Advice on interpretation of patterns and colours shown in supplied photographs of a rock from Mt Arapiles/Dyurrite, western Victoria.

Prepared by:

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updated with supplementary material July 30, 2020

RE Referral from DELWP Customer Contact Centre –
Case: CCC-364748-D5Q9B9 DCCD:015301602

Dear customer:

Thankyou for your enquiry to DELWP, and for the photos.

On Sunday 21/06/2020 @11:41 AM you wrote:

I would like to request a review of the attached photographs, taken at Mount Arapiles. I am interested in a geological analysis of the markings on the rock, in particular the horizontal oval feature prominently shown. I understand that Ross Caley has specialist knowledge in this field and I would like to seek his opinion on the likely origin of this marking.

I have a query

Kind Regards,

Supplied photographs:

Photo: 'oval a'

Photo 'oval b'

Photo 'oval c'

Geological Assessment of photographs:

That is a very interesting looking piece of rock, with a range of different patterns and textures evident that, in combination, indicate a whole sequence of different geological and weathering processes at play, and also the strong possibility of a human agency. While unfamiliar with this particular rock, I am very familiar with the general geology of Dyurrite/Mt Arapiles and can unravel and sequence the different patterns and textures visible in your photos using a deductive process called 'overprinting criteria' - a common analytical technique used by geologists to unpack the geological history of a rock or region (a reference: https://en.wikipedia.org/wiki/Overprinting_(geology).

In order to better illustrate my interpretations, and because I have recognised the possibility that human agency has played an important role in creating some of these patterns, I've gone to a bit of extra effort to answer this query, and have annotated your photos in a sequence that shows the main geological features that I can see, explains why and how I have interpreted them, and what I consider to be the significance of the order in which these features occur. I used this workflow in order to gain enough understanding of the rock photos to be able to address your main query – the possible origin of the small brown oval marking near the bottom of the rock, as detailed in photo 'oval a'. The rest is a bonus!

Because of the possibility of human agency, I encourage you to contact Aboriginal Victoria and request expert follow-up (https://www.aboriginalvictoria.vic.gov.au/aboriginal-cultural-heritage-register-information-system-access), particularly if you possess more precise location information for your photographs (which Aboriginal Victoria will require).

Geological Interpretation, in summary:

- The base rock at Dyurrite/Mt Arapiles is a Silurian-Devonian aged quartzite, a metamorphosed sedimentary rock which is now crystalline and pale cream colour when fresh, and is the rock in your photos.

- The rock in your photos is not in its original position of formation – bedding layering is obvious within the rock and is steeply oriented. Bedding layering was horizontal at the time of deposition of the original sediment and bedding remains sub-horizontal where in-situ across the rest of Dyurrite/Mt Arapiles. The steep dip of the bedding in the photos shows that it has fallen– it's probably a large freestanding boulder.

- The colours other than pale cream/grey visible in the photos are from several different types of rock alteration and physical processes that have been superimposed onto the base rock and have modified its appearance. I can interpret five distinct types of alterations, for which I can establish relative ages using 'overprinting criteria' analysis (explained further below). I have concluded that four of these alteration types and processes appear to be entirely natural, and typical, geological features. These are, from oldest to youngest:

1. Liesegang Rings (Bands) – these are the prominent heavy brown and red/purple coloured swirly-shaped and 'ring-shaped' iron-oxide alterations that appear mainly confined to the lower parts of the pale quartzite rock in your photos, and more faded brown 'ring-shaped' iron-oxide alterations dotted throughout the rock at higher levels. The Liesegang Rings can be seen to be overlain by silica 'Desert Varnish' veneers in places, and the prominent 'Leisegang Ring' near the base can be demonstrated as penetrating the fresh quartzite rock interior, since this is exposed on younger fracture surfaces at the base of the rock. Thus the lower 'Liesegang Ring' pigmentations can all be demonstrated to have 3-dimensional shapes within the quartzite, can be demonstrated to be older than the 'Desert Varnish'

veneers, and can be demonstrated to be older than the recent fractured surfaces. The brown and red/purple iron-oxide colours and 3-dimensional penetrative character of these pigmentation patterns are typical and diagnostic characteristics of Liesegang Rings. These iron-rich cement alterations develop as a by-product of the long-term weathering of rocks, particularly within soil profiles. **The Liesegang Rings visible in your photos exhibit the characteristic range of swirly, patchy and geometric or 'ring-like' shapes, and include the 'subhorizontal oval shaped pattern' that you are particularly interested in, photo 'oval a'**. **Overprinting criteria show this pattern to be a fracture-controlled Liesegang Ring (Band).** The elongated shapes of these features is typical, and due to them developing along pre-existing fractures and weaknesses in the quartzite. The Liesegang Rings are the oldest alteration colours I can see in the rock and are entirely natural.

2. Pigmented 'Desert Varnish' – these are the patchily-distributed semi-transparent orange/brown silica veneers that cover parts of the quartzite surface. They are responsible for the areas of brown colour visible in the photo. Pigmented 'Desert Varnish' silica veneers are very common on overhanging cliffs and in caves at Dyurrite/Mt Arapiles. They are usually quite shiny in appearance, although I can't tell this from your photos. The relative age and semi-transparent nature of the brown pigmented 'Desert Varnish' visible in your photos is revealed where it can be seen to have formed over the top of a part of the 'subhorizontal oval shaped' Liesegang Ring, photo 'oval a'. The 'Liesegang Ring' is visible through the semi-transparent 'Desert Varnish'. This proves that the brown 'Desert Varnish' is younger than the 'Liesegang Ring' formations that it overlies. Where the desert varnish has been recently fractured away, fresh pale cream underlying quartzite is exposed. This proves that the Desert Varnish is a thin veneer that gradually developed directly on the underlying cream-coloured quartzite but does not penetrate into the underlying rock. Like the 'Liesegang Rings', the brown desert varnish is entirely natural.

3. Unpigmented silica 'varnish' – these are the spaced yellowish pale subvertical vertical, downward-narrowing streaks that extend down the height of the rock. They have the appearance of long-established water flow runnels, which typically develop below persistent water seeps in fixed (usually fracture controlled) positions in rock. The water flow runnels are probably still intermittently active after rainfall today, charged by clean rainwater from above. The translucent silica 'varnishes' that form in these sorts of features are typical of surface veneers that form on quartzite that is regularly flushed by clean water – the flushing removes all the dust particles, etc, which would otherwise give the veneer a pigment, so that the pale cream/grey colour of the underlying quartzite bedrock shows through almost unmodified. The yellowish colour suggest that the 'varnish' does incorporate a very dilute dust pigment component. These features are also entirely natural. Unpigmented silica veneers can grade laterally into pigmented silica 'desert varnish', and this is also apparent in a few places in your photos.

4. Dark grey mottled rock with patches of living lichen – a patch of rock at the left hand side in photo 'oval c" shows the colours and textures typical of Dyurrite/Mt Arapiles stone that is exposed to direct rainfall and ongoing weathering, with sufficient moisture and direct sunlight to support life. The grey colour comes from the fragments of organic material that have naturally accumulated on the rock surface.

❖ The fifth alteration type I can see in your photos is the distinctive strips of opaque black pigmentation. I have listed alteration type as a separate dot-point because I have concluded that the black pigmentation is most likely to be soot. It is possibly the result of human agency, although archaeological expertise will be required to further investigate this key point – my advice to you is confined to interpreting the geological features. Overprinting criteria show that the black pigmentation overlies the brown 'desert varnish', and so must be younger. Overprinting criteria show that the black pigments have been eroded entirely by the water runnel streaks of unpigmented varnish, which form hard flanking boundaries to the black pigment stripes. Overprinting criteria show that the black pigment stripes have been removed, along with underlying brown 'desert varnish' and some underlying quartzite, by recent rock fractures and related rock spalling visible at the bottom of your photos. This proves that the black pigments are a surficial veneer on the rock and are older than the recent fracture surfaces exposed at the base of the rock. A thin ribbon of black pigment appears to be deposited in one place upon the newly exposed cream base rock on the recent fracture surfaces, below a thicker strip of black pigment and 'desert varnish', and adjacent to a water runnel. This indicates that some black pigment has been recently remobilised by water flow and is apparently redepositing directly on the freshly exposed fracture surface. This mobility indicates that at least some of the black pigment is not trapped within a siliceous 'desert varnish', implying that it may be a younger deposit that is still uncemented and still subject to water erosion. I suspect the black pigment is soot, and that the strips are remnants of a thick soot accumulation that probably once covered most of the rock, presumably sourced from a persistent fire position located at the base of the rock. Most of the black pigmentation is now eroded, so that only the spaced stripes remain. The soot was likely eroded by a combination of water flow (in the water runnels) and by gradual aeolian abrasion (elsewhere). The narrow stripes of the black pigment are remnants, only preserved on the most favourable areas which are the damp areas marginal to the water runnels. Because of the possibility of human agency, I suspect that the rock in your photos could be a site of cultural significance.

In detail:

1: General geology

The basic rock type that forms Dyurrite/Mt Arapiles is quartzite. Quartzite is a metamorphic rock formed from a quartz-rich sedimentary rock precursor that has been subjected to heating and recrystallisation – basically heating has converted the rock into a super-hard crystalline rock. The precursor rock was quartz-arenite sandstone and conglomerate, laid down as horizontal sheets of sand and gravel in an ancient river system. The Dyurrite/Mt Arapiles sequence is a part of the Silurian-Devonian -aged (~440 to 400 million years old) Grampians Group succession which is also well exposed in the main Gariwerd / Grampians Ranges to the southeast.

Geologists interpret the Dyurrite/Mt Arapiles strata to have been continuous with the rock sequences of the main Gariwerd/Grampians Ranges at the time of deposition. Subsequent deformation and erosion of the sequence now sees Dyurrite/Mt Arapiles as an erosional remnant, physically separated from the Grampians/Gariwerd Range sequence. Geologists have mapped the present-day distribution of Grampians Group, including in the subsurface.

The following reference shows the known distribution of Grampians Group across western Victoria, including at Dyurrite/Mt Arapiles and in the subsurface:

http://earthresources.efirst.com.au/product.asp?pID=1159&cID=64

Because of today's physical separation, precise correlation of the rock succession at Dyurrite/Mt Arapiles with Grampians Group rock units mapped and defined in the main Gariwerd/Grampians Ranges is tricky. The composition and textural features of the Dyurrite/Mt Arapiles rocks have previously been correlated with the Grampians Group package named the Murray Hill Sandstone, although correlation other thick quartz arenite packages mapped within the Gariwerd/Grampians Ranges is also possible, including the Kalymna Falls Sandstone that forms Mt Stapylton in the northern Gariwerd/Grampians.

The general rock descriptions for Grampians Group strata are given here:

http://earthresources.efirst.com.au/product.asp?pID=514&cID=39

The quartzite at Dyurrite/Mt Arapiles is composed of sand-sized grains of the mineral quartz, intermixed with small rounded pebbles that are also made of quartz. Quartz is a very stable resistant mineral, so that the rounded shapes of the pebbles within the quartzite testify to highenergy erosion in an aqueous environment at the time of deposition, over 400 million years ago. This is one of the reasons that we interpret an ancient fast-flowing braided river system as the likely environment of deposition of the Dyurrite/Mt Arapiles sediment.

The fundamental colour of the quartzite rock at Dyurrite/Mt Arapiles when fresh is white to pale cream. This colour is dictated by the colour of the predominant primary constituent mineral grains, which are quartz (typically ~90 to 95%+ by volume; quartz is translucent), feldspar (up to 5% by volume; the feldspar is typically opaque white) and minor amounts of small lithic grains and mica flakes, most of which are also white. Because the original sandstone has been recrystallised into a quartzite at Dyurrite/Mt Arapiles it is typically more translucent than Grampians Group sandstone elsewhere, and the translucency can give the fresh rock a cream/grey appearance.

