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Reconnaissance Geological Mapping in Dixon, SE McIntosh and Northernmost Halls Creek 1:100 000 Sheet Areas, East Kimberley, W.A. 1992-3

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DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Neil Williams

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SUMMARY

Reconnaissance geological mapping over parts of the Dixon, McIntosh and Halls Creek 1:100 000 Sheet areas in the East Kimberley in 1992 and 1993 revises 1:250 000 scale regional mapping carried out in the 1960s by the Bureau of Mineral Resources (now AGSO) and the Western Australia Geological Survey. The area lies to the east of the Halls Creek Fault, and consists mainly of the Palaeoproterozoic Halls Creek Group, which is represented by the upper part of the Biscay Formation and by the overlying Olympio Formation. To the east the Olympio Formation is overlain unconformably by Neoproterozoic and Palaeozoic cover rocks.

The upper Biscay Formation is represented by a variety of sedimentary rocks and a sequence of mafic volcanic rocks with minor interlayered sediments, some derived from mafic sources, and thin units of carbonate and chert.

The Olympio Formation consists mainly of turbidites, but also includes siliceous A-type volcanic rocks, the Maude Headley Volcanic Member, near its base. The turbidites vary from massive and thick bedded, with well-developed graded bedding, to thin beds that are locally ripple cross-bedded. Thick beds tend to be coarser grained than the thin beds. The turbidites are generally green to grey, but are red or purple in exposures along the Ord River and in the east. The contact between apparently undisturbed Olympio Formation and underlying Biscay Formation appears to be conformable.

The Maude Headley Volcanic Member can be subdivided into four units: a basal recessive unit of thin siliceous flows or sill and interlayered sediments or tuffs is overlain by a topographically prominent unit of fragmental volcanic rocks with a carbonate cement. This fragmental unit is overlain by a massive rhyolite in the central part of the outcrop-area. At the top of the member in the north and northwest, there is a unit of thinly interlayered chert and carbonate bands forming prominent outcrops. The Maude Headley Volcanic Member has A-type chemistry, like the Butchers Gully Member, which occurs in the lower part of the Olympio Formation about 25 km to the south. but is more siliceous and carries lower concentrations of Zr, REE, Zn, Ta and Sn. An analysis of the uppermost thinly layered unit of the Maude Headley Volcanic Mmber shows anomalous, but subeconomic, gold.

The mapping in the Grants Patch-Maude Headley-Dry Creek gold district shows that there are apparent gaps here in the stratigraphic succession from the upper Biscay Formation to the Olympio Formation above the Maude Headley Volcanic Member. The gaps coincide with thin zones of deformed rocks showing a layer-parallel fabric. These zones lie on a low-angle detachment or decollment surface. This surface has been folded by all subsequent events, and is considered to be a D_1 feature.

Regional D_2 folds have north-south trending axial traces and overturned eastern limbs. Axial planes vary from upright to steeply westerly-dipping. The D_2 folds become tighter

northwards, synclines becoming faulted out and faulted anticlinal crests becoming overthrust to the east.

D_3 faults have strikes close to north-south, and have tight folds immediately to their east. D_4 faults trend northeast. D_3 and D_4 faults were, at different stages, compressional and then extensional. Movements on these faults controlled deposition and erosion in the cover successions.

Several whole-rock chemical analyses reveal high arsenic contents in the area, and there is a distinct possibility of arsenic being leached into surface water that is used for human and stock supplies. Arsenic could become concentrated to dangerous levels when evaporation is intense,. Therefore, it is recommended that, as a precaution, the use of surface water for drinking purposes be avoided during the dry season.

Gold has been extracted from alluvial deposits, and small shafts have been sunk in the Grants Patch district to test for lode gold mineralisation at depth. Bedrock for most alluvial workings is the uppermost Biscay Formation, close to the contact with the lower Olympio Formation. Exceptions are workings in the Mount Slinkey area, where the underlying rocks belong to the Olympio Formation (close to a D_3 fault), and some parts of the Dry Creek district, where the alluvial workings are along creeks draining the contact between the Biscay and Olympio formations and draining outcrops of the Maude Headley Volcanic Member. Many alluvial workings are also close to D_3 fault traces. It is suggested that gold originally in the Maude Headley Volcanic Member was extracted by a mixed H_2O-CO_2 fluid (mineral assemblages in mafic rocks of the upper Biscay Formation indicate alteration by a mixed H_2O-CO_2 fluid phase) and carried downwards through the Olympio Formation along D_3 faults, becoming precipitated as the fluids interacted with the mafic rocks of the Biscay Formation. Removal of the lower part of the Olympio Formation, between the Maude Headley Volcanic Member and the Biscay Formation, by the D_1 detachment may explain the absence of gold working south and southwest of Maude Headley.

