VICTORIA RIVER
DOWNS,
Northern Territory
(Second Edition)

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1:250 000 GEOLOGICAL MAP SERIES
EXPLANATORY NOTES

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A CUTOVINOS and BA PIETSCH

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ABSTRACT

VICTORIA RIVER DOWNS\(^1\) includes the Proterozoic Victoria Basin, the northwestern extremities of Early Cambrian flood basalts and the Middle Cambrian Montejinni Limestone within the Wiso Basin. Remnants of a thin succession of platform cover sediments, which accumulated during the Mesozoic and Cenozoic, are unevenly distributed mainly in the eastern and central portions of the mapsheet, respectively.

The Victoria Basin formed after deposition in the underlying Birrindudu Basin was terminated by slow regional uplift of metamorphic basement, resulting in a widespread hiatus and a subsequent shift in the loci of sedimentation northward to southeastern WATERLOO and VICTORIA RIVER DOWNS. Several thousand metres of Palaeoproterozoic to Neoproterozoic sedimentary rocks accumulated within the basin and these have been subdivided into four lithostratigraphic groups; in ascending stratigraphic order, these are the Wattie, Bullita, Tijunna and Auvergne Groups.

The Wattie Group is a succession of mainly sandstone and siltstone, minor carbonate and rare tuffite. It is characterised by regional variations in thickness and was deposited in a shallow marine setting that was punctuated by subordinate deeper marine and evaporitic conditions.

The lower part of the unconformably overlying Bullita Group is an assemblage of mainly carbonates and subordinate siliciclastics. These were deposited on a shoaling, shallow marine platform that included some brine-logging of sediment and conditions that favoured extensive stromatolite deposition. Basin-wide carbonate deposition concluded with a transition to assemblages dominated by siliciclastics in the upper part of the group.

Unconformably overlying the Bullita Group is the newly recognised Tijunna Group, a succession of shale, siltstone, sandstone and mudstone deposited under predominantly shallow marine and minor low-energy deep-water conditions.

The Auvergne Group unconformably overlies the Tijunna Group and consists of sandstone that was deposited in a near-shore shallow marine environment during a regional transgressive phase of deposition. Progressive basement uplift in VICTORIA RIVER DOWNS moved the basin depocentre and the loci of Auvergne Group deposition to WATERLOO and AUVERGNE.

Uplift and erosion preceded the regional extrusion of Early Cambrian flood basalts of the Antrim Plateau Volcanics. This was followed by Middle Cambrian deposition of the Montejinni Limestone in the Wiso Basin. The Montejinni Limestone once mantled much of the mapsheet, but only thin remnants are preserved in eastern VICTORIA RIVER DOWNS. It was deposited under varying conditions that included restricted marine shelf and tidally influenced, open marine environments.

During the Mesozoic, basin margin facies of undifferentiated Cretaceous rocks, which include siltstone, sandstone, claystone and conglomerate, covered much of the mapsheet. Most of these have since been eroded. Cenozoic sediments have a limited distribution, mainly in the central portion of the mapsheet. Cenozoic silcrete overlies Proterozoic carbonates.

Exploration of the Proterozoic rocks has focused mainly on diamonds and base metals. Numerous epigenetic base metal occurrences have been documented from the Bullita Group, which also contains pyrobitumen and live oil.

\(^1\) Names of 1:250 000 and 100 000 map sheets are shown in large and small capital letters, respectively, eg VICTORIA RIVER DOWNS, MONTEJINNI.
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INTRODUCTION

VICTORIA RIVER DOWNS covers an area of some 18 100 km² and is located 450 km to the south of Darwin between latitudes 16°00’S and 17°00’S and longitudes 130°30’E and 132°00’E, in the Northern Territory. It includes portions of the Proterozoic Victoria Basin and Palaeozoic Wiso Basin, as well as a discontinuous cover of Mesozoic sedimentary rocks and Cenozoic sediments.

Geological investigations prior to 1974 included First Edition mapping by the Bureau of Mineral Resources (BMR)\(^2\). Sweet (1973) compiled the accompanying explanatory notes. Additional detailed reports on the geology of the Victoria River region, excluding some Cambrian units, were provided Sweet et al (1974a, b, c). Data from more recent studies, which include stratigraphic revisions of some units and a documentation of mineral occurrences and mineral exploration, have been incorporated into appropriate sections of this regional synthesis.

Recent NTGS activities have focused on studying the regional sequence stratigraphy and geology of the Victoria and Birrindudu Basins. This has culminated in the stratigraphic drilling of a composite 970 m stratotype section through the Bullita Group (Dunster and Cutovinos 2002, Table 1). Regional studies have focused on measuring sections and remapping areas in FERGUSSON RIVER, AUVERGNE, WATERLOO, DELAMERE, LIMBUNYA, WAVE HILL and VICTORIA RIVER DOWNS by up to four geologists and technical staff during the 1997, 1998 and 1999 field seasons.

In VICTORIA RIVER DOWNS, measured sections (Appendix) are located on the map and are referred to in the text with the prefix MS to distinguish them from type sections defined during First Edition mapping. Graphic logs of measured sections will be included in a forthcoming NTGS Technical Note.

Access to VICTORIA RIVER DOWNS was gained by four-wheel drive vehicles via the Victoria and Buntine Highways. Mapping was carried out on 1:50 000-scale colour aerial photographs and digital base maps that were modified from AUSLIG data. References to specific locations use the Geocentric Datum of Australia (GDA94) and the MGA94 map grid coordinate system, zone 52. To convert from the AGD66 AMGs used on older maps, block shift all data 130 m to the east and 161 m to the north.

Airborne magnetic and radiometric surveys (north-south lines, 400 m line spacing, 60 m average terrain clearance) were flown by NTGS during 1998 and cover approximately 50% of western VICTORIA RIVER DOWNS. Some closely spaced company data are also available over selected portions in the northeastern and northwestern part of the mapsheet. Digital data or false-colour images are available from NTGS.

Most of VICTORIA RIVER DOWNS is pastoral lease for cattle grazing. Gregory National Park straddles the western margin of the mapsheet and small portions are Aboriginal freehold land.

In these notes, the Proterozoic timescale is subdivided as follows: Palaeoproterozoic (2500-1600 Ma), Mesoproterozoic (1600-1000 Ma) and Neoproterozoic (1000-545 Ma), after Plumb (1991). The terms ‘stromatolite’ and ‘stromatolitic’, as used in this report, refer to planar, domed, columnar, cuspatel and conical forms and their variants.

REGIONAL GEOLOGICAL SETTING

The regional geological setting of VICTORIA RIVER DOWNS is shown in Figure 1. Structural and tectonic elements are depicted in Figure 2. Sedimentary rocks of the Proterozoic Victoria Basin, and volcanic and sedimentary rocks of the Palaeozoic Wiso Basin dominate the region. A thin veneer of discontinuous Mesozoic cover is exposed along plateaux margins in eastern VICTORIA RIVER DOWNS.

VICTORIA BASIN

LITHOSTRATIGRAPHY AND AGE

The Victoria Basin is underlain by the Birrindudu Basin and overlain by the Wolfe Creek Basin. It contains several thousand metres of sedimentary rocks divided into the Wattie, Bullita, Tijunna (new name) and Auvergne groups (Figure 3), all of which occur in VICTORIA RIVER DOWNS. Table 2 summarises the lithostratigraphy of these formations.

The depositional age of the Victoria Basin is poorly constrained by geochronological data. However, Sweet (1977) has correlated the stratigraphy with other known Proterozoic successions in the Northern Territory and Western Australia (see Beier et al 2000). A possible correlation with the Nathan Group of the McArthur Basin suggests that the Wattie and overlying Bullita Groups were deposited at 1.61-1.57 Ga (Lindsay 1998). Berryman et al (1999) reported a SHRIMP U-Pb zircon age of 1.46 Ga for a kimberlite that intrudes the lower Bullita Group, and inferred this to be a minimum

Table 1 NTGS stratigraphic drillhole data for VICTORIA RIVER DOWNS

<table>
<thead>
<tr>
<th>Drillhole</th>
<th>Formation</th>
<th>Group</th>
<th>Interval (m)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99VRD-DDH1</td>
<td>Bynoe</td>
<td>Bullita</td>
<td>00.00-16.42</td>
<td>16.42</td>
</tr>
<tr>
<td>52 706508E</td>
<td>Skull Creek</td>
<td>Bullita</td>
<td>16.42-245.90</td>
<td>229.48</td>
</tr>
<tr>
<td>8169009N</td>
<td>Timber Creek</td>
<td>Bullita</td>
<td>245.90-552.20</td>
<td>306.30</td>
</tr>
<tr>
<td>99VRD-DDH2</td>
<td>Seale Sandstone</td>
<td>Wattie</td>
<td>552.20-589.00</td>
<td>36.00</td>
</tr>
<tr>
<td>(Zone 52 754777E 8224697N)</td>
<td>Stubb</td>
<td>Tijunna</td>
<td>00.00-66.50</td>
<td>66.50</td>
</tr>
<tr>
<td>8224697N</td>
<td>Kidman</td>
<td>Tijunna</td>
<td>66.50-177.95</td>
<td>111.45</td>
</tr>
<tr>
<td>Battle Creek</td>
<td>Bullita</td>
<td>177.95-356.50</td>
<td>178.55</td>
<td></td>
</tr>
<tr>
<td>Weaner</td>
<td>Bullita</td>
<td>356.50-367.70</td>
<td>11.20</td>
<td></td>
</tr>
<tr>
<td>Bynoe</td>
<td>Bulitta</td>
<td>367.70-610.90</td>
<td>243.20</td>
<td></td>
</tr>
</tbody>
</table>

\(^2\) Subsequently renamed Australian Geological Survey Organisation (AGSO), then Geoscience Australia (GA).
Figure 1 Regional geological setting of VICTORIA RIVER DOWNS
Figure 2 Structural and tectonic elements of VICTORIA RIVER DOWNS
depositional age. However, Belousova et al (2001) reported a much younger emplacement age of 179 ± 2 Ma for the Timber Creek kimberlites, from laser-ablation ICP-MS U-Pb dating of zircons. They indicated that the older date did not constrain the age of sedimentation and instead interpreted it as being indicative of a magmatic event in the deep lithosphere. The Wattie and Bullita Groups were correlated by Sweet (1977) with the Tolmer Group which is exposed in a poorly defined, fault-bounded sub-basin on the northern margin of the Victoria-Birrindudu region, in FERGUSSON RIVER. The Tolmer Group is now correlated with the Birrindudu Group, which is the basal unit in the southern part of the Birrindudu Basin.

The depositional age of the Tijunna Group is tentatively about 1.43-1.35 Ga but may have been as late as 1.19 Ga (inferred from Webb and Page 1977).

Deposition of the Auvergne Group possibly occurred between 810-750 Ma (inferred from Walter et al 1995, Thorne et al 1999). Shale from the Angalarri Siltstone, which overlies the basal Jasper Gorge Sandstone elsewhere in the Victoria Basin (Dunster et al 2000), has been given a loosely constrained Rb-Sr whole-rock age of 838 ± 80 Ma (Webb and Page 1977). Sweet (1977) cautioned against using this age for regional correlation. However, a possible correlation between the Jasper Gorge Sandstone-Angalarri Siltstone and Ahern Formation-Helicopter Siltstone of the east Kimberley region of Western Australia (Thorne et al 1999) suggests that the Auvergne Group may correlate with the approximately 800 Ma Supersequence 1 of the Centralian Superbasin (Walter et al 1995). More recently, samples of shale from the Angalarri Siltstone in Bullo River 1 on AUVERGNE have been found to contain abundant organic matter, including filamentous and spheroidal bacteria, but no distinctive Neoproterozoic assemblages have been recognized as yet (K Grey, Geological Survey of Western Australia, personal communication 2000).

Wattie Group

The Wattie Group (Sweet et al 1974a) is predominantly a siliciclastic succession that contains minor carbonate intervals and rare tuffite. The group is divided into seven formations, all of which are exposed in southwestern VICTORIA RIVER DOWNS. In WATERLOO and WAVE HILL, exposure of this group is more extensive, whereas in AUVERGNE it is very thin and undifferentiated and in LIMBUNYA, only the basal Wickham Formation is significantly exposed. In VICTORIA RIVER DOWNS, the lower units are best exposed in scarps and low-relief ridges that flank a northeast-trending anticline in the extreme southwest of the mapsheet. The remaining units are mainly recessive in valley floors, or are poorly exposed as pavements on terraced slopes in low cuestas and outlying rounded knolls. Paucity of exposure precluded detailed study of all but the Hughie Sandstone during Second Edition mapping.

