THE GEOLOGY OF THE WAITE CONSERVATION RESERVE

GSA SA GEOLOGICAL FIELD GUIDEBOOK 2023

Notes for the GSA SA Field Excursion 31 March 2023

PART 1: THE INTRODUCTION

Part 2. THE MITCHAM QUARTZITE

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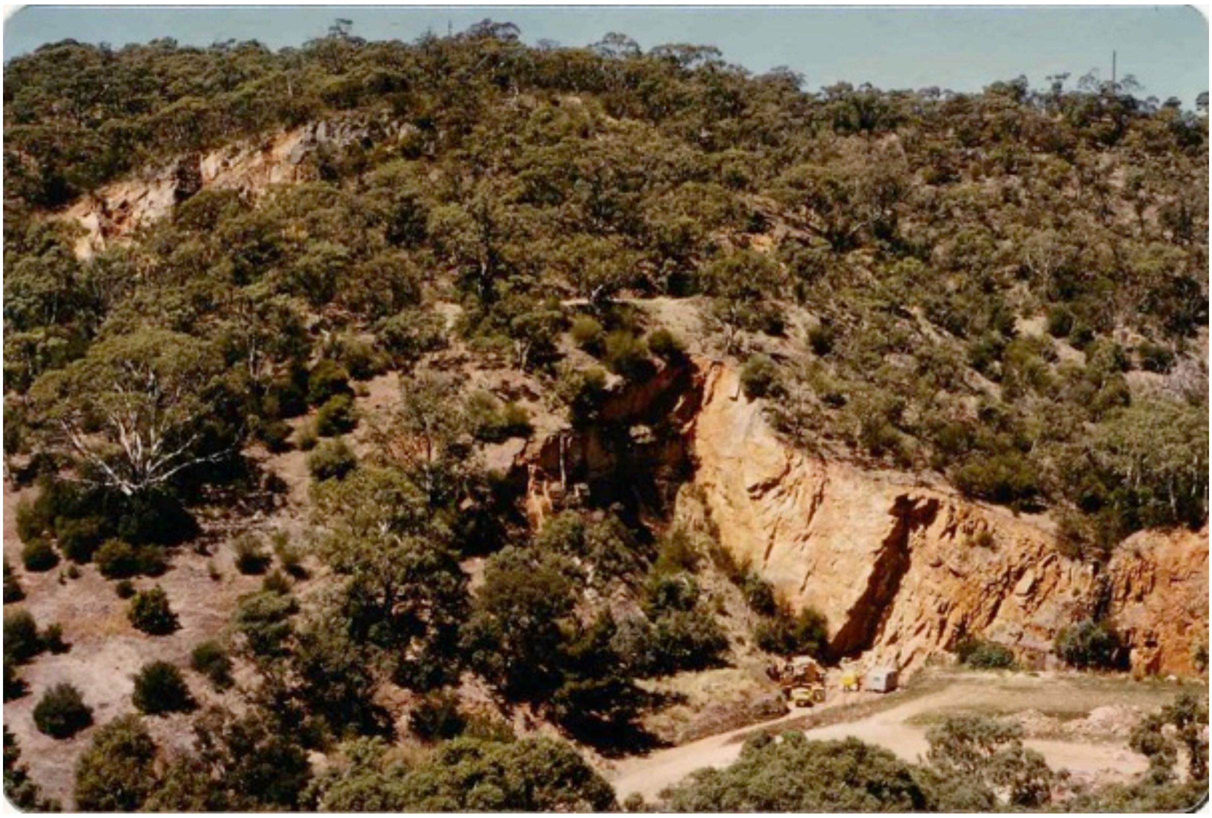

Union Anticline of the Waite Monocline exposed in the Union Quarry (1978, looking SE)

What to see, evidence recorded by the rocks of the Waite Conservation Reserve for:

- The ~750 Ma break up of Rodinia, deposition in a secondary rift basin in-board from the main Palaeo-Pacific ocean basin
- Sedimentation above an unconformity heralding the commencement of the Sturtian Glaciation
- The source shift of debris entering the basin
- The 500 Ma Delamerian Orogeny, prelude to the formation of Gondwana
- The evolution of the Mt Lofty Ranges and the current geomorphology
- Significant effects of the Anthropocene, notably the rock exposures

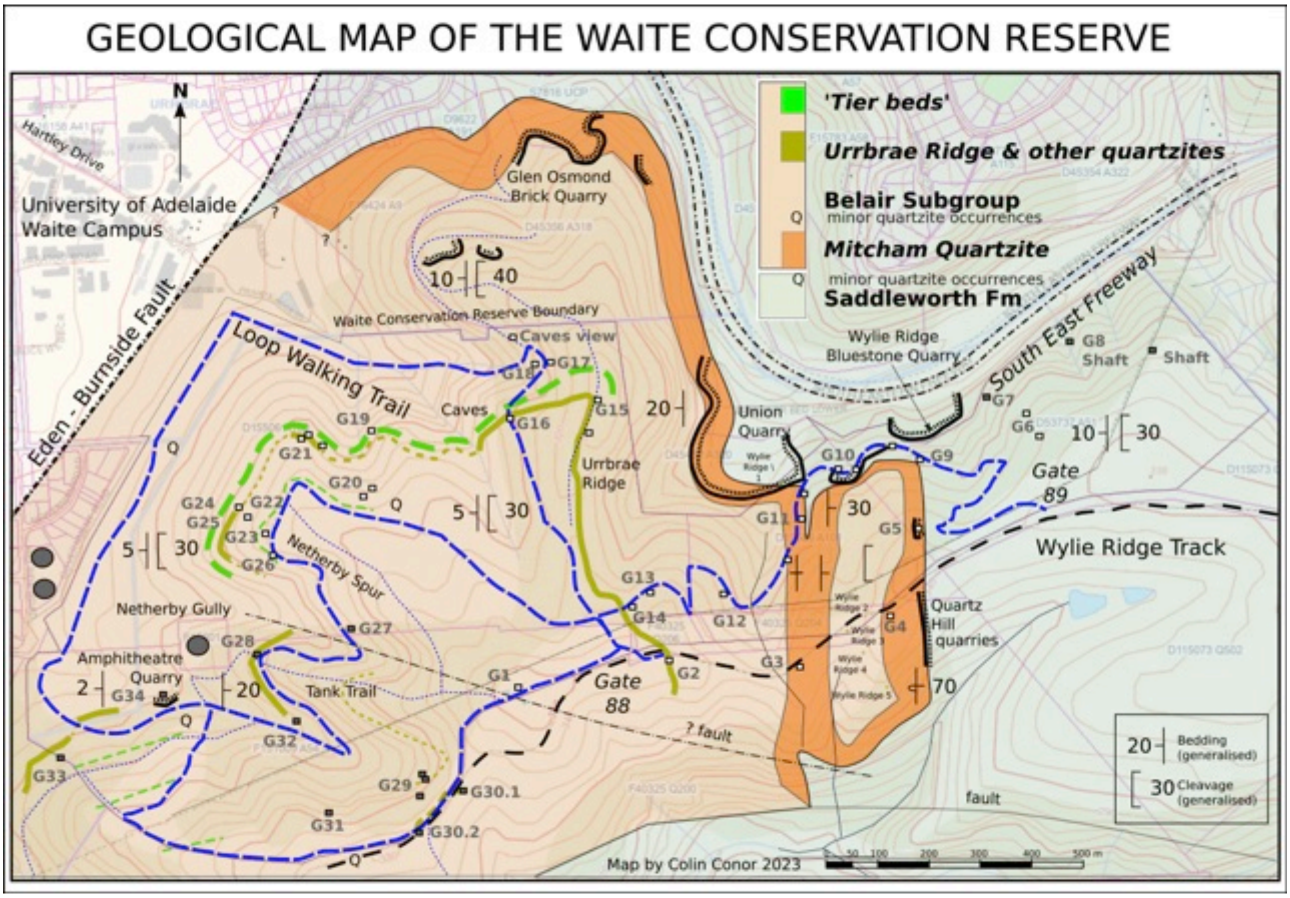

Figure 1. Geological map of the Waite Conservation Reserve

Geological Sites for Part 2, The Mitcham Quartzite (refer to the map – Figure 1)

Sites visited by GSA Members on Friday 31st March, 2023

Site G1. Tank Hill. The scenery, landform & its evolution (access from Gate 88)

Site G2. The Urrbrae Ridge quartzite (Belair Subgroup)

Site G3. Mitcham Quartzite, Union Anticline

Site G4. Quartz Hill. East limb of the Peregrine syncline and eastern limit of the Mitcham Quartzite

Site G5. Quartz Hill Quarry. Vertical rippled beds; Saddleworth\Mitcham Quartzite disconformity; first sign of the Sturtian; sediment source change; faults – Delamerian and 'recent'

Site G6.1 Glen Osmond Slate Member, Saddleworth Formation: planar beds and cleavage

Site G6.2 Glen Osmond Slate Member: hummocky beds, cleavage, alteration

Sites G7-8 are described in part 1 of the full version of the Geology of the WCR (in prep.)

SITE G9 View Towards Adelaide along Glen Osmond; base of the Mitcham Quartzite in the eastern limb of the WCR monocline.

SITE G10 Wylie Ridge Quartzite Quarries, the Mitcham Quartzite, and the Peregrine Syncline and Union Anticline

SITE G10.1 Eastern limb of the Peregrine Syncline

SITE G10.2 Axis of the Peregrine Syncline

SITE G10.3 Ball and pillow structure in the Mitcham Quartzite, evidence for rapid deposition

SITE G10.4 Base of the Mitcham Quartzite, western limb of the Peregrine Syncline & eastern limb of the Union Anticline

SITE G11 The Union Anticline
SITE G11.1 Gen Osmond Slate Member in the core of the Union Anticline
SITE G11.2 Disruption at the base of the Mitcham Quartzite
SITE G11.3 The last of the Mitcham Quartzite, entering younger Belair Subgroup
SITE G12 Moderately steeply dipping cleaved siltstone of the Belair Subgroup
SITE G13 'Normal' and mass-flow bedding
SITE G14 The Urrbrae Ridge quartzite (near Site G2)
END

General introduction and background setting

The intent of this excursion is to view some of the exposed rock outcrops of the Waite Conservation Reserve (WCR) and so obtain an understanding of the geology, that is an appreciation of what lies below the soil and vegetation cover of the steep slopes. The guidebook has been composed with the general public in mind along with previous iterations (e.g. Conor 2019 and 2023).

Stating the obvious, the whole Earth is made of rock, however in detail everywhere is unique, and so too is the Waite Conservation Reserve. Relevantly the geology has a significant influence on the distribution of biota, either due to the chemical make-up of the underlying rocks or to the landform carved by climate aided by the feedback of biological agencies. Rocks, plants and climate create the soils, which is good for the biota but not for geologists, however there is just enough outcrop in the Waite Conservation Reserve to make a good story. Also fortunately, the high ground that contains the Reserve, has provided Adelaide with a couple of its favourite building materials, which are the Mitcham Quartzite and the Glen Osmond Bluestone, and it is the quarries that provide the best windows to view the geology.

In one sense geology is a form of history, although the time scale stretches to billions of years, not just thousands. The rocks of the reserve are all sediments deposited in a narrow marine basin that is traditionally called the Adelaide Geosyncline, but is now also referred to as the Adelaide Rift Complex of the Adelaide Superbasin (Lloyd, 2020). Much has happened since these sediments were deposited in this ancient seaway including transport across much of the world (plate tectonics), the building of a great mountain chain (Delamerian Orogeny), inclusion and separation from the supercontinent of Gondwana, migration northward through climatic zones to the present latitude, and geologically recent and continuing faulting and uplift that are partly responsible for today's scenery.