INTRODUCTION

This report summarises the results of approximately 5 weeks of field reconnaissance in 1992 and 3 weeks in 1993, covering part of Dixon 1:100 000 Sheet area, the southeastern part of McIntosh 1:100 000 Sheet area and the extreme northern part of Halls Creek 1:100 000 Sheet area (Fig. 1). The area is bounded on the west by the Halls Creek Fault and on the east by platform cover successions, extending from the Mount Kinahan Sandstone (shown on previous maps as Mount Parker Sandstone) upwards. Observations made during the field season, augmented by airphoto- and geophysical-interpretation were used to prepare compilation sheets at a scale of 1:25 000.

Mapping was concerned essentially with the upper part of the Palaeoproterozoic Halls Creek Group, from the upper Biscay Formation to the upper Olympio Formation. Therefore most observations were made in the western part of the region. These units have been faulted, folded and metamorphosed to produce greenschist facies assemblages, for the most part without destruction of primary depositional textures. The Kimberley Basin succession crops out in narrow fault slices along the Halls Creek Fault. In the east, the Mount Kinahan Sandstone is locally preserved in down-faulted blocks, below the Late Proterozoic glaciated surface, but the Eliot Range Dolomite has been entirely removed by Late Proterozoic glaciation in the Dixon 1:100 000 Sheet area. The Moonlight Valley Tillite forms a thin discontinuous layer above the glaciated surface. The Ranford Formation and Mount Forster Sandstone have been involved in a thrust complex along the Albert Edward Range.

As field observations were focused on the Early Proterozoic sequence, Late Proterozoic and Early Cambrian units were encountered only fortuitously. Units above the Headleys Limestone were not studied at all. Information on Tertiary and Quaternary units comes partly from field observations and partly from photo-interpretation.

SHRIMP zircon ages quoted in this report are the work of R.W. Page (AGSO). At the time of completing this report, most of these determinations are not yet published, but are available in the public domain through the AGSO database OZCHRON.

This report is intended as a commentary on the 1:25 000 Scale compilation sheets prepared as the results of the field work. Letter symbols are those used on the compilation sheets; symbols recommended, circa late 1996, for the published maps are given in brackets where appropriate. Note that the compilation sheets may differ considerably from the final published maps.

PHYSIOGRAPHY

Dow & Gemuts (1967) recognised several descriptive physiographic units in the Dixon Range 1:250 000 Sheet area. These were set into a regional context and slightly modified by Plumb & Gemuts (1976), whose nomenclature, with modifications, is used here (Fig. 2). In particular, Plumb & Gemuts (1976) recognised the Lamboo Hills as a dissected outlier of the Canning Plain (Sturt Plateau). Warren (1994a) suggested the major streams draining the Lamboo Hills (the upper Ord River, McIntosh Creek and the Panton River) formerly were headwaters to the ancestral Sturt Creek System, but have been captured by the north-flowing Ord system and rejuvenated.

The **Kimberley Foreland** is a zone of steep ridges and deep valleys along the western edge of the Ord Plain. It corresponds topographically to the Albert Edward Range and its northern continuation, and geologically to the complex zone of thrust-faulting and steeply dipping sedimentary rocks along the basement-cover contact. The highest part of the foreland takes the form of small bevelled surfaces at about 500 m, which cap resistant ridges of sandstone. Lower areas, outliers of the Stuart Plateau, at about 420 m, are preserved on resistant units, especially the Antrim Plateau Volcanics and sandstones in the Albert Edward Range. Very little of the surface level corresponding to the Stuart Plateau is preserved in the Kimberley Foreland. Differential erosion of less resistant units has produced incised valleys within the Range. The valley floors are at the level of the Ord Plain, and have been infilled by thin sediments.

