ARTHUR RIVER MAGNESITE

GEOHERITAGE ASSESSMENT OF MINING LEASE

24M/2009

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Report prepared for Tasmania Magnesite NL

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(REVISED)

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1. Introduction

This paper reviews the potential geoscience significance of an area in northwest Tasmania in the catchment of the Arthur River (Figure 1).

Figure 1. Arthur River catchment and study area.

In particular it assesses mining lease 24M/2009 (Department of Infrastructure, Energy and Resources, Tasmania, 2009) of 230.5 hectares held by Tasmania Magnesite NL. The site is on the left (here south) bank of the Arthur River between the Keith River and Northern Creek (Figure 2). The Australian Heritage Council has included this area in the "Tarkine Might Have Values Area (Tarkine MHV) " map (Commonwealth of Australia 13/07/2011). Among the values listed for the entire Tarkine MHV area are "KEITH/ARTHUR RIVERS

MAGNESITE KARST - Karst landforms and springs developed in magnesite carbonate rock (Criteria: A.1, B.1, D.1)."

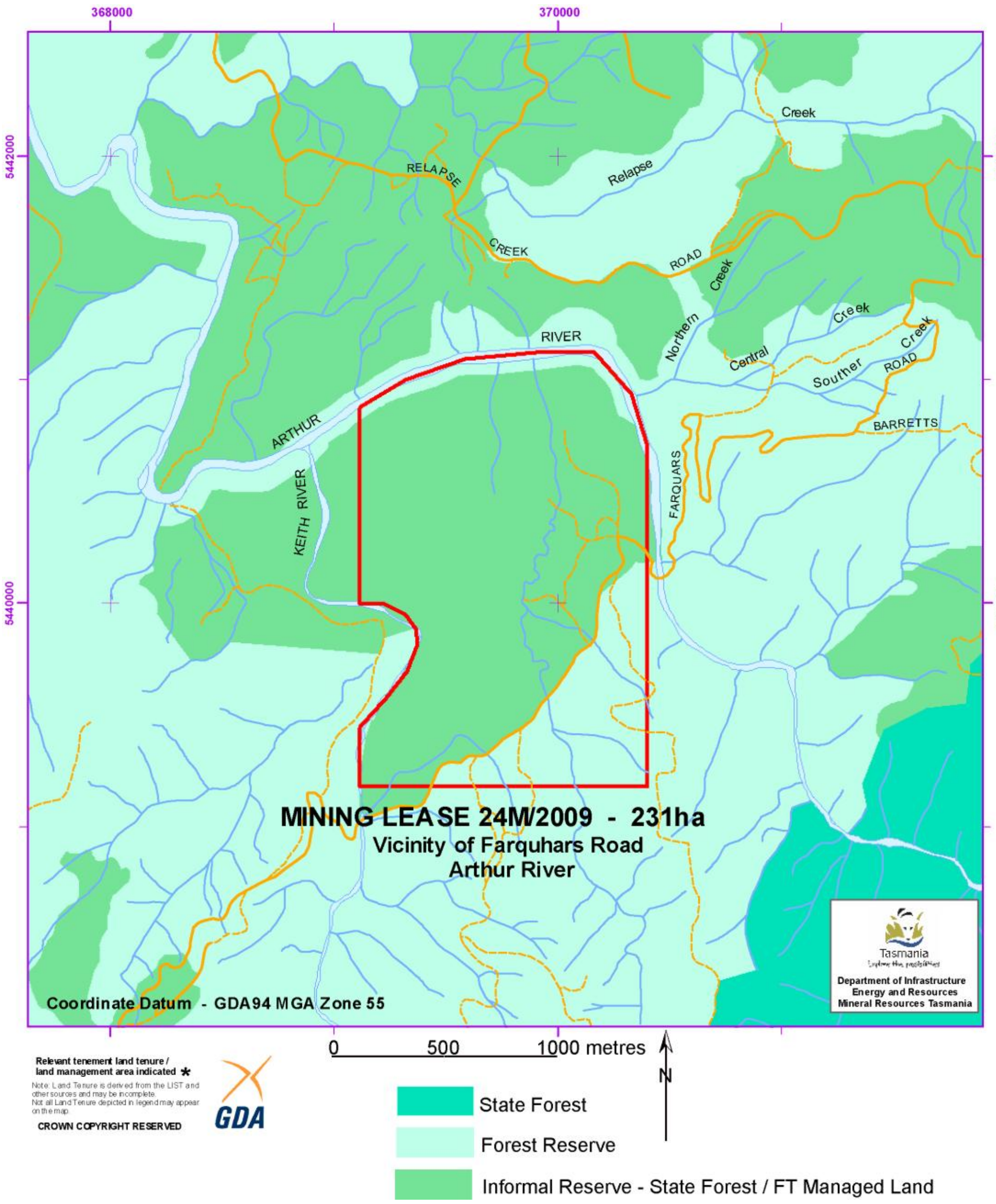

Figure 2. Mining Lease 24M/2009 and current land tenure (Mineral Resources, Tasmania).

This present paper reviews the available evidence for the occurrence of magnesite karst in the lease area and assesses the geoheritage potential of the site in the light of that evidence. It is based on published and unpublished literature and study of aerial photographs and topographical information including contour maps derived from LIDAR surveys with contour interval 0.5 metre. A field study (14/12/2011) was made with the assistance of consultant geologist Mr Stewart Capp of Derwent Geoscience, and samples of drill core were examined at the core shed of Tasmania Magnesite NL at Whyndham, Tasmania. Prior to the field survey information was obtained by e-mail and phone conversations with geomorphologists expert in karst systems and with specialist knowledge of the Arthur River magnesite areas. Meetings with two of these experts (Ian Household (Dept Primary Industries, Parks, Water and Environment, Tasmania) and Chris Sharples (University of Tasmania)) were held in Hobart on 16/12/2011 to discuss aspects of the karst geology and hydrogeology of the site and adjacent areas.

2. Magnesite

2.1. Magnesite mineralisation

Magnesite is a carbonate mineral (magnesium carbonate $MgCO_3$) and belongs to a mineral group that includes calcite ($CaCo_3$) and siderite ($FeCO_3$). Magnesite occurs as magnesite limestone rocks but these are much less common than calcite and dolomite limestone (Hatch, Rastall and Goldsmith, 1969). Magnesite commonly occurs in white, compact earthy to chalky masses and is normally cryptocrystalline (very fine-grained) and crystal structures are defined by x-ray diffraction rather than microscope resolution (Hurlbut, 1970). It may be formed either as strata-bound sedimentary beds from marine deposition, by weathering or other alteration by magnesium-rich solutions of ultrabasic olivine rocks (Hatch, Rastall and Goldsmith, 1969) or metamorphic/metasomatic processes operating on schistose and dolomite rocks (Berry and Mason 1959). The Australian deposits differ significantly from classic European types in certain details, arguably through development at lower temperatures (e.g. precipitation from groundwater instead of hot springs (Facer and Whitehouse 2007).

2.2. Magnesite in Australia

The major commercial occurrences of magnesite in mainland Australia is the Kunwarara magnesite deposit near Rockhampton, one of the world's largest deposits of cryptocrystalline magnesite, and the only major source of magnesite in Australia (Facer and Whitehouse 2007). The deposit, which had been mined since 1991, produced 470 000 tonnes of magnesite in 2003 (Geoscience Australia 2004). Other occurrences are in South Australia (in the Flinders Ranges) with lesser deposits near Darwin in the Northern Territory, Young in New South Wales (NSW), and east of Ravensthorpe in Western Australia. Tasmania contains the third largest known Australian deposits with a measured resource of 13.2Mt in the Arthur River deposit.

