than would be expected given its sizeable catchment (1280 ha). As a point of comparison, the observed discharge of this stream is no greater and probably less than the baseflow discharge of the well-known Growling Swallet streamsink (Mt Field Range). Growling Swallet has a catchment area half the size of that of the Forest Hills Depression and on average likely receives less annual precipitation. If the baseflow discharge of the Forest Hills stream is attenuated by partial capture of its flow to subsurface pathways above Forest Hills Cave, this would condition the scale and frequency of flood events capable of inundating the base of the depression. A spectacular example of this is available 12 km from the Forest Hills at Vanishing Falls, which engulfs the baseflow of the Salisbury River but episodically overtops, redirecting the flood peak to the limestone gorge below the falls (Eberhard and others 1992). We suspect something similar at Forest Hills Cave, whereby stream stage fluctuates in response to the finite capacity of diffuse or point source sink points above the cave to take water.

Canyon Cave differs from Forest Hills Cave in that it follows the strike of the steeply dipping beds of the host rock rather than obliquely cutting across the beds. In this case the passage is aligned with the inferred direction of underground drainage from the Forest Hills Depression to the New River, i.e. east. We interpret Canyon Cave as a former inflow point of the stream that now flows to Forest Hills Cave. The height difference between the cave entrances is modest (<10 m) compared to the height difference (40-50 m) between the caves and topographic low points on the surface drainage divides which separate the Forest Hills Depression from the New River. The scale of downcutting required to account for the abandonment of Canyon Cave in favour of Forest Hills Cave is therefore much less than that required to account for the overall depth of the depression.

It can be assumed that speleogenesis within the depression has been intimately connected with downcutting by the New River to form the present-day gorge. This has progressively lowered the hydrological baselevel and increased the hydraulic gradients within tributary catchments. This would have the effect of enhancing the susceptibility of runoff from Forest Hills to capture by an incipient karstic aquifer propagating headwards from the gorge. Enlargement of the depression to its modern size (80 ha) required it to propagate outwards in the surrounding siliclastic strata. The resultant landform occupies more than twice the area of the dolostone outcrop (37 ha) that initiated its development.

The status of the Forest Hills Depression as a distinctive landform of high conservation value is formally recognised by its inclusion as a listed geosite in the Tasmanian Government's Natural Values Atlas (www.naturalvaluesatlas.tas.gov.au). The geosite statement of significance reads:

> *This is Tasmania's largest fully-enclosed karst depression (sinkhole) in terms of depth, with the only larger karst depressions (the Mayberry and Dismal Swamp poljes) being much shallower (<10 m) flat-floored polje-type depressions. The Forest Hills Depression is also the least disturbed large karst depression in Tasmania, with an unbroken forest cover having no visible signs of burning, and no artificial ground disturbances except for two small tent-sized platforms of flattened soil adjacent the streamsink cave.*

This statement raises two points of difference in claiming exceptional significance for the Forest Hills Depression. Firstly, it proposes that this is the deepest karst depression in Tasmania and third largest in areal extent. This claim is open to question (Table 1). However, unlike Dismal Swamp and Mayberry, the Forest Hills Depression does not present as an alluviated basin resembling a European polje. This difference highlights the role of site-specific factors in conditioning the development of karst depressions in different environmental settings. In the case of the Forest Hills Depression, significant local factors include its modest elevation, which has protected the feature from heavy clastic sedimentation typical of glacial or periglacial settings. This difference draws attention to the fact that several of Tasmania's largest karst depressions (Table 1) are composite features derived from glacio-karstic interactions. That is, they are the products of both solution by meteoric water and mechanical erosion by moving bodies of ice. In contrast, the Forest Hills Depression stands out as a genetically less complex example, the initiation of which has been chiefly due to conventional solution-driven karstification. The existence of a significant hydraulic gradient between the depression and the New River, lowering the base level and promoting cavernous downcutting, is a further critical site-specific point of difference. Secondly, the statement proposes that the Forest Hills Depression is 'the least disturbed large karst depression in Tasmania', highlighting the absence of fire-tolerant vegetation indicative of anthropogenic burning or other visible disturbance by humans (excluding minor equivocal old tent platforms at the entrance to Forest Hills Cave). Given the increasingly pervasive effect of humans on the environment, we concur that the essentially natural condition of the Forest Hills Depression adds significantly to its geoconservation value. This underlines the appropriateness of its inclusion in the Tasmanian Wilderness World Heritage Area (TWWHA) and management to protect these remote areas from anthropogenic disturbance.