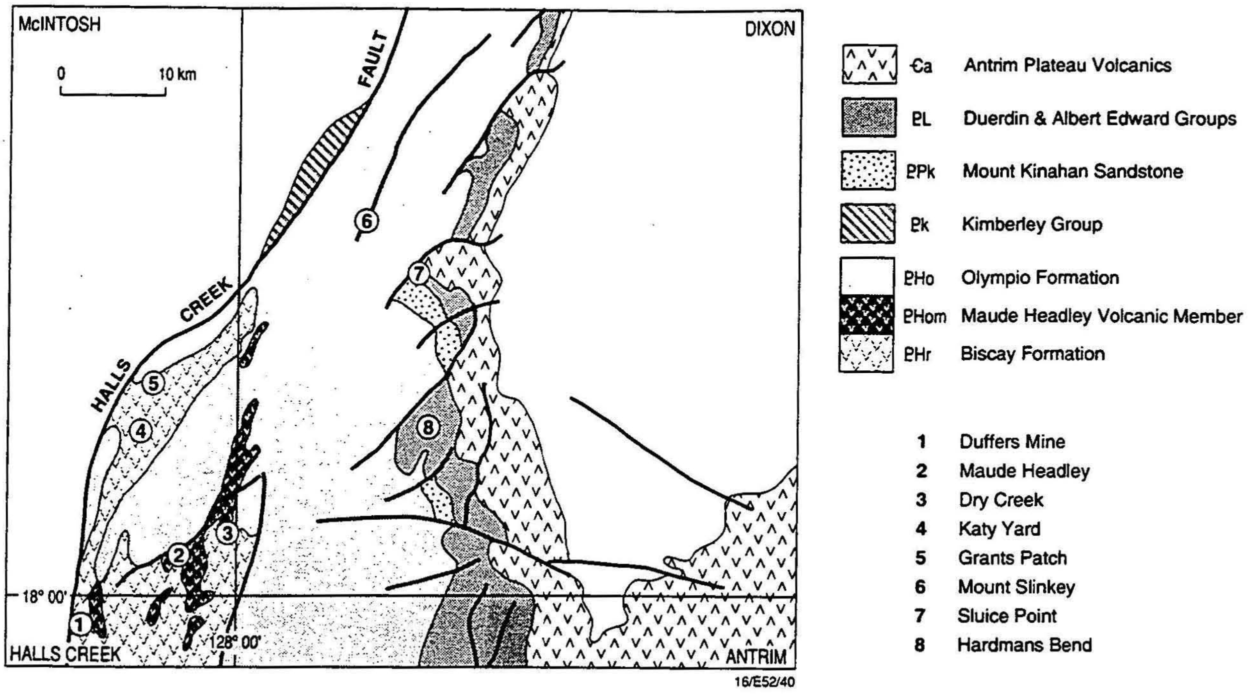

Fig. 1 Regional setting of the area covered by the report, east of the Halls Creek Fault, and north of the Sophie and Saunders Creek Domes. Scale approx. 1:500 000 (modified from Dow & Gemuts 1969).