2.3. Magnesite in Tasmania

The measured magnesite resource at Arthur River is part of a much larger global resource of 195Mt in the Arthur-Lyons River area (Geoscience Australia 2011). These magnesite deposits occur in the Arthur River Metamorphic Complex (AMC) in northwest

Tasmania. This is a narrow, NE-trending linear belt of Precambrian rocks that include magnesite bodies as a number of discontinuous, steeply dipping lenses up to 400 metres thick dispersed along this belt. Six main potentially economic magnesite bodies are known, three in the south and three in the north (Figure 2), but as the geology of parts of the AMC are poorly known there may be other occurrences (Calver 1999). The magnesites appear to have a complex origin and a multi deformational history.(Perry 2011).

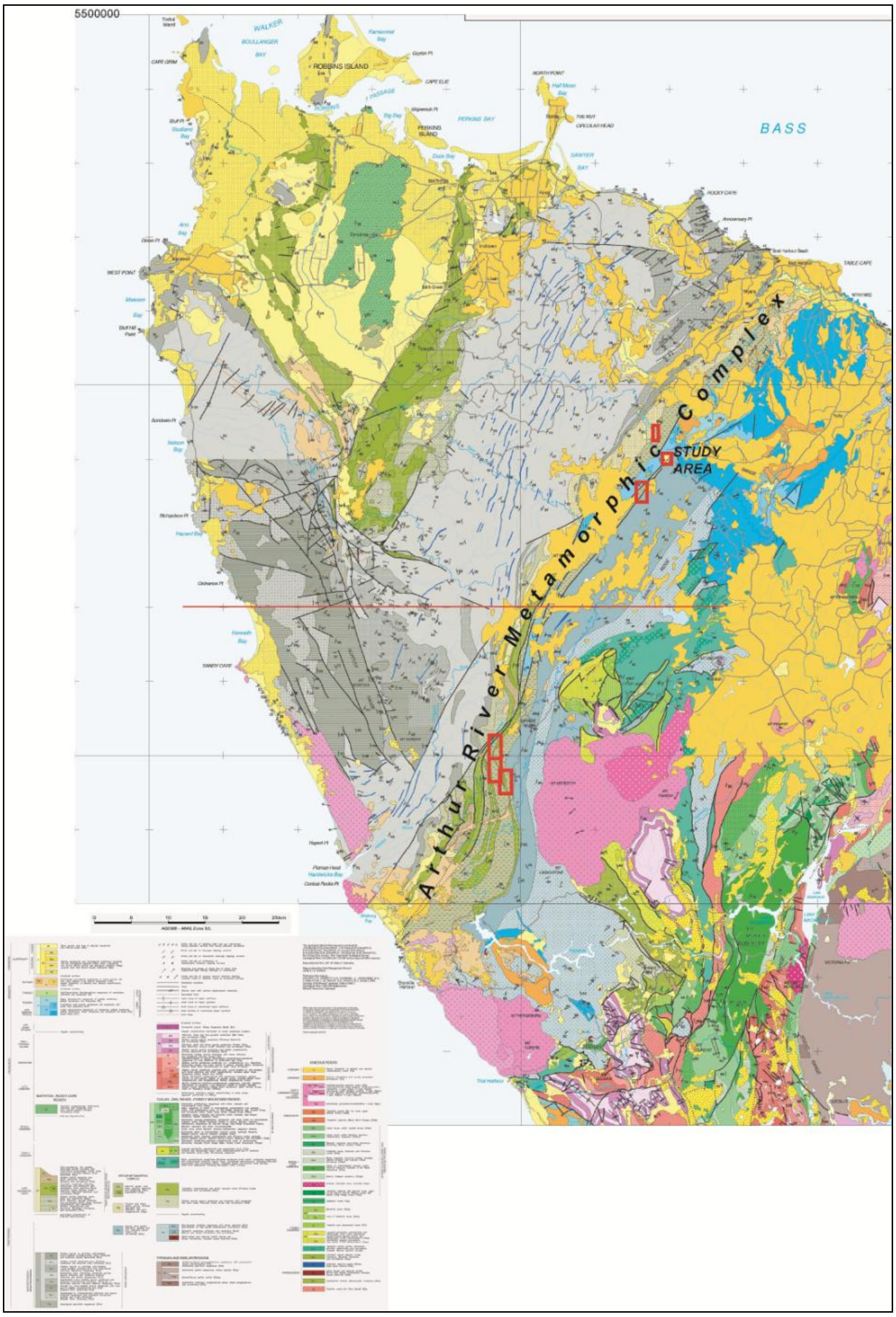

Figure 3. Geology of northwest Tasmania showing magnesite tenements in the Arthur Metamorphic Complex (after Calver 1999).

3. Arthur and Keith Rivers magnesite

3.1. Extent and outcrop

Despite the existence of several large magnesite bodies in the Arthur Metamorphic Complex, there is relatively little outcrop. The most extensive known outcrops are at Bowry Creek, Savage River Mine site, Main Rivulet and at Lyons River southwest of the Arthur River deposit. At the Arthur and Keith Rivers sites, small areas of magnesite as natural outcrop and as a result of past quarrying operations occur on the eastern side of the Arthur River at Victory Springs and along Central Creek and Southern Creek north of Farquhar's Bridge (Household *et al*. (1999)(Figure 4).