Part 1 of his guidebook starts with a general introduction which is a summary of the 1000 million years of time that is relevant to the Waite Conservation Reserve, the intention being to give an impression of what has happened over the eons of deep time. Then hopefully the viewing of the actual rocks in Part 2 will be a 'grounding' and so provide a sense of reality.

Starting at Tank Hill, the highest point of the Waite Conservation Reserve, the excursion commences by considering the scenery, and how it has evolved in the near geological past. Then the plan is to visit the older sedimentary rocks (via Gate 89) and move westwards in the Reserve, that is upwards in time. These older rocks display evidence of silt and fine-grained sand being deposited on a marine shelf which was subject to active current activity. At intervals coarser-grained quartz and feldspar swept in to form lenses of arkosic quartzite measuring from a few to hundreds metres in length, of these the Mitcham Quartzite at 30-40m is the thickest and the most extensive.

A simplified geological map of the Waite Conservation Reserve is presented as Figure 1. The legend of the map shows the following three main stratigraphic units: Saddleworth Formation, Mitcham Quartzite, and Belair Subgroup of which the Urrbrae Ridge quartzite and Tier beds are informally named components. Where recorded, infrequent lenses of quartzite are indicated by the letter 'Q'. Summary details of these formal and informal lithostratigraphic units are presented later.

Site G1. Tank Hill. Scenery and Landform

Figure 2. View looking south over the hills and valleys of the Mount Lofty Ranges. The rugged scenery is a product of the weather, the underlying rocks, and millions of years of geological activity that formed the rocks. The scarp of the Willunga Fault is in the far distance. The flat surface and subcropping ferruginous rock of this site shows it to be a remnant of an older land surface (discussed further, see Fig. 3).

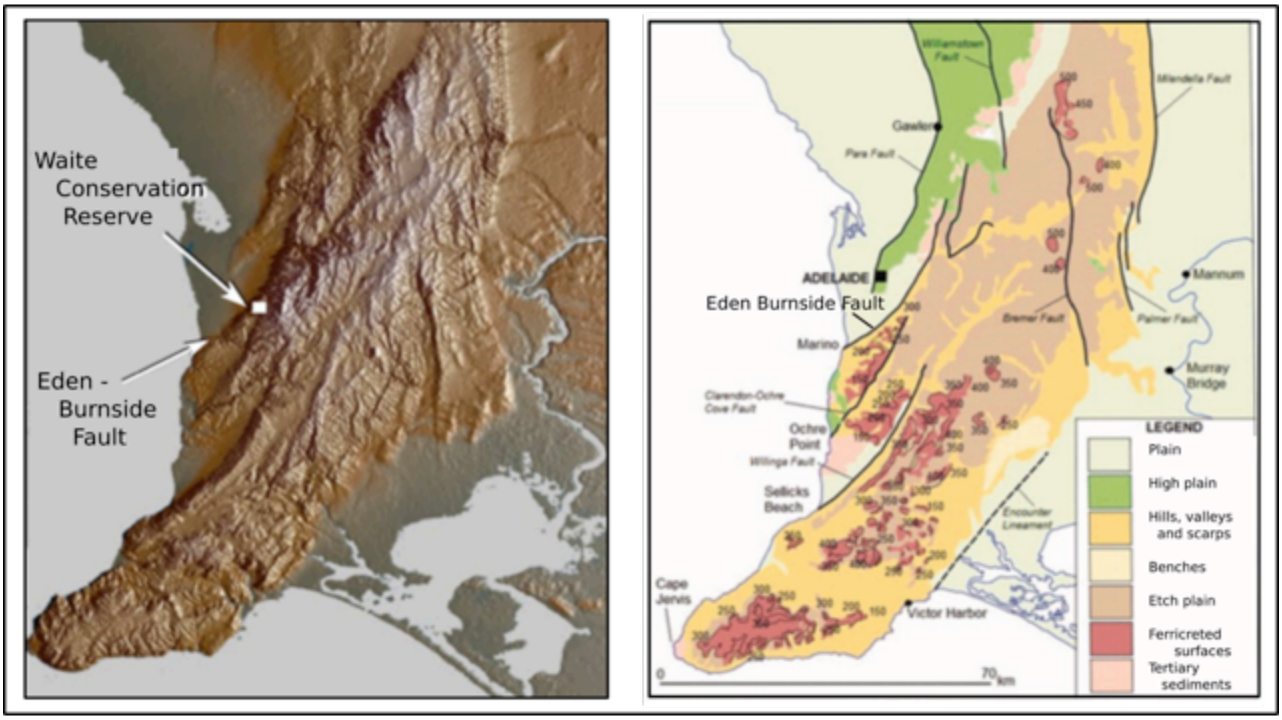

Figure 3. The two maps are designed to show the land form of the Mount Lofty Ranges and Fleurieu Peninsula, which is the composite result of the interaction between tectonics, e.g. faults, and climate, e.g. weathering and erosion. The left hand map is a digital terrain model (DTM) and the right hand map is a landform (geomorphic) map, showing aspects of the surface geology. The maps highlight the traces of the main geological faults that influence the landform of the southern Mount Lofty Ranges and Fleurieu Peninsula (the Eden-Burnside Fault is highlighted). The faults owe their origin to Rodinian rifting, the Delamerian Orogeny and the break up of Gondwana (discussed below), and they remain sporadically active. The Waite Conservation Reserve is part of the high ground to the east of the Eden-Burnside Fault across which the older rocks in the west have been depressed to lie below soft sediments and alluvium of the Adelaide plains.

The right hand map shows how the land is dissected by rivers that drain off or follow along fault scarps. Site G1 being one, the red patches represent iron pans or ferricrete that formerly formed in highly weathered soils under hot wet weathering conditions. These ferricretes developed sporadically over many millions of years as the land changed its shape. The former landscapes have been repeatedly disrupted by faulting with movement across individual faults determining whether the inter-fault blocks were raised or lowered (Preiss 2019). The geomorphic term used in this map for the present general landform is ‘etched plain’. These ferricretes developed sporadically over many millions of years as the land changed its shape. The former landscapes have been repeatedly disrupted by faulting with movement across individual faults determining whether the inter-fault blocks were raised or lowered. The geomorphic term used in this map for the present landform is ‘etched plain’. The map is a composite showing the effect of tectonics, e.g. faults, and climate, e.g. weathering and erosion (Twidale and Bourne, 1975; Preiss, 2019)

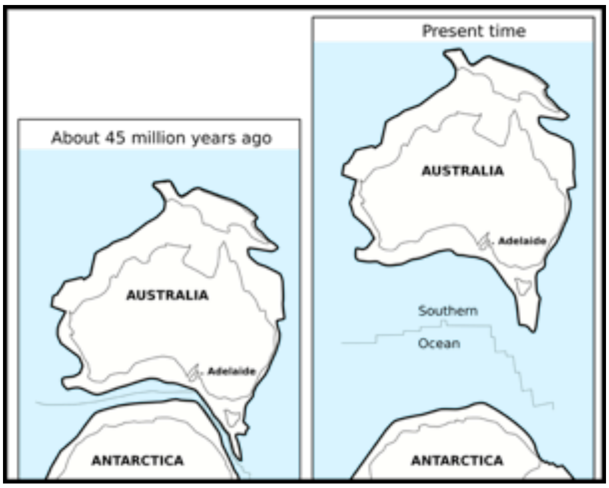

Figure 4. The closing stages of the break-up of the supercontinent of Gondwana. Australia is shown accelerating northward from Antarctica (its current rate of travel approximates 7 cm per year). It was from this time that the present form of Australia evolved as it traversed through different climatic zones. The present scenery of the WCR and surrounds is the result of the interaction of climate and tectonics (the process that controls the structure and properties of the Earth's crust and its evolution through time), not to mention the influence of biota, especially now Man, since ~65,000 years. (modified from White et al. 2013).

While the scenery is the most obvious visual aspect of geology, it represents only the current 3D snap-shot in time of all the tectonic, climatic and biotic happenings over the last 1000 million years. The science of geology includes the 4th dimension, which is time, not just historical time, but the 4.5 billion years of 'deep time'. Not surprisingly geological time is impossible to comprehend on a human scale, one can only take it on board as a form of shorthand. So an example, take the above mention 1000 million years (1000 Ma), and imagine one year to be represented by a one millimetre-sized pinhead, the distance equivalent of 1000 million years then becomes a thin line of pinheads connecting Adelaide to Devonport in Tasmania in the south, or Birdsville to the north if you prefer.

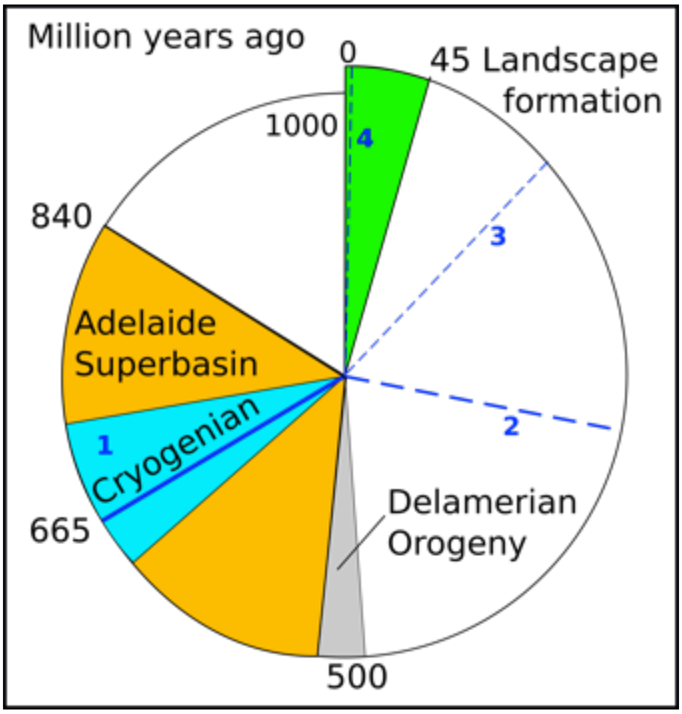

Figure 5. This backwards running clock, which started 1000 million years ago (1000 Ma), displays some items of geological activity of the Mount Lofty and Flinders Ranges. The green slice approximates the 45 Ma period when the current topography and scenery commenced to evolve to their present form. The large yellow-brown part is the formation of the rocks of the ranges, these are sediments deposited in a rift basin now called the Adelaide Superbasin (formerly the Adelaide Geosyncline) (Lloyd 2020). The contained blue slice represents a time on Earth when glaciations were frequent, it is a period called the Cryogenian. The blue line labelled '1' is the approximated age of glacial deposits (tillites) seen in such places as the Sturt and Onkaparinga River valleys. Blue numbers 2 (the Permian of Hallett Cove), 3 & 4 represent younger glacial events for which there is evidence in South Australia. The thin grey 500 Ma slice represents Delamerian Orogeny mountain building event that uplifted the previously buried sediments of the Adelaide Superbasin to create a lengthy mountain chain that once extended into Antarctica.