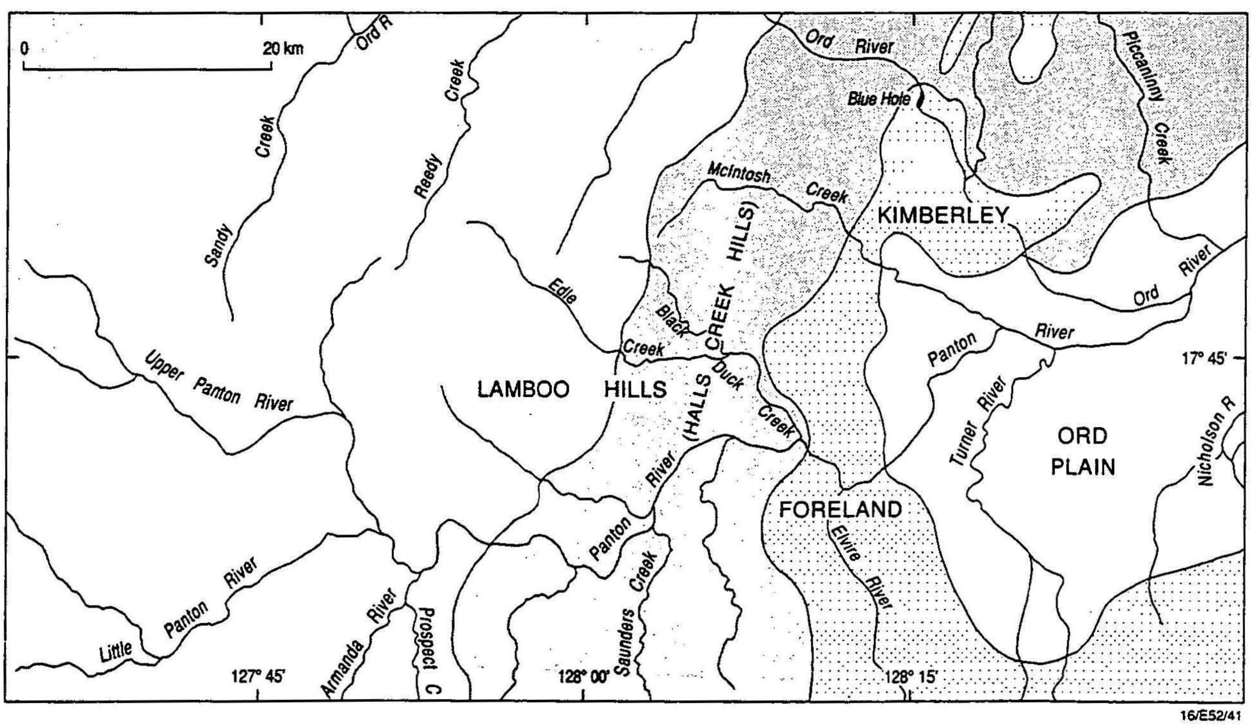

Fig. 2 Main drainage and the physiographic subdivisions. Scale approx. 1:500 000 (modified from Plumb & Gemuts 1976).

The **Lamboo Hills** occupy the western part of the map area. These have an extensive peneplained surface (outlier of the Sturt Plateau), falling from about 400 m at the southern edge of Dixon 1:100 000 Sheet area to about 260 m near the Ord River. From west to east, the fall, across the southern part of the region, is from about 420 m near Springvale Homestead (west of the Halls Creek Fault) to about 360 m near the Albert Edward Range. Low hills and ridges of resistant units rising above this surface are capped by older relict planar surfaces. Small pockets of poorly consolidated (Cainozoic) sediment infill areas within this region. Major drainage is east-flowing and is deeply incised in the east, where minor side-steams are lithologically controlled. This deeply incised area corresponds to the Halls Creek Hills of Dow & Gemuts (1967) and corresponds approximately to the topographic Bay of Biscay Hills. West of a zone about 5 km east of the Halls Creek Fault, the streams are less incised, and side-streams are less influenced by geology. West of the Halls Creek Fault, low hills of resistant rocks rise above a planar surface, an outlier of the Stuart Plateau. Partial erosion of the low hills has left tors, particularly in areas of granite, which are a feature of the landscape. As in the region to the east, there are small pockets of poorly consolidated sediments. Dow and Gemuts (1967) referred to this western region as the Bow River Hills.

The **Ord Plains** occupy the area east of the Albert Edward Range and south of the Dixon Range. On the south they are bounded by the dissected edge of the Sturt Plateau (lithologically controlled, by the outcrop of the Headleys Limestone above the Antrim Plateau Volcanics). Major channels are sharply incised to about 20-30 m below plain level. Minor streams are gullied close to the major channels, but poorly defined on the plain. The Hardman Range, rising 150-250 m above the plain level, is a ridge of fault-bounded resistant Devonian sediments, capped by a relict bevelled surface at 400 m, which is an outlier of the Sturt Plateau. Apart from low ridges of Linnekar Limestone, the remaining Ord Plain has little relief, and in Dixon 1:100 000 Sheet area is at 200-220 m.

The Dixon Range region (southern Bungle Bungle Range) has features that could be used to assign it to either the Lamboo Hills or the Kimberley Foreland. Dixon Range rises above a surface at 260 m which is a continuation of the dissected plain in the Lamboo Hills upstream of Blue Hole on the Ord River. The higher bevelled surface of the Range is at about 300 m, rising locally to 390 m, an elevation similar to the surface on the Antrim Plateau Volcanics, south of McIntosh Creek, at 320 m, rising locally to 400 m. The surface at 260 m is infilled by veneers of sediment, clays near Blue Hole (derived from the Olympio formation) and sands farther east (where their source is the Mahony Group). The gorge cut by the Ord River through the Dixon Range appears to be a feature inherited from an older drainage system, similar to the gorge cut by McIntosh Creek through resistant sandstone in the Albert Edward Range. The compromise adopted in Fig. 2 is to treat the ridge of Dixon Range as part of the Kimberley Foreland, and the planar surface with isolated hills to its north as part of the Lamboo Hills. In effect, this is equivalent to treating Dixon Range as a resistant residual hill within the relict plain of the Lamboo Hills.