The Wattie Group has an incomplete thickness of about 385 m in VICTORIA RIVER DOWNS and is approximately 300 m and 450 m thick in western WAVE HILL and southeastern WATERLOO, respectively. Regional thickness variations characterise Wattie Group stratigraphy, which generally thickens to the east and north of the type and

Figure 3 Stratigraphy of Victoria and Birrindudu Basins
Table 2  Stratigraphy of Wattie, Bullita, Tijunna and Auvergne Groups in VICTORIA RIVER DOWNS

<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUVERGNE GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jasper Gorge Sandstone (Paj) up to 80 m</td>
<td>Medium orthoquartzite, rare granular lags</td>
<td>Nearshore shallow marine</td>
<td>Unconformable on Stubb and Kidman Formations</td>
</tr>
<tr>
<td>TIJUNNA GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stubb Formation (Pct) up to 115 m</td>
<td>Micaceous claystone, siltstone, and minor mudstone and sandstone</td>
<td>Relatively deep marine, below storm wave base, shallowing-upward</td>
<td>Conformable on Kidman Formation</td>
</tr>
<tr>
<td>Kidman Formation (Pco) 30-145 m</td>
<td>Lower mudstone interval; upper sandstone and siltstone interval</td>
<td>Low-energy, relatively deep marine</td>
<td>Unconformable on Bullita Group</td>
</tr>
<tr>
<td>BULLITA GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battle Creek Formation (Pbs) 179 m in 99VRD-DDH2</td>
<td>Stromatolitic dolostone, mudstone, siltstone and subordinate sandstone and chert</td>
<td>Restricted, locally evaporitic shallow to slightly deeper marine, possibly lagoonal</td>
<td>Conformable on Weaner Sandstone</td>
</tr>
<tr>
<td>Weaner Sandstone (Bbw) 3-15 m</td>
<td>Sandstone and minor polymictic pebble conglomerate</td>
<td>Shallow, shoaling marine</td>
<td>Locally conformable to unconformable on Bynoe Formation; locally unconformable? on Skull Creek Formation</td>
</tr>
<tr>
<td>Bynoe Formation (Pby) 243 m in 99VRD-DDH2</td>
<td>Fine dolomitic sandstone; minor laminated mudstone and dolomitic siltstone</td>
<td>Lower and upper units intertidal, locally evaporitic; middle unit low-energy shallow? or deeper marine</td>
<td>Conformable on Skull Creek Formation</td>
</tr>
<tr>
<td>Skull Creek Formation (Pbs) 229 m in 99VRD-DDH1</td>
<td>Sandstone (more prevalent in lower part), dolarenite, stromatolitic dolostone; minor dololutite, dolorudite, oolitic grainstone and chert</td>
<td>Restricted, evaporitic shallow marine; minor open-water marine</td>
<td>Conformable on Timber Creek Formation</td>
</tr>
<tr>
<td>Supplejack Dolostone Mbr (Pbu) 17-28 m</td>
<td>Stromatolitic dolostone containing bioherms</td>
<td>Moderately shallow marine</td>
<td>Conformable unit within Skull Creek Formation</td>
</tr>
<tr>
<td>Timber Creek Formation (Bbt) 306 m in 99VRD-DDH1</td>
<td>Sandstone, dolarenite, dolostone, dolomitic mudstone; subordinate silty and quartzitic dolostone, siltstone and chert</td>
<td>Restricted, evaporitic shallow marine; minor open-water marine</td>
<td>Conformable on Seale Sandstone</td>
</tr>
<tr>
<td>WATTIE GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scale Sandstone (Eim) 80 m</td>
<td>Dolomitic sandstone; subordinate laminated dolomitic mudstone</td>
<td>High-energy shallow marine</td>
<td>Conformable on Gibbie Formation</td>
</tr>
<tr>
<td>Gibbie Formation (Eig) &lt;70 m</td>
<td>Micaceous and calcareous siltstone, fine sandstone and rare stromatolitic dolostone</td>
<td>Low-energy, shallow marine; periodic higher energy conditions more common in upper part</td>
<td>Conformable on Neave Sandstone</td>
</tr>
<tr>
<td>Neave Sandstone (Ein) 5-10 m</td>
<td>Sandstone (quartzarenite to sublitharenite); minor conglomerate</td>
<td>Shallow marine-fittoral</td>
<td>Disconformable on Mount Sanford Formation</td>
</tr>
<tr>
<td>Mount Sanford Formation (Eio) 52 m</td>
<td>Dolomitic siltstone, mudstone and fine sandstone; subordinate dolostone and chert</td>
<td>Low-energy, shallow marine</td>
<td>Conformable on Hughie Sandstone</td>
</tr>
<tr>
<td>Hughie Sandstone (Eih) 87 m</td>
<td>Fine to medium sandstone</td>
<td>Shallow marine</td>
<td>Conformable on Burtawurta Formation</td>
</tr>
<tr>
<td>Burtawurta Formation (Eib) 25 m</td>
<td>Micaceous siltstone, fine sandstone and dolostone</td>
<td>Low-energy, shallow marine; intermittent subaerial exposure</td>
<td>Conformable on Wickham Formation</td>
</tr>
<tr>
<td>Wickham Formation (Eiw) 176 m</td>
<td>Sandstone (sublitharenite)</td>
<td>High-energy shallow marine; intermittent subaerial exposure</td>
<td>Overlies Limbunya Group with marked angular unconformity</td>
</tr>
</tbody>
</table>

Table 2 describes the stratigraphic relations and depositional environments of the Wattie, Bullita, Tijunna, and Auvergne Groups in the Victoria River Downs. Each group is characterized by its own lithology, depositional environment, and stratigraphic relations with other formations.

Reference localities nominated by Sweet et al. (1974a) in WAVE HILL. Recent stratigraphic drilling by NTGS intersected a gradational contact with the conformably overlying Bullita Group in western VICTORIA RIVER DOWNS. The base of the Wattie Group is not exposed in this mapsheet, but in LIMBUNYA, it overlies the Limbunya Group with a marked angular unconformity.

**Wickham Formation (Eiw)**

The Wickham Formation is confined to the core of a small anticline, 6 km to the northwest of Mount Sanford homestead, where the upper 70 m is exposed as pavements and blocky rubble. In WAVE HILL, it is 176 m thick at the type section and in WATERLOO, the unit is of unknown thickness (Sweet et al. 1974a). As in adjoining mapsheets, the Wickham Formation is predominantly a fine to medium sandstone of sublitharenite composition. Sweet et al. (1974a) described the sandstone as containing white grains of claystone, feldspar and chert, and a small percentage of clay matrix. It is rarely micaceous and locally ferruginous. Planar stratification and trough cross-stratification (Figure 4) are common in thinly to thickly bedded sandstone throughout the formation, as are mud clasts, which are rarely imbricated. Sedimentary structures include current lineations, interference ripples and desiccation cracks, which are preserved on some dip.
slopes (section MS1). In LIMBUNYA, the basal Wickham Formation contains in situ, displacive botryoidal quartz nodules (cauliflower cherts probably after anhydrite) and rare tri-star casts after halite. In WAVE HILL and LIMBUNYA, the lower part of the formation includes minor interbedded pebbly sandstone, conglomerate, chert and rare siltstone.

The homogeneous cross-bedded sandstone of the Wickham Formation was probably deposited in a high energy, shallow marine environment during a regional transgressive event. In LIMBUNYA, the presence of pseudomorphs after evaporites, ripples marks and mudcracks, mainly in the lower part of the formation, suggests that intermittent evaporitic and subaerial conditions prevailed locally.

**Burtawurta Formation (Pib)**

In a recessive valley to the northwest of Mount Sanford homestead, the Burtawurta Formation (Sweet et al. 1974a) conformably overlies the Wickham Formation. At this location, it is very poorly exposed as arenaceous rubble and subcrop in scree slopes below the Hughie Sandstone. Some exposures are capped by secondary calcrite. Other minor outcrops are located 15 km to the southeast on the boundary with WAVE HILL. The formation varies from an estimated 25 m in VICTORIA RIVER DOWNS to measured thicknesses of 28 m and 53 m adjacent to the Wickham River in southeastern WATERLOO. The formation consists of laminated red-brown micaceous siltstone interbedded with subordinate light grey, very fine quartz sandstone and dolostone. Locally, siltstone is coloured with secondary reduction spots and flaggy sandstones contain some carbonate matrix. In WATERLOO, Sweet et al. (1974a) described mud clasts, ripple marks, mudcracks, and casts after halite. These indicate that the Burtawurta Formation was deposited under relatively low energy, shallow marine conditions that included minor evaporite deposition and subaerial exposure.

**Hughie Sandstone (Pih)**

The Hughie Sandstone (Sweet et al. 1974a) is locally weathered into blocks and is best exposed in benches, 6 km to the northwest of Mount Sanford homestead, where it forms prominent dip slopes of an anticline. Minor outcrops also occur adjacent to and 10 km to the east of the homestead in weakly terraced hills. In WATERLOO, the sandstone forms regionally extensive high-relief ridges and cuestas between recessive lithologies. The Hughie Sandstone is conformable on the Burtawurta Formation, except in northern WATERLOO, where the Burtawurta Formation is locally absent and the Hughie Sandstone directly overlies the Wickham Formation. In VICTORIA RIVER DOWNS, the basal contact is sharp, from fine, thinly bedded and rippled sandstone of the Burtawurta Formation to medium to thickly bedded, fine to medium sandstone, which contains up to 15% chert, feldspar, clay and igneous rock fragments as grains (Sweet et al. 1974a).

Sandstone beds of the formation are trough, tabular and rarely parallel planar cross-stratified. They contain various ripple morphologies and rare mudcracks that generally increase in abundance near the top of the formation (section MS2). Shale clasts are common throughout and occur as moulds on some partings. Locally, the sandstone displays liesegang banding and contains differentially weathered, spheroidal, iron-rich diagenetic nodules. In WATERLOO, the Hughie Sandstone exhibits minor undulose bedding, is rarely micaceous and contains current lineations on some bedding surfaces. Sweet et al. (1974a) also noted the occurrence of scattered angular and subangular chert pebbles and rare mudcracks in the lower half of the type section. In VICTORIA RIVER DOWNS, the formation is 87 m thick, but it thins to about 51 m adjacent to Neave Creek in WAVE HILL (Bultitude 1971). The Hughie Sandstone was probably deposited in a transgressive shallow marine setting.

**Mount Sanford Formation (Pio)**

Outcrop of the Mount Sanford Formation (Sweet et al. 1974a) is of limited aerial extent and is usually in the form of low relief mounds of subcrop and rare exposures surrounded by scree aprons. An exception is the basal part of the formation, which is locally well exposed in the vicinity of the anticline in the southwestern corner of the mapsheet. The formation conformably, but sharply overlies the Hughie Sandstone, but the contact with the overlying Neave Sandstone is rarely exposed. In VICTORIA RIVER DOWNS, the formation consists predominantly of interbedded dolomitic siltstone, mudstone, fine sandstone and subordinate dolostone and chert. Carbonate content increases up-section and the presence of brecciated, silicified dolostone and green chert near the top of the succession distinguishes it from the otherwise similar Gibbie and Burtawurta Formations. In the

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**Figure 4** Large trough cross-beds in Wickham Formation (54 m above base of measured section MS1)
lower part of the formation, sandstone is rarely micaceous and contains low-angle and undulose parallel stratification, climbing and current ripple cross-lamination, convolute laminae, fluid escape structures and casts after halite. Flaggy sandstone is interbedded or amalgamated with other thinly bedded sandstone units, and is separated by parallel and undulose laminated siltstone, mudstone or dolostone layers. Locally, dolostone contains domed and columnar stromatolites (up to 20 cm synoptic relief). Botryoidal quartz nodules (cauliflower chert) occur as float. In WATERLOO (at 636312mE, 8141584mN), minor claystone, rare dolarenite and tuffite are exposed, and bedded chert units, which possibly overprint dolostone and arenaceous facies, become more abundant up-section. Dolarenite and siltstone display some flaser bedding and sandstone is small-scale trough cross-stratified and contains ripples, mudcracks and scour and fill structures and, in the lower part of the formation, rare imbricated flute breccias. Diagenetic reduction spots, concretions and stylolites are locally abundant, and radial mm-scale ferroan carbonate lozenges are common in the lower part of the unit. These lozenges are interpreted as evidence of the sub-surface diagenetic replacement of carbonate, related to flushing by Fe-Cl-rich brines (J Warren, Petroleum Geoscience, University of Brunei Darussalam, pers comm 1999).