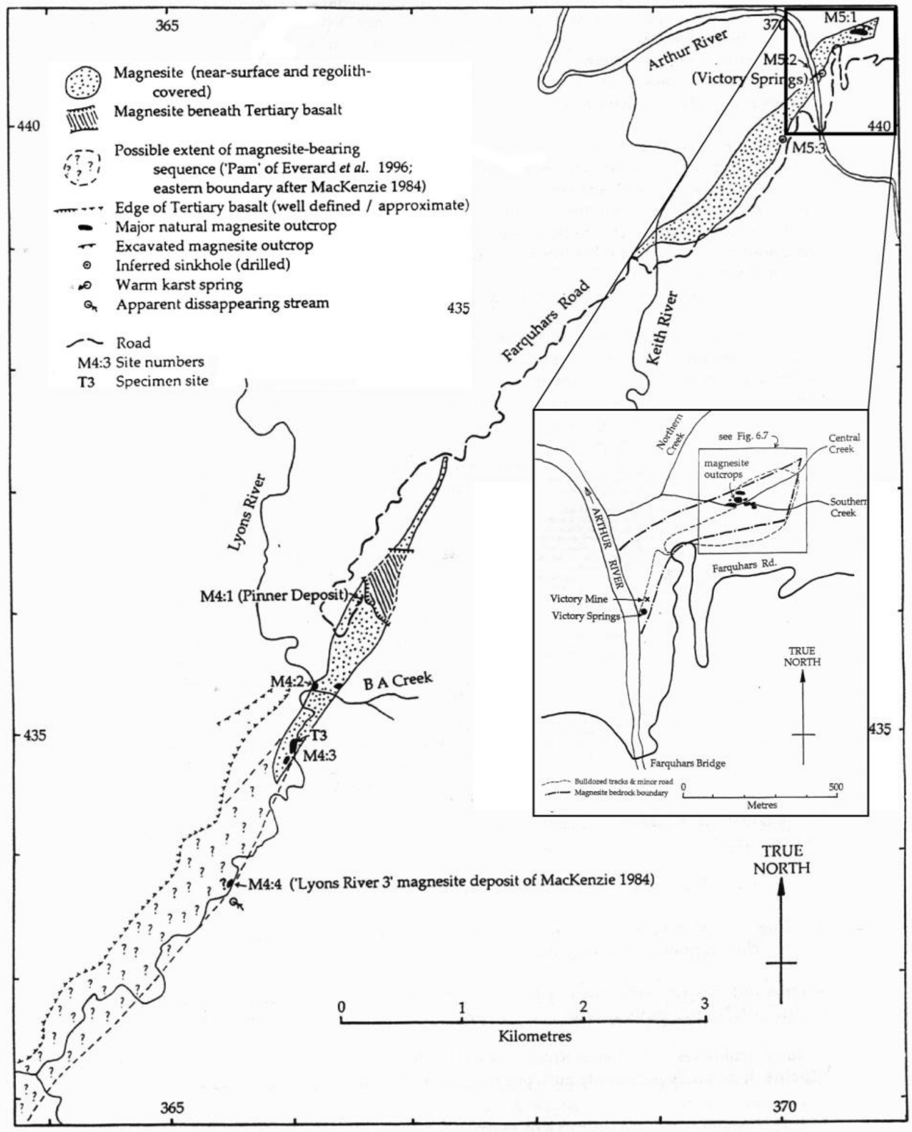

Figure 4. Magnesite extent and outcrop between Arthur River and Lyons River (after Sharples 1997).

3.2. Geology

The magnesite deposit is contained in rocks of the Arthur Metamorphic Complex and has been the subject of a number of reconnaissance and detailed geological investigations since the earliest surveys in 1924, (Nye, 1925; CRA Exploration, 1983, 1984; Tasmania Magnesite, 1999; Crest Magnesium, 1999,2000; Sharples, 1997; Houselhold *et al*., 1999; Derwent Geoscience 2011; Perry 2011). The studies including field mapping, geophysical aerial and ground surveys and an extensive drilling programme provide a good record of the nature and distribution of the magnesite bodies and the enclosing and overlying geologies.

The geological relationships in the area of the Arthur and Keith Rivers confluence are complex due to tectonic, intrusive, and metamorphic subsurface events. A combination of past and contemporary surficial processes has produced a widespread and thick regolith, including periglacial and glacial deposits, a deep weathering profile and colluvial and alluvial material (Figure 5). There is virtually no outcrop across the 24M-2009 lease area and the extent of the magnesite body here has been defined by geophysical interpretation supported by extensive drilling. Surface visibility of geological material is constrained by dense vegetation cover although logging operations and wildfire in 1982 resulted in a short period when the ground surface was exposed. Aerial seeding has facilitated the extensive and dense regrowth that now covers the site. The reports of exploration and other geological mapping projects in the area consistently record the lack of surface expression of geological features e.g. Indcor (2001): *The geology of the deposits is almost totally concealed beneath a 10-15 metres deep cover of recent sand, gravel and boulder sediments, scree and residual soils together with a dense cover of regrowth forest vegetation. Outcrop is negligible, being confined to in-situ magnesite in watercourses draining the area, together with scree material commonly exposed adjacent to the main, formed gravel forestry maintenance track which skirts the southern side of the resource zone".*

In addition to an extensive alluvial cover, core logs and seismic studies reveal a variable thickness of deeply weathered magnesite overlying unweathered rock, so the depth of overburden to fresh magnesite can be between five to more than 40 metres.

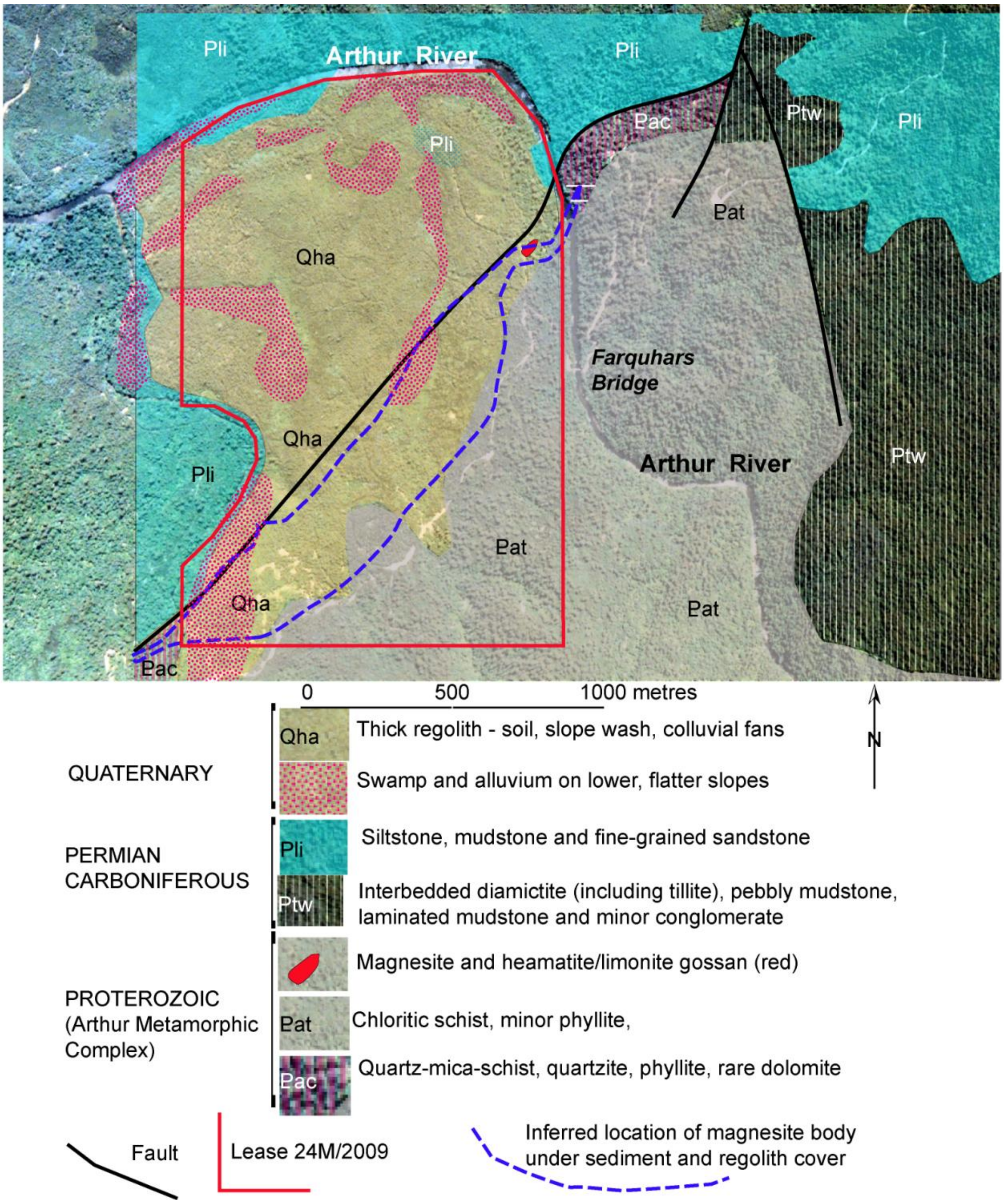

Figure 5. Geology of the Arthur River magnesite body (after Perry 2011).