REGIONAL SETTING (Figs 1 & 3)

The mapped area lies east of the Halls Creek Fault, north of the Sophie and Saunders Creek domes.

The Halls Creek Fault divides the basement of the East Kimberley region into two distinct tectonic regimes. West of the fault, the geology is complex, involving at least three episodes of intrusion of mafic and felsic bodies, and corresponding related packages of volcanic and sedimentary rocks, dated between 1860 and 1830 Ma (e.g., Page et al. 1995). East of the fault, the Early Proterozoic geological sequence appears much simpler, made up of four discreet packages of sediments and volcanics, probably separated by major time-breaks. The oldest package is exposed in the cores of the domes, south of the area of interest. The remaining three units form the Halls Creek Group. The lowest unit, the Saunders Creek Formation, crops out in the rims of the domes. The middle unit, the Biscay Formation (see below), consists of mafic volcanics and sediments, and the uppermost unit, the Olympio Formation, is predominantly turbidites and contains an interval of A-type felsic volcanic rocks near the base. The Olympio Formation includes turbidites of several ages (shown by SHRIMP zircon determinations). The stratigraphy of the Halls Creek Group (Fig. 4) has been revised by Griffin & Tyler (1992) from previous usage: Dow & Gemuts (1969) originally defined the top of the Biscay Formation as the top of a persistent dolomite layer. This is now recognised as a fragmental volcanic rock cemented by a carbonate matrix (cf. Griffin & Tyler 1992), part of the A-type volcanic interval within the Olympio Formation, known as the Maude Headley Volcanic Member. The top of the Biscay Formation is taken as the "chert" at the top of the uppermost mafic rocks, or in its absence, the top of the uppermost mafic layer.

STRATIGRAPHIC UNITS

HALLS CREEK GROUP

Biscay Formation ṔHr

The upper part of the Biscay Formation consists predominantly of mafic rocks; fine-grained green rocks, originally basalt flows, some coarser-grained layers with amygdaloidal tops, mafic tuffs and/or sediments derived from erosion of mafic rocks. There are meta-pelites, thin layers of sandstone, chert, and in the area investigated, rare small lenses of carbonate rock with dimensions of a few metres. The uppermost beds in the Biscay Formation appear to be cyclic units in which basalt was followed by mafic tuff and sediments, capped by thin layers of chert, and/or carbonate in thin layers and pods. The fine-grained meta-basalts tend to form low ridges and hills. Rocks that may be felsic volcanics are rare. Thin layers of fine-grained cherty rocks, which are possible felsic tuffs, occur in the Biscay Formation north of Grants Patch and east of Katys Yard. The uppermost unit of the Biscay Formation in the Grants Patch and Dry Creek areas is a fine-grained chert or siliceous tuff. A felsic sill (related to the Maude Headley Volcanic Member) with a feldspar-rich granophyric cap, containing abundant zircon and interstitial fluorite, occurs south of the Dry Creek area. Felsic volcanics to the south of this ridge also have A-type chemistry, indicative of the Maude Headley Volcanic Member, and so are probably a faulted outlier of the Member.