In VICTORIA RIVER DOWNS, the Mount Sanford Formation is estimated to be of similar thickness (52 m) to that measured in southeastern WATERLOO. The formation varies in thickness regionally from 23.5 m in WA VE HILL to at least 200 m in northern WATERLOO (Sweet et al 1974a).

The Mount Sanford Formation was deposited under low-energy shallow marine conditions, which included brine-logging of the sediment. Rare stromatolites may indicate localised, quiescent open water deposition.

Neave Sandstone (Ein)

The poorly exposed Neave Sandstone (Sweet et al 1974a) sharply and disconformably overlies the Mount Sanford Formation and is estimated to be only 5-10 m thick in VICTORIA RIVER DOWNS. In WAVE HILL, it is up to 20 m thick and thins northward to about 5-6 m thick in southeastern WATERLOO. It weathers to form blocky pavements and low ridges. Fine to medium quartz arenite that contains minor discontinuous pebble beds and conglomerate predominates. The sandstone contains up to 15% feldspar, chert, clay and rock fragments of probable igneous origin (Sweet et al 1974a). Framework clasts in conglomerate beds are mainly subangular chert eroded from the underlying Mount Sanford Formation. Sandstone is commonly trough cross-stratified and ripple marks and mud clasts are present on some partings. In WATERLOO, the Neave Sandstone is thinly to medium bedded, displays undulose and low-angle cross-stratification, is quartz cemented at the base and contains some mica.

The Neave Sandstone overlies a regional sequence boundary and is interpreted to be a shallow marine littoral unit that formed during a transgressive or regressive phase of deposition (Sweet et al 1974a).

Gibbie Formation (Eig)

The Gibbie Formation (Sweet et al 1974a) is conformable on the Neave Sandstone. In southwestern VICTORIA RIVER DOWNS, it is recessive, and forms small plateaux and platy, scree-covered, low rounded hills that are dissected by small runnels. The formation is best exposed along Neave Creek in WAVE HILL and adjacent to the Wickham River in WATERLOO. It is typically <70 m thick in VICTORIA RIVER DOWNS, 33 m thick in WAVE HILL and is in the range 87-144 m in southeastern WATERLOO. Thinly bedded, micaceous and calcareous siltstone and fine, in places flaggy sandstone predominate in this coarsening-upward succession, which contains rare stromatolitic dolostone interbeds. Sandstone is typically reddish-brown, thinly bedded and contains some low-angle trough cross-stratified medium beds, and in the upper levels of the formation, rare thick beds. Sandstone and siltstone interbeds display a variety of sedimentary structures including synaeresis cracks, polygonal and sinuous mudcracks, ripple marks, ripple cross-laminations, soft sediment deformation features, halite casts, load casts, green mud flakes and some diagenetic barite and calcite crystals. In WAVE HILL and WATERLOO, other sedimentary structures include slump folds, runnel marks, gutter and flute casts, undulose bedding and parallel planar cross-stratification.

The Gibbie Formation was deposited under low-energy shallow marine conditions, possibly in a lagoon or embayment. The occurrence of gutter casts, runzel marks and rare slump folding suggests that the environment was periodically inundated with higher energy deposits, which gradually came to dominate the upper part of the unit.

Seale Sandstone (Eim)

The Seale Sandstone (Sweet et al 1974a) forms low discontinuous ridges and crude pavements of massive blocky rubble in VICTORIA RIVER DOWNS. Elsewhere, it usually forms benchy outcrops in low-relief ridges and plateaux. The contact with the conformably underlying Gibbie Formation, which is generally not well exposed, is sharp from medium bedded, fine sandstone to thickly and very thickly bedded, fine to medium quartz sandstone of the Seale Sandstone. The maximum thicknesses of the formation are 80 m in VICTORIA RIVER DOWNS, 87 m in WATERLOO and 111 m in WAVE HILL. There is a gradational contact with the conformably overlying Timber Creek Formation of the Bullita Group and this was intersected in NTGS fully cored drillhole 99VRNTGSDD1. A 37 m cored interval (552.2-589 m) of fine and medium dolomitetic sandstone (of quartz arenite composition) and subordinate, laminated dolomitic mudstone is assigned to the Seale Sandstone. The sandstone contains rare coarse to granular lags, stilolites, carbonate mud clasts, pyrobitumen and live oil (see Economic geology of the Victoria Basin). In outcrop, the Seale Sandstone is off white to pink and contains up to 10-15% feldspar, clay and chert fragments (Sweet et al 1974a). It contains abundant trough, parallel planar and rarely undulose cross-strata, and mud flake and chert pebbles are locally common.

Located at AMG 706508E, 8169100N.
The Seale Sandstone was probably deposited under high-energy, shallow marine transgressive conditions.

**Bullita Group**

The five formations of the Bullita Group (Sweet *et al* 1974a) are distributed in the central and western part of VICTORIA RIVER DOWNS. They include, in ascending stratigraphic order, the Timber Creek Formation, Skull Creek Formation, Bynoe Formation, Weaver Sandstone and Battle Creek Formation. The lower formations outcrop extensively in WATERLOO and DELAMERE, but only minor exposures of the group occur in WA VE HILL and AUVERGNE. Recent stratigraphic drilling in VICTORIA RIVER DOWNS by NTGS intersected a composite stratotype section of 969 m that defines the Bullita Group in fully cored drillholes 99VRNTGSDD1 and 99VRNTGSDD2*. The high carbonate content of the Bullita Group distinguishes it from the conformably underlying Wattie Group.

**Timber Creek Formation (Pbt)**

The Timber Creek Formation (Sweet *et al* 1974a) forms the basal unit of the Bullita Group. It consists of thinly interbedded siltstone, fine sandstone and dolostone, and is poorly exposed within an area of approximately 400 km² in Gregory National Park in southwestern VICTORIA RIVER DOWNS. The formation is better exposed and more widely distributed in eastern WATERLOO, but in WAVE HILL, DELAMERE and AUVERGNE, it is poorly represented. The ribbed outcrop pattern and colour of the Timber Creek Formation are distinctive on aerial photographs throughout the region. The best exposure of the formation is that adjacent to Gibbie Creek (Figure 5), where it forms terraced outcrops in low-relief, scree-covered slopes capped by Jasper Gorge Sandstone. Elsewhere, subhorizontal pavements form between recessive units in rounded and undulating hills. Locally, the recessive intervals are carbonates or rocks of dolomitic arenaceous facies. Significant outcrop also occurs in the vicinity of the Wickham River and Gibbie Creek junction, where the contact with the overlying Skull Creek Formation is exposed.

In VICTORIA RIVER DOWNS, the basal contact is conformable and sharp from medium to thickly bedded, medium quartz arenite of the Seale Sandstone to thinly to medium bedded, fine sandstone and interbedded dolarenite of the Timber Creek Formation. Both the lower and upper contacts of the Timber Creek Formation were intersected in drillhole 99VRNTGSDD1 and the boundary with the conformably overlying Skull Creek Formation has been documented in several sections (MS5, 6). The upper contact is gradational from very thinly to medium bedded fine sandstone and minor dolarenite of the Timber Creek Formation to silicified stromatolitic dolostone and subordinate fine sandstone of the Skull Creek Formation. Outside of VICTORIA RIVER DOWNS, stromatolitic dolostone is usually absent and the upper portion of the formation is locally considered to be a lateral facies equivalent of the basal Skull Creek Formation. However in VICTORIA RIVER DOWNS, poor exposure does not allow this relationship to be demonstrated. The contact is mapped at the break in slope, where dolomitic siltstone and sandstone of the Timber Creek Formation is overlain by more carbonate-rich lithofacies of the Skull Creek Formation.

The maximum exposed thickness of the Timber Creek Formation in VICTORIA RIVER DOWNS is 45 m (measured section MS3). However, in cored drillhole 99VRNTGSDD1, it is 306 m thick. In WATERLOO, the formation is estimated to be 200 m thick, although average incomplete sections are about 150 m (Sweet *et al* 1974a). The Timber Creek Formation consists of thinly interbedded, very fine to medium sandstone, dolarenite, dolostone and dolomitic mudstone, subordinate silty and quartzic dolostone, dololutite and siltstone, and rare claystone and chert. In drillhole 99VRNTGSDD1, the lower clastic-dominated facies contains ripple and undulose cross-laminations, small-scale and low-angle trough cross-beds, fluid escape structures, mud clasts, sandstone lenses and pseudomorphs after cubic halite. Also present are diagenetic chert nodules, fenestrae, reduction spots, pyrobitumen and disseminated pyrite. Interbedded carbonate and arenaceous units contain intraformational flat-pebble conglomerates.

*Located at AMG 754777E 8224697N.

Figure 5 Typical exposure of Timber Creek Formation, Gibbie Creek area
scour and fill structures, load structures, convolute laminations, climbing ripples and graded beds. Laminated and dendroidal stromatolites with up to 15 cm of synoptic relief contain rare pseudomorphs after acicular gypsum and halite, including pagoda, hopper and reticulate (Figure 6) forms. Diagenetic features include low- and high-amplitude stylolites, quartz nodules lined by pyrobitumen and rare quartz-filled fractures. The occurrence of epigenetic galena and pyrite suggests that the Timber Creek Formation has some potential as a target for base metal mineralisation (see Economic Geology of the Victoria Basin).

Adjacent to Gibbie Creek, carbonate facies are often deeply weathered or obscured by calcrete and there are abundant cm-scale ferroan carbonate lozenges in quartzic dolostone of the uppermost Timber Creek Formation. These are interpreted as evidence of the diagenetic replacement of carbonates related to through-flushing of Fe-Cl-rich brines. In this case, the unconformity with the overlying Jasper Gorge Sandstone may have acted as a stratigraphic conduit for these fluids. Discoidal ferroan carbonate is locally concentrated along fractures and bedding planes, and this also supports a late-stage diagenetic origin.

In WATERLOO, the Timber Creek Formation contains millet seed gypsum (Figure 7), acicular radiating and swallowtail twin evaporite pseudomorphs after probable gypsum, and botryoidal quartz nodules (cauliflower cherts probably after anhydrite). Oolitic grainstone occurs in float.

Regionally, the Timber Creek Formation was deposited under restricted, shallow marine evaporitic conditions that included subaerial exposure and minor open water settings. The upper, carbonate-rich facies were probably mostly deposited under higher energy marine conditions, but with continued intermittent evaporitic deposition.

In AUVERGNE, the Timber Creek Formation hosts diamond-bearing kimberlite pipes. Mantle-derived zircons extracted from these kimberlites have yielded weighted mean SHRIMP $^{206}\text{Pb}/^{238}\text{U}$ ages of $1462 \pm 53$ Ma and $179 \pm 2$ Ma (Berryman et al. 1999, Belousova et al. 2001). Belousova et al. indicated that the older date does not constrain the age of sedimentation as suggested by Berryman et al., but instead is indicative of a Mesoproterozoic magmatic event in the deep lithosphere. The younger date is the probable age of emplacement of the kimberlites.
**Skull Creek Formation (Pbs)**

This widely distributed clastic dolostone and siltstone unit was defined by Sweet *et al* (1974a) and is regionally best exposed in central and western VICTORIA RIVER DOWNS. It also outcrops extensively in adjacent DELAMERE and WATERLOO and has a limited distribution in WAVE HILL and AUVERGNE. The Skull Creek Formation forms a well exposed, moderate relief, benched topography. It also forms scattered tabular blocks and drainage pavements in the Fitzgerald Range and in the vicinity of Burt and Station Hills in VICTORIA RIVER DOWNS. The lower part of the formation is poorly exposed in low rounded terraced topography, scree slopes and ground-level outcrop to the west of Mount Hodgson and adjacent to the Humbert River. In northwestern VICTORIA RIVER DOWNS, it is flat-lying and exposed through an erosional window in two small anticlines to the south of Jasper Gorge. Generally, the formation is best preserved by overlying formations, or a duricrust cap. In VICTORIA RIVER DOWNS, the Skull Creek Formation has a maximum exposed thickness of about 162 m (section MS7) and it is 229 m thick in drillhole 99VRNTGSDD1. Originally, the Skull Creek Formation contained two members as defined by Sweet *et al* (1974c); of these, the Supplejack Dolostone Member has been retained, but the Bardia Chert Member has been remapped as Tertiary duricrust [see Silcrete/Duricrust (Czo)].