2: Textural features visible in the photos:

Prominent layering and an open fracture are visible at the right side of the photos (Figure 1). I interpret these steeply inclined features to be primary bedding layering in the quartzite, a legacy from the original accumulation of the quartz-arenite sediment, 400 million years ago.

Since the primary bedding layering was horizontal at the time of its formation, and bedding layering in-situ Dyurrite/Mt Arapiles quartzite remains sub-horizontal today (see figure 9 in Geological Survey Victoria Report 107, reference link above), the steep inclination of the bedding layers in your photos indicates a quartzite boulder that is lying on its side, compared to in-situ quartzite. The open fracture is parallel to bedding, and thus likely opened during the process of the boulder moving to its present position.

The origin of the many smaller, closed fractures visible within the boulder in a range of different orientations is unclear, but they influence all the visible weathering and alteration textures and pigmentation in places, and so predate them.

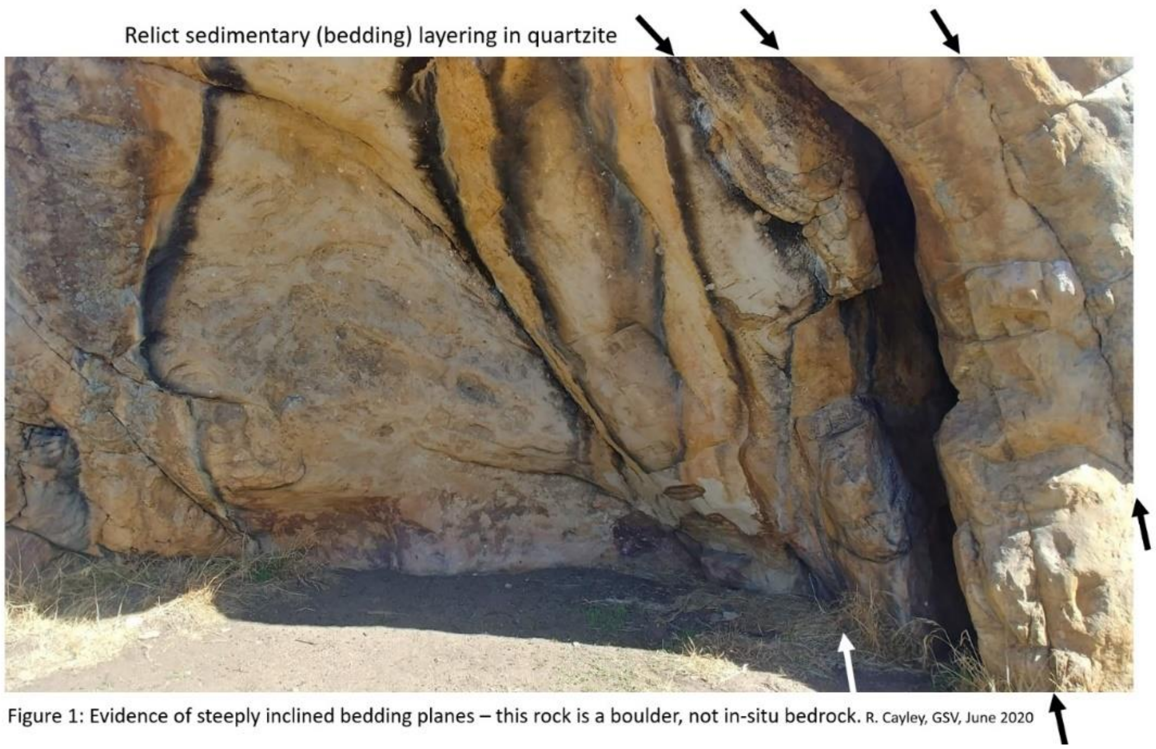


Figure 1: Evidence of steeply inclined bedding planes – this rock is a boulder, not in-situ bedrock. R. Cayley, GSV, June 2020

3: Interpreting the pigmentation and patterns visible in your photos

Most of the quartzite at Dyurrite/Mt Arapiles, and significant parts of the rock visible in your photos, shows a range of colours different to the base white and cream/grey colours of the quartzite. This is because the base quartzite colour has been modified into a range of other colours; uniform grey on gentle to moderately steep terrain; reds, oranges, browns, yellows and, occasionally, blacks, usually in vertical streaky shapes, on steep terrain and on cave interiors. All these other colours are secondary.

The subvertical orientations of some of the streaky coloured pigmentations align with gravity, and I therefore interpret their formation to have been influenced by persistent and localised areas of downwards water flow across the boulder surface, with the boulder in its current position. The localisation of the water flow streaks and other pigment features indicates that most of the rock in the photos is overhanging, and thus protected from direct rainfall that would not otherwise be so localised.

Most of these superimposed colours are very thin veneers that only extend a mm or less into the underlying rock – this is because the base quartzite rock structure is generally relatively impermeable to water, and because some of the colours – particularly the even red/orange, yellow, brown colours – are known to form by a secondary surface silica precipitation process called a 'Desert Varnish' that is inherently confined to moist rock surfaces.

Explanation of 'Desert Varnish' formation

Secondary silica growth to form 'Desert Varnish' is controlled primarily by countless episodes of wetting, followed by water evaporation from the rock surface, which leaves behind a microscopically thin 'skin' of coloured secondary silica, formed over the top of the base white quartz-arenite. (See: https://en.wikipedia.org/wiki/Desert_varnish). Pigmented 'Desert Varnishes' are only able to form in environments where water evaporation from rock surfaces consistently predominates over water run-off from rock surfaces. A great example of a suitable environment for 'desert varnish' formation in Australia are the 'gibber' deserts that form in the consistently arid and hot deserts of Central Australia – evaporation is predominant in these deserts, and 'desert varnish' on the rock fragments baked in the searing sun is ubiquitous. Uluru is another great example of Central Australian 'Desert Varnish' colouration.

In consistently seasonally wet to semi-arid climates like SE Australia, including Dyurrite/Mt Arapiles, the only places where water evaporation consistently predominates over water run-off to form pigmented 'desert varnish' are over-vertical cliffs and cave interiors which are protected from direct washing by the consistent seasonal rainfall. That is why it is only caves and over-vertical cliffs in the Gariwerd/Grampians Ranges that show the striking red, yellow and brown colourations of 'desert varnish' – the less steep rock surfaces that are exposed to seasonal rainfall are washed clean every year, so that the thin pigmented 'desert varnish' veneers never get a chance to form. Any varnish that does form in consistently water washed environments is generally translucent and unpigmented.

Because pigmented 'Desert varnish' formation is so sensitive to disruption from rainwater flow and particularly from clean rainwater that is able to penetrate fractures in the host rock and then leak persistently out at points in the cliff to flow over parts of otherwise dry overhanging cliff and cave surfaces, 'Desert Varnishes' in wetter climates like Victoria, including at Dyurrite/Mt Arapiles and in the Gariwerd/Grampians Ranges, generally look very streaky – they are almost invariably disrupted by water flow.

Red/orange and brown 'Desert Varnishes', including those at Dyurrite/Mt Arapiles, but also in many other places in Australia and in ancient landscapes on other arid continents, get their striking colours from the thin (fraction of a mm) multiply-stacked layers of tiny coloured clay particles that they are made from (*a reference: Potter RM, Rossman GR (1977): Desert varnish: the importance of clay minerals. Science 196:1446-1448.*)

The clay particles in 'Desert Varnishes' are derived from dust storms and from soil, gradually accumulated over thousands to millions of years. Australia is an ancient, rusted continent, and clay particles within dust storms in Australia are relatively homogeneous and are red/orange from the iron oxides (ie 'rust') they contain. Some dust storms originating within the Murray Basin contain younger, more organic-rich particles that are brown. This is the origin of the reds, browns and yellows of red, orange and brown 'desert varnishes' at Dyurrite/Mt Arapiles, and the red/orange 'desert varnishes' that are found across arid Australia. (a reference: *Garvie L.A.J, Burt D.M., Buseck P.R. (2008) Nanometer-scale complexity, growth, and diagenesis in desert varnish. Geology 36(3), 215-218)*.

The clay particles are cemented together by the secondary silica, so that pigmented 'desert varnishes' are very tough features that are as tough as the base quartzite rock upon which they have accumulated. (a reference: *Perry R.S., Lynne B.Y., Sephton M.A., Kolb V.M., Perry C.C., Staley J.T. (2006) Baking black opal in the desert sun: the importance of silica in desert varnish. Geology 34: 537-540)*.

The origin of the silica in the 'secondary silica' that forms the 'desert varnish' at Dyurrite/Mt Arapiles is the base quartzite. Quartzite comprises nearly 100% quartz, SiO_2. Quartz is relatively resistant to weathering and erosion but can be dissolved by weak acids. Humic and tannic acids, derived from vegetation (including, over geological time periods, vegetation like lichens that can grow on otherwise 'clean' looking quartzite), have long been recognised as a significant agent that can dissolve small quantities of quartz, liberating silica into solution in water run-off that can then wet cliff faces and other features (a reference: *Huang, W., Keller, W. (1972) Organic Acids as Agents of Chemical Weathering of Silicate Minerals. Nature Physical Science* ***239,*** *149–151*). https://doi.org/10.1038/physci239149a0). Such acids are implicated as an important agent in the gradual formation of 'desert varnish' at Dyurrite/Mt Arapiles and in the Gariwerd/Grampians Ranges nearby. This is because all these ranges have carried significant vegetation that, for millions of years, has been regularly flushed by rainfall. Rainwater run-off from the Grampians and from Dyurrite/Mt Arapiles is typically strongly naturally stained by tannic and humic acids.

Where acidified silica-loaded rainwater run-off gets an opportunity to evaporate, the silica that was carried in solution is forced to precipitate out to be left behind as a microscopic layer of 'Desert varnish' on the rock surface (a reference: *Thiagarajan N., Lee C. (2004) Trace element evidence for the origin of desert varnish by direct aqueous atmospheric deposition. Earth and Planetary Science Letters. 224:,131-141.*). It is the clay and dust particles that are trapped within the new silica skin during this process that gives the 'desert varnish' its colour. The 'desert varnish' gradually builds up layer by layer, as in an onion, over thousands of years. The vertical streaky appearance of many of these colours reflects the creeping flow of the source water down these surfaces, from which the varnish layers were subsequently able to form through evaporation, and reflects the disruption to pigmented 'desert varnish' that occurs when clean water runoff (as opposed to evaporation) consistently washes away the pigments.

Interpretation of surface pigmentations visible in your rock photos:

i. Areas of unmodified rock colour

Cream/grey colours that are typical of the base fresh Dyurrite/Mt Arapiles quartzite are visible in a number of areas in your photo (Figure 2; see also Figure 7a). These areas are separated by the vertical brown and black 'stripes' of pigment (the 'grey interiors' in Figure 2) or are exposed as the result of recent rock fracturing (centre-bottom; see Fig 7A). Where the rock surface has been fractured, the pale even cream colour is the clearest example of the base colour of the quartzite.