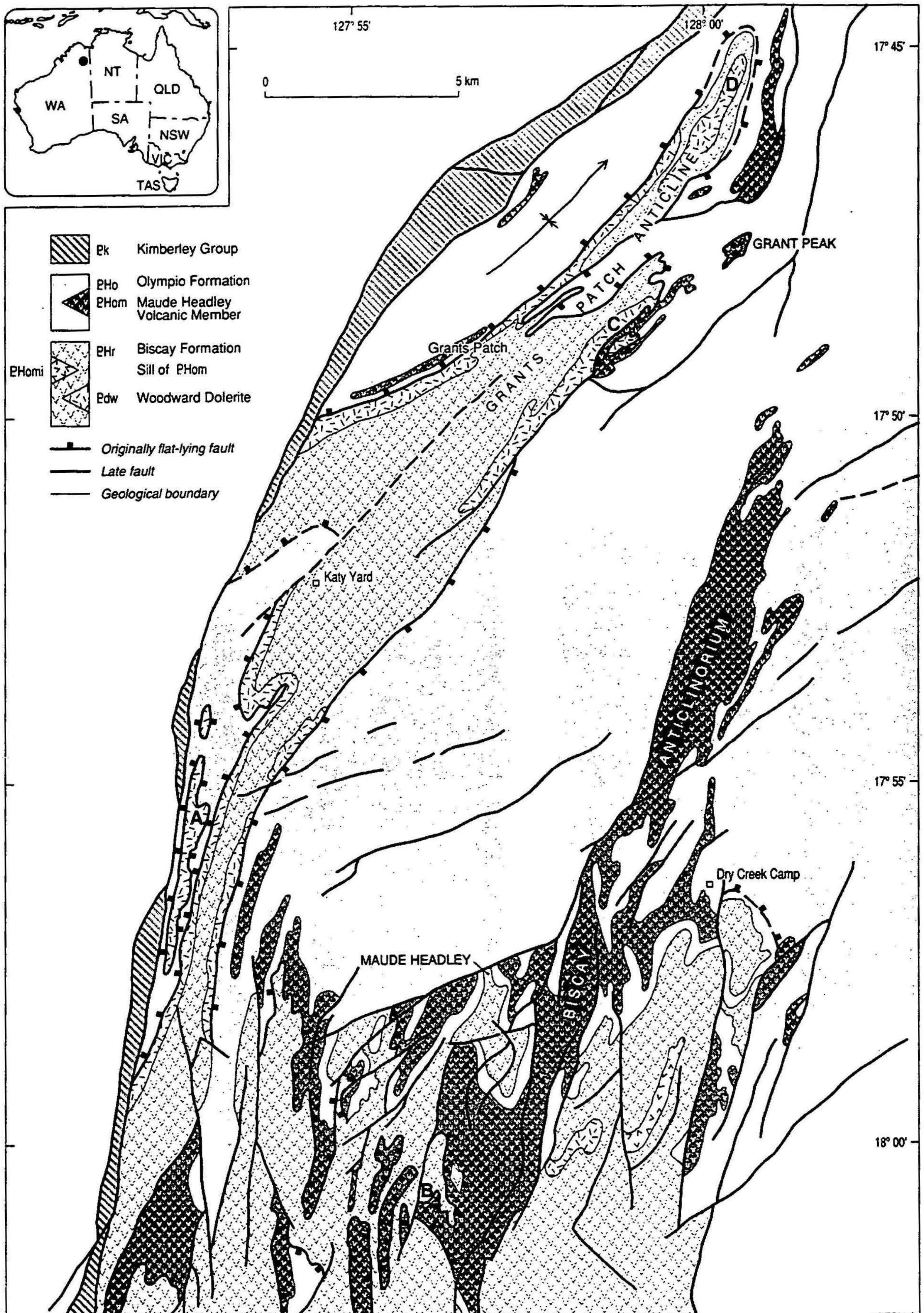

Fig. 3 Simplified geological map of the area from Grants Patch to Dry Creek in the northern part of the East Kimberley district, showing the main geological units east of the Halls Creek Fault. Position of the D_1 detachment indicated; locations A to E refer to reference areas for the D_1 detachment.

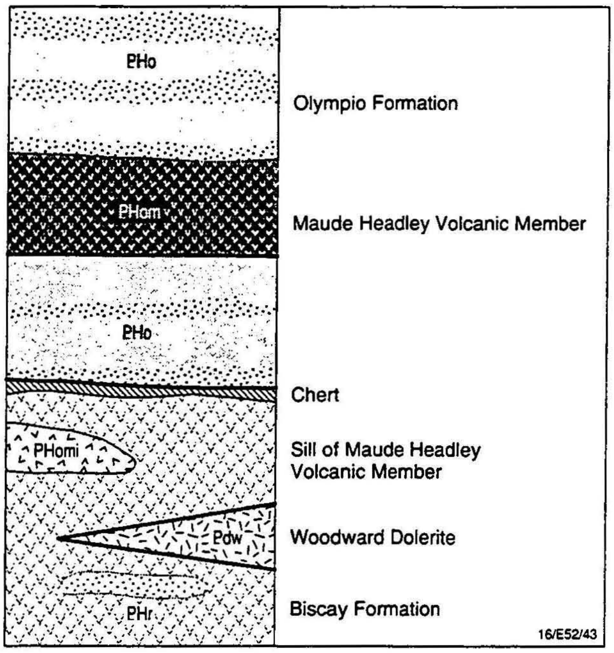

Fig. 4 Stratigraphic section

Sandstone and pelitic sediments occur in the middle part of the Biscay Formation. A band of layered sandstone forms a persistent light-coloured photogeological marker near the faulted top of the Biscay Formation south of Katys Yard. Pelitic sediments occur in and north of the Grants Patch area.