The basal Skull Creek Formation is differentiated from the conformably underlying Timber Creek Formation by the presence of a three-metre thick stromatolitic dolarenite and chert marker unit that also outcrops in DELAMERE. This interval is variably silicified, laminated and digitate, and locally contains mm-scale, ferroan carbonate pinolitic prisms (*Figure 8*). In drillhole 99VRNTGSDD1, it contains pyritobitumen, disrupted laminations, fenestrae structures and disseminated pyrite.

The Skull Creek Formation typically comprises interbedded fine to medium sandstone and dolarenite, stromatolitic dolostone and minor dololutite, quartz dolostone, dolomitic siltstone, oolitic grainstone, dolorudite and chert (sections MS5-11). Sandstone is more prevalent in the lower part of the formation and carbonate content increases up-section. The formation is locally intensely silicified, and has undergone varying degrees of dolomitisation, weathering and more than one generation of stylolitisation. In drillhole 99VRNTGSDD1, subordinate lithologies include dolomitic mudstone and claystone. The formation contains a variety of sedimentary structures similar to those of the Timber Creek Formation, including small-scale channels (section MS5), reticulated and cubic halite casts (up to 2 cm wide), bladed and millet seed gypsum (including some bottom nucleated varieties), synaeresis cracks, intraformational flat-pebble conglomerate, nodular discontinuous chert beds, flake and edgewise breccia (*Figure 9*), and rare slump folding (section MS8). Drillhole 99VRNTGSDD1 also intersected rare graded beds.

The Skull Creek Formation was deposited under similar conditions to the Timber Creek Formation, at least until deposition of the Supplejack Dolostone Member.

**Supplejack Dolostone Member (Pbu)**

The Supplejack Dolostone Member (Supplejack Dolomite Member of Sweet *et al* 1974c) is a conformable, thickly bedded dolostone unit within the Skull Creek Formation (*Figure 10*). Because of its distinctive appearance, it is regionally significant as a marker unit throughout the basin and is best exposed in the Fitzgerald Range where it forms crudely bedded, karstically weathered benches of dark grey stromatolitic dolostone and dolarenite. The maximum exposed thickness of the member is 17 m in VICTORIA RIVER DOWNS and it is 28 m thick in drillhole 99VRNTGSDD1. It is well exposed along the Bullita Track in Gregory National Park in WATERLOO and in a series of northwest-trending anticlines in southwestern DELAMERE (Beier *et al* 2002).

The Supplejack Dolostone Member often lacks internal structures due to silicification and dolomitisation and is generally considered to be thickly to massively bedded. Where diagenetic effects are less intense, bioherms are locally well preserved. These consist of basal, laminated stromatolites that are superseded by domed, conical “*Conophyton sp.*” and by hemispherical, tabular, irregular, interconnected bulbous and columnar forms. At the base of the Supplejack Dolostone Member in section MS7, domed stromatolites have an irregular sharp contact with overlying conical forms (*Figure 11*) and this may represent a localised diastem formed during relative sea-level rise. In
Figure 9 “Edgewise breccia” in Skull Creek Formation (677400mE, 8155200mN)

Figure 10 Upper part of Supplejack Dolostone Member of Skull Creek Formation. Humbert River area (687700mE, 8177300mN)

Figure 11 Conical linked stromatolites overlying domed forms in Supplejack Member (10.5 m above base of measured section MS11)
this section, at least two beds of conical stromatolites with up to 2 m of synoptic relief are separated by domed and laminated varieties. Some inclined forms are indicative of current or wave action. Elsewhere, conical morphologies are gradational to low-relief laminated forms along strike (section MS8). Throughout the unit, synaeresis cracks (Figure 12) are locally abundant on bedding planes and flake breccia infills buttress positions between stromatolites. In drillhole 99VRNTGSD1D, stacked columnar, laminated and domed stromatolites, calcite-lined vugs and rare disseminated pyrite and galena occur within the member. Regionally the upper and lower contacts of the unit are anomalous in base metals (see Economic geology of the Victoria Basin).

The Supplejack Dolostone Member may be indicative of a regional transgressive event and was probably deposited in an open marine setting, no more than a few tens of metres deep, but slightly deeper than the underlying, restricted, shallower water facies. The occurrence of interbedded stromatolitic dolostone and dolorudite intraclastic flake breccia throughout the Skull Creek Formation, particularly above the Supplejack Dolostone Member, may indicate that some facies were deposited within the storm wave zone.

The upper and lower contacts of the Supplejack Dolostone Member are regionally anomalous in base metals, especially Pb, and epigenetic galena is commonly visible below and between stromatolitic facies.

Bynoe Formation (Phy)

Dolomitic sandstone and siltstone of the Bynoe Formation is widely distributed around the margin of the Fitzgerald Range, where it conformably but sharply overlies the Skull Creek Formation in central northern VICTORIA RIVER DOWNS. In the northwest, it forms dissected terraced subcrop in scree slopes capped by the Jasper Gorge Sandstone. In the southwest, it is poorly exposed to recessive in the Mount Warburton area and adjacent to the Humbert and Wickham Rivers. Minor exposures of the Bynoe Formation are in northeastern WATERLOO and it is well exposed in the type section nominated by Sweet et al. (1974b) at Wondoan Hill in DELAMERE, where it is about 190 m thick. No complete sections of the formation were measured in VICTORIA RIVER DOWNS, due to paucity of outcrop and it is best exposed at Station Hill, where it is about 66 m thick (section MS12). In cored drillhole 99VRNTGSD2D, the Bynoe Formation is 243 m thick.

In drillhole 99VRNTGSD2D, the lower contact is gradational from laminated dolarenite and quartzitic dolarenite of the Skull Creek Formation to thinly to medium bedded dolomitic sandstone and rare laminated mudstone and dolarenite of the Bynoe Formation. In this drillhole, the lowermost part of the formation contains low-angle and small-scale trough cross-beds, ripple cross-laminae and casts after halite. The uppermost part of the Bynoe Formation, near the sharp contact with the overlying Weaner Sandstone, contains minor laminated dolomitic siltstone and mudstone characterised by evaporite pseudomorphs, mudcracks and other shallow water depositional indicators. The remainder of the Bynoe Formation consists almost entirely of medium to very thickly bedded, homogenous, fine dolomitic sandstone, which contains rare low-angle and trough cross-strata, mudclasts, ripple cross-laminae and diagenetic reduction spots. At Station Hill, the formation consists mainly of thinly to medium bedded, variably micaceous, fine to medium quartz arenite and sublithic siltstone. Halite casts, ripples and vugs of gypsum occur on some bedding planes and rare gutter casts and runzel marks occur in float. Elsewhere, poorly preserved or recessive Bynoe Formation is commonly represented by thinly bedded tabular sandstone and by purple and grey secondary calcrete, which caps recessive shales or carbonates.

In DELAMERE, lower parts of the Bynoe Formation are dominated by massive micaceous siltstone. Interbedded sandstone and siltstone containing halite casts, ripple marks and mudcracks dominate in the upper parts of the formation. This may indicate an overall shallowing of the succession.

Regionally, lithofacies indicate that the Bynoe Formation contains at least three units of variable thicknesses in the Victoria Basin. The lower and upper units comprise interbedded sandstone, siltstone, mudstone and minor dolarenite, and were deposited under a current-influenced

Figure 12 Synaeresis cracks developed in dolostone of Supplejack Member (36 m above base of measured section MS8)
sweet indicators give southerly transport directions (Sweet 1973; oolitic grainstone and volcanogenic clasts. minor polymictic pebble conglomerate that contains rare Sandstone comprises thinly to thickly bedded sandstone and Formation, respectively. at this locality, the Weaner and is overlain by the Weaner Sandstone and Battle Creek VICTORIA RIVER DOWNS. Remapping has demonstrated of the junction of Wilson and Waterbag Creeks, in central parts of the mapsheet. Locally, runnels and creeks dissect cuestas where the Weaner Sandstone forms small discontinuous rounded knolls capped by blocky sandstone facies. Minor exposures occur in scree slopes overlain by plateaux-forming Wondoan Hill Formation or Jasper Gorge Sandstone next to the Wickham River in the central west. The best exposures are low-relief scarp in the western limb of a small anticline isolated by Antrim Plateau Volcanics, 4 km to the southwest of the junction of Wilson and Waterbag Creeks, in central VICTORIA RIVER DOWNS. Remapping has demonstrated that the Bynoe Formation occupies the core of the anticline and is overlain by the Weaner Sandstone and Battle Creek Formation, respectively. At this locality, the Weaner Sandstone comprises thinly to thickly bedded sandstone and minor polymictic pebble conglomerate that contains rare oolitic grainstone and volcanogenic clasts. The thickness of the formation varies from 3 m in the north, where the Weaner Sandstone has a westerly provenance, to about 15 m in the south, where current indicators give southerly transport directions (Sweet 1973; Sweet et al 1974a). In drillhole 99VRNTGSD2, the unit is 11.2 m thick and the sharp lower contact is unconformable from a succession of thinly to medium bedded, well sorted fine sandstone, siltstone and mudstone of the Bynoe Formation to moderately sorted fine sandstone, containing some pebble lags, of the Weaner Sandstone. Elsewhere in VICTORIA RIVER DOWNS, the Weaner Sandstone is locally conformable over the Bynoe Formation. In section MS14, the unit is about 8 m thick and sharply overlies a succession of interbedded micaceous siltstone and sandstone, containing halite casts, of the Bynoe Formation. The upper contact is conformable and sharp from very thinly to medium bedded fine sandstone of the Weaner Sandstone to interbedded, laminated to thinly bedded, dolomitic mudstone, siltstone and sandstone of the Battle Creek Formation. In drillhole 99VRNTGSD2, the Weaner Sandstone consists of predominantly medium to thickly bedded, subangular to subrounded, medium-grained micaceous sublitharenite, which displays low-angle trough cross-bed structures and scour surfaces. The sandstone contains coarse to granular, poorly to moderately sorted lag deposits, minor pebble clasts (mostly of quartzite), minor chert and some mudclasts. Elsewhere in VICTORIA RIVER DOWNS, the Weaner Sandstone is dominantly coarse sandstone that contains up to 5% feldspar grains (Sweet et al 1974a), minor discontinuous pebble lags and locally well developed conglomerate facies containing some vein quartz and rare dolostone clasts. Locally, megacrystals, desiccation cracks, bi-directional and trough cross-strata, ripples, and rare load casts are evident within the sandstone (MS13, 14). The Weaner Sandstone overlies a regional sequence boundary and possibly represents a regressive high-energy phase of deposition. Ripples and mudcracks indicate that it was probably deposited under shoaling, shallow water marine conditions and the relative immaturity of the sandstone suggests that it has undergone minor reworking and may have been rapidly deposited proximal to its source. The presence of oolitic grainstone and probable volcanogenic clasts indicates that the Weaner Sandstone may be locally unconformable on the Skull Creek Formation. This may be the result of regional uplift associated with volcanic activity focused outside of the Victoria Basin, possibly from the west or southwest. Battle Creek Formation (Eba) The youngest unit in the Bullita Group, the Battle Creek Formation (Sweet et al 1974a), is exposed in the northern and central parts of VICTORIA RIVER DOWNS. It is conformable on the Weaner Sandstone and is unconformably overlain by the Tijunna Group. In an arcuate belt to the east of the Fitzgerald Range, where it is locally obscured by the Antrim Plateau Volcanics, it forms poorly exposed, low-relief rounded ridges and isolated hills. Adjacent to the Wickham River, it forms minor, poorly exposed scree slopes and in the southern effluence of Gordon Creek, it is sparsely distributed as dissected tabular rubble and screecrop. The formation is best exposed as recessive rocky pavements in the hinge of a north-trending low-relief anticline to the west of Waterbag Creek in the central part of the mapsheet. At this locality, the base of the formation is not exposed, the upper contact is overlain by the Antrim Plateau Volcanics and the maximum exposed thickness is about 77 m (section MS15). The succession comprises interbedded stromatolitic dolostone, mudstone, siltstone and subordinate sandstone and chert. Locally, calcrite forms over dolostone and other dolomitic facies. Bioherms, which are about 2 m thick, are preserved where diagenetic effects are less intense. These consist of laminated stacked stromatolites, which are tabular, domed, columnar and pseudo-columnar in form. Some are inclined and elongated, and these are indicative of current or wave action. Dolostone is typically red or grey and locally glauconitic. It contains imbricated flat-pebble conglomerate, barite infillings and diffuse Fe haloes around fractures, ferroan carbonate lozenges and euhedral fluorite crystals, up to 5 mm long. Linked hemispherical stromatolites up to 5 m in diameter are common. Sandstone is thinly bedded, fine- to medium-grained and displays small-scale trough cross-stratification, mudclasts, casts after halite, mudcracks and ripple cross-lamination. Elsewhere, Sweet et al (1974a) described slump bedding, climbing ripples, current lineations, and pyrolusite and manganese along fractures (see Economic Geology of the Victoria Basin).
Drillhole 99VRNTGSDD2 intersected a 179 m thick section of the Battle Creek Formation, that consists of basal mudstone, middle mixed clastic and upper carbonate intervals. The laminated dark olive and grey basal mudstone interval contains subordinate claystone, dolarenite and sandstone, and stylolites, diagenetic nodules and ferroan carbonate lozenges. The middle interval consists of interbedded siltstone and mudstone with undulose and disrupted laminations, and minor, very thin to medium bedded fine sandstone with small-scale trough cross-strata and some mudclasts. The upper interval is predominantly of interbedded dolarenite and subordinate siltstone, mudstone, sandstone and quartzic dolarenite. The dolarenite contains a variety of stromatolitic structures, with synoptic relief up to 25 cm, within thicker bioherms. These include laminated, bulbous, domed, columnar and irregular forms, which are rarely truncated by overlying sandstone beds. Carbonate rocks are also glauconitic and contain flat-pebble conglomerate, flake breccia, diagenetic nodules, disrupted laminations and low- and high-amplitude stylolites. Sandstone is very thinly to thinly bedded, fine- and medium-grained and contains rare fluid escape and slump structures, gutter casts, moulds after halite, ripple cross-lamination and mudclasts. Disseminated pyrite is locally abundant and in some cases replaces ferroan carbonate lozenges in the lower part of the formation. Rare galena is also present (see Economic Geology of the Victoria Basin).