3.3. Geomorphology of Arthur River site

The ML24M/2009 is inside a broad bend of the Arthur River east of the Keith River confluence. The magnesite body is oriented SW-NE and extends from the southwest corner across the lease over a strike length of 1. 9 km with a maximum width of about 300 metres (Figure 6). The land ranges in elevation from a high of 395 metres in the south east to 140 metres beside the Arthur River in the north. The major elements of the terrain are dissected N-S ridges with flanking spurs separated by the broad, shallow valley of Johnny's Creek. The upper slopes are steep (to >15^0) and there are broad terraces and several palaeochannels and flood chutes of the Arthur and Keith Rivers at lower elevations (Figure 6).

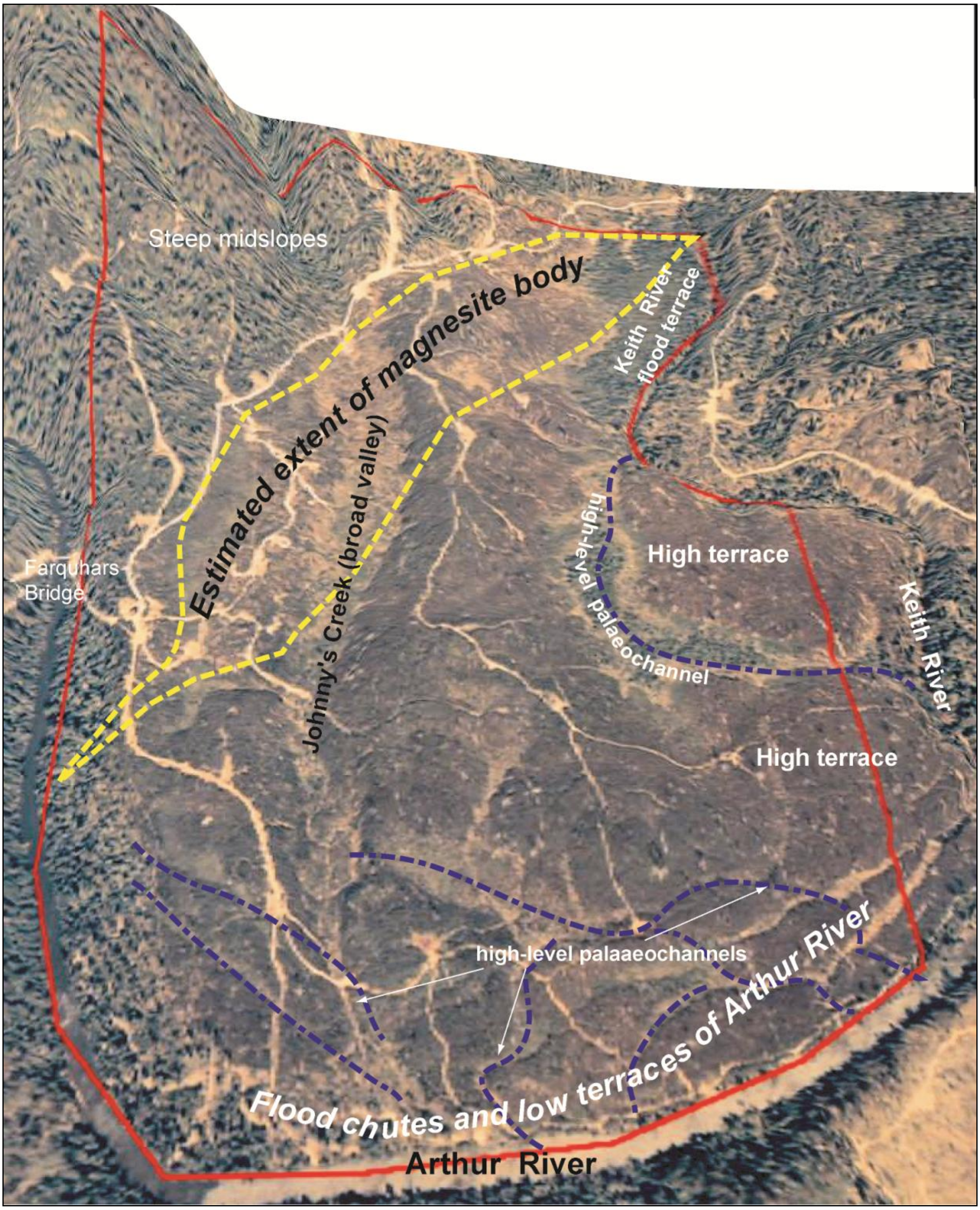

Figure 6. Terrain features shown as 3-D photo-drape on 1984 aerial photograph.

The ground surface is irregular with low ridges and swampy depressions and localised areas of slope movement although no large scale active slope failures are recorded in any of the geological surveys. Some changes in the terrain coincide roughly with the interface of the buried magnesite body, with lessening of slopes and broadening of the valley of Johnnys Creek (Figure 7).