Dolerite Ƥdw

There are two probable dolerite units in the area investigated. The more-widespread type is a recessive unit. It has a red-brown phototone, and, in outcrop, is everywhere recrystallised to a dark green, medium-grained, even-grained rock. In exposures near the base of the weathering profile, it shows spheroidal weathering. It differs from the fine-grained metabasalt in that it is recessive, generally thicker and irregular in form. Analysis of a specimen of the main type showed this to be tholeiitic. Element abundances are similar to those in samples of Woodward Dolerite reported in Wallace & Hoatson (1990) who described the Woodward Dolerite in the area south of Halls Creek township as consisting of numerous sills and dykes of tholeiite basalt, intruding both the Biscay Formation and the Olympio Formation. In the area investigated, all dolerites are entirely within the Biscay Formation. There is no evidence for crosscutting relationships with, or chilling of the margin of the dolerite against, the Olympio Formation. Where contacts against the Olympio Formation are exposed, these are faulted and the margin of the dolerite becomes deformed (see Appendix).

In the Grants Patch district, a second dolerite, with fine-grained margins and relict ophitic texture, forms a thin (~100 m) recessive layer between a thin (<20 m) metapelite within the Biscay Formation and the more extensive dolerite type.

Olympio Formation ƤHo

The Olympio Formation is a thick turbidite sequence which contains near its base an interval of A-type volcanics. This northern unit of volcanic rocks is at the same stratigraphic position as the Butchers Gully Volcanic Member of Griffin & Tyler (1992) (informally, the Brockman Volcanics of Ramsden et al. 1993, and Taylor et al. 1995a&b), south of the Sophie Dome, but is now considered, from SHRIMP zircon ages, to be older, and so has been named separately as the Maude Headley Volcanic Member. For convenience, the intervals below and above the Maude Headley Volcanic Member, in the mapped area, are referred to in this text as the *lower* and *upper* Olympio Formation.

Areas with a high magnetic response correspond to outcrops of very coarse-grained turbidites containing abundant feldspar and small clasts of microgranite. A sample from one of these outcrops has been shown to include in its provenance a terrain much younger than the Maude Headley Volcanic Member. Detrital zircons from a coarse grit (arkosic turbidite) in one of the magnetically anomalous areas include a population as young as 1847±6 Ma and thus derived from a coarse-grained (granitic?) terrain much younger than the Volcanic Member. These outcrops are referred to in this text as the *late* Olympio Formation. There are no data to show whether the magnetic signature is diagnostic of the late sediments (in which case they are not extensive, but are confined to small half graben) or whether much of the coarse-grained upper Olympio Formation should be classified as late sediments.

In the northern Grants Patch and Dry Creek areas, where the contact between the Biscay and Olympio Formations is undisturbed, the contact is conformable, and is marked by a band of chert or siliceous tuff (Fig. 5). In the Maude Headley area, the chert band is absent; and south of Maude Headley, a few pebbles of sedimentary rocks occur at the contact. However, in the southwestern part of the mapped area, the basal contact of the Olympio Formation has been removed by D_1 faulting (see below). As a result, the Olympio Formation, either turbidites or the Maude Headley Volcanic Member, is in faulted contact with mafic rocks of the Biscay Formation or with dolerite (see Structure, also Appendix).

Dow & Gemuts (1969) estimated the thickness of the Olympio Formation to be at least 12000 feet (~ 3.7 km). Page & Hancock (1988) give the thickness as in excess of 4 km.

The Olympio Formation consists almost exclusively of turbidites. These vary from massive, thick-bedded and coarse-grained, to laminated, thinly-layered and fine-grained. Many of the coarse-grained turbidites are essentially lithic arkoses, containing abundant feldspar, and small lithic clasts. The basal part of some turbidite layers is coarse enough to be described as granule conglomerate. One boulder bed was found in the Ord River section, apparently high in the succession. The fine-grained layers are siltstone or mudstones. Mature sandstone is a rare component; one layer northeast of Grant Peak is conspicuous on the air photographs because of a vegetation change, and on the radiometric maps as a low. The outcrops in the east, underlying the Mount Kinahan Sandstone, are dark red to purple in outcrop, have a dark phototone and high gamma-ray spectrometric signatures for K, Th and U. Carbonate rocks, southwest and north of Black Point, supposedly occurring high in the succession (Dow & Gemuts 1969), were not examined. The enhanced images from spectrometrics suggest these may be within the lower part of the Olympio Formation and therefore possibly part of the Maude Headley Volcanic Member. Manipulation of images of the airborne spectrometric data suggests that it may be possible to define subunits within the upper Olympio Formation marked by subtle and gradational variations in U and Th contents. The variations may be the result of changing sources of sediment supply.