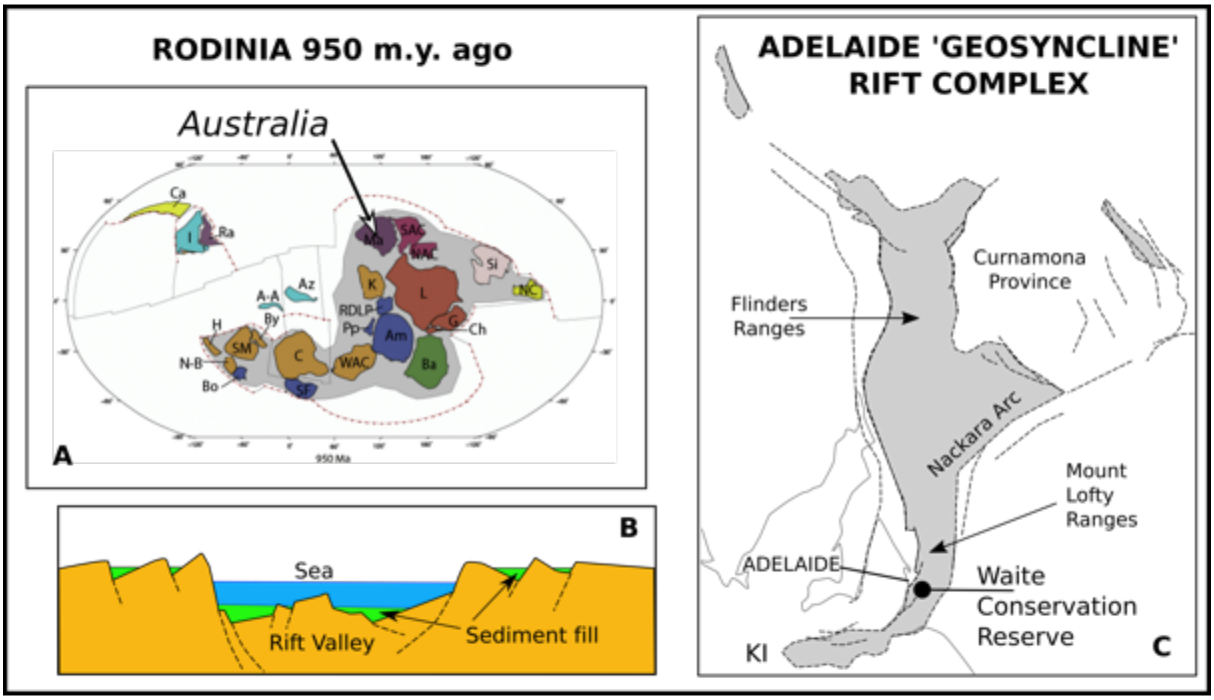

Figure 6. The diagram on the top left (A) shows a version of another and even earlier amalgamation of continents (Merdith et al. 2017). Rodinia is the name of this supercontinent and it was thought to exist from 1100 to 800 Ma. Australia and Antarctica are shown attached at the north. Cracks in the crust of South Australia, which filled with basalt (called dykes), are a sign of the break-up. Then followed the formation of rifts (B) that evolved into elongate sedimentary basins, the Adelaide Superbasin being one. C: A portion of Adelaide Superbasin (formerly the Adelaide Geosyncline), and now exposed to be seen as the Mount Lofty & Flinders Ranges.

Figure 7. Modern rift valley – an example from Ethiopia, the western rift valley flank. In the case of South Australia the rift width would in places have exceeded 200 km, and the deepest part might have been as much as 15 km. Rift valleys erode places where the Earth's crust has been domed upwards and so stretched. The rift valley pulls apart (tectonic), the raised sides erode and rivers wash the debris into the valley as alluvial fans (climate & weather). These tectonic-induced changes happened over a long period of time, approximately 340 Ma for the Adelaide Superbasin. Since then the Delamerian Orogeny caused the Adelaide Superbasin to be compressed and inverted into a much narrower belt, the remaining stub of which includes the Flinders and Mount Lofty Ranges.

THE GEOLOGY OF THE WAITE CONSERVATION RESERVE

The Waite Conservation Reserve is a block of relatively high ground overlooking the plains of Adelaide to the west, the other geomorphic boundaries are the Glen Osmond Creek to the east, and to the south one of the tributaries to Brown Hill Creek, Ellison's Creek. Influenced by the underlying rocks, the creeks have shaped the land so that the Reserve can be considered as an L-shaped backbone made of the W-E Wylie Ridge and the N-S Urrbrae Ridge, then with the land falling away to the Adelaide Plains in the west (Fig. 8).

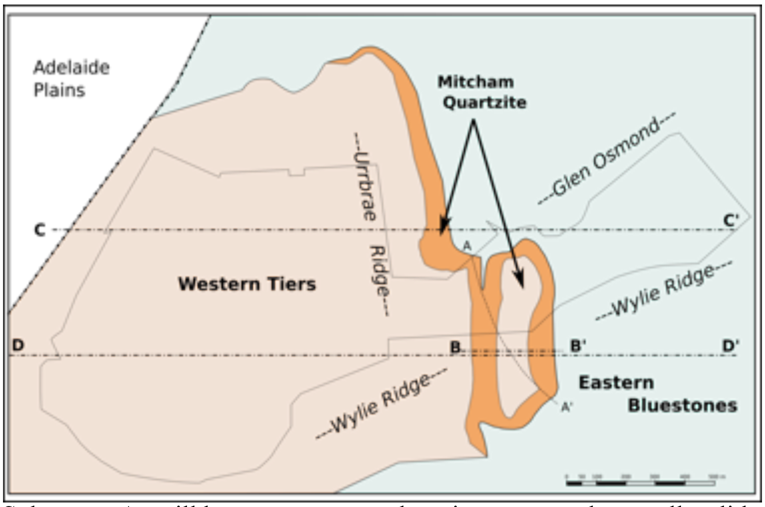

Figure 8. From a geological perspective the Waite Conservation Reserve can be viewed as three domains – Eastern Bluestones, Mitcham Central, and the Western Tiers, the differences relate to the make-up of the underlying rocks and also how they relate structurally. The Eastern Bluestones includes the oldest rocks, which are dominantly siltstones of the Saddleworth Formation. The Western Tiers are composed of the upper part of the overlying Belair Subgroup, with the prominent Mitcham Quartzite (Mitcham Central) separating the eastern and western domains. The Mitcham Quartzite is the basal member of the Belair Subgroup. As will become apparent there is a structural, as well as lithostratigraphic, reason for separating the domains.

Historically the hills overlooking Adelaide were referred to as 'the Tiers', in that sense the tiers related to the step across major fault blocks. In this account of the WCR the word 'tier' is used to describe steps in the landscape relating to strata which have been resistant to erosion; these tiers do not have dimensions of fault blocks never-the-less they form striking cliff lines and steps along the sides of the valleys. In the northwestern part of the reserve there are two prominent tiers, the lower one is riddled with caves and thus is called the Caves Tier. The higher, the Netherby Knoll Tier, is prominent around the Netherby Spur and is followed by the WCR loop trail. Further south tiers are less obvious although the Yurrebilla Trail does track across one of them.

The Rocks of the WCR

All the rocks in the WCR are anciently deposited sediments, and one purpose of the excursion is to study their makeup (lithology), and consider their depositional environment, to that end many of the features mentioned below will be illustrated by field examples. The evidence suggests shallow water marine conditions affected by waves and bottom currents, and perhaps signs of slope instability. The Glen Osmond Slate Member of the Saddleworth Formation is the oldest stratigraphic unit of the WCR, it is overlain disconformably by the Belair Sub-Group with the Mitcham Quarzite representing its basal unit (Figs. 1 & 8). The depositional styles of the Glen Osmond Slate Member and Belair Subgroup are similar, thus the incursion of the disconformable Mitcham Quartzite possibly indicates the switch of sediment source. Later all units suffered the deformational affects of the Delamerian Orogeny, and both the deposition and the later deformation provide evidence of the Australia's place in the global tectonic regimes of those two periods.

In recent times all three of the major stratigraphic units of the WCR, i.e. Glen Osmond Slate Member of the Saddleworth Formation, Mitcham Quartzite and the overlying part Belair Subgroup were previously quarried either for building stones and aggregate or for brick making material, e.g. the Glen Osmond City Bricks Ltd quarry (Figs 1 & 9).

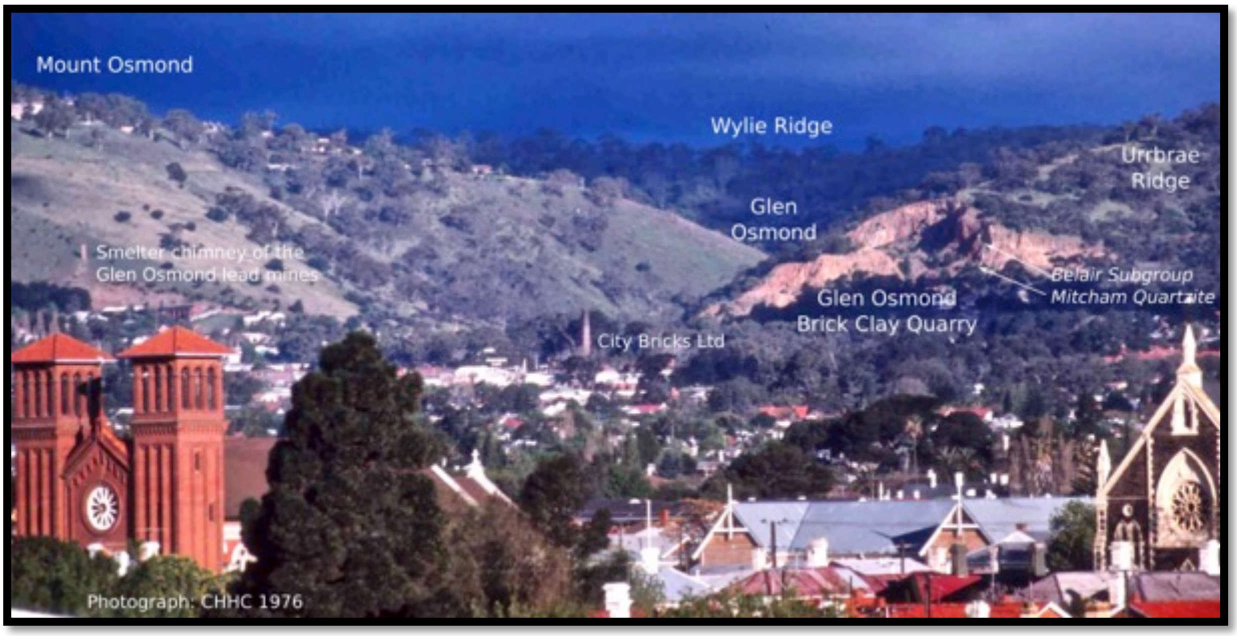

Figure 9. 1976 eastward view of Glen Osmond showing the Glen Osmond City Bricks Ltd Quarry that exposed the Mitcham Quartzite and overlying part of the Belair Subgroup, both overlying the Saddleworth Formation. Subsequently the quarry was rehabilitated, its place being taken by the housing of the Mira Monte Estate. The City Bricks chimney has gone, and trees now cover the northern slopes of Glen Osmond, so obscuring the Glen Osmond Mines smelter chimney that once was a marker for shipping.

GLEN OSMOND SLATE MEMBER

The **Glen Osmond Slate Member** of the Saddleworth Formation includes the oldest rocks of the WCR. The sediments are blue-grey in colour where freshly exposed, e.g. the SE-Freeway cuttings. Bedding is of variable thickness, that is laminated to thinly bedded, and composed of fine-grained detritus that varies through mudstone (shale and slate), siltstone, and fine-grained sandstone. Quartzite lenses are rare. Bed forms vary from thinly planar to hummocky. In Glen Osmond the Saddleworth Formation was once quarried for both building material, i.e. bluestone, and brick-making. Additionally the Saddleworth Formation hosts lead-silver mineralisation, which promoted the development of the Mount Osmond Mines, as well as other historic mine workings and exploratory shafts that still exist in the region (e.g. MacFarlane's Mine, Site G8; Ellison's Creek).

BELAIR SUBGROUP

The Belair Subgroup is the youngest part of the Burra Group in the WCR, it and its stratigraphic equivalents are separated from the overlying Umberatana Group by a major regional unconformity seen elsewhere (e.g. Magpie Creek, Sturt Gorge).