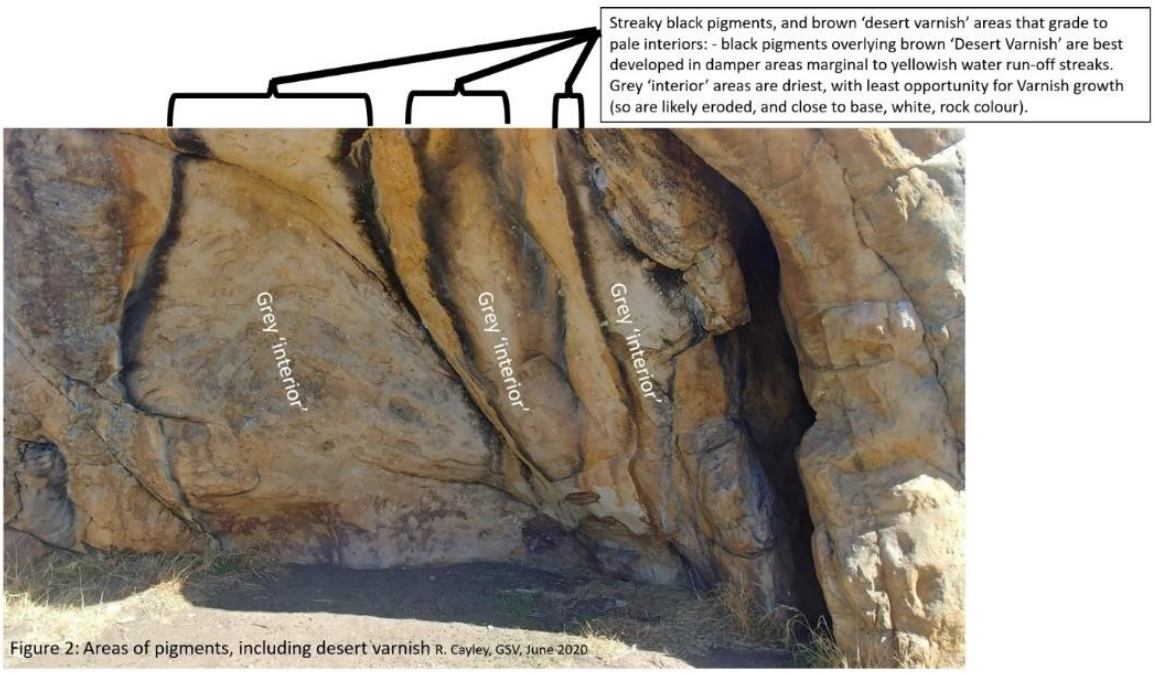


Figure 2: Areas of pigments, including desert varnish R. Cayley, GSV, June 2020

I interpret the generally 'mottled' appearance of the 'grey interior' areas identified in Figure 2 to be places where pigmented 'Desert Varnish' growth has been inhibited. The absence of varnish in these regions likely reflects the microclimate or areas beneath the overhang that are too dry for desert varnishes to properly form. In these places, most brown 'desert varnish', and other overlying pigments appear to be either poorly formed, or eroded, so that the underlying fresh, pale rock colour is revealed.

Some parts of the band of rock at the right hand side of Figure 2 are also close to the unmodified quartzite colour, although the scattered yellowish/brownish hues here suggests a weak 'desert varnish' pigment is developed in places.

ii. Areas of dark grey mottled rock with patches of living lichen

A patch of rock visible at the left hand side of your photo 'oval c', outlined by the white dashed line in Figure 3, shows the colours and textures typical of Dyurrite/Mt Arapiles stone that is exposed to direct rainfall and ongoing weathering, with sufficient moisture and direct sunlight to support life. Continual exposure to rainfall runoff and the physical elements tends to cause erosion of the rock into a rough surface, rather than net deposition on the surface, and in such settings life can gain a foothold, however tenuous. The grey colour of this bit of the rock comes from the fragments of organic material that have naturally accumulated on the rock surface. The underlying quartzite will still be pale cream in colour.

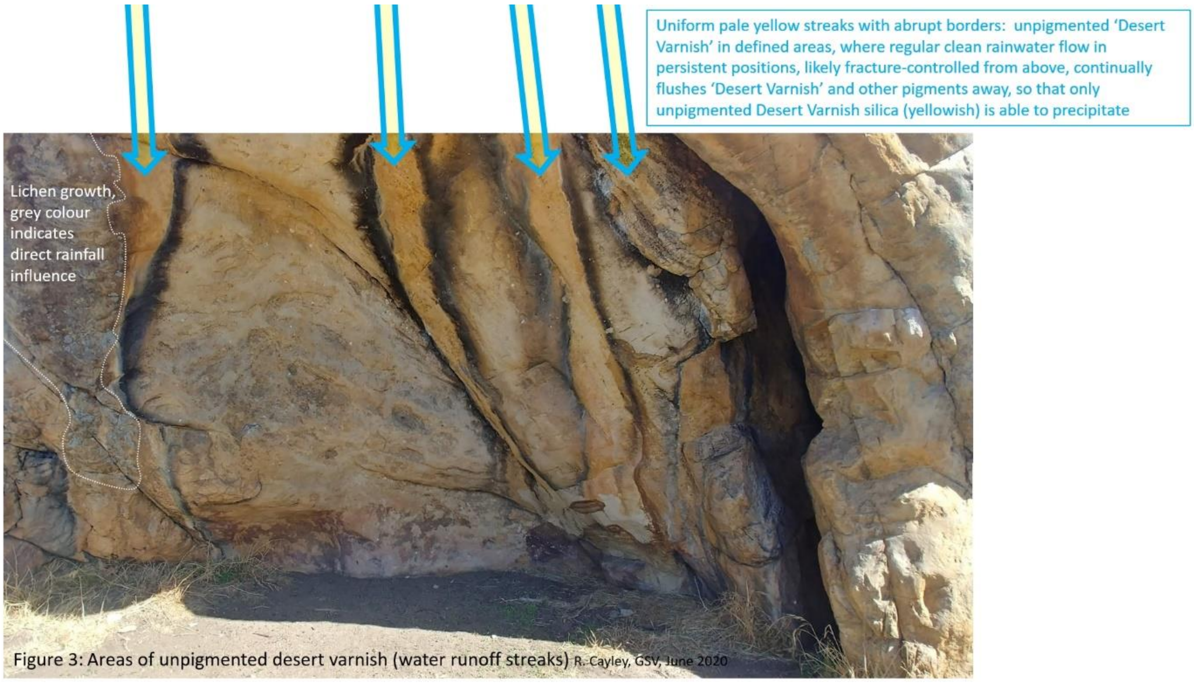


Figure 3: Areas of unpigmented desert varnish (water runoff streaks) R. Cayley, GSV, June 2020

iii. Unpigmented desert varnishes.

These typically form in areas protected from direct rainfall, but where clean, rainwater surface runoff or seepage regularly exceeds water evaporation so that pigments that have accumulated on the rock surface are continually flushed away by clean running rainwater, but where evaporation to form silica 'varnishes' is still possible at the end of each wetting event. After each rain event, when the running of water ceases, the remaining moisture gradually evaporates so that clean, unpigmented silica 'desert varnish' can form in-situ. These 'desert varnishes' are often yellowish in colour (from dilute pigment), and are usually best developed beneath overhangs and in caves on rock surfaces that are protected from constant cleaning and erosion by direct rainfall, but are subjected to regular washing from clean water, particularly groundwater that has had the opportunity to pass through the interior of the rock and thus accumulate the dissolved silica required for 'desert varnish' formation. Yellowish streaks of unpigmented desert varnish are clearly visible in your photographs (arrowed, Figure 3). The abrupt boundaries with the black pigment strips, and with brown 'desert varnish', indicate the edges of the yellow rainwater runoff runnels. They are most likely still intermittently active after rainfall today (note the grasses growing at the base of the water runnels in figure 3).

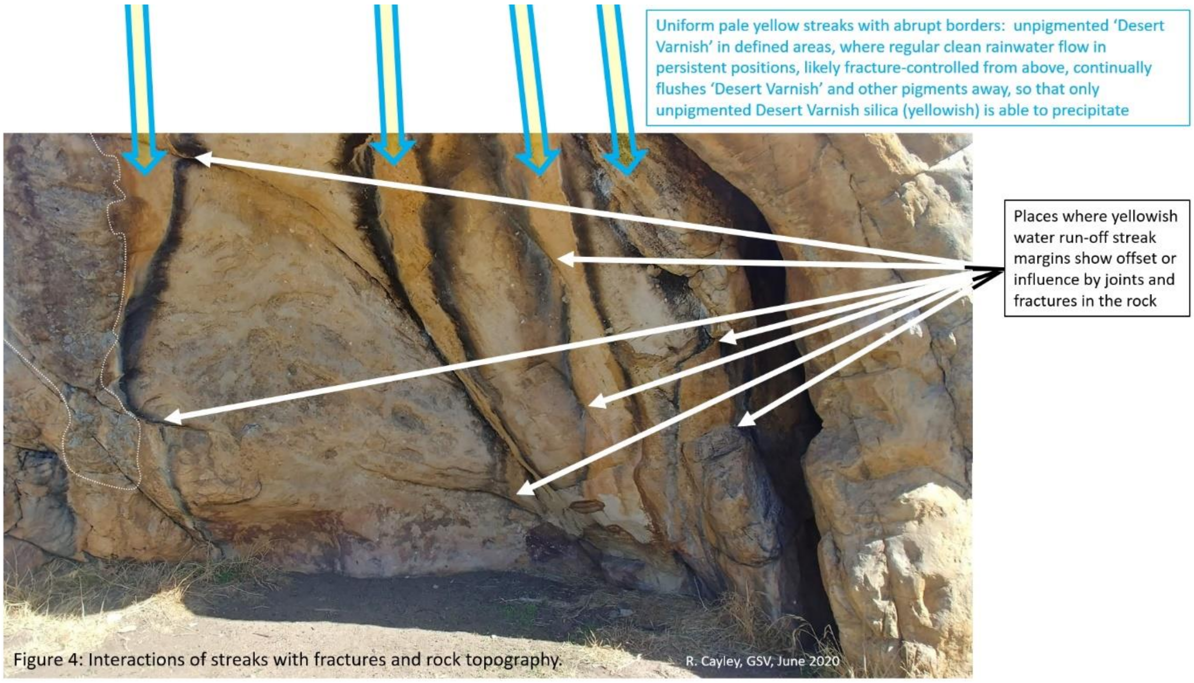


Figure 4: Interactions of streaks with fractures and rock topography.

Dyurrite/Mt Arapiles quartzites have very low primary porosity and permeability, because the small mineral grains that constitute the rock are all completely sutured together, with no interstitial spaces available to 'hold' or 'transmit' internal water. However, the Dyurrite/Mt Arapiles quartzite is a very brittle rock. Episodes of gentle deformation at different times in the 400+ million years since the rock was lithified to a solid mass has fractured the rock so that today it is rent by a ramifying network of fractures and joints, some too small to be visible to the naked eye, and others clearly visible, including in your photographs. It is the small voids along these various anastomosing fracture and joint planes, down to sub-mm scale, that are able to capture, absorb, host and transmit either rainwater that falls onto the rock from above or, below surface, groundwater that infiltrates the rock laterally. This is called 'secondary porosity' and is very common in these sorts of rocks.

The joints and fractures occur at all sorts of different orientations (see Figure 6), so that they intersect with one other – thus the groundwater held within them is 'linked' between them – this interconnectivity gives the quartzite a high 'fracture permeability' for groundwater—which is why water is able to 'flow through' the rock interior, to 'leak out' or 'leak in' at points where joints intersect the atmosphere, periodically, but at relatively consistent rates and in persistent locations, after every heavy rainfall event. In such instances, the fractures are acting as natural 'springs', draining groundwater that has percolated downwards within the rock interior via the distributed joint and fracture network. This consistency of rate and location is why streaky stains on the rock surface, or gaps-in-stains where water runoff has washed stains away, are seen to develop on rock surfaces located below and beside certain rock fractures, even under rock overhangs, as is likely the case in the rock in your photographs.

As for the pigmented desert varnishes, these are very gradual processes that, in places like Victoria, likely take thousands of years or more to make a visible difference. But, plenty of time is available in geology.

The positions of the rainfall runoff runnels are also clearly influenced by (deflected across) pre-existing fractures in the rock, and irregularities in surface rock topography (Figures 4, 6).

iv. Pigmented brown 'desert varnishes'.