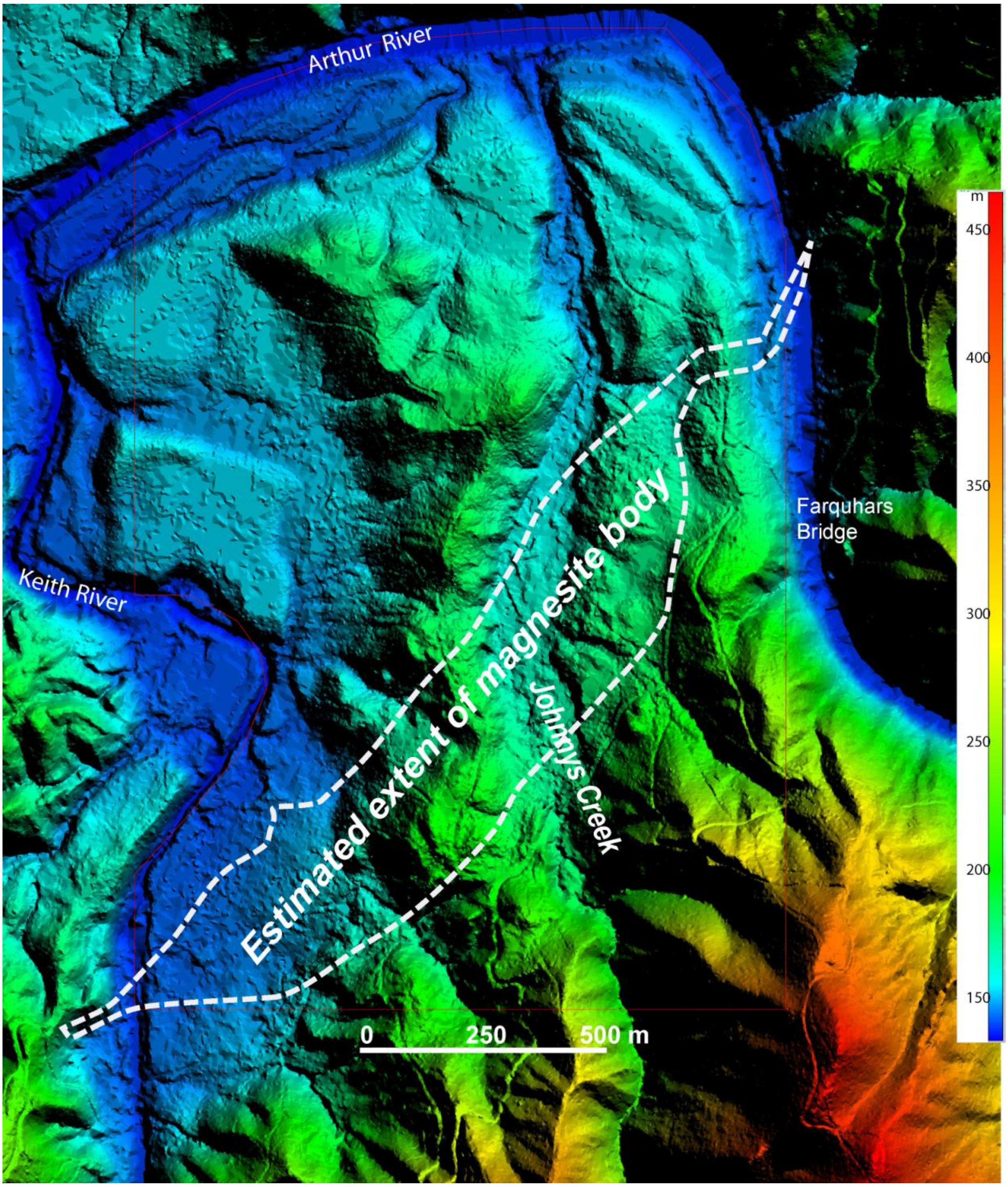

Figure 7. Digital elevation model from Lidar data showing changes in the form of Johnny's Creek valley that coincide with magnesite boundary.

3.4. Karst

Karst is the term used to describe a terrain with distinctive hydrology and landforms that has formed due to a combination of high rock solubility and well developed secondary (fracture) porosity (Ford and Williams 2007). As carbonate minerals are particularly susceptible to dissolution in natural waters karst is developed principally on limestones (calcite and dolomite), but can also develop in other rock types. Although often characterised by extensive complex cavern systems, caves are only one of a suite of surface and sub-surface features at a variety of scales that comprise a karst terrain. These include solutional and depositional features and are often a response to complex groundwater chemistry and hydrology. Karstification is the suite of processes that convert a body of susceptible rocks into a karst landscape. The key drivers are weathering and hydrological regimes but the rate at which these processes work varies over time in response to changes in climate, tectonic regime and other geological processes. Karst systems may become relict or fossil as a result of being buried by later consolidated sediment or lava flows i.e. they are hydrologically decoupled from the contemporary system and become inert and referred to as palaeokarst (Ford and Williams 2007).

3.4.1. Magnesite karst

Magnesite is a carbonate mineral and under appropriate groundwater conditions can develop surface and sub-surface karst features. Although magnesite deposits are widespread on a world scale, the international literature on karst systems developed in these is sparse and recent major scholarly works (Gilleson 1996, Finlayson and Hamilton-Smith 2003, Ford and Williams 2007) make no reference to magnesite karst localities, features or processes. The most comprehensive and relevant inventory and process studies of Australian magnesite karst (and one of the few detailed studies of any magnesite on a global scale) are of the Tasmanian magnesites by Sharples (1997) and Household *et al.* (1999). Wylie (2011) reviewed the history of the knowledge of the potential karst systems in the Tarkine area of Tasmania.

Possible reasons for the sparse literature and apparent lack of scientific effort into researching magnesite karst systems are:

- Surface or visible and accessible sub-surface magnesite karst systems are rare.

- Magnesite does not usually occur as extensive discrete geological bodies but are often small in area and either strata-bound in other sediments or contained as an alteration product of restricted extent in other lithological or structural units.
- The weathering and groundwater conditions required for dissolution of magnesite are less common than those that produce karst in calcite limestone and dolomite.
- Magnesite karst is of subdued form so as to be not conspicuous.
- Magnesite karst has few significant characteristics to distinguish from karst forms and processes in other carbonate rocks.
- It occurs as palaeokarst rather than as active karst.

Sharples (1997) and Household *et al.* (1999) have shown there are active karst systems in magnesite in the Arthur Metamorphic Complex in the Savage River area at Bowry Creek and Main Rivulet, and in the Lyons River area. They describe and map in detail the complex geology and hydrology of the magnesite karst area immediately east of the Arthur River. at Victory Springs and the stream complex of Northern, Central and Southern Creeks. This is the most accessible of the known karst magnesite in Tasmania and includes a warm spring, dry and blind valley systems, caves, solution pipes, karst arches and a gorge in magnesite with overhangs. All features lie outside 24M\2009 mining lease.

3.5. Surface magnesite karst at the Arthur River 24M/2009 site

The mapping by Sharples (1997) and Household *et al.* (1999) and the various exploration reports referred to in Section 3.2 (page 6) above confirms there is very little magnesite outcrop and surface karst in the 24M/2009 lease. Household *et al.* (1999) describe only three features that may be in part related to active or former karst processes (Figure 8).

A. An unambiguous karst feature is a small warm spring 270 metres east of the Keith River and 20 metres higher than the river level. They measured the spring water temperature at 15^0C with a pH 7.7 with the most abundant anion being bicarbonate.

B. A small shallow depression (approx 25 m x 7 m x 1.5?m) with possible subsurface drainage 380 metres northwest of Farquhars Bridge was described as a likely subsidence doline.

C. Part of the valley of Johnny's Creek across the site was described as "...a flat, swampy *karst* (my italics) valley." This description applies to the changes in the long profile and cross-valley profile of Johnny's Creek across the magnesite body. However, no magnesite outcrop is recorded along the valley and the low pH indicates no contemporary interaction with the carbonate body, and the valley morphology is more likely to be a result of incision into the thick alluvial, colluvial and weathering cover rather than a primary relict karst feature.