OLDER BELAIR SUBGROUP, MITCHAM QUARTZITE

The **Mitcham Quartzite** is the basal unit of the Belair Subgroup with a very distinct base, parallel with the underlying siltstone beds of the Saddleworth Formation. Non-intuitively regional evidence indicates the disconformable contact is part of a regional unconformity, therefore suggesting a significant age difference between the two. The Mitcham Quartzite in the Glen Osmond area is consistently 30-40m thick, locally a pebbly, coarsely-grained arkose, but with the proportion of feldspar being variable. It is thickly bedded and locally displays rippled surfaces, cross-beds, and de-watering structures. Cementation to form quartzite is variable, however the lower portion is more indurated. The Mitcham Quartzite forms a noticeable geomorphic expression that outlines its folded nature where it crosses the Wylie Ridge (more fully explained later).

YOUNGER BELAIR SUBGROUP

The Belair Subgroup sediments that overlie the Mitcham Quartzite are similar to those of the underlying Saddleworth Formation, but with the exception of having a greater frequency of lenticular feldspathic quartzite units. The bulk of the sediments are fine-grained, varying from laminated shale and siltstone to fine-grained sandstone. Syn-depositional traction current activity is amply advertised by sedimentary structures such as ripples and hummocky cross-bedding. Structures indicating dewatering and slumping are common, and additionally there are examples of local rip-ups, with diamictite beds demonstrating sediment disruption and mass flow. Locally scour features confirm aggressive current activity.

The informally named **Urrbrae Ridge quartzite and the Tier beds** represent significant components of the Belair Subgroup. Following the observations of Sprigg, Whittle and Campana (1951) an amalgamation of these units is presented as Nsd1 on geological maps of the SA Geological Survey, additionally the Urrbrae Ridge quartzite was recorded by King (1953) and Valentine (1972). The Urrbrae Ridge quartzite is a thin, locally cross-bedded arkosic quartzite bed, occurring in siltstone and stratigraphically well above the Mitcham Quartzite (~140m). Outcrop shows it to project as a depositional sheet at least 700m in extent in the east, however it separates into small lenses to the west. As with the Mitcham Quartzite, the Urrbrae Ridge quartzite is shown to suddenly terminate in the south , the reason possibly related to faulting (see the south-central part of the geological map, Fig. 1, and SA Geological Survey 1:100,000 scale geological map). There are other restricted lenticular quartzite bodies within the Belair Subgroup ('Q' on Figure 1, the geological map).

The Tier beds are represented by cliff lines where best developed, but elsewhere by less laterally extensive geomorphic steps. Along the southern side of Wild Dog Glen the Urrbrae Ridge quartzite tracks around the top of the most obvious of the tiers, the Caves Tier. Up slope is a second tier which the WCR trail follows around the Netherby Spur, hence the Netherby Spur Tier. As with the Caves Tier, cross-bedded quartzite is recorded, albeit rarely. The tiers exist partly because more siliceous 'sand'-rich portions of the Belair Subgroup succession are resistant to weathering, and also due to the prominence of a W-E set of joints. [Cave formation of the Caves Tier is discussed in Part 3 of the WCR guidebook).

THE DEPOSITIONAL ENVIRONMENT

Glen Osmond Slate Member & Belair SG

The Glen Osmond Slate Member of the Saddleworth Formation and the overlying Belair Subgroup comprise the stratigraphy of the WCR. Sedimentary structures in both are similar thus apparently suggesting similar depositional conditions. The main difference between the two stratigraphic units relates to the prevalence of arkosic material in the Belair Subgroup, the disconformable base of which is the Mitcham Quartzite. However a small body of arkose outcrops below and to the east of the Mitcham Quartzite, and a 60m long arkose lens was mapped to the north in the former Glen Osmond Brick Clay Quarry (Valentine, 1972), perhaps indicating an earlier influx of arkose from the same source as the Mitcham Quartzite.

Mitcham Quartzite

The 30-40m thick Mitcham Quartzite, with its disconformable base on the siltstones of the underlying Saddleworth Formation, represents a striking anomaly in a succession otherwise showing similar depositional characteristics. An hypothetical shallow water deltaic environment for the deposition of the Mitcham Quartzite is consistent with observed sedimentary features such coarse-grained sands, pebble beds, ripples, and cross-beds (Fig. 10). Moreover de-watering structures are indicative of rapid deposition.

The Mitcham Quartzite is the oldest component of the Belair Subgroup and originally was considered to represent the initial stage of the Sturtian glacial period (Mawson and Sprigg, 1950). To date no certain evidence for glacial activity has been observed in the Belair Subgroup, which led Thomson et al. (1964) to redefine the base of the Sturtian glaciation as the base of the Sturt Tillite further up the section. However rare lonestones, which are known from the Saddleworth Formation equivalent in the mid-north, i.e. the Mintaro Shale, are likely to represent early ice-rafted debris, although admittedly the situation remains unclear (Preiss, 1993).

More recently a significant breakthrough has indicated that the detrital zircon population of the Mitcham Quartzite registers a change in the source of sediment supply. Whereas pre-Mitcham Quartzite sand originated, either locally, or from the Musgrave Block to the north, the new interpretation is for receipt of the material from the south as a part of a northward growing delta (van der Wolff 2020).

Upper Belair SG (UBSG)

The incursion of coarse-grained arkosic material into the basin continued after deposition of the Mitcham Quartzite, although to a lesser degree. Examples are the Urrbrae Ridge quartzite and other sporadic restricted feldspathic quartzite lenses.

Above the Mitcham Quartzite observations of sedimentation from within younger parts of the Belair Subgroup indicate syn-depositional erosion and episodic deposition of laminated still-water siltstone, and current affected silts and fine-grained sands. Syndepositional erosion is exemplified by ripped up and redeposited clasts, and scour-related features. Signs of sediment disruption such as water escape and slump structures are common, additionally there are beds of massive, structureless unsorted psammite or diamictite, which are interpreted to represent mass flows.

The environment is one of shallow marine, near shore sedimentation in which quiet settling of fine-grained material was interspersed with rapid influx of material associated with active bottom currents. Packages defined by laminated bedding, and hummocky and swaley beds suggest storm affected deposition, but below fair weather wave base (Collinson and Mountney, 2019). A pro-delta setting fits where a relatively quite marine situation is punctuated by sporadic high energy fluviatile induced activity (Fig.10).

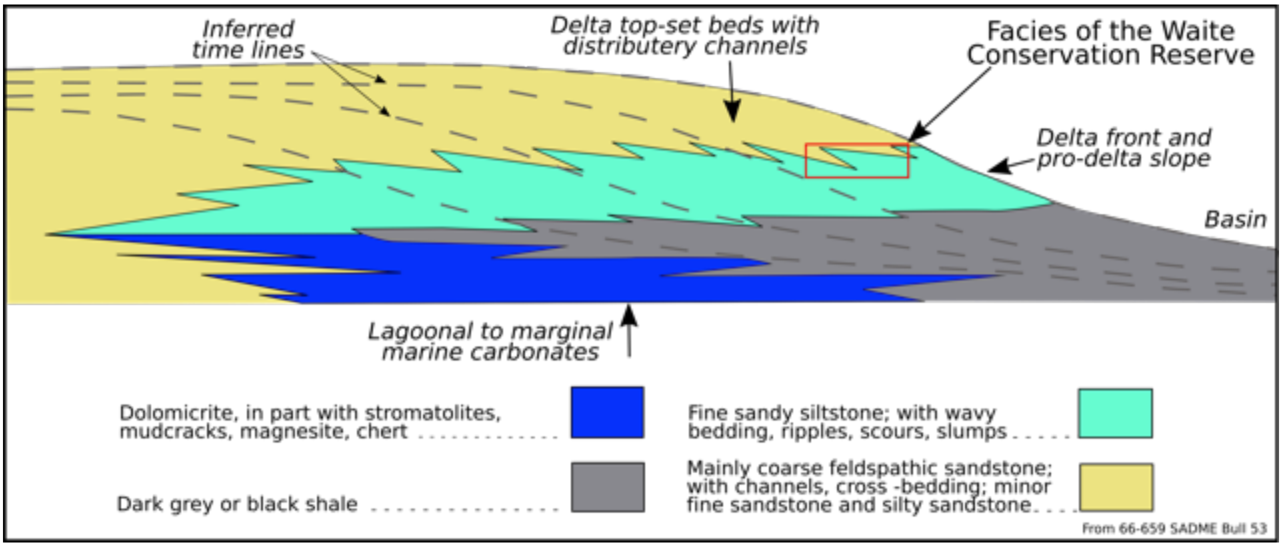

Figure 10. A depositional model for the Burra Group (from Preiss 1986). The part relevant to WCR is the upper part of the pro-delta slope where sporadically coarse sands interdigitate with deeper water fine-grained clastic sediments. Additionally the model provides for sporadic rapid deposition and slope instability, the later perhaps augmented by the seismicity of a subsiding rifted basin.

The sudden introduction of coarse-grained feldspathic sands involving the switch of fluviatile input from northerly and local sources to southerly as suggested by Van der Wolff (2020) represents a further influence on the evolution of the delta. Of more local significance the sporadic distribution of restricted quartzite lenses higher in the Belair Subgroup is perhaps due to migration of distributary channels across the deltaic fan.

Part 2 of the Waite Conservation Reserve geological guidebook follows. *Part 3 'Geology of western WCR,' and Part 4 'Geology of the Amphitheatre Quarry' are not included.*

Part 2. The Geology of the Sheoak Loop Trail and the Mitcham Quartzite

Prior to visiting the field sites it is worth introducing the structural form of the ancient sedimentary units of the Eastern Bluestones, Mitcham Quartzite, and the upper part of the Belair Subgroup of the Western Tiers. At the time of sedimentation about 750 million years ago the sediments were deposited so as to form near horizontal beds. As mentioned previously the Mitcham Quartzite is a distinctive 30-40m thick, coarse-grained, yellow-brown feldspathic sandstone. Being so distinctive it can be considered as a 'marker unit', meaning it can be used as a reference stratum that can be traced and mapped over a long distance. This is illustrated by the geological map (Fig. 1) and the orange coloured unit in Figure 8. Something that is striking about the form of the Mitcham Quartzite in those two figures is that it does not give the appearance of a flat sheet, this is because 500 million years ago it was affected by a collision between two tectonic plates. The collisional event is known as the previously introduced Delamerian Orogeny. The collision resulted in intense compression directed from what is now the east, this caused the originally flat lying strata to be bucked by folds, and partly dismembered by faults.

The style of this deformation is illustrated by the diagrammatic cross-sections in Figure 11. In a regional sense the style of fold is a monocline because it has two long relatively horizontal limbs separated a short vertical limb. Although in this particular case of the WCR the central limb is further buckled into a subsidiary anticline and syncline. Evidence for this rather complex structure is visible in the field at Sites G3, G4, G5, G10 and G11.