Red/Brown 'desert varnish' veneer appears preserved only as remnants in your photos, visible as a translucent brown film that borders the base cream/grey quartzite areas, is gradational with the yellow 'desert varnish' areas, and locally borders the black pigment areas. Where the rock surface has been fractured and spalled (Figure 7a, 7b), the pigmented brown 'desert varnish' layer has been removed, confirming the varnish as a thin veneer that is developed directly upon the base cream quartzite (see Figure 11, 3a). The brown 'desert varnish' pigmentation is similar to 'desert varnishes' elsewhere at Dyurrite/Mt Arapiles and in the Gariwerd/Grampians and reflects the presence of iron oxide-rich particles trapped into the silica veneer.

The brown 'desert varnish' veneer is locally developed over other weathering features within the rock, such as the upper end of the 'horizontal oval' dark brown staining visible in Figure 11 (3b, arrowed). This relationship shows the semi-transparent nature of the brown 'desert varnish', since underlying rock patterning are still clearly visible through the varnish. This relationship also serves as a great example of an 'overprinting relationship', since it demonstrates that the brown 'desert varnish' must be younger than the 'horizontal oval' brown stain over which it has formed.

A lateral gradation from strips of black pigment, to a flank of brown 'desert varnish' (orange in high-intensity colour stretch, below) to the cream/grey colours of the base quartzite colour (yellow in high-intensity colour stretch; see figure 5a, 5b) is particularly interesting, because it reveals relative position, and therefore relative age – another example of an 'overprinting criteria'. The black pigment must overlie the brown 'desert varnish' because, if the brown 'desert varnish' was uppermost the opaque black colour would be overprinted and dulled - but it isn't. Therefore, a relative age can be interpreted – the brown 'desert varnish' is older than the opaque black pigment.

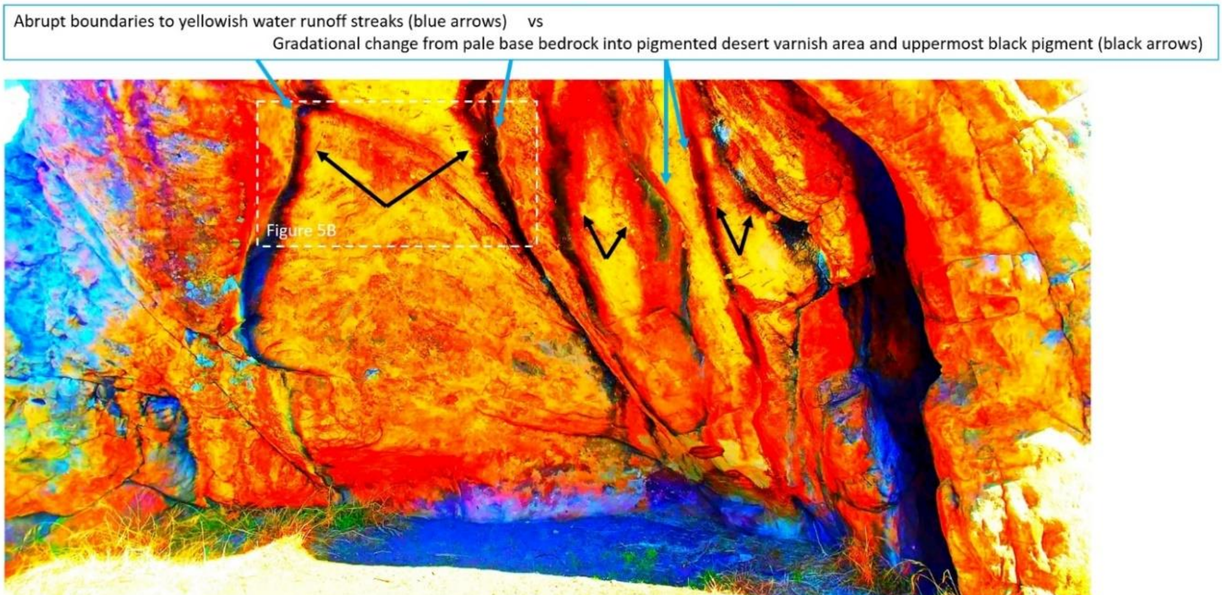
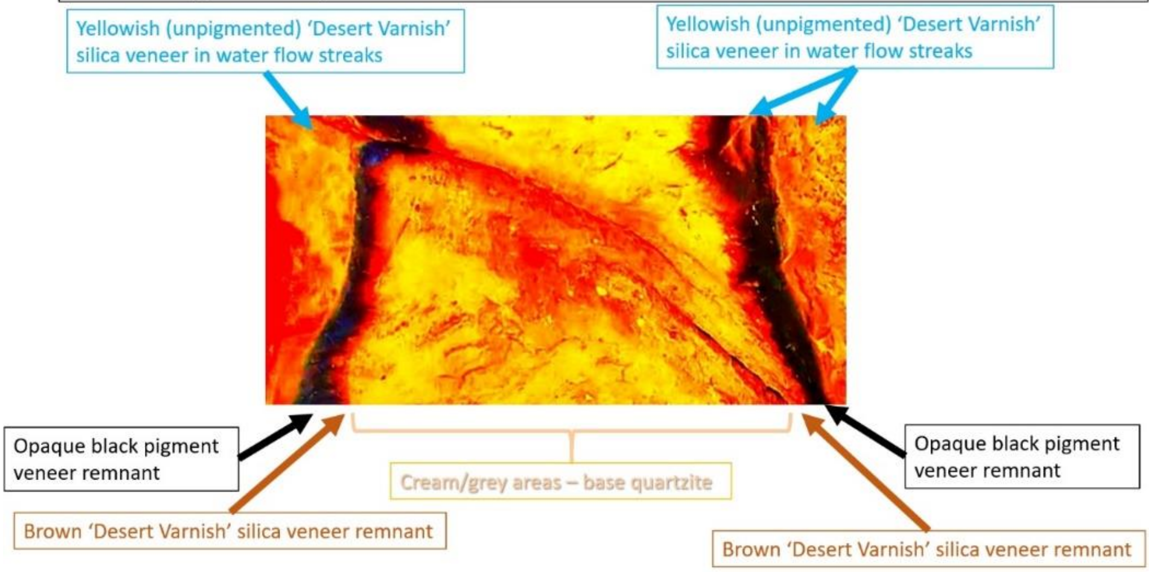


Figure 5A: High Intensity Colour Stretch to highlight subtle colour changes R. Cayley, GSV, June 2020

Figure 5B: High Intensity Colour Stretch to highlight subtle colour changes and overprinting criteria: base quartzite (centre), overlain by mostly eroded brown 'Desert Varnish' remnants, overlain by mostly eroded opaque 'black pigment remnants', and with both pigments entirely absent from water flow areas R. Cayley, GSV, June 2020



This relationship implies that, prior to the accumulation of the uppermost black pigment, the rock surface was likely more widely covered only by brown 'desert varnish', as is typical of many overhanging cliffs and caves at Dyurrite/Mt Arapiles and elsewhere.

The brown 'desert varnish' appears to be the earliest pigment that has developed on the surface of the quartzite rock in your photos, since it lies directly on the base grey quartzite bedrock. However, the brown 'desert varnish' is not the earliest pigment visible in your photos, since it is seen to also overgrow the underlying brown geometrically-shaped pigments.

v. Opaque black pigment.

Of particular note in your photographs is the intense jet black colour of some of the streaky pigments visible in your photos (Figure 2).

Pigment colour is dictated by chemistry, and black colours in natural pigments are typically due to the presence of either manganese oxide or, more commonly, carbon (soot). In your photos, the black pigmentation can be seen to grade laterally to the underlying brown 'desert varnish' pigmentation and thence to the base pale grey/cream colours of Dyurrite/Mt Arapiles quartzite on one flank (see Figure 5b), and to be abut abruptly against the yellowish water streaks on the other flank (see Figures 3, 5a).

The black pigments maintain their colour intensity from top to bottom in your photos but are completely absent from adjacent places subjected to regular water washing or abrasive erosion. This indicates to me that the black pigments were likely once developed at this intensity relatively evenly across the whole height and much of the width of the rock in your photos, but subsequent erosion has removed the black pigment in most places so that only the narrow strips remain.

Where the black pigment strips appear to have been gradually worn away by abrasion, the underlying colours of the brown 'desert varnish' and the base colour of the underlying quartzite are revealed in turn (see Figure 5a, 5b). These colour patterns are repeated systematically across the width of the boulder. In Earth Science a systematic appearance is typically interpreted as reflecting a systematic geological process.

My impression from the photographs is that the black pigment looks organic, which would be carbon dust (soot). The photos do not discriminate if the soot is young and uncemented or older and silicified within a desert varnish. One clue I note is visible in Figure 7A, where a section of black pigment and underlying brown and yellowish 'desert varnish' veneer has all been recently removed by fracturing, along with some underlying rock, to reveal the underlying fresh cream-coloured quartzite on a fracture surface – a thin black streak can be seen extending down over the cream coloured quartzite, implying that a small amount of the black pigment has being washed downwards by rainwater runoff since the fracturing occurred, and is starting to re-form a new black stain onto the freshly exposed rock fracture surface. My interpretation of this is that at least parts of the opaque black pigment are still able to be easily reworked by water flow, and so are likely to be uncemented. It therefore seems likely that most of the black pigment is too young to have been incorporated into a siliceous 'desert varnish'.

If the black pigments are soot I would suppose that the most likely origin, at the intensities observed, is as an even accumulation from the smoke of repeated fires. To me, this would imply a long-term fire position located close and directly underneath the rock face, but an expert archaeological assessment will be required to confirm this. Whatever the origin, the black pigment is old enough for most of the soot to have been washed away from other parts of the boulder (abrupt margins controlled by water streaks) or eroded through surface abrasion (gradational margins to underlying brown 'desert varnish' and base rock areas), so that soot now only remains in the most favourable locations for preservation, which are the damp areas adjacent to the water streaks.

It is possible, but in my opinion less likely, that the black pigments could be manganese oxide. The evidence of young remobilisation of parts of the black pigment argues against this interpretation, as does the context of the geology, particularly in a free-standing boulder at Dyurrite/Mt Arapiles. Natural black-coloured streaky stains do occur in other locations at Dyurrite/Mt Arapiles, and are likely to contain a manganese oxide component – but in most of the other cases I know of at Dyurrite/Mt Arapiles, dark stains are fed from overlying regions that include old soil profiles that are a credible local natural source for manganese.

Whatever the cause of the deposition of the black pigment, the current streaky shapes clearly represent subsequent erosion and control by both water runoff and by abrasion, acting on the black pigment.

The material causing the black pigment would need to be chemically analysed in order to confirm its composition and to allow a better estimation of age and context.