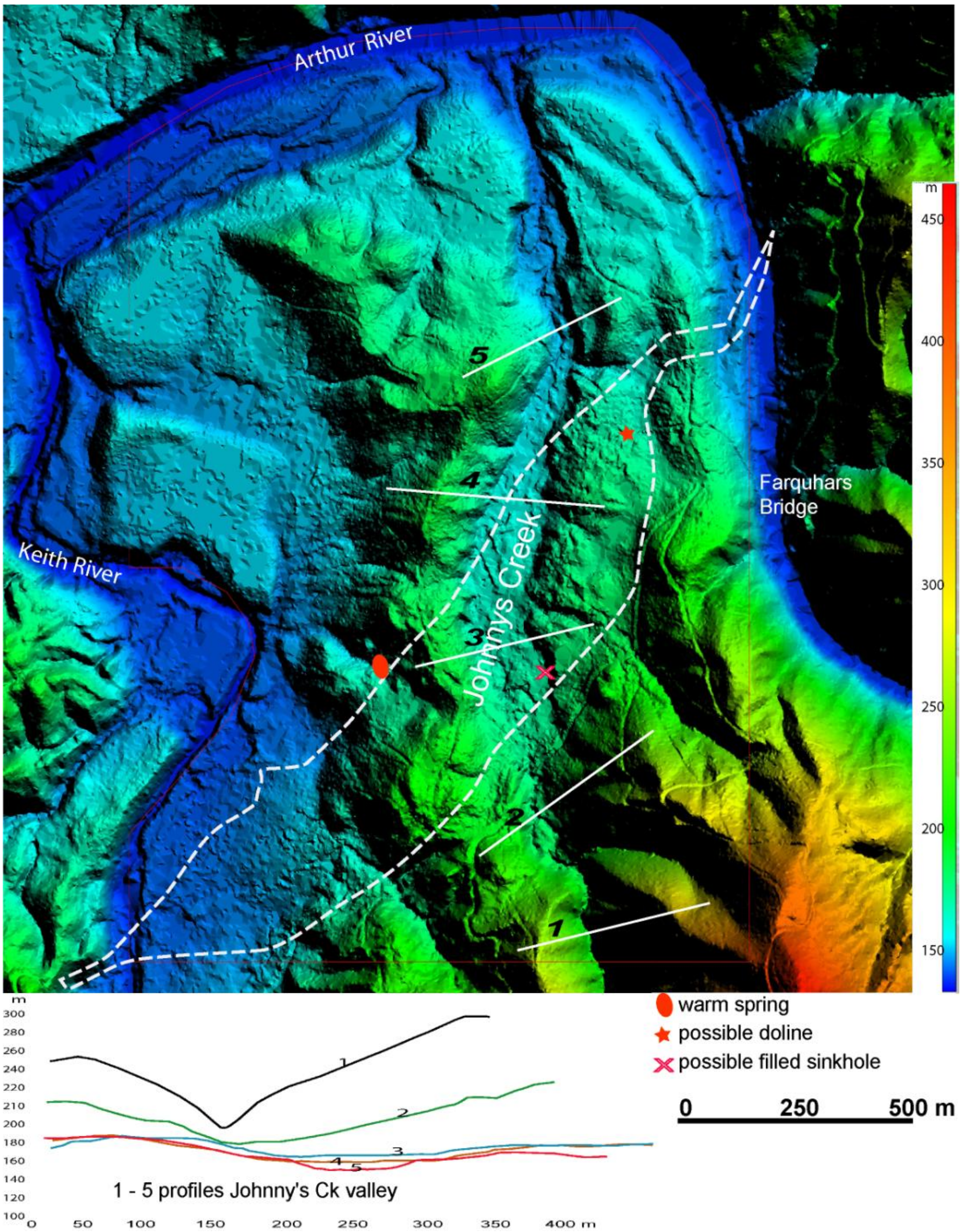

Figure 8. Possible karst features of 24M/2009 lease area and profiles of Johnny's Creek valley.

3.6. Possible sub-surface magnesite karst at the Arthur River 24M/2009 site

The extensive drilling, geophysical and other exploration activities at Arthur River 24M/2009 provide a clear record of the variation in the nature of the magnesite body. These have confirmed that the main magnesite body lies beneath a variable cover of weathered magnesite and younger alluvial and colluvial deposits.

3.6.1. Evidence from drilling

The drill log of AR3 600 metres southwest of Farquhars Bridge passed through 70+ metres of strongly weathered carbonate and yellow carbonate sand (Figure 9) interpreted as "karst fill" (DD83 AR3 drill log). The feature was also interpreted as a large buried solution doline 56 metres deep by Household *et al*. (1999). However, given its location at the eastern margin of the magnesite body, and the subsequent recognition of adjacent weathered dolerite dykes (Stewart Capp *pers. com* Dec 2011), the karst nature of this feature is doubtful.

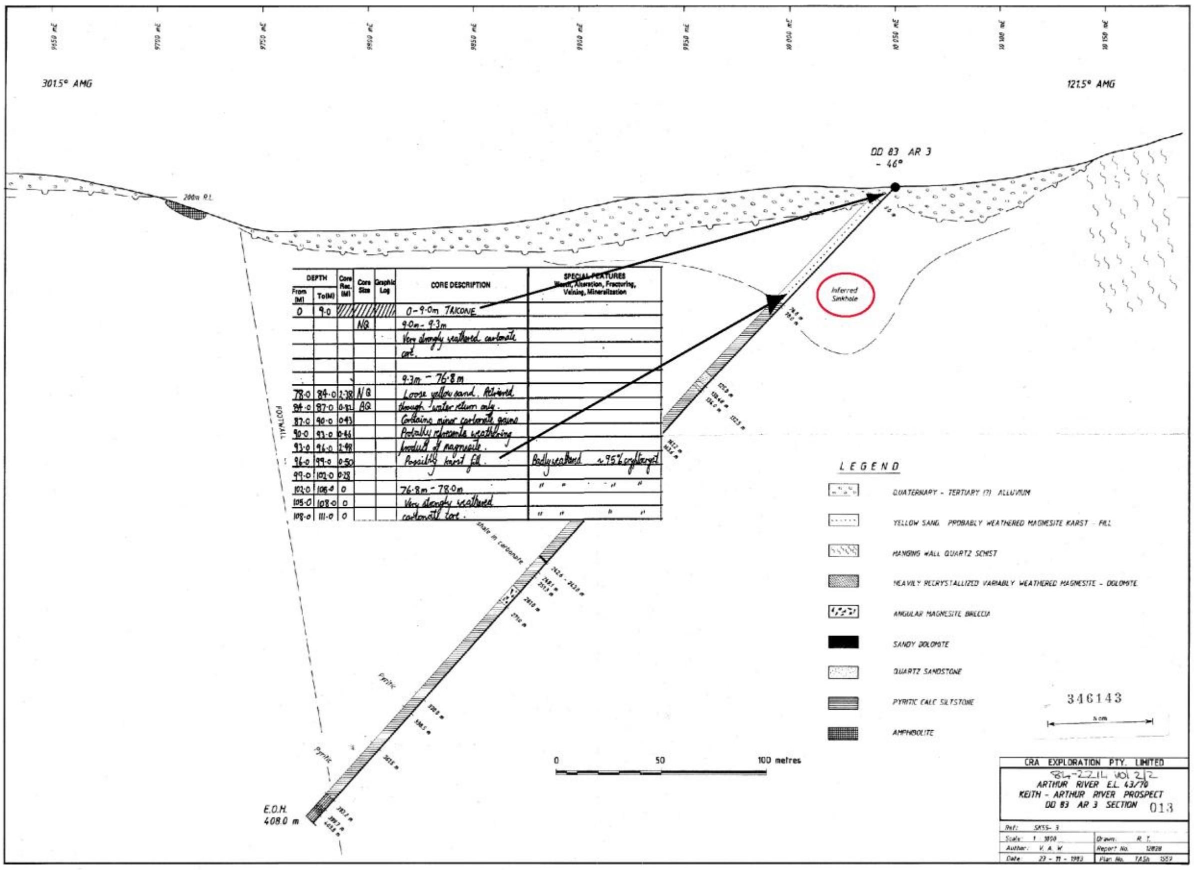

Figure 9. Inferred sinkhole at DD83 AR3 (CRA Exploration 1984).

A consistent feature of the drill logs are areas of non-recovery of core and rapid transitions from unweathered to weathered magnesite and non-magnesite units. There are several interpretations that may be made of these variations.

Some drill logs interpret non- or poor recovery of core as "cavities" (Figures 10& 11).