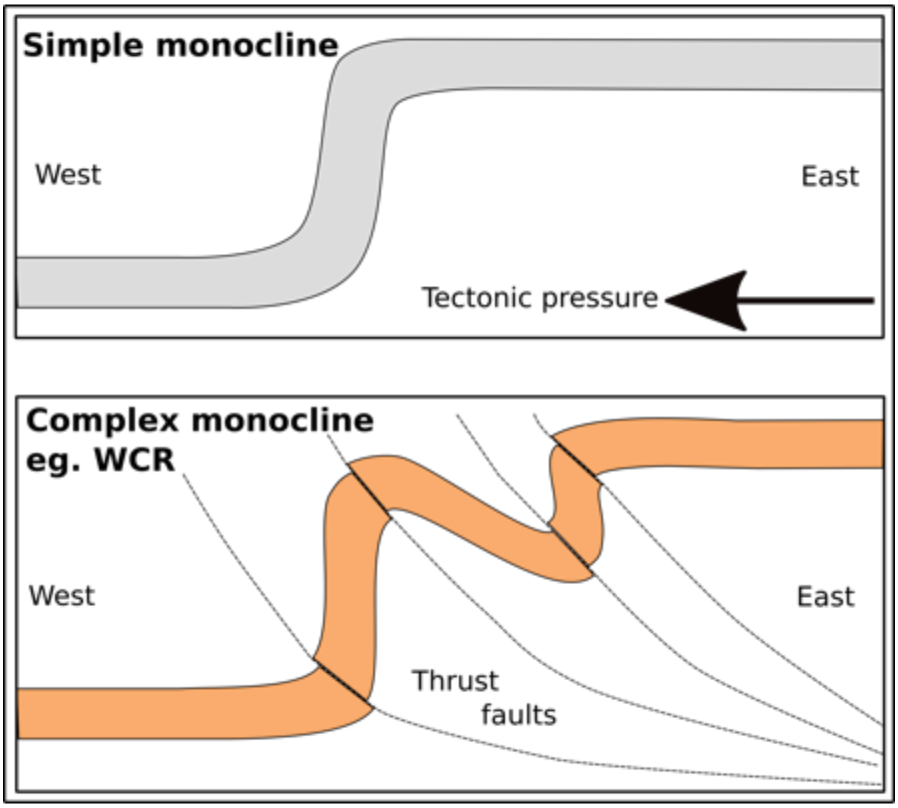

Figure 11 Two forms of monocline are shown, this upper one is a typical simple text book version with two horizontal limbs stepped across a vertical limb.

The lower version shows the middle steeply inclined limb to be, not only complexly folded, but also segmented by the splays originating from a major parent thrust fault. Something like this is expected to be the case in the Waite Conservation Reserve.

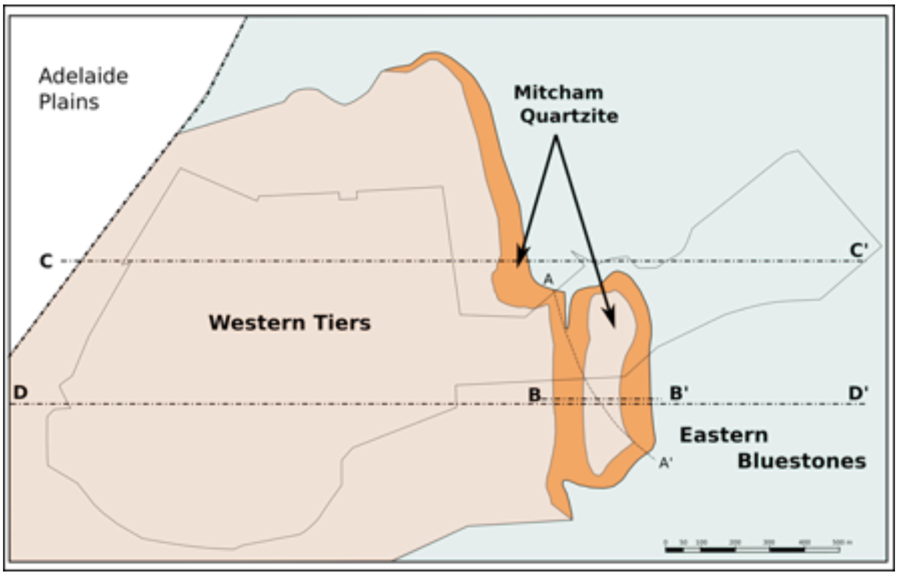

Figure 12. Repeated from Figure 8, compare this with the lower cross section of the preceding Figure 11. The outcrop pattern of the Mitcham Quartzite is due to 3D form of the quartzite overlaid upon the rugged terrain. The left hand arrow points to the western lower limb of the monocline near the base of Glen Osmond. He right hand arrow points to the synclinal part of the central limb of the monocline where it crosses over Wylie Ridge. The east limb of the monocline is not visible, it being lost to erosion.

Site G5. QUARTZ HILL QUARRY. Depositional layering (bedding), ripples, folds, faults, veins and weathering

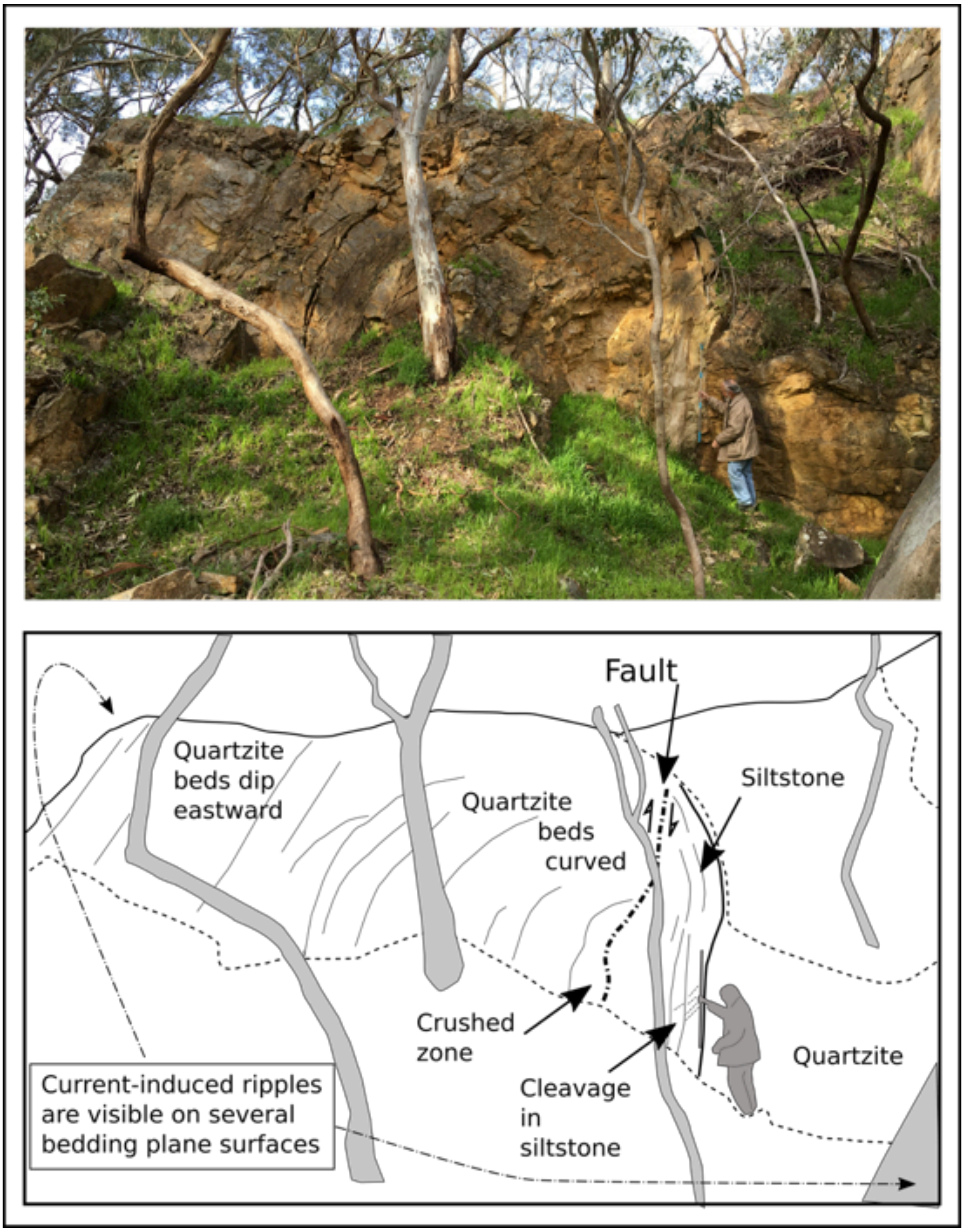

Figure 13. The Ripple Quarry is the easternmost occurrence of the Mitcham Quartzite, it is the vertically dipping east limb of the Peregrine Syncline, and the eastern remains of the eroded WCR monocline. The fold was formed during the Delamerian Orogeny (refer to the cross-section, Fig. 22). The quarry face displays quartzite and siltstone, but the relationships are complicated by faulting. Dr Wolfgang Preiss stands beside the contact of the siltstone with the Mitcham Quartzite, which is interpreted as the disconformity separating the Saddleworth Formation from the Belair Subgroup. The curved (folded) quartzite beds to the left of the vertical fault are interpreted to have been raised up relative to the rocks on the right. The crushed zone (breccia) is the result of brittle failure with the fault developing at a stage later than the formation of the metamorphic cleavage, there are several examples of this style of fault in the vicinity. (The term cleavage is explained in Figure 16). The photograph originates prior to remediation of the site and the installation of the two geological displays.

Figure 14. Ripple marked details of the underside of a 700 million year old sea floor: Near vertical, steeply easterly-dipping overturned quartzite beds (strata) near the base of the Mitcham Quartzite indicate that the sea was shallow because wave action and shoreline currents were active (as they do on modern beaches).

Figure 15. Cleavage in the siltstone: The interpretation is that this is the basal and disconformable contact of the Mitcham Quartzite (brown unit on the right) with the older siltstone of the Saddleworth Formation to the left (W.V. Preiss pers. com.). Bedding in both the siltstone and quartzite is vertical. The parallel lines that incline to the left (i.e. easterly) are traces of metamorphic cleavage planes that were formed coincident with the folding. The folding is a result of the 500 million year old mountain building event called the Delamerian Orogeny.

The white colour of the siltstone and iron staining of the cleavage planes is due to alteration resulting from weathering.

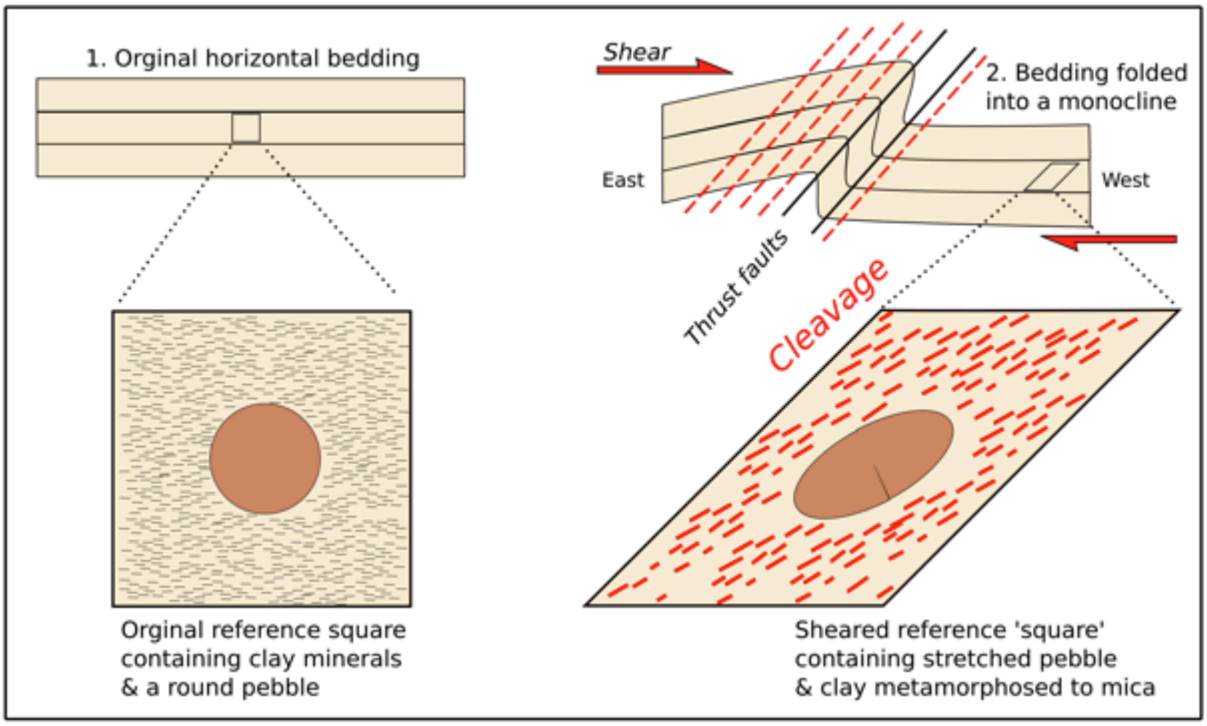

Figure 16. Metamorphic cleavage, how it forms: Sedimentary beds are generally deposited horizontally below water (*top left diagram*), and tiny platy clay minerals sink down to the sea floor where they tend to lie flat (*bottom left diagram*). During mountain building events (orogenies) it is common for the rock mass to get compressed from the side, so that the original bedding becomes folded (*top right*). All this happens at great depths in the Earth's crust and the heat and pressure converts original minerals such as clay into new 'metamorphic' minerals such as platy white mica. The platy crystals grow at right angles to the pressure direction and so form the cleavage (*bottom right*). Also illustrated is how a round rock pebble (called a clast) has become stretched e.g. examples in the Sturt Gorge (Conor and Pyle, 2021).