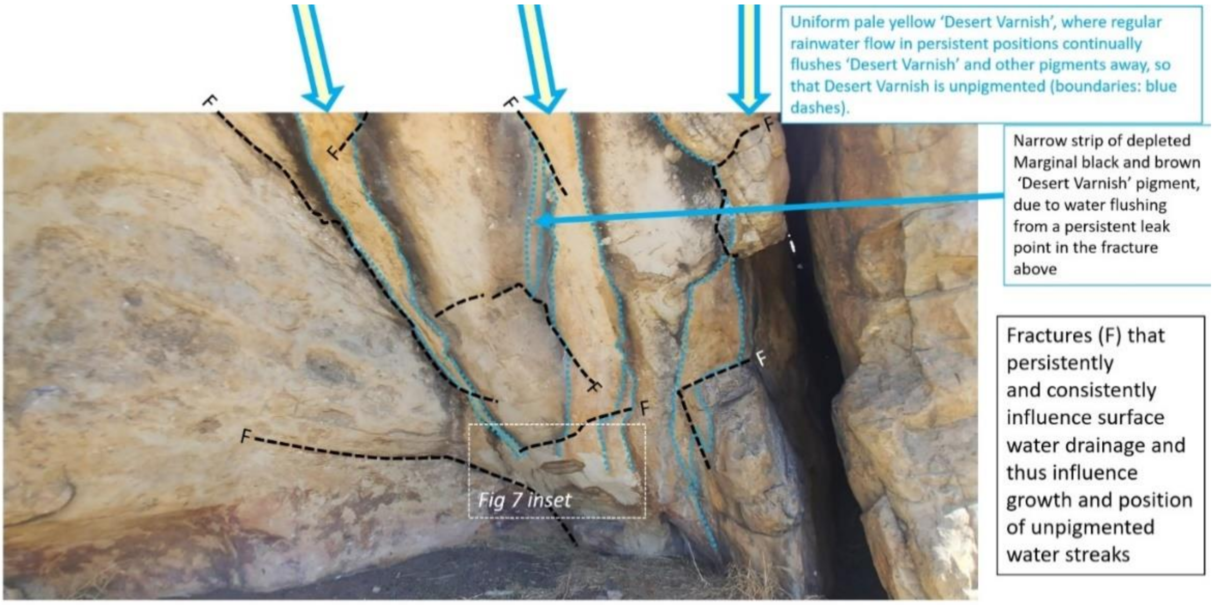


Figure 6: Map of rock fractures that influence water drainage streak positions R. Cayley, GSV, June 2020

vi. Areas of recent rock fracturing

Figure 7a and 7b is my annotation of your photo 'oval a', depicting where parts of the brown and yellowish 'desert varnish' silica veneers, the black pigments and some underlying quartzite have fallen off (spalled) along shallow fractures (marginal fracture line marked with the brown dashed line in Fig 7a, 7b) to reveal the underlying fresh pale quartzite bedrock. The most likely cause of this fracturing is thermal shock due to a recent fire in close proximity. Spalling of surface rock layers due to thermal shock is ubiquitous in quartzite and quartz-arenite rock-types, after bushfires in particular, and particularly close to ground level.

Figure 7a: Interpretation of part of the outer limit of an area of recent rock spalling (fall-off)

R. Cayley, GSV, June 2020

Figure 7B: same image, shaded and annotated to emphasise intact 'Desert Varnish' above the area of rock-spalling

The area of recent rock fracturing is particularly instructive in deciphering the patterns and colours in your photo, because it reveals that the brown and yellowish 'desert varnishes', together with the strips of overlying black pigment, stop exactly at the shallowly stepped fractures (s) that mark the outer limit of the rock spalling, thus demonstrating that they are surficial features, a millimetre or less thick, that have been superimposed onto the base pale quartzite, and have fallen off the areas of recent rock-spalling (Figure 8). Other fracture steps that lie within the area of brown 'desert varnish' and black pigment but show a similar form to the fresh rock-spalling fracture steps are probably relicts of earlier generations of rock-spalling that have since been overgrown with 'desert varnish'.

In a few places, thin black pigment strips can be seen to extend down over the pale cream quartzite, particularly adjacent to yellowish 'water streaks' (see * in Figure 8). As mentioned above, I interpret this as evidence of mobile black pigment, able to be washed by water runoff to redeposit over the fresh quartzite exposed by the recent episode of rock spalling. This process appears to be happening much faster than 'desert varnish' re-establishment (there is no evidence of any 'desert varnish' reestablishment on the freshly spalled bedrock areas).

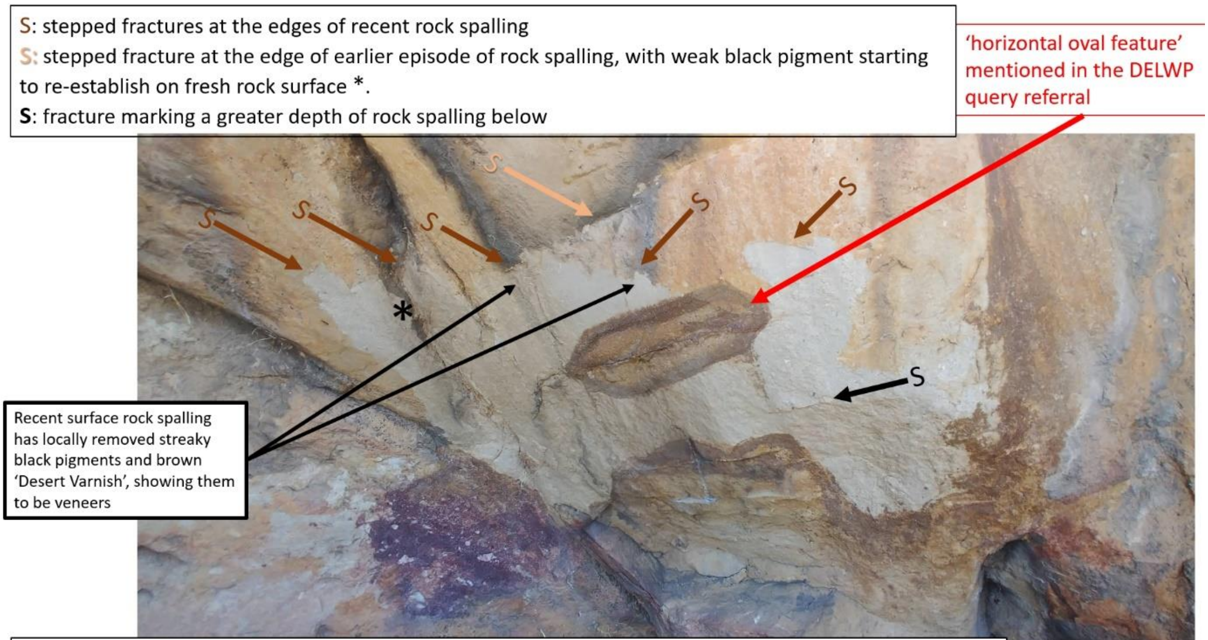


Figure 8: Fracture step locations that demonstrate rock spalling, and the 'horizontal oval feature' R. Cayley, GSV, June 2020

The recent stepped fractures that bound the limit of rock-spalling cut across the upper side of the geometric, tabular shaped 'horizontal oval feature' of your particular interest. This is a very instructive relationship because parts of the 'horizontal oval feature' lie above the line of recent rock spalling and thus retain remnants of the overlying yellowish-brown 'desert varnish'. This proves beyond doubt that the horizontal oval feature is older than the 'desert varnish'. Parts of the same oval feature below the line of recent rock spalling have had the 'desert varnish' veneer and some underlying rock removed, thus revealing details of the oval feature within the fresh quartzite base rock more clearly, while also demonstrating that the 'horizontal oval feature' is not a pigmentation confined to the rock surface – the pigmentation persists into the rock interior. The 'horizontal oval feature' visible at the surface is just the surface expression of a 3-dimensional brown geometric-shaped pigmentation that extends deep into the quartzite bedrock.

vii. Geometric brown and red/purple stains – Liesegang Rings (bands)

These are the patchily-developed prominent brown and red/purple coloured swirly- and geometrically- shaped iron-oxide alterations that appear mainly confined to the lower parts of the pale quartzite rock in your photos, including the brown 'horizontal oval feature' of your particular interest (Figure 8, Figure 9).

As mentioned above, the upper end of the brown 'horizontal oval feature' can clearly be seen to be overlain by a silica 'Desert Varnish' veneer (see Figure 11). This proves that the 'horizontal oval feature' is an old pigmentation pattern in the quartzite rock which the 'desert varnish' has overgrown.

The most crucial characteristic of the brown 'horizontal oval feature' is revealed by the area of recent rock-spalling which has cut across the bottom three-quarters of it, removing the 'desert varnish' veneer along with some underlying rock in the process (see figure 7). If the 'horizontal oval feature' was a surface pigmentation veneer, this recent fracturing would surely have removed it, as it has done for the 'desert varnish' that is even younger. Instead, the 'horizontal oval feature' persists in the freshly fractured surface, even more clearly visible because the overlying surface 'desert varnish' has been removed. The persistence of the 'horizontal oval feature' into the rock interior, as revealed by the young fracturing, is the critical evidence that has allowed me to interpret the brown 'horizontal oval feature' as a 3-dimensional pigmentation that extends deep into the interior of the quartzite host rock. It is definitely not a pigmentation confined to the rock surface. This 3-dimensionality is a typical and diagnostic characteristic of Liesegang Rings, and rules out any surface process for the origin of this striking feature.

Liesegang Rings: a reference:

https://en.wikipedia.org/wiki/Liesegang_rings_(geology)

The geometric and elongated shapes of some of these stain-like alterations, including the brown 'horizontal oval feature', reflect fracture-control on their formation – alteration (pigmentation) growth within the rock has been facilitated by pre-existing fractures which have helped direct the flow of the fluids that carried the brown pigments into the interior of the quartzite rock (see Figures 10, 11). Joint-controlled Liesegang Bands are obvious and ubiquitous across Victoria (and Australia, and the world) anywhere regolith is developed in fractured rock in hot, wet climates, and Dyurrite/Mt Arapiles is no exception.

An example of Liesegang Rings in quartzite for comparison, in an accessible urban setting, is the blocks of stone from the Kimberley Ranges in WA that have been used to pave Federation Square, Melbourne (reference: https://en.wikipedia.org/wiki/Federation_Square).

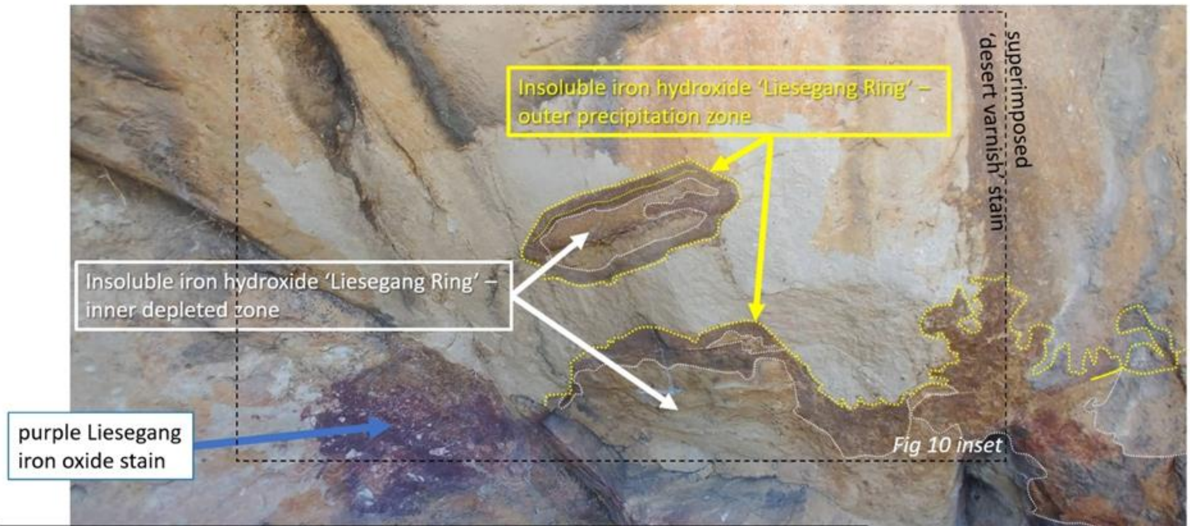


Figure 9: Liesegang Band (Ring) distribution, illustrating some internal features R. Cayley, GSV, June 2020

Fault-controlled brown Leisegang Ring rock alteration:
diagenetic (secondary) penetrative iron-hydroxide precipitation

'Liesegang Rings' typically initiate as iron hydroxide and iron oxide precipitations that have precipitated along, and 'grow out from' pre-existing fracture planes within a rock, coating all the constituent grains and infilling any spaces between them. The iron that is needed to form the brown pigments in Liesegang Rings is introduced into the rock in reduced form, dissolved in groundwater residing within a waterlogged soil profile.

The lower portions of continually water saturated soil profiles are normally low in oxygen or 'reduced'.