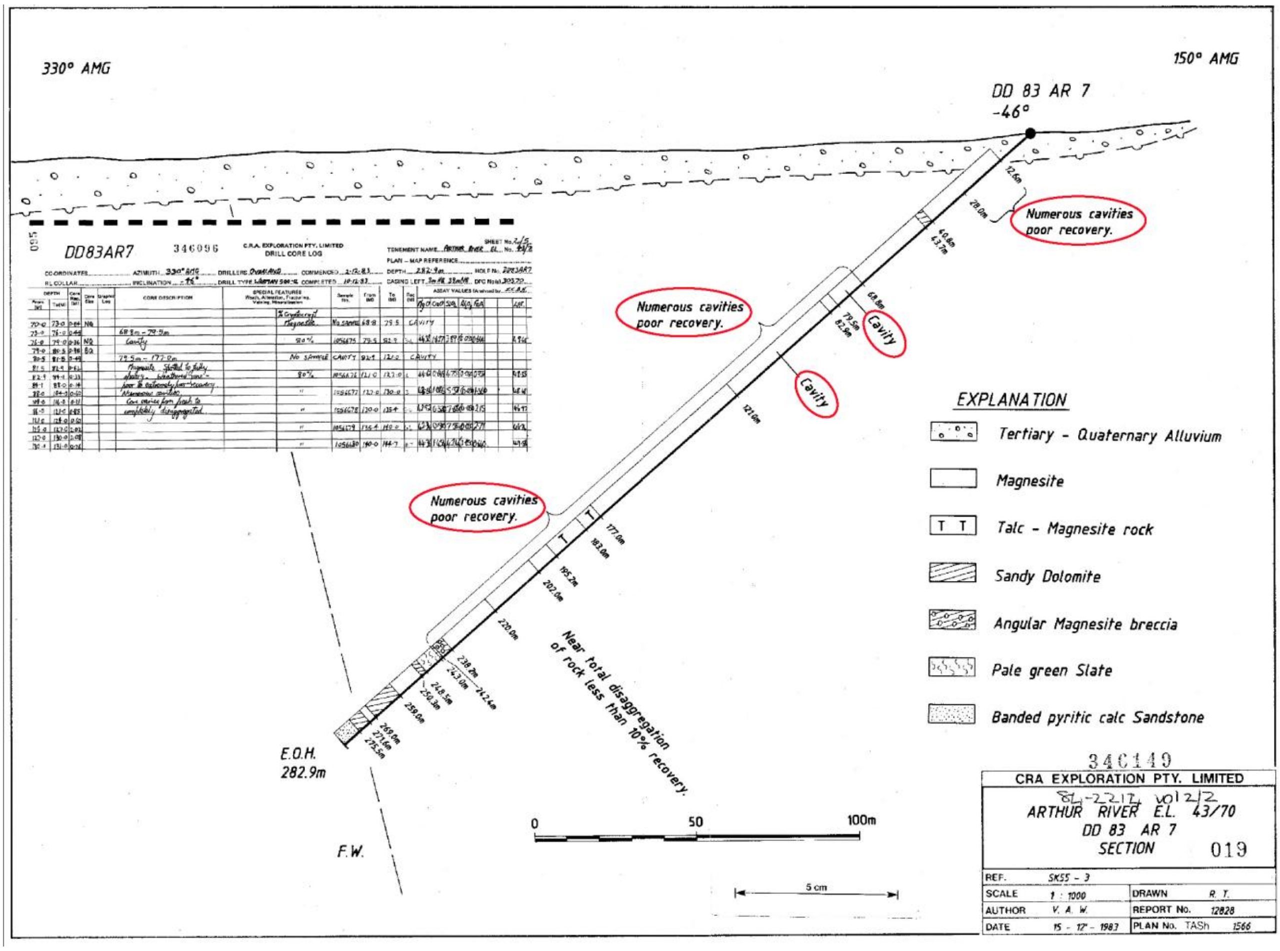

Figure 10. Diagrammatic section and extract from log of drill hole AR7 showing poor recovery attributed to cavities (red outline). (CRA Exploration 1983).

However, non-return of core does not necessarily mean there is an open cavity but may result if the core passes into unconsolidated material that supports the drill stem but is dispersed by drilling fluids and not preserved as intact core. It was noted that cavities recorded in early drill holes at Arthur River "...were not repeated in later check drill holes. The initial core loss may have been a result of less sophisticated drilling equipment - especially core barrels" Crest Magnesium 2000).

The widespread record in drill core logs of core non-return attributed to cavities suggests that some sub-surface karst features have developed in the magnesite karst of the Arthur River area. Similar features have been recorded elsewhere in drill core e.g. at Lyons

River. Household *et al.* (1999) interpret the drill logs to indicate there is a substantial relict karst and palaeokarst associated with the Arthur River magnesite. Along with other geological and hydrogeological features of the Arthur and Lyons Rivers, they suggest the karstification is relict rather than related to a contemporary and ongoing hydrothermal karst system.

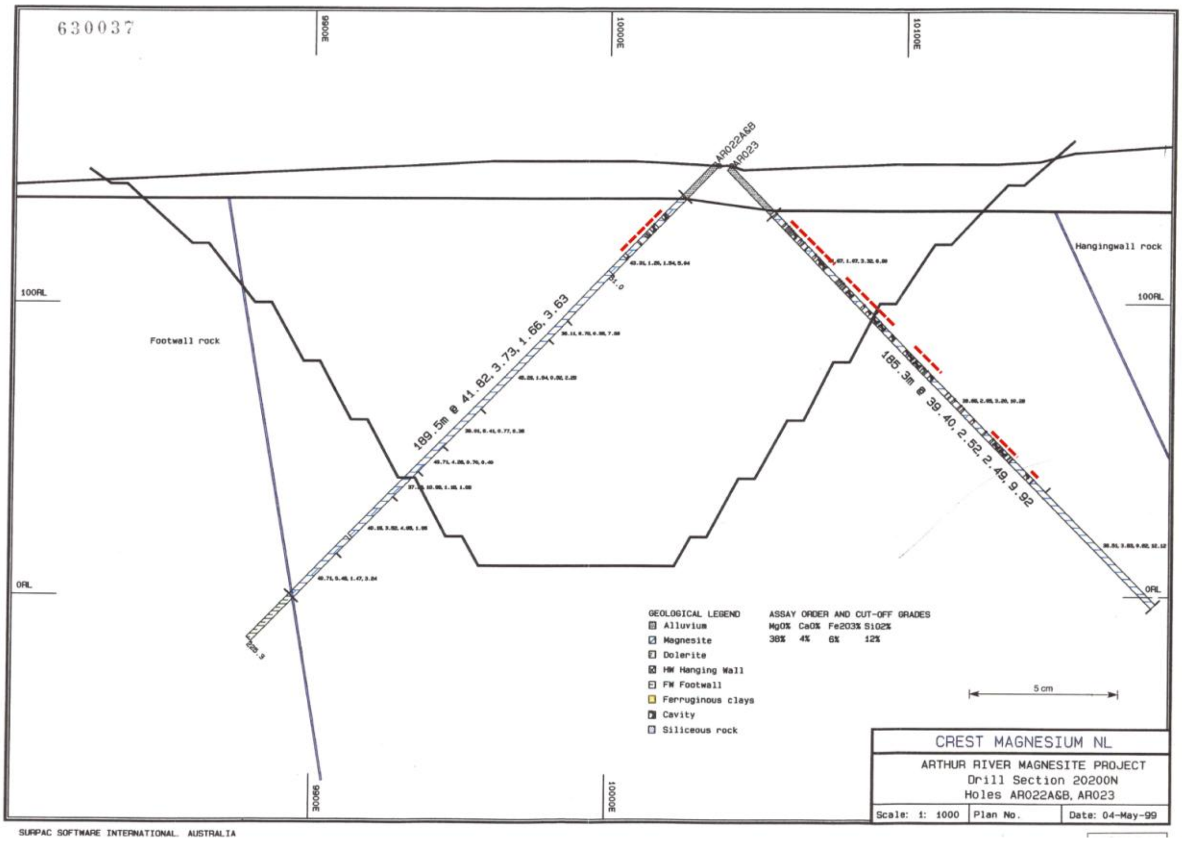

Figure 11. Interpreted cavities (red lines) in drill hole AR23 (Crest Magnesium 2000) suggesting relict karst processes.