The Battle Creek Formation was deposited in restricted, locally evaporitic, shallow marine to slightly deeper marine environments, which were subjected to minor, periodic higher energy conditions; a lagoonal setting is possible.

**Tijunna Group**

The Wondoan Hill and Stubb Formations collectively form the unconformity-bounded Tijunna Group (Beier et al. 2002). Both formations are sandstone and mudstone assemblages and are locally difficult to differentiate in outcrop, because of the similarity in appearance of the shale facies of each formation. The group is named after Tijunna Bore, which is located approximately 5 km to the south of George Creek in northern VICTORIA RIVER DOWNS. Regional variations in thickness characterise the group, which is up to 230 m in VICTORIA RIVER DOWNS and about 300 m in FERGUSSON RIVER and DELAMERE, where it is widely distributed. Only minor exposures are found in northeastern WATERLOO and central WAVE HILL. Generally, the Tijunna Group is poorly exposed as scree over subcrop, in slopes adjacent to areas capped by the Jasper Gorge Sandstone. It locally forms ridges and mesas in the north and low-relief plateaux in the vicinity of Victoria River and Gordon Creek, and adjacent to Wickham River to the south in VICTORIA RIVER DOWNS.

**Wondoan Hill Formation (Eco)**

The Wondoan Hill Formation was named after Wondoan Hill in central western DELAMERE by Sweet et al. (1974b), but outcrops previously assigned to the formation at the top of this hill are now mapped as Jasper Gorge Sandstone. In the northwest and along the northern margin of VICTORIA RIVER DOWNS, the Wondoan Hill Formation is poorly exposed as subcrop in the flanks of slopes capped by the Jasper Gorge Sandstone and locally forms low-relief rounded ridges and isolated mesas and buttes. It is best exposed in Sundown Hill, in adjacent high-relief mesas and in the vicinity of Jasper Gorge, where Sweet et al. (1974a) measured a composite section of 145 m. Generally, the unit thins southward and is plateaux-forming in the Wickham River, Victoria River and Gordon Creek areas, where it is about 30 m thick. A 130 m section was measured through the formation, 8 km to the northeast of Pigeon Hole outstation in a northwest-plunging anticline (Sweet et al. 1974a). At the type section, defined by Sweet et al. (1974a) in the eastern end of the Fitzroy Range in DELAMERE, the formation reaches a maximum thickness of 108 m. The Wondoan Hill Formation overlies the Bullita Group with a low-angle unconformity. It is conformable with the overlying Stubb Formation and is unconformably overlain by the Jasper Gorge Sandstone in VICTORIA RIVER DOWNS.

Drillhole 99VRNTGSDD2 intersected a 111 m thick section which can be broadly divided into lower mudstone and upper sandstone and siltstone intervals. In this section, the basal contact is sharp from interbedded mudstone and dolarenite of the Battle Creek Formation to homogenous purple mudstone of the Wondoan Hill Formation. The upper contact is sharp from interbedded sandstone and siltstone of the Wondoan Hill Formation to homogenous, green, laminated, micriticaceous claystone of the Stubb Formation. The lower mudstone interval of the Wondoan Hill Formation contains subordinate very thin beds of sandstone, siltstone and rare black shale. These are up to 1 m thick and contain planar and undulose laminations, fractures infilled with calcite and traces of disseminated pyrite that are associated with diagenetic nodules. The upper part of the formation consists of very thinly to medium bedded sandstone, and planar- and undulose-laminated siltstone and mudstone. Sandstone is typically glauconitic and contains small-scale trough cross-beds, slumped bedding, mudclasts and rare load casts, gutter casts, ripple cross-laminae and granular lags. The upper portion also contains diagenetic nodules and rare haematite, disseminated pyrite and galena associated with fractures.

Regionally, the Wondoan Hill Formation varies considerably in composition. In Jasper Gorge, the basal unit is a massive glauconitic sandstone, which contains minor specular haematite bands. Up-section, interbedded sandstone, siltstone and shale predominate and commonly contain slump bedding features and ripple marks on some partings. In DELAMERE, in the vicinity of Wondoan Hill, the formation is represented by up to 30 m of blocky plateau-forming sandstone and in southern VICTORIA RIVER DOWNS adjacent to Victoria River, it locally contains at least three prominent sandstone units (Sweet et al. 1974a). In the Gordon Creek area in the southern part of the mapsheet, it forms plateaux of fine to medium sandstone underlain by shale, siltstone and thin glauconite sandstone units.

The presence of glauconitic sandstone indicates deposition under marine conditions and siltstone and shale lithofacies indicate deposition under lower energy, deeper water conditions, possibly below storm wave base. Where basal sandstone is overlain by more argillaceous facies, it was
considered by Sweet et al (1974a) that deposition may have taken place in one transgressive and regressive cycle.

The Wondoan Hill Formation unconformably overlies strata of the Bullita Group that generally increase in age from east to west. This relationship may be related to a basin inversion event, which in part locally influenced depositional conditions within the Tijunna Group (see Structure of the Victoria Basin. Regional structural setting).

**Stubb Formation (Pct)**

The Stubb Formation (Sweet et al 1974b) is poorly exposed over an area of about 80 km² in VICTORIA RIVER DOWNS, is more widely distributed in DELAMERE and has a limited distribution in WATERLOO. It was included within the Auvergne Group in First Edition mapping. In northwestern VICTORIA RIVER DOWNS, the formation forms high scarps, which are overlain by the resistant Jasper Gorge Sandstone, and adjacent buttes. It is best exposed to the south of George Creek in the north central part of the mapsheet, where it forms recessive plains, low ridges that are capped by its upper sandstone facies and flaggy rubble over low relief undulose hills that are dissected by steep runnels. The Stubb Formation is conformable on the Wondoan Hill Formation, unconformable on the Bynoe Formation and is unconformably overlain by the Jasper Gorge Sandstone.

The succession of interbedded micaceous claystone, siltstone, and minor mudstone and sandstone is up to 115 m thick in VICTORIA RIVER DOWNS and locally up to 210 m thick in DELAMERE, where it is better exposed. NTGS drillhole 99VRNRTGSD2 intersected 39 m of the lower part of the formation, which consisted of homogenous green claystone, and rare siltstone. In this drillcore, the unit is planar laminated and contains rare slump structures, fault breccia and micro-faults that are infilled by calcite and pyrite. The Stubb Formation is well exposed in road cuttings in Jasper Gorge, where thinly to medium bedded micaceous sandstone is pitted, due to weathered-out glauconite grains, and is interbedded with siltstone. Sedimentary structures include ripples, megaripples, trough and microhummocky cross-stratification, flute casts, sole marks and rare desiccation cracks on bedding surfaces. Medium to thickly bedded medium sandstone forms resistant layers near the top of the formation and is variably friable and indurated. Locally, this sandstone contains thin haematite bands, mudclasts and ripples on some partings (Sweet et al 1974a). In DELAMERE, siltstone and shale contain gutter and load casts, synaeresis cracks and runzel marks.

Initially, the Stubb Formation was deposited in a low-energy moderate to deep water setting that locally included storm-generated deposits, as is indicated by the presence of hummocky cross-stratification. Sandstone near the top of the unit indicates a gradual shallowing that was interrupted by rapid sedimentation under marine shelf conditions.

**Auvergne Group**

The Auvergne Group, as defined by Sweet et al (1974c), comprises seven formations, of which only the basal Jasper Gorge Sandstone outcrops in VICTORIA RIVER DOWNS. This group is best exposed in AUVERGNE where it is about 950 m thick. The lower part of the group forms extensive outcrop in DELAMERE and WATERLOO and minor exposures in WAVE HILL and LIMBUNYA. The Auvergne Group overlies Wattie, Bullita and Tijunna Group rocks with a low-angle unconformity and is unconformably overlain by the Antrim Plateau Volcanics in western VICTORIA RIVER DOWNS.

**Jasper Gorge Sandstone (Paj)**

In VICTORIA RIVER DOWNS, the Jasper Gorge Sandstone (Sweet et al 1974c) forms extensive plateaux and mesa caps, and is best exposed in cliff sections up to 80 m thick in Jasper Gorge within Gregory National Park. In many places it is differentially weathered and friable, and is poorly preserved as blocks and flaggy rubble. The Jasper Gorge Sandstone is predominantly a medium orthoquartzite, which contains rare granular lags (Sweet et al 1974a). Outside of VICTORIA RIVER DOWNS, it also contains subordinate conglomerate and rare lenses of siltstone and mudstone (Dunster et al 2000; Beier et al 2002). Trough and low-angle cross-stratification, scour surfaces, mudclasts, and scattered quartzite and chert pebbles are common in the Gibbie Creek area.

Deposition of the Jasper Gorge sandstone is interpreted to have taken place under nearshore shallow marine conditions during a regional transgressive event (Sweet et al 1974c).

**Structure of the Victoria Basin**

**Regional structural setting**

The Proterozoic Birrindudu Basin (Birrindudu, Tolmer and Limbunya groups) and overlying Victoria Basin (Wattie, Bullita, Tijunna and Auvergne Groups) are underlain by metamorphic basement of the Pine Creek and Halls Creek Orogens, which were cratonised during the Barramundi Orogeny, and by younger rocks of the Tanami Region. Underlying basement is exposed as quartz-mica schist of the Inverway Metamorphics in central LIMBUNYA, to the southwest of VICTORIA RIVER DOWNS. Initial deposition in the overlying Birrindudu Basin was accompanied by regionally extensive north-trending growth faults. These were periodically reactivated throughout deposition of the Birrindudu and Tolmer Groups and may have been associated with a rifting phase in western LIMBUNYA during deposition of the Limbunya Group.