Figure 17. Some exposed surfaces in the quarry display red-brown irregular concentric marks, these are called 'liesegang rings', and are due to litmus-like movement of iron-bearing groundwater working its way into the rock from joints (natural cracks like the vertical one in the middle of the photo). Some sandstones, patterned by liesegang rings, provide an attractive building stone. Also visible are near horizontal joints which have been infilled by crystalline quartz, these structures are called quartz veins. As well as the quartz of the veins there are also small gaps, which at the time of formation would have been filled by the fluid from which the quartz silica was precipitated, the gaps indicate that walls of the veins had been forced apart either under vertical tension or due to relaxation as the E-W pressure was released. Such veins are the source of the quartz debris on Quartz Hill (Site G4).

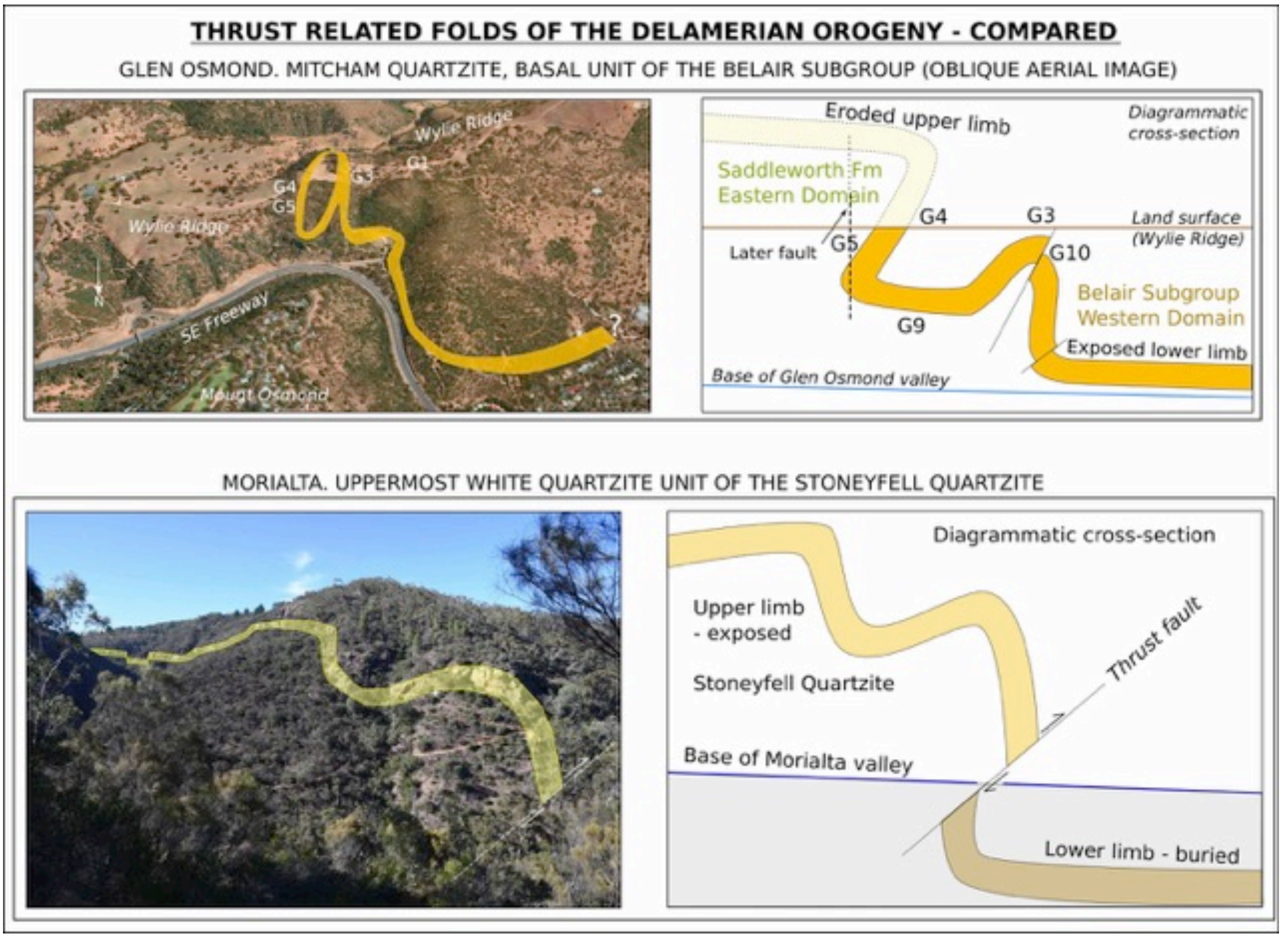

Figure 18. The fold-thrust structures in Glen Osmond and Morialta are compared, both sections look south. The viewing point for the Morialta structure was from the northern side of the valley, a similar photographic view for Glen Osmond was not possible due to tree coverage, hence the oblique aerial view (Apple Maps image). The reverse fault (thrust) at Morialta is well constrained, those shown in Glen Osmond are less so due to outcrop restrictions. Erosion by the Glen Osmond and Brown Hill Creek systems has fully exposed the syncline (Sites G4 – G3) to give the '0' shaped pattern on Wylie Ridge (top left), the syncline plunges at approximately 3° to the south (i.e. towards the top of the image). It is to be expected that the steep reverse (thrust) faults, which are depicted in the cross sections, will flatten out at depth to merge with parent thrusts (as shown diagrammatically in Figure 11). An historical aside: compare the tree cover of Glen Osmond with that of the 1976 photo of Figure 9.

SITE G6. SADDLEWORTH FORMATION

SITE G6.1 Saddleworth Formation, planar beds and cleavage

Figure 19. The outcrop here is a good example of the Saddleworth Formation, it represents the oldest package of rocks present in the Waite Conservation Reserve. Downhill from here the 'bluestones' are clearly visible in the cuttings of the S-E Freeway. Here the rock is mainly siltstone because the sizes of the particles or grains are very small. However thin apparently right-sloping resistant beds show that at times fine-grained sand was introduced, perhaps the result of storms. Actually the rock is a metasiltstone, with the prefix 'meta' indicating that it has been metamorphosed, the rock mass having been buried to a depth of several kilometres and then compressed. The lines or planes that cut across the bedding and slope steeply left are the cleavage, the same cleavage that was visible at the last site (G5). The cleavage was the result of compression when a tectonic plate was driven into the east of the proto-Australia 500 million years ago. This tectonic event was the mountain-building Delamerian Orogeny.

Geologists have ways of getting some order out of seeming chaos, this outcrop nicely shows items of use in working out structural shapes, such items are: a) bedding, b) cleavage, c) the line forming the intersection of the cleavage with the bedding, i.e. the 'intersection lineation'. Ideally the intersection parallels the axis of any large or small fold of the same generation, and in the Reserve this seems to be the case.

Example, the structures at this outcrop measure:

a) Bedding: 16 degree dip towards 260 degrees west
b) Cleavage: 37 degree dip towards 108 degrees east
c) Intersection lineation: 1 degree dip towards 175 degrees south

SITE G6.2 Saddleworth Formation, hummocky beds and alteration

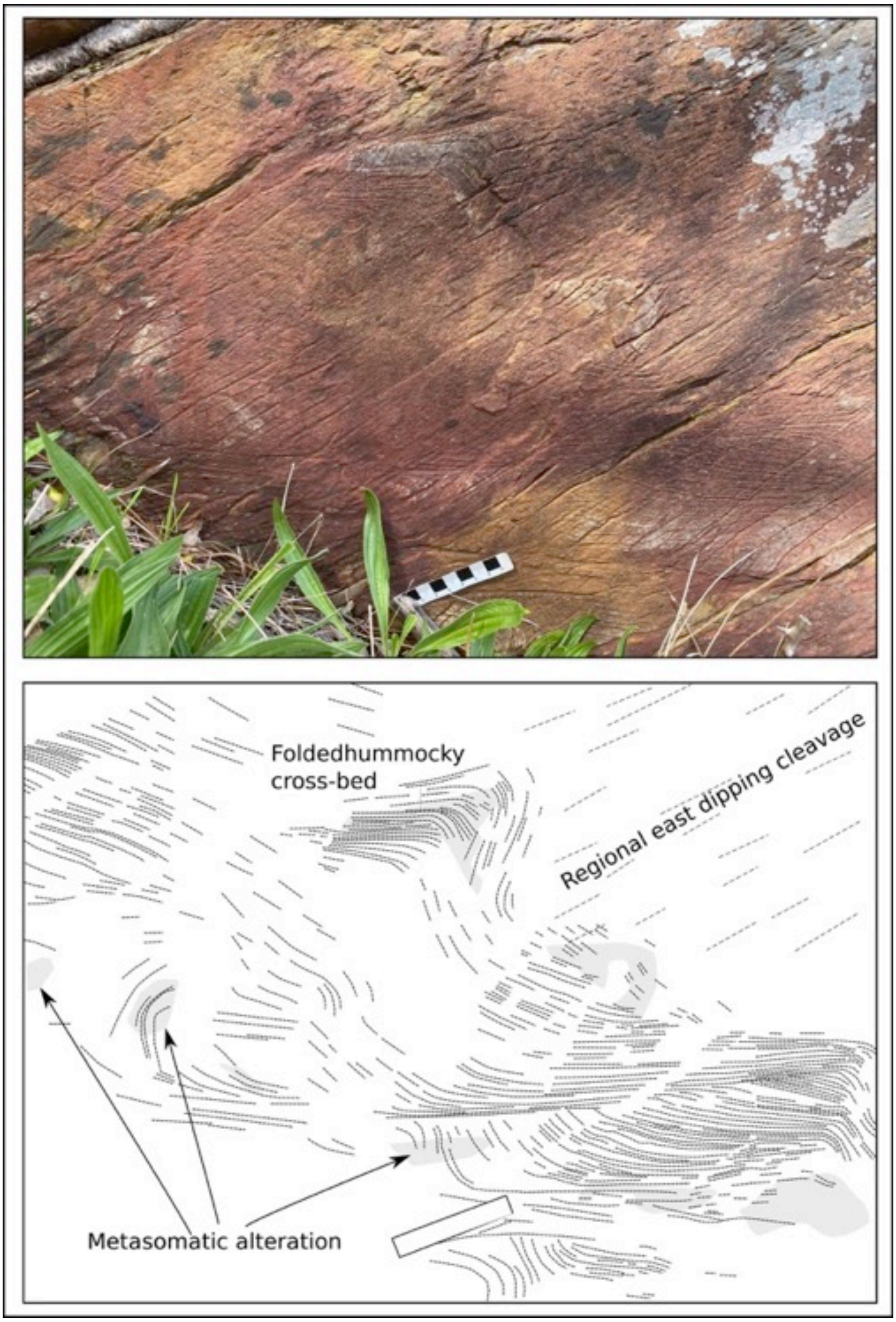

Figure 20. The evidence here is for a different local depositional environment than that displayed at Site G6.1. A north facing joint surface shows traction current-related sedimentary structures, mainly hummocky cross-stratification. It would appear that the structures have been tightened by compression during the Delamerian Orogeny. The metamorphic cleavage is intense and crosscuts small areas of white metasomatic alteration (possibly feldspathic). The style of bedding displayed in this outcrop suggests relatively shallow water shelf conditions where oscillating bottom currents were active. The joint prominently displays the regional east dipping cleavage which tends to dominates in appearance over the bedding of the siltstone.