A reference: https://soils.ifas.ufl.edu/wetlands/publications/PDF-articles/283.Anaerobic%20Soils.%20In%20Encyclopedia%20of%20Soils%20in%20the%20Environment..pdf

The anaerobic parts of soil profiles are a typical supply of reduced iron which is able to be dissolved in the resident groundwater. As resident groundwater migrates upwards towards surface, or as groundwater levels fluctuate within the soil in response to seasonal or longer-term climatic variations, the groundwater will move across a 'Redox' boundary (or 'front') within the soil profile. A 'Redox boundary' in a soil profile is an interface between an oxygen-poor environment and an oxygen-rich environment where direct chemical interactions with atmospheric oxygen can occur.

A reference:

https://en.wikipedia.org/wiki/Redox#Redox_reactions_in_geology

Above the 'Redox boundary', atmospheric oxygen is available to react with reduced iron carried in solution in groundwater. This reaction forms iron-oxides (ie. the iron 'rusts'). Iron oxides are insoluble in water and so they immediately precipitate out of the groundwater to form rusty brown pigmentation infillings that are aligned precisely along the location of the ''redox boundary' in the surrounding rock.

'Redox boundaries' (fronts) that reside within soil profiles and within rocks embedded within soil profiles, are invariably complex and 3-dimensional in shape. 'Redox boundaries' often follow fractures and other weaknesses in rocks (oxygenated water can penetrate rocks more readily along fractures). Redox boundaries can vary in position through time in response to changes in the level and movement of groundwater within the soil profile, so that the iron-oxide precipitations they cause will also vary in position through time. It is the typically complex shapes of 'redox' reaction fronts within the soil profile and within any rock contained within the soil profile that cause the typical and diagnostic complex, 3-dimensional swirly- and ring- shapes of 'Liesegang Rings'.

The actions of migrating 'Redox boundaries' and accumulation of oxide pigments around fractures in rocks within soil profiles mean that, over time, the redox boundary and associated oxide pigmentation will gradually infiltrate the entirety of any fractured rock close to a 'redox boundary' position in the surrounding soil. Oxygen infiltration and pigmentation growth is facilitated and controlled by groundwater influx along fracture networks that range in size from those big enough to be visible to the naked eye (as in Figures 10, 11) to hairline fractures that would never be visible in outcrop-scale photographs (eg see Figure 13).

Eventually, over geological time, the pigments form the characteristic 3-dimensional periodic depleted and concentrated oxide precipitation zones that give Liesegang Rings (bands) their name (Figure 9). Note that the distinctive brown rim of the 'horizontal oval feature' 'Liesegang Ring' is exactly replicated in the more irregularly shaped 'Liesegang Band' beneath (see Figure 9). This is because the stains are all part of the same weathering profile, in the same rock, and grew in response to exact same environmental conditions, over the same time period. Since Liesegang Ring alteration stains are always complex and three dimensional in shape, I consider it very likely that the 'horizontal oval feature' Liesegang 'Ring' is continuous, within the quartzite interior, with the similarly patterned, irregularly shaped Liesegang Band that is visible below it – this would explain the closely matching brown rim pattern – they are the exact same 'Liesegang Band' pigmentation, twisted back on itself within the rock.

The brown and red/purple colourations of these 'Liesegang Ring' pigments is also typical. Brown stains tend to reflect the predominance of iron hydroxides. Red and purple 'Liesegang Ring' pigments tend to reflect the predominance of iron oxides. Both are clearly evident in the photos you have supplied (see figures 9, 13).

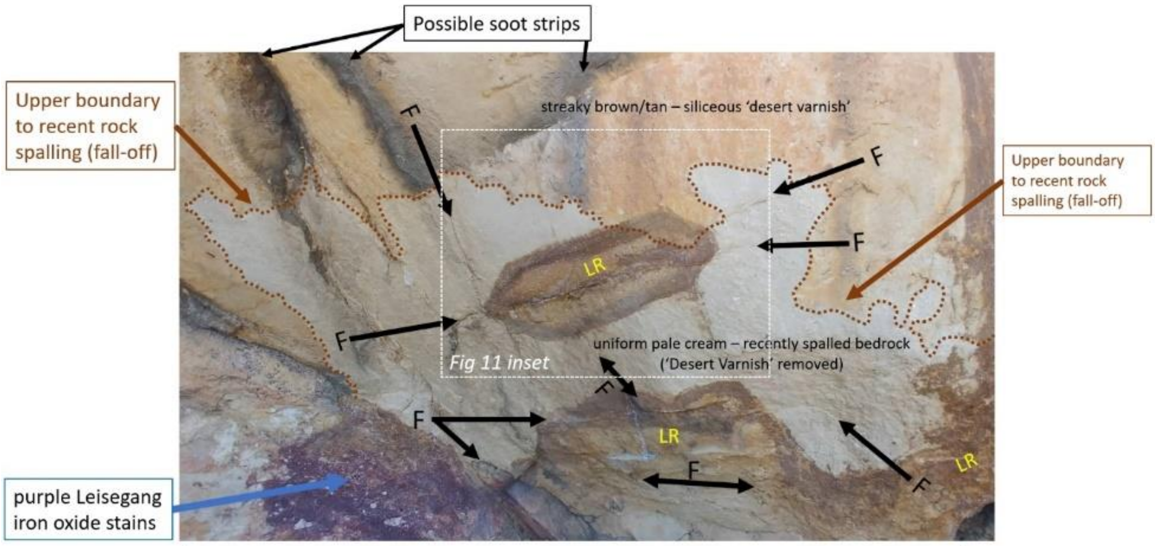


Figure 10: Rock fractures (F) that localise Liesegang Ring (LR) growth R. Cayley, GSV, June 2020

Overall, a happy coincidence of 'overprinting criteria' from a sequence of pigmentation and fracture events all evident in the one rock have allowed the origin, relative age and context of the brown 'horizontal oval feature' to be determined with great confidence – it is a natural 'Liesegang Ring'. The 'Liesegang Ring's are the oldest alteration/pigmentation colours I can see in the rock, and are penetrative and 3-dimensional.

Given the regional geological history, 'Liesegang Rings' of similar appearance and context will likely occur at the base of cliffs and in boulders all around Dyurrite/Mt Arapiles, particularly in places where soil erosion may have exposed bedrock that was once buried within a soil profile.

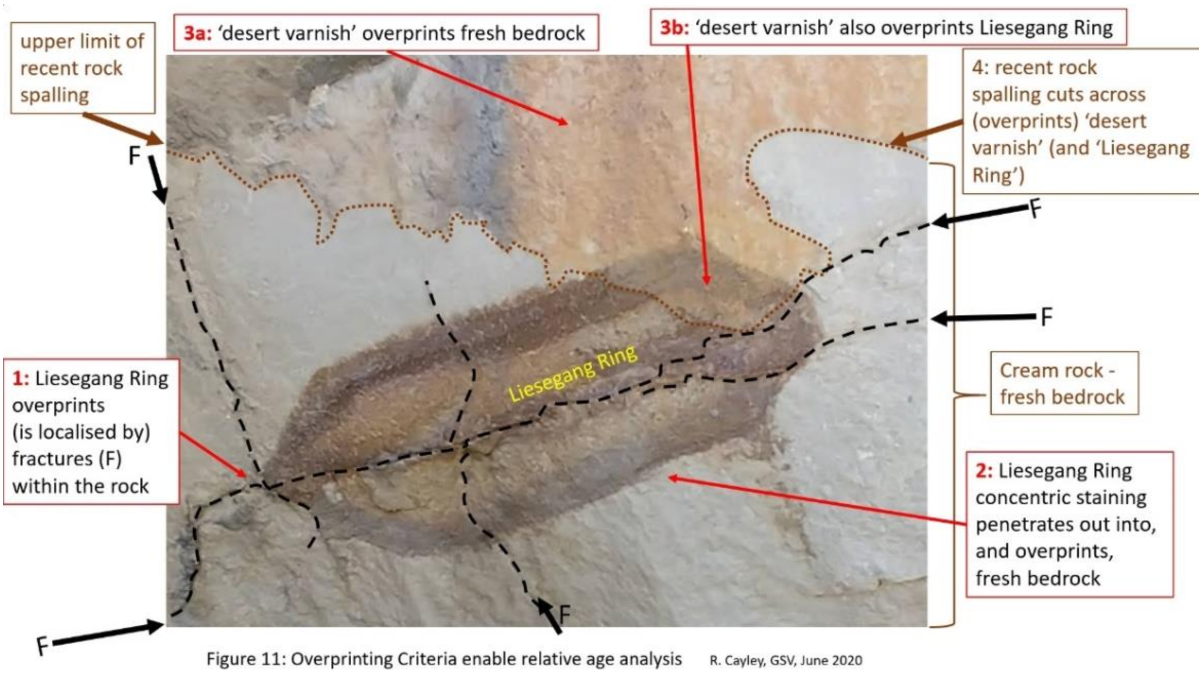


Figure 11: Overprinting Criteria enable relative age analysis R. Cayley, GSV, June 2020

‘Liesegang Rings’ are, by the very nature of their episodic redox and fracture-controlled growth, haphazard and complex in appearance and patchy in their distribution. Nevertheless, the most prominent generation of ‘Liesegang Bands’ visible in your photos appear to be confined to a band close to ground level. This is not unexpected to me. ‘Liesegang Ring’ growth in any rock is predicated on a regular supply of iron rich groundwater and a ‘redox boundary’, both of which require the rock to lie embedded within a soil profile. Reduced iron in groundwater is unlikely to come from above (ie from rainfall) in the current setting of the rock imaged in your photos. Rainwater is oxidised and so can hold virtually no dissolved iron. Clean Dyurrite/Mt Arapiles quartz arenite above ground level contains virtually no reduced iron-bearing minerals (previous generations of Liesegang bands that are visible at higher levels in the rock are oxides and so are poorly soluble), and so the Dyurrite/Mt Arapiles quartzite itself has very limited capacity to contribute any reduced iron to groundwater passing down through fractures in the rock.

Since ‘Liesegang Rings’ in rock are most commonly developed within soil profiles, I interpret the prominent ‘Liesegang Rings’ visible around the base of the boulder in your photos to be evidence of a deeper level that the boulder was buried in a past soil profile. The approximate past soil profile ‘redox boundary’ level is preserved within the rock today as a ‘bath ring’ line that marks the uppermost limit of the most recent episode of ‘Liesegang Ring’ formation (Figure 12).

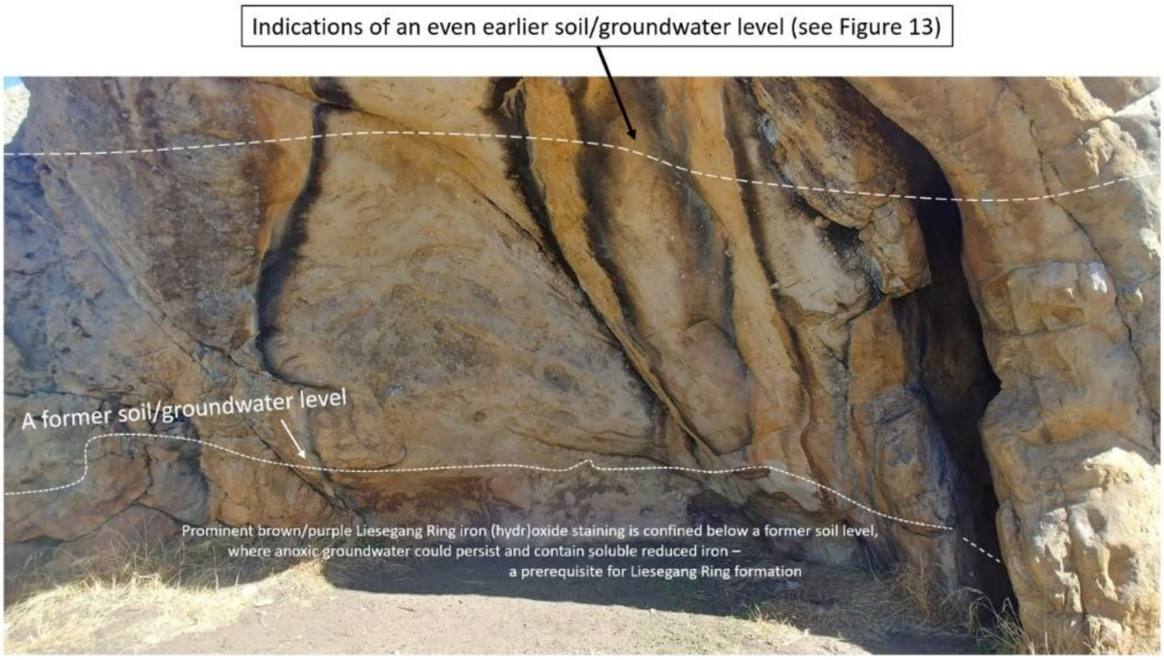


Figure 12: Upper limit of youngest generation of Liesegang Ring development interpreted as top of an ancient water table.
R. Cayley, GSV, June 2020

Today, these ‘Liesegang Rings’ are exposed above soil level, cut off from any possible supply of iron-laden groundwater. Therefore, the ‘Liesegang Rings’ that are visible are fossilised structures that are no longer growing. The early timing of the soil erosion is indicated by the fact that some of the lower generation of ‘Liesegang Ring’ alterations have been overgrown by silica ‘Desert Varnish’ (see Figure 11). ‘Desert Varnish’ only grows on rock surfaces that are exposed to water evaporation. Therefore I interpret the soil to have been removed long enough for subsequent desert varnish silica to be precipitated over the exposed ‘Liesgang Rings’ at the base of the rock.