Deposition in both the Birrindudu and Victoria Basins includes several phases of intracratonic sag that in part correspond to regional sequence boundaries, which separate the component lithostratigraphic groups. In their present structural configuration, strata dip away from the centres of depositional basins and this is attributed to basement uplift and subsequent inversion of basin successions (Dunster et al 2000). The loci of deposition subsequently shifted from LIMBUNYA to VICTORIA RIVER DOWNS. In VICTORIA RIVER DOWNS, uplift was probably initiated contemporaneously with deposition of the Tijunna or Auvergne Groups. At this time, areas of structural relief were likely controls on regional sedimentation patterns in the

*Battle Creek Formation, Weaner Sandstone, Bynoe Formation, Nero Sandstone.*
Birrindudu and Victoria Basins. The Auvergne Group was restricted to a northwest-trending sub-basin in WATERLOO or AUVERGNE between uplifted metamorphic basement and overlying sediments, and the Halls Creek–Victoria River Fault Zones. However in LIMBUNYA and WAVEHILL, the Auvergne Group was more widely deposited as thin veneers on the Limbunya, Wattie, Bullita and Tijunna Groups.

The cessation of sedimentation in the Victoria Basin was associated with regional uplift throughout the Kimberley Region. Two major Palaeozoic intraplate orogenic events are believed to have had significant effects (Haines et al. 2001). The first, which was related to the King Leopold and Petermann Ranges Orogenies, preceded the extrusion of Cambrian flood basalts and sedimentation in the Wiso, Daly and Ord Basins. The later Alice Springs Orogyny resulted in the faulting and folding of Proterozoic and Cambrian rocks, which in some cases involved rejuvenation of older basement faults, particularly in the south. Deformation is most intense adjacent to the Victoria River Fault Zone in AUVERGNE.

**Structural geology in VICTORIA RIVER DOWNS**

Exposed Proterozoic rocks in VICTORIA RIVER DOWNS are generally not strongly folded or faulted and deformation progressively decreases from the Wattie Group through to undifferentiated Cretaceous rocks (Sweet 1973). The relatively undeformed Wattie and Bullita Groups outcrop in broad domes and small linear anticlines overlain by nearly flat-lying rocks of the Tijunna Group and Jasper Gorge Sandstone. Northwest of Mount Sanford homestead in the southwest, the Wattie Group outcrops on the flanks of a small anticline, where dips of up to 30° become progressively shallower (up to 5°) to the northeast.

A broad antiform, which is cored by the Skull Creek Formation, displays near four-way dip closures in the Fitzgerald Range and dominates the regional structural fabric in the central part of the mapsheet. This domed structure is flanked by arcuate outcrop of more gently dipping (about 5°) younger Bullita Group strata and by nearly flat-lying rocks of the Tijunna Group and Jasper Gorge Sandstone. Immediately to the west of the dome, a north-trending asymmetric anticline in the Skull Creek Formation, which is bounded by a series of north-trending normal faults to the east, extends for at least 45 km from Burt Hill in the north to the Wickham River in the south. Southeast of Mount Warburton, the Skull Creek Formation is exposed in an irregularly shaped anticline, which has three-way dip closure, and which is displaced on the western margin by a northeasterly oriented fault.

Similar anticlines at the same stratigraphic level are displaced by east-southeast-trending faults to the north of the Humbert River and are also exposed in erosional windows in the northwestern portion of the mapsheet. In this area, faults have components of lateral and vertical displacement of tens of metres (Sweet 1973). This younger generation of faulting is parallel to southeast-trending linear exposures of remnant sandstone interbeds within the Antrim Plateau Volcanics. Stream sediment sampling for base metals indicates that anomalous Pb values are associated with these small anticlinal structures in VICTORIA RIVER DOWNS (see *Economic geology of the Victoria Basin*). In DELAMERE, a series of northwest-trending anticlines with comparable structural affinities may have resulted from an earlier pre-Jasper Gorge Sandstone thrusting event (Hulton and Morris 1998), but this event at least postdates deposition of the overlying Bynoe Formation (Beier et al. 2002).

Isolated anticlines in the Battle Creek Formation in central VICTORIA RIVER DOWNS were probably topographic highs during the extrusion of the Antrim Plateau Volcanics. A northeast-trending lineament across almost the entire central part of the mapsheet crudely separates a series of similar axially oriented synclines and anticlines in the Proterozoic rocks from the Antrim Plateau Volcanics. This lineament probably once represented a regional feature of topographic relief, possibly induced by deep-seated fault movement in the basement, and at least predates the northeasterly oriented structural fabric that is evident in southern VICTORIA RIVER DOWNS.

Regionally, the Jasper Gorge Sandstone is nearly flat-lying except in the vicinity of Jasper Gorge, where it is gently folded and faulted.

The Antrim Plateau Volcanics and younger rocks generally show little evidence of folding, but in the eastern portion of the mapsheet, they are gently warped, and have easterly dips of up to 2° (Sweet 1973).

**Economic geology of the Victoria Basin**

**Base metals**

Carbonate and shale units of the Wattie, Bullita and possibly Tijunna Groups are prospective for base metals. Carbonate lithofacies in the Timber Creek, Skull Creek, Battle Creek and possibly Mount Sanford Formations are prospective for stratabound replacement-style mineralisation. The Victoria Basin also has potential for Century-style epigenetic mineralisation and syngenetic sediment-hosted base metals similar to the McArthur River ore body. Target formations include argillaceous facies in the Burtawurta, Mount Sanford, Gibbie, Timber Creek, Skull Creek, Bynoe, Stubb and Wondoan Hill Formations (Dunster 1998).

Early exploration for lead and zinc was based on Mississippi Valley- and HYC-type models and focused on regionally anomalous upper and lower contacts of the Supplejack Dolostone Member of the Skull Creek Formation. This exploration culminated in the drilling by Australasian Minerals of four shallow (64-122 m) percussion holes to target IP anomalies in the Colt Prospect, which is located near the southern margin of the Fitzgerald Range (Starkey 1972a, b, Cranley 1972, Jones and Muhling 1993). No significant mineralisation was found.

Weak malachite mineralisation is present in the Mount Sanford (659873mE, 8124711mN) and Skull Creek Formations (712713mE, 8189914mN, 703578mE, 8208359mN) in southwestern and northwestern VICTORIA RIVER DOWNS, respectively. Fenestrae replacement by mm-scale aggregates of galena also occurs in upper dolostone beds of the Timber Creek Formation adjacent to Gibbie Creek in the southwest of the mapsheet (676213mE, 8144198mN). Locally, the Wondoan Hill Formation contains specular haematite sandstone beds in the Jasper Gorge area (694697mE, 8225569mN), but this has not been explored systematically.
Elsewhere, visible galena, copper and manganese mineralisation occurs at several localities in VICTORIA RIVER DOWNS and adjoining mapsheets, and is usually associated with minor barite in carbonates of the Timber Creek, Skull Creek and Battle Creek Formations (Cranley 1972, Hooker Mining and Australasian Minerals 1973, Jones and Muhling 1993, Stephens 1998). Possible gossanous outcrops overlying faulted Skull Creek Formation has also been identified in an outlying anticlinal crest about 4 km to the southwest of Mount Warburton in central western VICTORIA RIVER DOWNS (Hooker Mining and Australasian Minerals 1973).

Table 3 gives typical background elemental geochemistry for outcrops of the Timber Creek and Skull Creek Formations.

**Hydrocarbons**

Recent stratigraphic drilling by NTGS intersected biologically degraded bitumen and pyrobitumen in the Skull Creek Formation, Timber Creek Formation and upper Seale Sandstone in drillhole 99VRNTGSDD1. Live oil bleeds were also intersected in the lower Timber Creek Formation and upper Seale Sandstone. Light yellow-orange, high viscosity oil was contained in porous sandstone and dolarenite and rarely along fractures. Analyses of oil extracts from dolarenite in the Timber Creek Formation (Dunster and Cutovinos 2002) indicate that the oil was generated from an early mature, clay-poor carbonate source (possibly of Cambrian or Proterozoic age) and is predominantly of algal-bacterial origin. Oil was probably expelled from a source rock deposited under marine conditions, from which it migrated slightly up-dip to its current reservoir. This suggests that the underlying Wattie Group may have been the source.

Thick shale units in the Stubb and possibly Wondoan Hill Formations contain organic matter and have some potential as source rocks, but have not been systematically evaluated.

**Diamonds**

Early exploration for diamonds focused on stream sediment sampling programs over Proterozoic successions in central and western VICTORIA RIVER DOWNS (Ashton and BHP). Stockdale continued regional exploration by stream sediment and barrage sampling, firstly in eastern parts of the mapsheet and progressively in western areas. Numerous basaltic chromite and spinel grains and one possible kimberlitic garnet were recovered, but generally results were poor (Winzar 1997). Exploration in the northwest of VICTORIA RIVER DOWNS included a closely spaced magnetic survey that delineated eleven anomalies. However, field sampling above magnetic targets for diamonds and kimberlitic indicator minerals proved to be negative. To date, five subeconomic kimberlite pipes have been discovered by Stockdale in eastern AUVERGNE (Berryman 1995, Berryman et al 1999).

**Dimension stone**

Laminated, silicified mudstone and siltstone in the Battle Creek Formation may have some potential as dimension or ornamental stone, at localities where fracturing is less intense (Sakurai 1991b).

**Groundwater**

Proterozoic strata in VICTORIA RIVER DOWNS include low- to moderate-yield aquifers, which have been enhanced by fractures and cavernous porosity, in dolostone in the upper Skull Creek Formation. Other high-risk targets that yield some water include sandstone and siltstone intervals with intergranular and fracture porosity in the Bynoe, Stubb and Battle Creek Formations and Jasper Gorge Sandstone. Bore yields from these formations are highly variable and range from 0-2.0 L/s (Sweet 1973). However, boreholes in these formations usually have a poor success rate and low yields in the range 0-0.6 L/s are more typical. Generally, flow rates are largely dependent on structural setting and lithology rather than stratigraphic position and the chances of success would be enhanced if bores are drilled on photo-linear features (Sweet 1973).

Water resources of the Victoria River district have been described by Tickell and Rajaratnam (1998), who indicated that average groundwater depths are around 60 m.

**WISO BASIN**

The Wiso Basin unconformably overlies the eastern margin of the Victoria Basin in VICTORIA RIVER DOWNS. Northward in DELAMERE, it is contiguous with the Daly Basin and forms part of a more widely distributed, thin, shallow, intracratonic sedimentary cover succession that mantled much of northern Australia, following an initial marine transgression in the early Middle Cambrian (Kruse 1990). Remnants of this cover can also be found in the Ord, Bonaparte and Georgina Basins. The Wiso Basin succession is herein taken to include the Antrim Plateau Volcanics, associated undifferentiated sedimentary rocks and the Montejinni Limestone.

**CAMBRIAN LITHOSTRATIGRAPHY**

**Antrim Plateau Volcanics ( Cla )**

The Antrim Plateau Volcanics form a nearly continuous belt that obscures the eastern limit of the Victoria Basin (Mory and Beere 1985). In VICTORIA RIVER DOWNS, the unit covers an area of some 8500 km² and attains a maximum known thickness of 240 m (Sweet 1973). The Antrim Plateau Volcanics unconformably overlie Proterozoic rocks and are in turn unconformably veneered by rocks of the Wiso Basin, and by undifferentiated Cretaceous sandstone.

The formation is dominated by flood basalt lava flows and also includes minor interbedded sedimentary and pyroclastic material (Sweet et al 1974a). In LIMBUNYA, where the formation is best exposed, it contains at least seven identifiable lithofacies, two of which have been designated as members. These are a lower Bingy Bingy Basalt Member and an upper Blackfella Rockhole Member, which consists of agglomerate and minor sedimentary rocks (Sweet et al 1974a). In VICTORIA RIVER DOWNS, three similar lithofacies ( Cla å , Cla å , Cla å ) are recognised within the Antrim Plateau Volcanics. Of these, only Claå (agglomerate) is a possible lateral facies equivalent of the Blackfella Rockhole Member, but due to paucity of outcrop and the unknown stratigraphic position of these units they cannot be confidently correlated.
In south central VICTORIA RIVER DOWNS, Sweet et al. (1974a) described flows containing large plagioclase phenocrysts exposed in the Pigeon Hole region as possible Bingy Bingy Basalt Member.