***Site G9 NW VIEW TOWARDS ADELAIDE ALONG THE S-E FREEWAY VALLEY**
[*Beware, below the path the slope is a steep and slippery and leads to the vertical drop into Wyllie Ridge Bluestone Quarry*]

Figure 21. The base of the Mitcham Quartzite is exposed in the road-cut along the eastern wall of the Urrbrae Ridge spur, and clearly displays a shallow southerly dip (readily visible as a passenger when driving along the S-E Freeway). The change in orientation of the Glen Osmond Creek from E-W to S-N (followed by the S-E Freeway) was controlled by the resistant quartzite which retards erosion. Additionally, the shape of the overlying Urrbrae Ridge crest is in part controlled by a second quartzite, the Urrbrae Ridge quartzite.

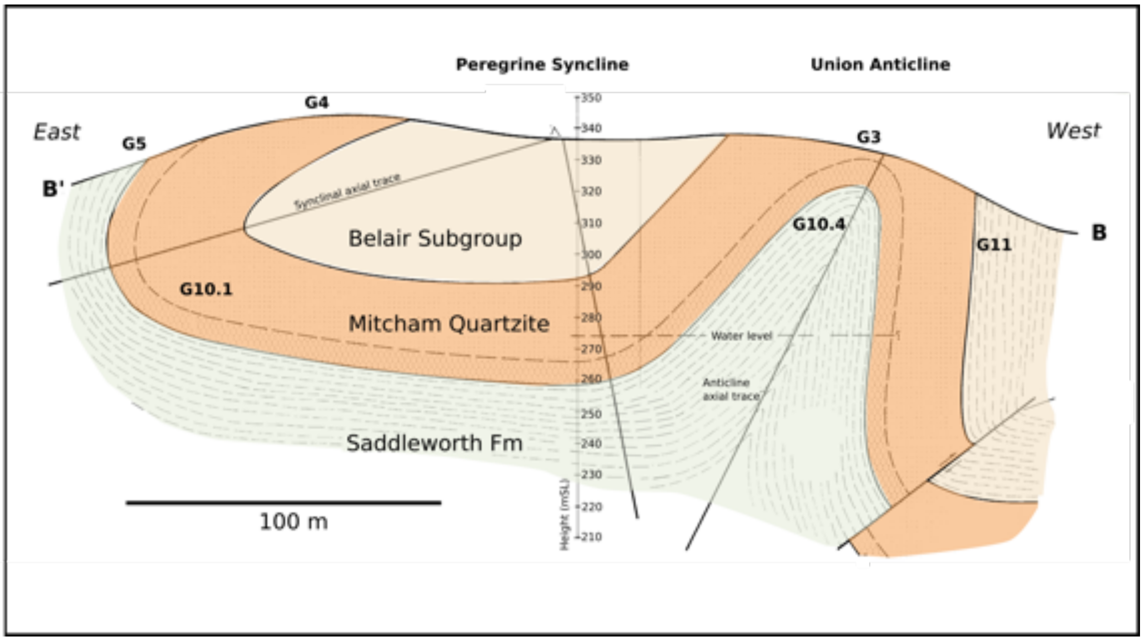

Figure 22. The WCR Monocline. View looking south, this syncline\anticline pair represents the central limb of the WCR monocline. The simplified cross-section B' – B relates to the 1979 investigation for the proposed Wylie Ridge S-E Freeway tunnel (modified from Conor, 1981, though the structure was worked out by D. King in 1953). The location of selected excursion Sites G3 to G11 are shown. The Mitcham Quartzite from above Site G4 has been lost to erosion.

Site G10.1 Eastern limb of the Peregrine Syncline

Figure 23. A small excavation exposes the locally rippled Mitcham Quartzite (refer to the cross-section, Fig. 22). The bedding dips shallowly westerly and is 'upright', that is the sediments young upwards (in contrast to Site G5 where the dip is steeply eastward and the beds overturned).

Site G10.2 Disrupted area of the quarry where bedding in the Peregrine Syncline changes from west to east dipping. (No site photo)
[Be aware of the potential for rock falls from the quarry face at this site and Site G10.3]

Site G10.3 Ball and pillow structure in the Mitcham Quartzite

Figure 24. Towards the western end of the large quarry, differing from Site G10.1, the bedding dips shallowly towards the east. The base of the photo displays an interesting clot-like sedimentary feature which characterises a bed tracking up the quarry face to the west. The feature is a 'ball and pillow structure', which indicates the escape of water from a rapidly deposited submarine debris slurry. This sedimentary structure also shows the succession to be upright and not overturned.

***Site G10.4 Base of the Mitcham Quartzite, western limb of the Peregrine Syncline. i.e. eastern limb of the Union Anticline** (refer to the cross-section, Fig. 22)
[*Beware, the climb up to this exposure is over loose rock, also check for unstable rock in the quarry face*]

Figure 25. An exposure of the base of the Mitcham Quartzite is visible higher up on the western end of the excavation where the quartzite is sharply underlain by thinly laminated siltstone of the Saddleworth Formation (the cm scale is at the contact). This is the same contact that was seen at Site G5, thus it represents a disconformable surface (W.V. Preiss pers com.). Another occurrence of Saddleworth Formation is represented by an outcrop beside the track. Although weathered, the similarity of the finely layered siltstone with varves might have influenced the glacial interpretation of Mawson and Sprigg (1950). This site (G10.4) is near the western end of the syncline, hence approaching the faulted Union Anticline that drops the quartzite vertically down into the Union Quartzite Quarry to the west.

The Union Anticline

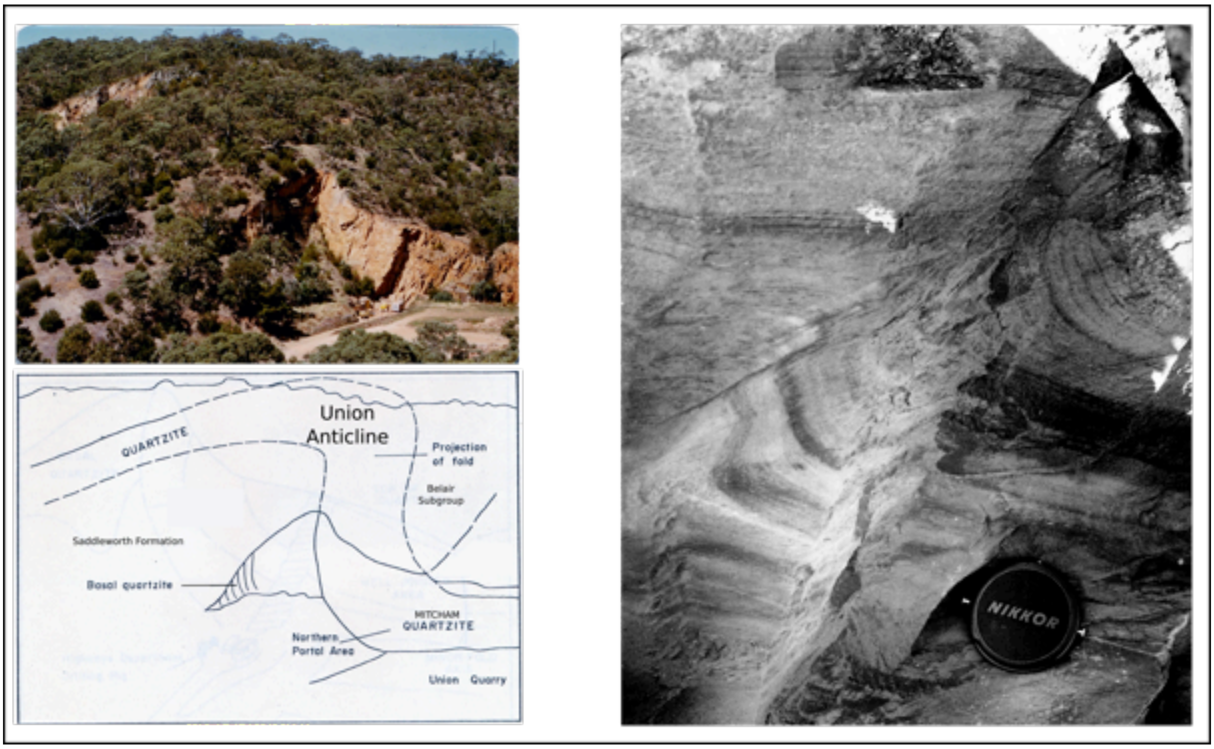

Figure 26. Examples of large- and small-scale folds of the same generation having a similar form. In the left hand, southeast looking, coloured photo, the scale is given by the quartzite face, about 40m high (also a caravan and drilling equipment). The photo dates from 1979, it and the interpretive drawing shows the Mitcham Quartzite that was deformed into a knee-shaped fold during the Delamerian Orogeny. The Waite Conservation Reserve track passes between the two Mitcham Quartzite quarries (the upper one being the subject of Sites G10). The machinery at the base of the Union Quarry was drilling a horizontal hole along the line of the then proposed Devil Elbow by-pass tunnel. The monochrome photo on the right (lens cap for scale) was taken in the Wylie Ridge Bluestone Quarry below the left-hand Mitcham Quartzite quarry. The rock is siltstone of the Saddleworth Formation. Although there is a difference of scale, the photo shows a style of folding similar to that developed in the overlying quartzite. The east dipping cleavage, which is associated with the fold, disrupts the bedding showing east over west thrust displacement. A similar style of thrusting is to be expected affecting the Mitcham Quartzite in the Union Anticline, albeit at a larger scale.

Site G11.1 The western limb of the Union Anticline

Figure 27. The track now runs southward paralleling the axis of the Union Anticline, albeit along the western limb (Fig. 1). The siltstone and sandstone beds exposed here are interpreted to be at the base of the Mitcham Quartzite (refer to Fig. 22). The bedding is orientated slightly past the vertical indicating that this limb of the fold is steeply overturned as it dips down behind eastern wall of the Union Quartzite Quarry. The cleavage has been distorted away from its normal eastward inclination, suggesting that locally deformation reactivated after the development of regional structure.

Steep slopes, scree and vegetation make detailed mapping of the Union Anticline difficult, however the mesofold shown in Figure 26 (grey scale photo) does suggest a form where the upper limb, i.e. western limb of the Peregrine Syncline, remains relatively flat while the western vertical limb of the Union Anticline is a west verging curve. An east dipping reverse fault is interpreted to coincide with the axial plane of the fold.