However it is not been clearly established that the variation in core material and the logged non-return intervals are true cavities and/or that they are a result of dissolution of magnesite.

3.6.2. Evidence from groundwater and hydrological surveys

Hydrogeological studies at the site have aimed at determining the interaction of potential mining operations with groundwater and streamflow (Golder Associates 1999, Coffey Mining Pty Ltd 2010, GHD 2011). Studies included monitoring bores, pumping tests and development of models to predict groundwater conditions and response to mining.

Golder Associates (1999 Section 5.3 page 8) found the magnesite body had relatively high hydraulic conductivity and attributed this to the potential karstic nature of part of the subsurface as they logged cavities in some of the monitoring boreholes and pumping boreholes (*Ibid.* Appendix B). However, they also concluded (*ibid.* Section 11.1 page 19) that the calibrated groundwater model based on test pumping data showed much lower hydraulic conductivity than would be expected from karstic rock with good interconnection of open cavities. It was concluded that many of the apparent cavities logged during drilling (and in the magnesite body) were sediment filled, thus reducing the flow rates. They also concluded there would be minimal impact of a mine on the flow at Victory Springs (*ibid.* Section 10.1 page 18).

Coffey Mining Pty Ltd (2010) critically reviewed previous hydrogeological work and identified the key risks to a potential mine associated with hydrogeology and hydrology at the site. They also conducted limited site water quality studies. Based on their interpretation of borehole logs and personal communication with geologists and drillers familiar with the site, Coffey (2010) accepted that sub-surface karst was possibly extensive within the magnesite at the site at various depths but that "cavities" are generally filled with alluvial or sedimentary material. They also provided comprehensive recommendations for a programme of geological and hydrogeological investigations to further clarify the groundwater conditions and responses and the nature of the fill in the drill intervals logged as cavities.

GHD (2011) conducted further groundwater monitoring, pumping tests and a modelling exercise utilising the extended data sets. The document does not make specific reference to sub-surface karstic potential but concludes that the magnesite aquifer is compartmentalised (*ibid.* Section 3.1.8, 3.3.1, no page numbers), with the summary statement: "The compartmental nature (the presence of inferred barriers) of the magnesite aquifer presents both possible benefits and difficulties for the proposed mining operation" (*ibid.* Section 4.1, no page numbers. I interpret this to imply there is less hydraulic connectivity in the magnesite body than would be expected if there was extensive, connected sub-surface karst.

4. Geoconservation and National Heritage Listing assessment

4.1. Geoconservation significance of magnesite karst

There is no doubt that clear examples of active and relict magnesite karst are of high geoconservation value. The exploration of karst terrain is a long established and ongoing activity at professional and recreational levels and research into contemporary and palaeokarst features and processes (speleology) is very active worldwide. This is evidenced by major works of scholarship in texts and refereed journals and the existence of local to international societies and federations engaged in the study of caves and related features. It has been established (Section 3.4 above) that there has been little recognition of the occurrence of extensive areas of magnesite karst on a global scale, hence the Tasmanian sites are at least of National and possibly of International Significance. This significance has been determined by Professor Paul Williams, an international authority on karst terrain and hydrology (Williams 1998) and reaffirmed by him in personal communication in Dec 2011. The studies by Williams (1998) and others cited in this report confirm that magnesite karst does exist in several areas of the Arthur Metamorphic Complex. It is also clear that the geomorphological features displayed warrant recognition and management to maintain their character and integrity as landscape units, and, where appropriate, the nature of related hydrogeological processes.

4.2. Geoconservation significance of mining lease 24M/2009

4.2.1. Surface karst

The minimal occurrence of surface magnesite karst in the mining lease 24M/2009 area does not warrant inclusion in a listing that specifies the high significance rating of the adjacent areas of Victory Springs and Central and Southern Creeks. There is no apparent continuity of features across the Arthur River east to west from these highly rated sites to the mining lease 24M/2009 site.

Williams (1998) concludes: "There are no features of geoconservation significance in the [mining lease 24M/2009] area except for the subsurface cavities which may be of scientific interest in the event of deep quarrying" (page 6). On the evidence presented in this present report, I concur with that conclusion.

4.2.2. Subsurface karst

As noted in section 3.6 above, drilling records have frequently interpreted the existence of filled or open cavities at various levels in the magnesite body based on non-return of core. This interpretation has been accepted by Williams (1998), Sharples (1997) and Household *et al.* (1999), and in some of the hydrogeological studies (Golder Associates (1999, Coffey Mining 2010), but has been questioned by Derwent Geoscience (2011). However it is clear that many of the interpreted cavities are either sediment filled or are bodies of weathered magnesite rather than open karst cavities. The hydraulic modelling and interpretation by GHD (2011) suggesting the magnesite body is compartmentalised, also casts doubt on wide scale sub-surface karstic connectivity.

Given that adjacent and broadly equivalent magnesite bodies (e.g Lyons River and Central Creek) do contain surface and sub-surface karst expressions (pipes, arches, pinnacles, and caves), it is not unreasonable to assign some of the buried features at the Arthur River body as palaeokarst.

As such, these features are of potential geoconservation significance, but clearly there is presently insufficient evidence as to their nature and distribution to warrant inclusion in a National Heritage Listing.

4.2.3. Hydrogeological association with adjacent magnesite karst systems

There are mimimal indications of an active karst hydrological system at the mining lease 24M/2009 site and no known hydrogeological link with the adjacent magnesite karst has been established - although such interaction should not be discounted. The hydrogeologial modelling (Golder Associates (1999, Coffey Mining 2010) suggests connectivity with the Arthur and Keith Rivers but there is no definitive data to determine the magnitude of this. Further hydrological investigations as suggested by GHD 2011 in relation to potential mine development may clarify such relationships.

5. Conclusion

There are no proven geoconservation values in the area of mining lease 24M/2009 that satisfy National Heritage Listing Criterion B: *The place has outstanding heritage value to the nation because of the place's possession of uncommon, rare or endangered aspects of Australia's natural or cultural history.* The most significant potential geoconservation value is the possibility of palaeokarst in part of the magnesite body. This is an unknown value and is not of sufficient strength to warrant inclusion under this criterion.

Any buried or palaeokarst features that exist are not accessible by the standard speleological research and exploration techniques but would be revealed during magnesite mining operations. Under these circumstances, they would be appropriately managed by an environment management plan that would require ongoing expert assessment of the nature and content of any cavities (filled or open) that were so revealed.

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