Flood basalt forms extensive, deeply weathered, benched rounded hills punctuated by bare scree slopes, cuestas, mesas, and residual blocky rubble over black soil and undulating plains. Locally, the Antrim Plateau Volcanics are of intensely jointed, mainly massive, vesicular or non-vesicular, fine to medium crystalline tholeiitic basalt, which is intercalated with subordinate agglomerate, sandstone, conglomerate, siltstone, chert and limestone (Sweet 1971, Sweet et al. 1974a). A variety of structures including rare columnar jointing, dyke swarms, sandstone dykes and spheroidal weathering has been documented beyond VICTORIA RIVER DOWNS.

The Antrim Plateau Volcanics and correlatives underlie fossiliferous rocks of early Middle Cambrian age (Kruse 1990, 1998) and have traditionally been accorded an Early Cambrian age (545-509 Ma). This is confirmed by a (513 ± 12 Ma) SHRIMP zircon date, obtained from a dolerite dyke (Milliwindi Dolerite) in the West Kimberley region (Hanley and Wingate 2000). This dolerite is geochemically indistinguishable from basalts of the Antrim Plateau Volcanics and Hanley and Wingate suggested that it probably represents a feeder dyke for basalts that have been subsequently eroded.

Sedimentary rocks within the Antrim Plateau Volcanics are broadly grouped into three dominant lithofacies: chert and limestone containing abundant chert nodules (C1a); sandstone of quartz arenite composition (C1a2); and agglomerate containing minor sandstone and siltstone (C1a3). The regional stratigraphic position of these lithofacies within the Antrim Plateau Volcanics is uncertain and subsequent definition of units, other than the Bingy Bingy Basalt Member and the Blackfell Rockhole Member, is not practical without detailed mapping. Individual units are of limited areal extent and are locally not contiguous. They are commonly exposed in lenticular outcrops.

Lithofacies C1a2 consists of laminated chert, which forms resistant benches, and rare limestone up to 8 m thick. It is exposed in the Coolibah Creek, Illawarra Creek and Armstrong River areas in central eastern VICTORIA RIVER DOWNS. Limestone facies outcrop to the west of Top Springs and to the northwest of Mount Crawford (Sweet et al. 1974a). To the south of Moolooloo homestead, at least two chert beds separated by basalt flows suggest a conformable relationship (Sweet et al. 1974a). In the vicinity of Gibbie Creek and in an area 5 km to the east of Gordon Creek in southwestern VICTORIA RIVER DOWNS, poorly exposed chert unconformably overlies the Jasper Gorge Sandstone. South of Wilson Creek in central VICTORIA
RIVER DOWNS, chert containing domed and columnar stromatolites is interbedded with laminated limestone and medium bedded, fine quartz arenite containing mudclasts. At this locality, unit C1a, directly overlies the Battle Creek Formation (at 755782mE, 8194017mN), but outcrop is too small to be resolved on the mapface. Chert is considered to be a product of limestone replacement. It is locally brecciated and vuggy, and contains rare glass shards and geodes lined with quartz and amethyst (Sweet et al 1974a).

Lithofacies C1a, consists of several interbedded sandstone lenses and more extensive beds at various stratigraphic levels. These form mainly elongate parallel exposures up to 15 km long that overlie an older northwesterly structural fabric in southern and southwestern VICTORIA RIVER DOWNS. Along Gordon Creek, up to 30 m of C1a, unconformably overlies the Wondoan Hill Formation, Battle Creek Formation and Jasper Gorge Sandstone (Sweet et al 1974a).

In this area, the sandstone contains rare basal conglomerate and siltstone and is directly overlain by volcanic rocks. The friable fine to medium sandstone is massive and flaggy, contains mud flake, and locally displays cross-beds and slump structures. Similar elongate ridge-forming sandstone, to the west of Pigeon Hole outstacpy, typically has rounded, highly spherical grains and large-scale cross-beds. This sandstone was interpreted to be of probable aeolian origin by Sweet (1973) and Sweet et al (1974a). A more common sandstone facies up to 15 m thick, which includes rare interbedded chert and siltstone, is conformable within and underlies the Antrim Plateau Volcanics in the Mount Sanford and Pigeon Hole areas in southeastern VICTORIA RIVER DOWNS.

Lithofacies C1a, is predominantly agglomerate, which contains minor intercalated sandstone and siltstone (Sweet 1973, Sweet et al 1974a). The agglomerate is up to 9 m thick and is conformable within the Antrim Plateau Volcanics in central and southeastern VICTORIA RIVER DOWNS, mainly in the Armstrong River region. Locally it is unconformably overlain by the Montejinni Limestone and by undifferentiated Cretaceous sandstone. Agglomerate typically contains angular and rounded clasts, up to 15 cm across, of extensively altered and ferruginised, vesicular and massive basalt and minor siltstone and sandstone. These are set in a fine aphanitic basaltic matrix (Sweet et al 1974a). The presence of angular basaltic clasts and interbedded sedimentary rocks indicates minimal reworking, and deposition under subaqueous conditions, at least in part.

Massive cross-beded sandstone of probable aeolian origin and associated marine and lacustrine sediments indicate that the volcanics were extruded in both subaerial and shallow marine settings (Sweet 1972, Sweet et al 1974a).

**Montejinni Limestone (Cmm₁, Cmm₂, Cmm₃)**

The basal formation of the Wiso Basin is the Montejinni Limestone (Kennewell and Huleatt 1980). It is widely distributed to the east of VICTORIA RIVER DOWNS, where it consists of two limestone intervals separated by mudstone. The formation is considered to be a lateral correlative of the Middle Cambrian Tindall Limestone and Gum Ridge Formation in the Daly and Georgina Basins, respectively (Randall and Brown 1969, Sweet 1973, Donnellan et al 1999). The maximum known thickness of the Montejinni Limestone is 151 m in BMR drillhole Green Swamp Well 6. However, exposed thicknesses of up to 100 m are more common in VICTORIA RIVER DOWNS (Kennewell and Huleatt 1980). The formation is contiguous across the entire Wiso Basin and all three units (Cmm₁, Cmm₂, Cmm₃) are well exposed on the northwestern fringe of the basin, including VICTORIA RIVER DOWNS. It forms crudely terraced, low-relief mesas with small steep escarpments and subcrop scattered with a layer of residual rubble and boulders, which has been intensely silicified and lateritis. Northward in DELAMERE, only the upper two units are exposed and in WAVE HILL the succession remains undivided. Thin veneers of Montejinni Limestone unconformably overlie the Antrim Plateau Volcanics and are locally unconformably overlain by undifferentiated Cretaceous sandstone (Sweet 1973). Kruse (1990) documented the fauna of the Montejinni Limestone, which includes Redlichia cf. foraminifera and other trilobites, brachiopods, hyoliths, molluscs, bradoriides and sponge spicules. These indicate an Ordian-early Templetonian (early Middle Cambrian) age.

Lithofacies Cmm₁ is a succession of pervasively silicified stromatolitic limestone, thinly bedded mudstone and minor dolostone. The succession is up to 30 m thick, lenses out about 15 km north of Top Springs and is best exposed in southeastern VICTORIA RIVER DOWNS. Locally, the basal succession contains a laterally extensive stromatolite bed. Common bioclasts include hyoliths, brachiopods, molluscs and trilobites (Kruse 1998). Lithofacies Cmm₂, is 10-45 m thick and consists of calcareous mudstone, minor argillaceous limestone and a basal siliceous breccia (Sweet 1973). Lithofacies Cmm₃, attain a maximum thickness of 30 m and is an abundantly fossiliferous unit of interbedded dolostone and limestone (Sweet 1973, Donnellan et al 1999). The dolostone includes stromatolitic, bioclastic and oncolith rocks.

Diagenetic nodules, veins, and dissolution textures are locally abundant throughout the Montejinni Limestone. Sedimentary structures and faunas indicate that deposition occurred under variable conditions, which included a restricted, oxygenated marine shelf with periodic high salinities (Cmm₂) and tidally influenced open marine settings (Cmm₃, and Cmm₄; Sweet 1973).

**Economic Geology of the Wiso Basin**

**Copper**

Early mineral exploration in VICTORIA RIVER DOWNS established the presence of a 3 m thick discontinuous cupriferous horizon near the top of the Antrim Plateau Volcanics (Sampay Exploration Services and Tipperary Land Corporation 1968). Later exploration for native copper deposits delineated a 2.5 m thick mineralised zone...
(Sakurai 1991a). Collectively, exploration for stratabound copper in the Antrim Plateau Volcanics has located only minor anomalous areas. Rare, irregularly shaped breccia mounds up to 10 m in diameter, which have developed in the Montejinni Limestone (at 779030mE, 8145860mN), contain minor malachite and azurite veinlets between clasts and infill voids, and may have been sourced from the underlying Antrim Plateau Volcanics by ‘hot’ or ‘cold’ hydrothermal fluid seeps. The potential of such mineralising mechanisms to host larger deposits in Cambrian cover successions has not been examined in VICTORIA RIVER DOWNS or adjacent mapsheets. Minor secondary copper mineralisation also occurs in the basal Montejinni Limestone at the contact with the underlying Antrim Plateau Volcanics in VICTORIA RIVER DOWNS. As in adjoining mapsheets, localised copper anomalism in Cambrian units has been traced to malachite-coated geodes weathering from the flow tops of the Antrim Plateau Volcanics (Sweet et al 1974a).

Other base metals

Regional exploration for base metals hosted in the Cambrian succession has been associated with simultaneous exploration of the Antrim Plateau Volcanics in eastern VICTORIA RIVER DOWNS (Howells 1991, Piromanski 1992, Crowe 1993, Crowe and Armfield 1994).

Hydrocarbons

Currently, no petroleum resources are known from the Wiso Basin, but outcrops of the Montejinni Limestone, located adjacent to the Buchanan Highway about 5 km to the south of Top Springs, have a strong foetid odour of hydrocarbons when struck.

Diamonds

Semi-detailed stream sediment sampling programs conducted by Stockdale Prospecting targeted the Antrim Plateau Volcanics for diamonds (Burryman 1996, 1997, 1998), but no significant diamond or kimberlite indicator suites were recovered.

Industrial minerals and gemstones

Localised small pods of barite, hosted in the Antrim Plateau Volcanics and associated sedimentary facies, are known in FERGUSSON RIVER. Although some potential for barite mineralisation exists in VICTORIA RIVER DOWNS, no resources have been reported to date. Geodes and amygdales in the Antrim Plateau Volcanics are commonly lined with prehnite, agate, chalcedony, quartz, amethyst, smoky quartz, and calcite (Sweet et al 1974a). Approximately 500 kg of amethyst, smoky quartz and agate were recovered from vertical, north-oriented mineralised joints within the Antrim Plateau Volcanics in Moolooloo station (Thompson 1996a). Similarly, about 400 kg, including 50 kg of faceting-grade amethyst within the Antrim Plateau Volcanics were recovered from a mineral claim in south-central VICTORIA RIVER DOWNS (Thompson 1996b). The majority of semi-precious gemstones are considered to be low grade.

Groundwater

Groundwater is utilised mainly in eastern VICTORIA RIVER DOWNS, where surface water is usually in minimal supply during the dry season. In this area, the Antrim Plateau Volcanics and Montejinni Limestone have significant groundwater potential. Most of the groundwater is fresh and suitable for stock, but airlift yields are generally low (0.5-2.0 L/s) in fracture-controlled aquifers (Tickell and Rajaratnam 1998). In the Antrim Plateau Volcanics, known producing aquifers occur in weathered horizons, which contain chert with fracture-enhanced porosity and porous sandstone. However, to date, about half of the bores that have been drilled in the unit are low-yielding or dry. The remainder generally have flow rates in excess of 2.0 L/s (Sweet 1973). The Montejinni Limestone forms extensive fissured and cavernous aquifers in eastern VICTORIA RIVER DOWNS. Limestone is capable of large storage capacities and high-yielding bores in this region are common. In contrast, the Montejinni Limestone on the western edge of the Wiso Basin is generally thinner and median airlift yields for bores are low, probably because most bores only penetrate the top of the aquifer. It is plausible that deeper bores would produce higher yields in the range 5-15 L/s (Tickell and Rajaratnam 1998).