Other more faded iron oxide ‘Liesegang Ring’ shapes are apparent in several places at much higher levels in the rock (see Figure 13), with the rings developed in fresh cream-coloured quartzite and showing through the overlying brown pigmented 'Desert Varnish' where remnants of that remain. I interpret these faded Liesegang Rings to indicate a former much higher level of a 'redox boundary' once active within the rock. The higher level of these older faded 'Liesegang Rings' indicates that, in a past time, iron-laden groundwater was able to infiltrate most of the rock. This is evidence that the boulder has been much more deeply buried in waterlogged soil in the geological past (see interpretation of upper soil level in figure 12). As for the lower Liesegang Rings, these higher faded 'Liesegang Rings' show a mix of strong elongated shapes that are aligned and controlled by sub-vertical hairline fractures in the quartzite, and blob-like shapes with controls not apparent in your photos. The sub-vertical orientations of the largest faded 'Liesegang Rings' closely matches the orientation of bedding planes in the boulder. It is very common for 'Liesegang Rings' to show elongation parallel to bedding layering in sedimentary rocks. A physical examination of the rock will be required to determine beyond doubt that the higher-level faded ring-like brown stains penetrate into the bedrock interior as 'Liesegang Rings'.

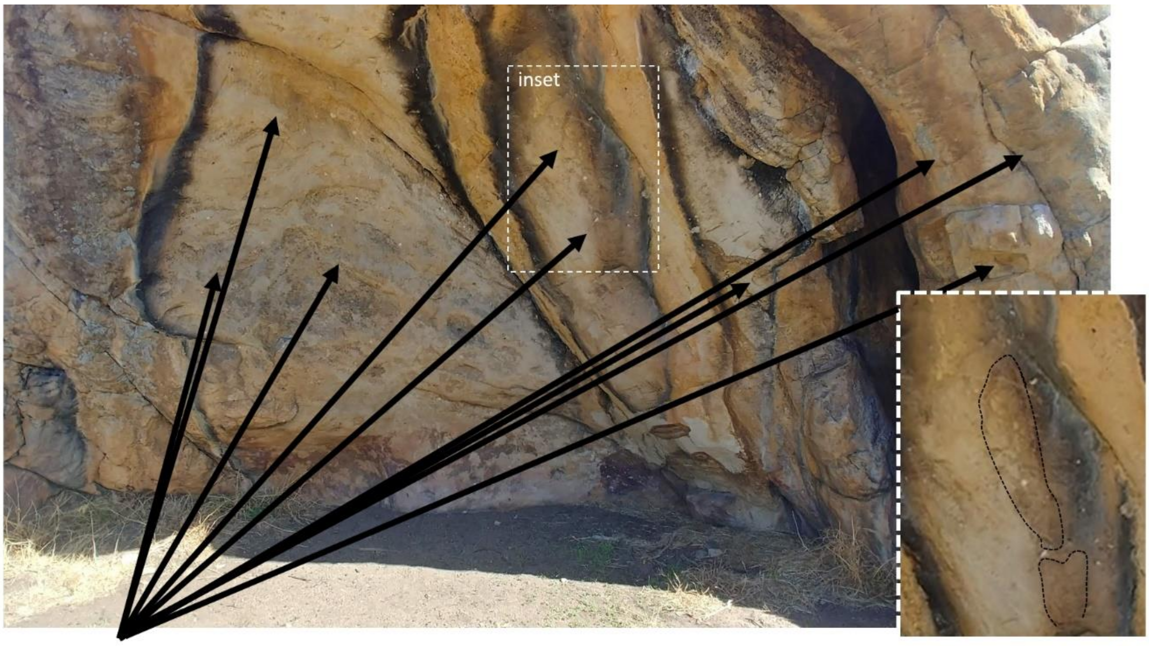


Figure 13: Remnant (faded) fracture-controlled brown 'Liesegang Rings' in quartzite; evidence for an earlier time when the rock was buried much more deeply in a soil profile.

R. Cayley, GSV, June 2020

Viii Modern pigments on the rock

Possible Magnesium Carbonate powder (climbers chalk – dusty white appearance) stains are apparent at a few different places in those photos (figures 14a, 14b).

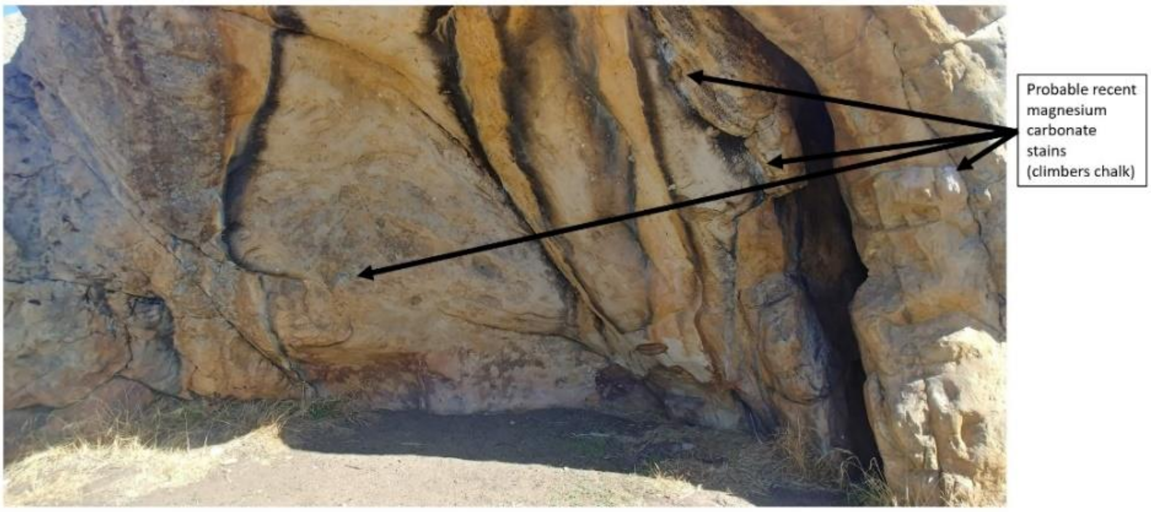


Figure 14A: Evidence of chalk stains from Rock Climbing on the boulder. R. Cayley, GSV, June 2020

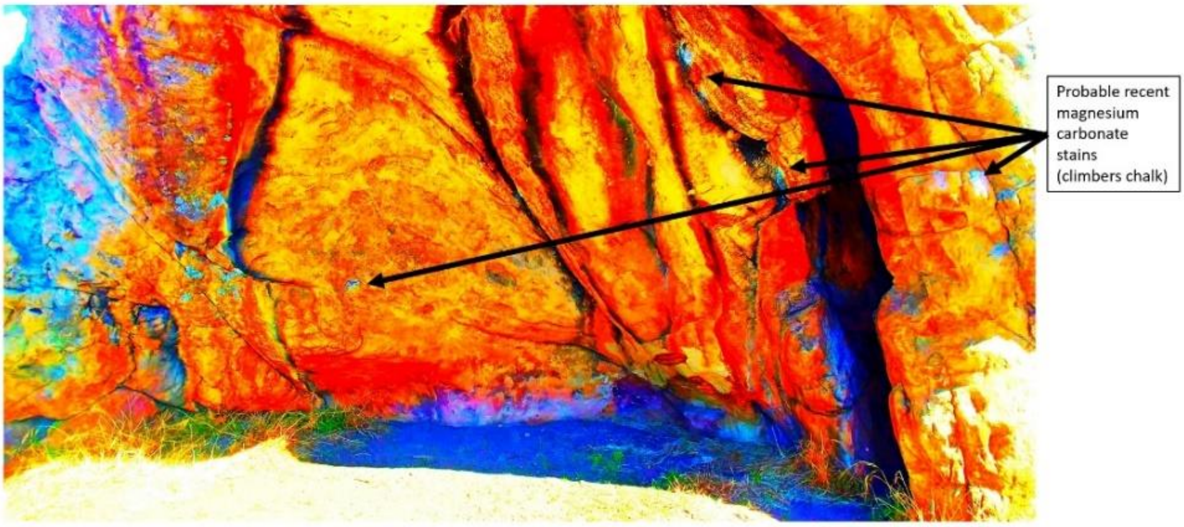


Figure 14B: High Intensity Colour Stretch to highlight chalk stains from Rock Climbing on the boulder. R. Cayley, GSV, June 2020

Supplementary questions and additional images received 30 July, 2020

On Thursday 30 July 2020 at 12:07 you wrote:

I have a few follow up questions that you may be able to answer:

Q1. Regarding the vertical oval shapes circled at the top of the enhanced photo 'check 1'. Are these Liesegang Rings or are they man-made rock paintings?

Q2 Regarding the straight line markings (including a right angle shape) in the enhanced photos 'check 1' and 'check 2'. Are these natural markings or are they man-made rock paintings?

Q3 Do these photos show any evidence of man-made rock painting at this site over the last 50,000 years?
(This is a key question for further follow up on site, to include geological and archaeological review)

Q4 Can you estimate the age of either of the ground level changes?

Q5 Could any of the ground level changes be man-made e.g. excavation to improve a shelter?

Q6 Can you estimate (potentially with samples) the age of the soot deposits (assuming that they are soot deposits)? (Could this be a key item in establishing a cultural timeline in the absence of other tangible evidence?)

If relevant, would it be possible to add further detail about these items within the report?

Kind Regards,

Supplied photographs:

Photo 'check 1'

Photo 'check 2'

Answers to supplementary questions (30 July, 2020).

Question 1:

I am not qualified to comment with authority on rock paintings or art, but I am able to provide expert commentary on geological features and related patterns that I recognise in false colour image 'check 1'. I consider that the most likely origin of the 'vertical oval shapes circled at the top of the enhanced photo 'check 1' is that they are 'Liesegang Rings', and natural rock features. However, I qualify this conclusion by stating that a physical examination of the rock in your photos is required in order to be certain. A definitive test for a 'Liesegang Ring' origin to the pigmentations is to test if the pigmentations are penetrative into the rock interior (as demonstrated for other 'Liesegang Rings' in this same rock – eg see Figure 11).