Site G11. 2 Disruption of the Mitcham Quartzite

Figure 28. This is one of the last sites where the Mitcham Quartzite is visible in the WCR (although outside of the WCR to the north it does curve around the toe of the Urrbrae Ridge, through the former Glen Osmond Brick Clay Quarry, and up to the Eden-Burnside fault, see Map Fig. 1). At this locality the top of the Mitcham Quartzite is represented by two quartzite masses (boudins) separated by siltstone. Interbeds of the Mitcham Quartzite have been disaggregated during the folding suggesting that the fold apex combines with a reverse fault. This is interpreted as direct evidence of fold-trust style deformation.

Site G11.3 The last of the Mitcham Quartzite

70 m south of Site G11.2 the outcrop beside the track is the last to show quartzite and is interpreted to represent the top of the Mitcham Quartzite. Above the track debris masks the steep slope so that the first quartzite outcrop at the ridge crest is of the shallow easterly dipping west limb of the Peregrine Syncline.

REVIEWING PROGRESS, A SUMMARY CROSS-SECTION (looking north)

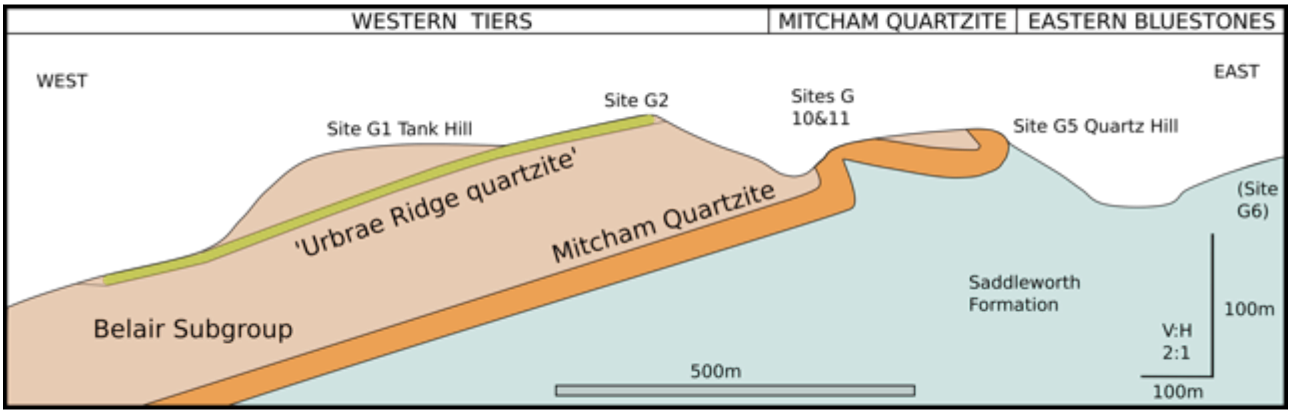

Figure 29. Cross-section D-D' approximately follows along Wylie Ridge (see Fig. 12 for location). The cross-section shows the shallow southwesterly inclined WCR Monocline (NB the vertical exaggeration), part of a system of fold-thrust structures of which the Adelaide Hills are made. The Mitcham Quartzite of the western limb of the monocline is buried below the western part of the WCR, the east limb has been lost to erosion. The central connecting limb is a complex of reverse fault related folds, which are marked at sites G3, 4, 5, 10 & 11. The older stratigraphic unit is the Glen Osmond Slate Member of the Saddleworth Formation in the east, the younger is the Belair Subgroup is in the west, of which the Mitcham Quartzite is the basal member. Younger than the Mitcham Quartzite, the Urrbrae Ridge quartzite (Site G2) is the largest of several discontinuous quartzite units higher in the Belair Subgroup.

THE WESTERN TIERS

The Western Tiers is a domain of the Waite Conservation Reserve (Fig. 8), which is dominated by Belair Subgroup sediments younger than the Mitcham Quartzite, and to the west of the Union Anticline (Fig. 12) (Ref: Conor, Part 3, WCR Field Guidebook, in prep.).

SITE G12 WESTERLY DIPPING SILTSTONE OF THE BELAIR SUBGROUP

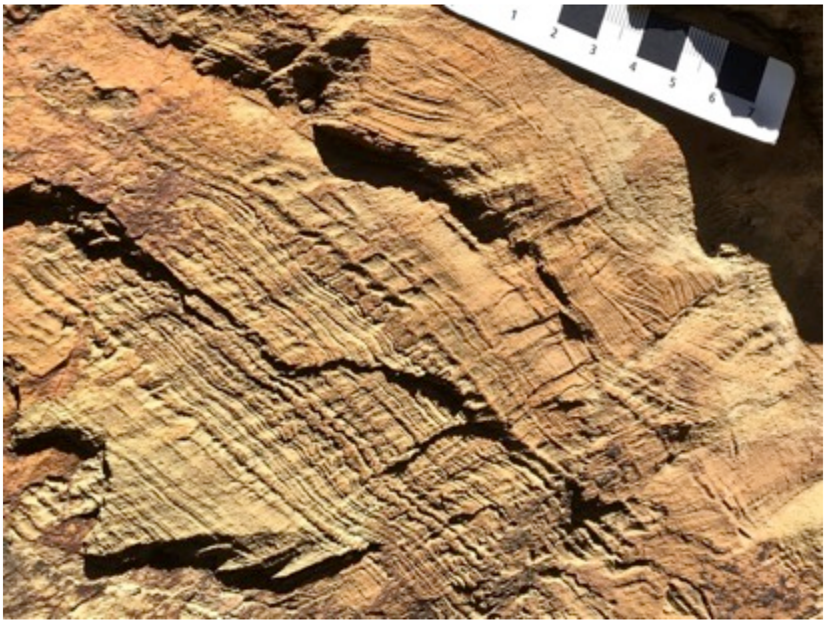

Figure 30. An excavated exposure beside the walking track a short distance to the west of the Union Anticline. The exposed siltstone is slightly higher in the Belair Subgroup, i.e. younger than the Mitcham Quartzite. In dropping diagonally across the photo from left to right the thin sedimentary beds demonstrate a moderate dip to the west. Some beds show grading, fining up to the west, and there are examples of hummocky cross-beds. The information from this small outcrop suggests sedimentation of silt and fine sand in relatively deep calm water, but at times when fairly substantial currents swept the sea floor. The metamorphic cleavage dips at a similar angle to the bedding but to the east. Locally the bedding appears to be slightly crenulated by the cleavage. If the line marking the intersection of the bedding and cleavage was expose, it would be seen to dip shallowly to the south (matching the plunge of the Peregrine Syncline and Union Anticline). In the WCR the orientation of bedding/cleavage lineation is remarkably consistent, unlike the orientations of both the bedding and the cleavage.

SITE G12 PEBBLES AND ANOMALOUS DIP CHANGES

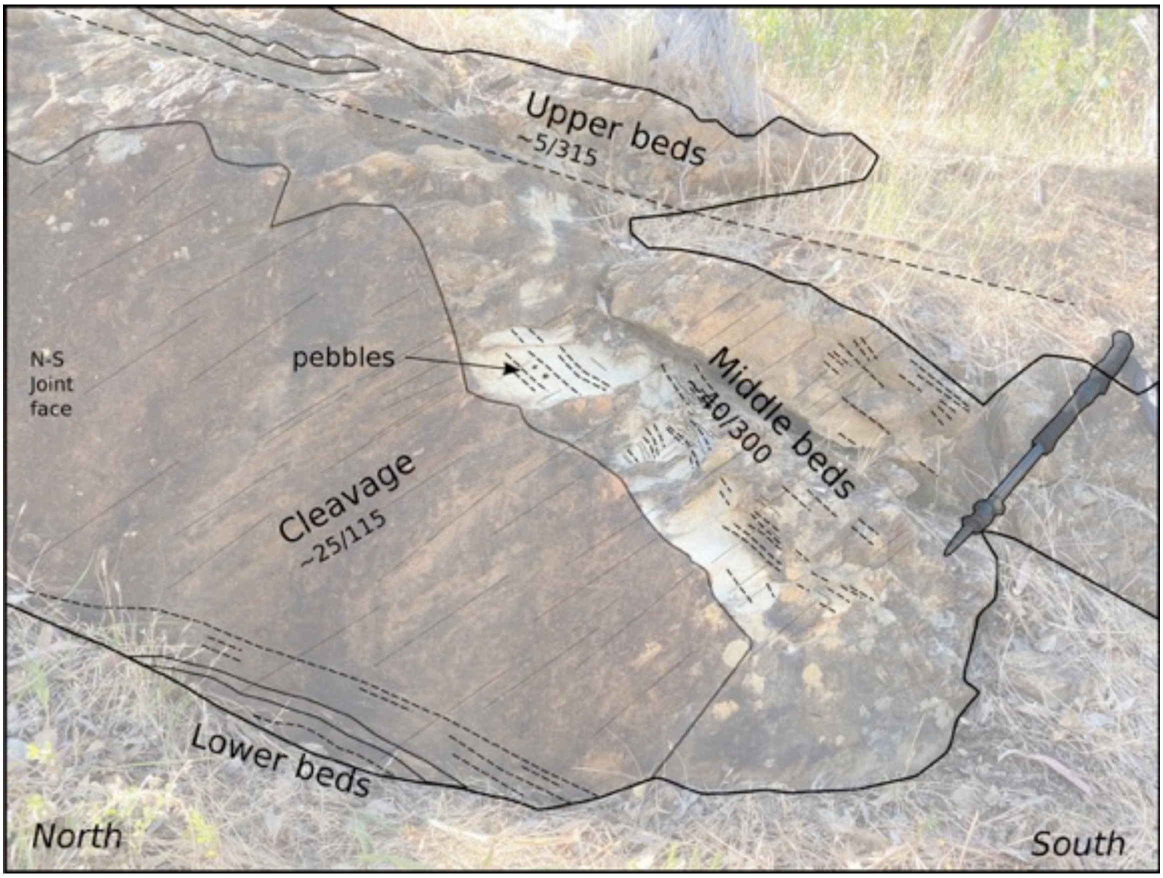

Figure 31. A thin hard sandstone layer (at the top of the photo) overlies two siltstone packages in which the particle or grain-size of the rock is very fine and micaceous. Small pebbles embedded in the main body of the siltstone infer that at the time of deposition older sediments were being eroded elsewhere in the succession. The pebbles are enigmatic because the fine-grained nature of the siltstones of the Saddleworth Formation and upper Belair Subgroup would normally suggest that deposition was distal, therefore in a less energetic environment than that of the Mitcham Quartzite. Hence either the current was of sufficient strength to transport small pebbles, or the pebbles are small dropstones, so raising the possibility of floating ice (Mawson and Sprigg, 1950). Elsewhere in the WCR units similar to the 'Middle beds' depicted here are thicker and better exposed. These beds can be considered as diamictites representing events where pre-existing sediments have become unstable and been converted into water-supported mass-flow debris slurries. These mass-flow units are generally capped by laminated sand beds as is the case here.

SITE G14. THE URRBRAE RIDGE QUARTZITE

Figure 32. This is an outcrop of the 'Urrbrae Ridge quartzite', which was previously seen at Stop G2 (uphill to the left). Here the containing siltstone of the Belair Subgroup is visible on both sides, bottom (east) and top (west). This feldspathic quartzite can be traced to the north, as float running along the eastern slope of the Urrbrae Ridge, to where it crosses over the ridge crest at Site G15.

VIEW OF THE CAVES TIER & THE NETHERBY SPUR

This is what is seen by looking southwest from 'Caves View' at the top of Wild Dog Glen, it is the first of the geological sites of Part 3 of the Geology of the Waite Conservation Reserve.

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GEOLOGICAL MAP OF THE WAITE CONSERVATION RESERVE