MESOZOIC

Mesozoic sedimentary rocks are thin remnants of once extensive lower Cretaceous fluvioid and shallow marine sediments that mantled much of the northeastern Northern Territory. They are typically lateritised and deeply eroded. In VICTORIA RIVER DOWNS, most have been stripped from the region or masked by superficial deposits.

CRETACEOUS (KI)

Cretaceous sedimentary rocks are widely distributed in mesas, buttes and dissected plateau margins in eastern VICTORIA RIVER DOWNS, where they unconformably overlie the Montejinni Limestone and rarely the Antrim Plateau Volcanics. Small isolated mesa caps in the vicinity of Sundown Hill in the northwest of the mapsheet were previously mapped as possible Cretaceous strata, but are now referred to the Jasper Gorge Sandstone. Preserved Cretaceous sections are up to 30 m thick and can be subdivided into lower and upper units, separated by a possible disconformity (Sweet 1973). The lower unit consists of basal non-marine sandstone, containing leaf and wood fragments, overlain by an interval of marine claystone and siltstone, containing some molluscs (Sweet 1973). Faunal assemblages include Rhizocorallium, Neritokrikus tuberosis and belemnites of Aptian age. The upper part of the succession consists of micaceous siltstone and claystone, overlain by poorly sorted sandstone and ferruginous pebble conglomerate, and contains foraminifers of Albian age (Sweet 1973). These rocks were previously assigned to the “Mullaman Beds” (Skwalko 1966). Hughes (1978) dispensed with this name in recognition of the fact that Mesozoic rocks in the northwestern part of the Northern Territory are probably
onshore equivalents of plant fossil-bearing terrestrial arenaceous sediments of the Petrel Formation and the overlying shallow marine mudstone-dominated Darwin Formation (Bathurst Island Group), both of which have been intersected in off-shore petroleum holes.

**Cenozoic**

Cenozoic geology was not studied closely during Second Edition mapping; hence, descriptions of the mapped units are based on Sweet (1973) and Sweet _et al._ (1974a).

Unconsolidated deposits cover approximately 15% of the bedrock, predominantly in eastern and northwestern VICTORIA RIVER DOWNS. Elsewhere, the distribution is patchy, mainly over the Antrim Plateau Volcanics and along drainage. Palaeogene-Neogene deposits have been divided into Silcrete (Czo), Laterite (Czl), Undifferentiated Gravels (Czg), Black Soil (Czb) and Superficial Soils (Czs). Quaternary sediments are represented as Terrace Deposits (Qt) and Alluvium (Qa).

**Paleogene-Neogene**

**Silcrete/Duricrust (Czo) (formerly Bardia Chert Member)**

Laminated and brecciated siliceous duricrust up to 30 m thick commonly forms prominent residual caps on various stratigraphic levels of the Skull Creek and Bynoe Formations in the northern Fitzgerald Range, and in northwestern VICTORIA RIVER DOWNS. It also overlies the Campbell Springs Dolostone, and Fraynes, Timber Creek and Shoal Reach Formations in AUVERGNE (Sweet _et al._ 1974c, Dunster _et al._ 2000). Previously mapped as the Bardia Chert Member of the Skull Creek Formation (Sweet _et al._ 1974a, b, c), it was remapped as Cenozoic silcrete during Second Edition field mapping. Recent drilling by NTGS (drillhole 99VNTGSDD1) confirmed that it does not occur at depth. Consequently, the Bardia Chert Member is no longer considered a valid lithostratigraphic name in the Victoria Basin.

**Laterite (Czl)**

_In situ_ and reworked ferruginous laterite is locally up to 30 m thick and commonly forms a thin cap on mesas and plateaux that overlie undifferentiated Cretaceous strata and Antrim Plateau Volcanics in the east of the mapsheet. To the west, lateritisation has formed ferruginous sandstone rubble and skeletal soils over Proterozoic strata. In WAVE HILL to the south, laterite is unconformably overlain by the middle or upper Miocene Camfield Beds.

**Undifferentiated Gravels (Czg)**

Rare unconsolidated fluvial gravel and conglomerate is exposed about 4 km to the south of Anderson Lagoon in central-north VICTORIA RIVER DOWNS. Sweet (1973) considered this to be topographically higher than Quaternary alluvial terrace sediment, but much lower than laterite.

**Black Soil (Czb)**

Residual black soil, derived from underlying volcanics and carbonates, has a localised distribution in the western half of VICTORIA RIVER DOWNS. The most extensive black soil plains form excellent grazing land for cattle, adjacent to the northern part of the Victoria River.

**Superficial Soils (Czs)**

Residual soil and sand, eluvium and minor calcrete are locally extensive in the Fitzgerald Range area and in eastern VICTORIA RIVER DOWNS. Residual soil includes sandy soil and colluvium developed over or adjacent to Proterozoic sandstone, and loamy soil on carbonate units. Colluvium also includes scree and talus, deposited on the sides and bases of steep slopes and formed by the mechanical weathering of bedrock.

**Quaternary**

**Terrace Deposits (Qt)**

Terrace deposits, mainly of sand and silt, form banks and levees up to 7 km wide adjacent to the Victoria, Wickham and Humbert Rivers, as well as minor accumulations along Gordon Creek. They are perched up to 20 m above the present river level and locally merge with residual black soil profiles. Terrace deposits are susceptible to erosion by run off and flooding during the wet season. They typically form well developed soil profiles that are suitable for grazing.

**Alluvium (Qa)**

Alluvium includes streambed or overbank deposits, up to 10 m thick, in active drainage channels. It consists of unconsolidated fluvial mud, silt, sand and gravel.

**Economic geology of Mesozoic-Cenozoic deposits**

Exploration for opal in VICTORIA RIVER DOWNS has targeted siliceous undifferentiated Cretaceous units in the southeastern part of the mapsheet. This exploration culminated in the drilling of 26 shallow (4-22.5 m) RAB holes that in some cases intersected the Montejinni Limestone and Antrim Plateau Volcanics (Crowe and Armfield 1994). Results were disappointing and the area was subsequently relinquished.

Porous pisolithic and nodular ironstone lateritic units that cover undifferentiated Cretaceous strata have low silica, but are also too low in iron and aluminium (Sweet 1973) to be a potential source of these commodities. Lateritic gravels have good compactive properties and are used as road base throughout the region.

Unconsolidated alluvial sand and gravel forms localised low-yielding aquifers (typically 1.5 L/s), at depths of 6-30 m, adjacent to the Wickham River in the vicinity of Yarralin Community in central western VICTORIA RIVER DOWNS (Tickell and Rajaratnam 1998).
GEOLOGICAL HISTORY

The oldest rocks exposed in VICTORIA RIVER DOWNS are those of the basal Wattie Group of the Victoria Basin. These unconformably overlie the Limbunya Group of the Birrindudu Basin, which is exposed in areas to the northwest and northeast of the mapsheet. The Limbunya Group was deposited over basement metamorphic rocks, and was cratered during the 1880-1850 Ma Barramundi Orogeny, as can be observed in LIMBUNYA, where the basal contact is exposed (Cutovinos et al. 2002).

Deposition of the regionally transgressive Wickham Formation (basal Wattie Group) marked a change from predominantly carbonate to siliciclastic deposition, and was contemporaneous with regional uplift, erosion and possible volcanic activity located to the south or west of LIMBUNYA. The Wickham Formation was deposited under high-energy shallow marine conditions that initially included minor subaerial and evaporitic settings. Siliciclastic sediments, sourced from a proximal landmass in LIMBUNYA and from more distant areas in WATERLOO, inundated a slowly subsiding platform environment, resulting in a regional depositional hiatus. The main loci for Wattie Group sedimentation at this time was in northern LIMBUNYA, southeastern WATERLOO and western VICTORIA RIVER DOWNS.

Marginal marine deposition continued on extensive, broad stable shelves and included periods of minor deeper water deposition, possibly under reducing conditions (Mount Sanford Formation). Clastic sedimentation was punctuated by intervals of stromatolite development and by the deposition of rare distally sourced tuffite, possibly from waning volcanic activity in the west or south. Some carbonates in this formation were flushed with Fe-rich brines during early diagenesis. The Neave Sandstone was deposited under regressive or possibly transgressive shallow marine conditions and represents a sequence break of regional extent before continued stable platform deposition.

The Timber Creek and Skull Creek Formations of the Bullita Group signified a return to widespread carbonate and evaporite deposition, but minor siliciclastic sediment sourced from a proximal landmass continued to be deposited onto an intermittently shoaling platform. A short-lived regional transgressive event probably coincided with microbial deposition of the Supplejack Dolostone Member and this was followed by shallow marine, storm-influenced depositional conditions.

Deposition of the Bynoe Formation is related to an increased supply of continental sediments along the axis of the Victoria Basin. This effected a gradual termination of the previous carbonate system. Locally, the Bynoe Formation accumulated in deeper water, possibly below storm wave base. The Weaner Sandstone was rapidly deposited under shoaling, high-energy regressive conditions, and formed a localised erosional hiatus focused in VICTORIA RIVER DOWNS. Deposition of the Bynoe Formation and Weaner Sandstone was probably related to brief episodes of tectonic uplift and erosion and may have included a pulse of volcanic activity sourced outside the basin. Mixed carbonates and siliciclastics of the overlying Battle Creek Formation were deposited in a predominantly shallow marine, stable platform setting that included brine-logging of the sediment and stromatolite development. Previous minor tectonic instability eventually culminated in minor folding that was related to significant tectonic uplift and the formation of an erosional hiatus, prior to deposition of the Tijunna Group.

Deposition of the Tijunna Group began with the Wondoan Hill Formation, which transgressed the Bullita Group. Sands and silts were deposited in a shallow marine setting that was possibly contemporaneous with coastal fluvial deposition in a slowly subsiding basin. Locally, some facies from below wave base are preserved. The Stubb Formation was instigated by an influx of silts to the subtidal and shallow marine environment. Tectonic activity produced regional uplift and erosion and a gradual migration of the main depocentre to western WATERLOO and southwestern AUVERGNE. Deposition of the Auvergne Group began with the Jasper Gorge Sandstone transgressing firstly the Wattie then the Bullita and Tijunna Groups. Sedimentation continued after deposition of the Jasper Gorge Sandstone, but these rocks have subsequently been stripped from the area. Hydrocarbons may have been expelled from early mature source rocks in the lower Wattie Group and may have migrated to upper Wattie and lower Bullita Group reservoirs.

Reactivation of strike slip faults and regional uplift during the King Leopold Orogeny (560 Ma) terminated sedimentation in the Victoria Basin, prior to regional extrusion of the Antrim Plateau Volcanics. Intercalated limestone and sandstone facies indicate that these volcanics were extruded in both subaerial and shallow marine settings. Volcanism appears to have been synchronous with minor epigenetic base metal mineralisation in the Bullita Group.

The Antrim Plateau Volcanics underwent minor erosion prior to an extensive marine transgression during the early Middle Cambrian. Tidally influenced open marine conditions, which included a restricted, oxygenated marine shelf with periodic high salinities, characterised the deposition of the Montejinni Limestone (Wiso Basin). Elsewhere, sedimentation continued at least to the Ordovician, followed by a hiatus until the Early Cretaceous. By this time, Cambrian volcanic and carbonate rocks that originally blanketed much of VICTORIA RIVER DOWNS had been eroded.

The Timber Creek Formation was intruded by diamond-bearing kimberlites at 179 Ma.

Mesozoic deposition of shallow marine and subaerial sandstone, conglomerate, silt and mud was widespread across the Victoria River region. A period of erosion, deep weathering and laterisation followed. Cenozoic deposits, derived from continental processes of erosion and redistribution, form a thin cover over much of the present land surface.

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REFERENCES


### APPENDIX – list of measured sections

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<th>Section</th>
<th>Field code</th>
<th>GDA co-ordinates (base)</th>
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* Composite of sections 99vrprbms20 (base) and 99vrprbms4 (top), section offset not resolvable on mapsheet; Fm = Formation; Sst = Sandstone.