I have annotated your supplied image 'check 1' to help explain my geological interpretation of it (see Figure 15A below)

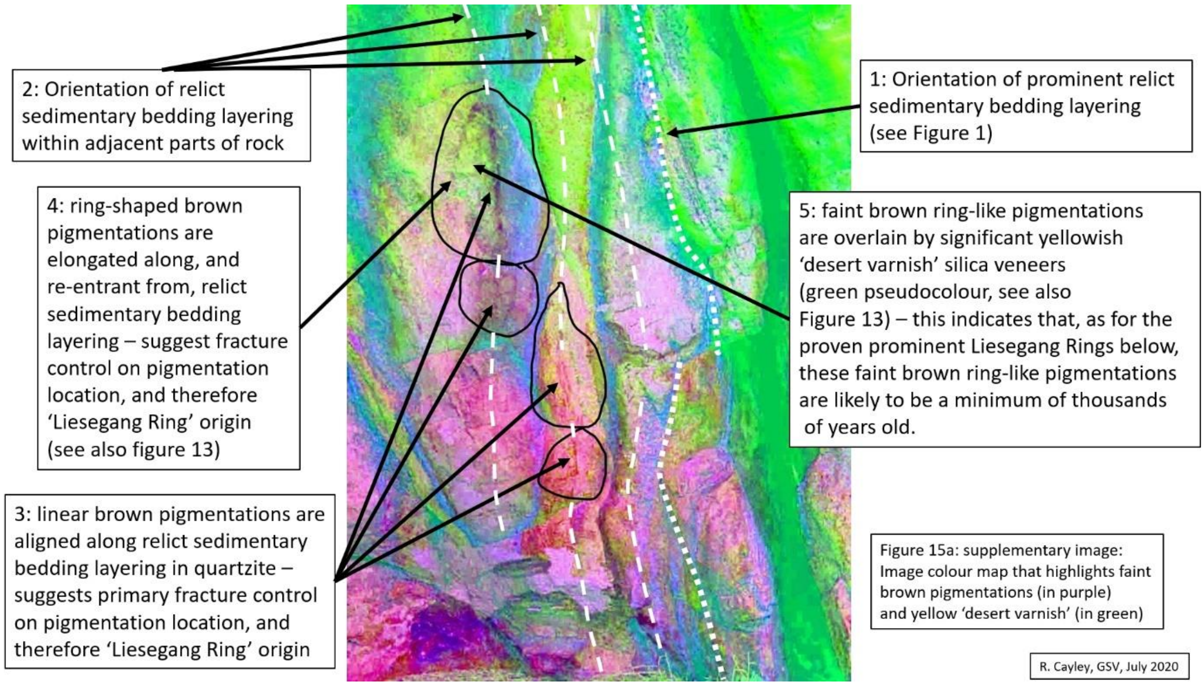


Figure 15a: supplementary image: Image colour map that highlights faint brown pigmentations (in purple) and yellow 'desert varnish' (in green)

As illustrated in Figure 1, original sedimentary bedding layering is steeply oriented within this rock. The dotted line (Fig 15a-1) is an obvious sedimentary bedding layer visible in the rock in a position transferred directly from Figure 1. The dashed lines (Fig 15a-2) are subparallel bedding fracture traces that are subtly visible within the rock (bedding layers are generally subparallel to one another at Dyurrite/Mt Arapiles). Note that linear brown pigmentation strips that bisect the centre of the brown ring-shaped pigmentations are mostly aligned along the bedding fracture traces (Fig 15a-3). This suggests fracture orientation has exerted a primary control on pigmentation formation, a characteristic that is typical for Liesegang Ring formation. Note that the ring-shaped portions of the pigmentations are elongated parallel to the bedding fracture traces (Fig 15a-4; as also interpreted previously in Fig 13), and show influence by bedding fractures where they intersect, another feature typical of Liesegang Ring formation. The overall morphology of these rings is exactly the same as for the proven Liesegang Rings that occur elsewhere in this same rock (Figure 11).

Finally, the false colour image confirms my earlier interpretation that some of the weak brown pigmentations are overprinted by a pale translucent 'desert varnish' (coloured green in the false colour image; see Fig 15a-5). The brown pigmentations circled in the false colour image are therefore old.

How old?

I am unaware of any research into the formation rates of 'desert varnishes' at Dyurrite/Mt Arapiles or Gariwerd/Grampians, so estimating the significance of overlying 'desert varnish' on the age of underlying features here is uncertain.

'Desert varnish' growth in North American deserts has been measured to occur within thousands of years, but at highly variable rates depending on location and rock-type. Measured thickness growth rates ranged between ~1.0 and 40 µm per thousand years. The variable rate of growth of 'desert varnish' in North America lead these researchers to conclude that varnish thickness studies were of limited value as precise relative age indicators in geomorphology and archaeology.

A reference: *http://www.vmldating.com/Images/rvgrowthpaper2000.pdf*

The American studies are consistent with studies in Saudi Arabia where manganese-iron 'desert varnishes' on petroglyphs of different, but known, ages have been demonstrated to grow at similarly variable but linear rates, but certainly within the timespan of recorded human occupation there (several thousands of years):

A reference: *Macholdt, Dorothea & Al-Amri, A. & Tuffaha, Husam & Jochum, Klaus & Andreae, Meinrat. (2018). Growth of desert varnish on petroglyphs from Jubbah and Shuwaymis, Ha'il region, Saudi Arabia. The Holocene. 095968361877707. 10.1177/0959683618777075.*

Without on-location growth-rate measurements for Dyurrite/Mt Arapiles, it is impossible to estimate the growth rates of 'desert varnish' on the rock in your photos, other than to conclude that, within the realm of published 'desert varnish' growth rates, it likely takes a minimum of several thousand years for silica 'desert varnish' to attain sufficient thickness (eg. <100μm thickness+) to have the appearance and texture of a 'varnish'.

Thus, I would conclude that the brown pigments beneath 'desert varnish' in your photos are likely to be thousands of years old at a minimum.

Question 2

The 'straight line markings (including a right angle shape) in the enhanced photos 'check 1' and 'check 2' include the linear markings that lie parallel to bedding fractures within the elongated oval-shaped pigmentations (as interpreted in Figure 15A), and other linear markings that appear to intersect these at high angle. The other linear markings appear to be areas of faint brown pigment coincident with (ie aligned along) fractures that are clearly visible in all your photos, and cut across bedding layering at a high angle. Where these differently oriented fracture-aligned pigment traces intersect, they produce 'right angle shapes'.

I have annotated your supplied image 'check 2' with bedding layering as depicted in Figure 15A, and with the position of prominent fractures that all belong to a single fracture set that cuts across the whole rock with very little change in geometry. (Figure 15B below). It is clearly evident in Figure 15B that these fractures exert a strong control on some of the 'straight line' brown pigmentations.

Note that the set of fractures indicated in Figure 15b is the same orientation as the main fractures that control the proven Liesegang Ring in the rock just below, as depicted in Figures 10 and 11.

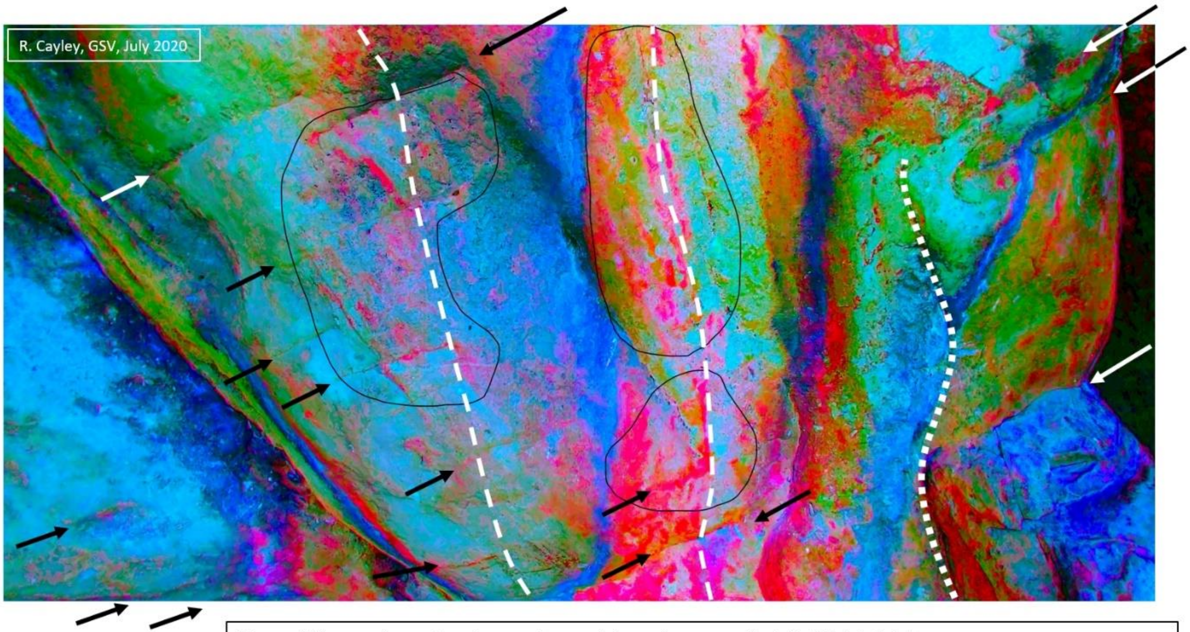


Figure 15b: supplementary image: Image false colour map that highlights faint brown pigmentations (in pink).

- Sedimentary bedding layering lines transferred from figure 15a (white dashed lines)
- Natural fracture set in the quartzite is indicated by the arrows. Note that many of these fractures align with (controlled formation of) linear streaks of brown pigmentation. Note that this fracture set includes the prominent fractures that controlled growth of proven Liesegang Rings (see Figure 10)

Given the very strong coincidence of the linear brown pigmentations with fracture sets within the rock, I conclude that all these pigmented patterns are highly likely to have a natural 'Liesegang Band' origin. Their geometrical appearance is a consequence of the geometrical arrangement of fractures within the rock, which is common throughout Dyurrite/Mt Arapiles. Again, I qualify this conclusion by stating that a physical examination of the rock in your photos is required in order to be certain. A definitive test for a 'Liesegang Ring' origin to the pigmentations is to test if the pigmentations are penetrative into the rock interior (as demonstrated for other 'Liesegang Rings' in this same rock – eg see Figure 11).

Question 3

I am not qualified to comment with authority on rock paintings or art. I personally did not recognise anything in any of your supplied photographs that I would consider a 'rock painting'.

Question 4

I am unable to provide a precise estimate the age of the different former soil levels that I have interpreted for this rock (see Figure 12). As mentioned above, it likely takes thousands of years at a minimum for a significant thickness of 'desert varnish' to form. Since 'desert varnish' only forms above soil level, it is reasonable to conclude that the former soil levels must be thousands to tens of thousands of years old at a minimum, since 'desert varnish' development across the rock is quite widespread, including on the lowermost 'Liesegang Rings' of the most recent former soil level (as in Figure 11). The maximum possible age of the former soil levels here is given by the general geology – Mt Arapiles was an island in an inland sea as recently as ~6 million years ago, so that any former soil levels around the base of Mt Arapiles must be younger than this.

Question 5

I guess so – sure, why not? But again, I have to reiterate I am a geologist, not an archaeologist. You will have to seek the advice of a qualified archaeologist to answer these sorts of question.

Question 6

The possible black soot deposits I have interpreted on the rock can be inferred to be of relatively young age. As I outlined in Figure 6 (*) some of this black pigment appears to have been remobilised by water flow since the young rock spalling occurred at the base of the rock. This indicates that at least some of the black pigment has yet to be incorporated (cemented) into a 'desert varnish'. Therefore I consider it likely that the black pigments in your photos are less than thousands of years old.

In terms of determining a more precise age – several different analytical techniques are possible, depending on the composition of the black pigment. I am not an expert in carbon geochronology. An archaeologist will be able to advise on this matter with much more authority.

Cheers,

Ross Cayley.