Table 1. Indicative metrics for large karst depressions in Tasmania. Area was calculated conservatively using the highest enclosing depression contour. Depth was calculated conservatively using the highest and lowest depression contours (or mapped spot height), as published by Land Information System Tasmania (www.thelist.tas.gov.au). Catchment area includes karstic and non-karstic portions. Dismal Swamp is a polje-like feature, portions of which are fully enclosed. The currently available mapping only delineates the broader feature.

Location	GDA Easting & Northing (m)	Area (ha)	Depth (m)	Highest enclosing depression contour (m)	Catchment area (ha)
Dismal Swamp	318300 5462500	600	<10	<50	1030
Liena	439000 5399300	240	38	400	1460
Lake Timk	457100 5246400	98	69	520	1090
Forest Hills	460400 5202100	80	50	390	1280
Lake Sydney	468300 5207100	15	4	680	290
Weld River	455940 5253730	15	50	380	33
Mt Gell	417300 5335580	14	30	810	83
Cook Creek	468200 5216500	9	30	480	380
Lake Ovoid	466150 5218000	8	30	770	40
Styx River	465255 5258650	7	<10	420	47

Conclusions

The status of the Forest Hills Depression as a substantial karst landform in dolostone, probably a correlate of the Weld River Dolomite (Calver 1989), is confirmed. Cavernous development within the depression includes at least two spacious caves, the larger of which is the sinking point of a stream that likely drains to a presently unknown resurgence on the New River. Considerable scope exists to further improve the very limited geological mapping in this remote area and to extend the exploration of karst features, beyond the present reconnaissance-level study. However, the standard of documentation is now adequate to confirm the evaluation of the Forest Hills Depression as a significant element of the karst geodiversity protected within the Tasmanian Wilderness World Heritage Area.

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Appendix 1

Table 2. Waypoints relevant to observations presented in this paper (see also map Figure 6). Waypoint co-ordinates were obtained with a hand-held Garmin Etrex Summit HC GPS (estimated horizontal accuracy +/- 4 metres), except note Waypoint 12 had poor GPS reception, and this position was estimated manually.

Waypoint (shown on Figure 6)	**Feature (including bedrock outcrop type)**	**Geographical co-ordinates (decimal degrees, WGS84 datum)**		**Projected co-ordinates (metric MGA Zone 55 UTM, GDA94 datum)**	
		Longitude	Latitude	Easting	Northing
001	New River: entry point / bivvy site.	146.501906	-43.320077	459 612	5203 519
002	New River: dolomitic siltstones.	146.504108	-43.320671	459 791	5203 455
003	New River: red-brown slate.	146.503137	-43.320900	459 713	5203 429
004	New River: red-brown slate.	146.502483	-43.320642	459 659	5203 457
005	New River just upstream of bivvy site: well-bedded quartzite.	146.501625	-43.319790	459 589	5203 551
006	New River: red-brown slate outcrop.	146.502595	-43.320735	459 669	5203 447
007	New River: well-bedded quartzite.	146.503534	-43.320847	459 745	5203 435
008	Forest Hills Depression: point on route high on north slope: red-brown slate lag fragments.	146.511876	-43.330043	460 427	5202 417
009	Forest Hills Depression: point on route low on north slope. Siltstone with secondary carbonate.	146.510022	-43.332168	460 278	5202 181
010	Forest Hills Depression: surface watercourse with no exposed bedrock at this point.	146.509758	-43.332529	460 257	5202 141
011	Forest Hills Depression: dolostone outcrop at cave entrance (Canyon Cave).	146.511038	-43.332632	460 361	5202 130
012	Forest Hills Depression: dolostone cliff at cave entrance bivvy site (Forest Hills Cave); poor GPS reception at this location, waypoint position estimated from existing 1:25,000 mapping (error margin approximately ±20 metres).	146.512066	-43.332644	460 444	5202 127