Fine-grained pyrite-bearing layers east and northeast of Dry Creek camp may be felsic volcanics, or more likely, volcaniclastic sediments. Thin layers of chert or fine-grained siliceous volcanic ashstone near the base of the upper Olympio Formation, above the Maude Headley Volcanic Member, occur in the Grants Patch area and northeast of Dry Creek Camp. If these chert-like rocks are of volcanic origin, they may result from very late activity in the centre that generated the Maude Headley Volcanic Member. Alternatively, they may have formed as distal deposits from felsic volcanic activity of similar age to the Maude Headley Volcanic Member. The Whitewater Volcanics are the most probable source in the region.

Turbidite layers vary from coarse-grained and thick (2-10 m, apparently greater north of the Ord River) to fine-grained and thin (centimetres to 1m). There is a direct correlation between the thickness of layering and the roughness of the terrain. Thick-bedded, coarse-grained Olympio Formation forms rugged hills, thinly-layered fine-grained Olympio

Formation has subdued relief. Thick layers show graded bedding with soft-sediment basal structures, particularly flames and dismembered fragments torn from the top of the underlying layer. Fine-grained layers show graded bedding and, locally, ripples and ripple cross-bedding.

Clasts are commonly angular to subrounded. Quartz and fragments of feldspar predominate; minor components include red jasper, lithic fragments (microgranite, black shale, fine-grained mafic rock-chips), and tourmaline. Medium- to coarse-grained layers contain flakes of detrital muscovite. (This is a feature useful for identifying the Formation in weathered outcrop.) The boulder bed in the Ord River section contains, *inter alia*, granite clasts and blocks of fine-grained cream-coloured limestone to 0.5 m on their largest dimension. The presence of rounded clasts that are similar to coarse-grained Olympio Formation is taken to indicate some erosion within the Formation, though channels and other erosional features were not found. (If the outcrops belong to the late Olympio Formation, then erosion of the older Olympio Formation may have contributed some sediments to the late Olympio Formation.) In general, the matrix of the turbidites in the Olympio Formation consists of quartz, chlorite and clay minerals. Fresh sulphides are rare in outcrop, but large (to 0.5 cm) cubes of iron oxide and cube-shaped voids occur in some outcrops.

Colour of outcrops ranges from grey through green. In the north and east, red to purple matrices occur in the turbidites, both in the shales and also in coarser-grained beds. Since the clasts include fragments of green shale torn up from within the Olympio Formation which have retained their colour (and thus their redox condition), it is concluded that the red to purple matrix is a characteristic inherited from the source region and not an effect of modern weathering. In the Ord River section, red and green beds are interlayered.

A distinctive dark layer, exposed near Black Point adjacent to the Ord River, consists of carbonate and quartzose rocks. It occurs at a sharp lithological change from coarse-grained turbidites (probably late Olympio Formation) to the west, to fine-grained, thinly layered beds on the eastern side. It appears to be a fault breccia infilling a D_3 fault, rather than a weathering horizon within the Olympio Formation.

For the present, all that can be said is that the Olympio Formation is a composite unit of turbiditic lithologies deposited in more than one cycle of sedimentation. Discussion of the source of the sediments in the Olympio Formation is hampered by the lack of exact knowledge of what part of the Formation is late Olympio Formation. However, some general conclusions can be drawn: The composition of the Olympio Formation, containing high K_2O, Th and U, requires a major contribution from felsic igneous source(s). Feldspar is angular and little weathered, showing that the source was in part coarse-grained (granitic), and granite clasts occur in conglomerate exposed in the Ord River section, together with possible felsic volcanics clasts. Microgranite occurs as small clasts in the late Olympio Formation. The source region also contributed large (to about 0.5 m) blocks of fine-grained carbonate rock to the boulder bed in the Ord River section. Lithic fragments include red jasper, vein quartz, basalt, black shale, chert, microgranite, and reworked Olympio lithologies. Flakes of muscovite are diagnostic of the unit in outcrop for all but the finest-grained rocks, and may be present in these at thin-section scale. These observations show that the source area was continental crust, erosion in the source-area

Fig. 5 Conformable contact, marked by light band of chert, between the Biscay Formation (dark, mafic rocks) and the Olympio Formation (lighter-toned layered rocks), about 1 km southeast of Dry Creek camp.

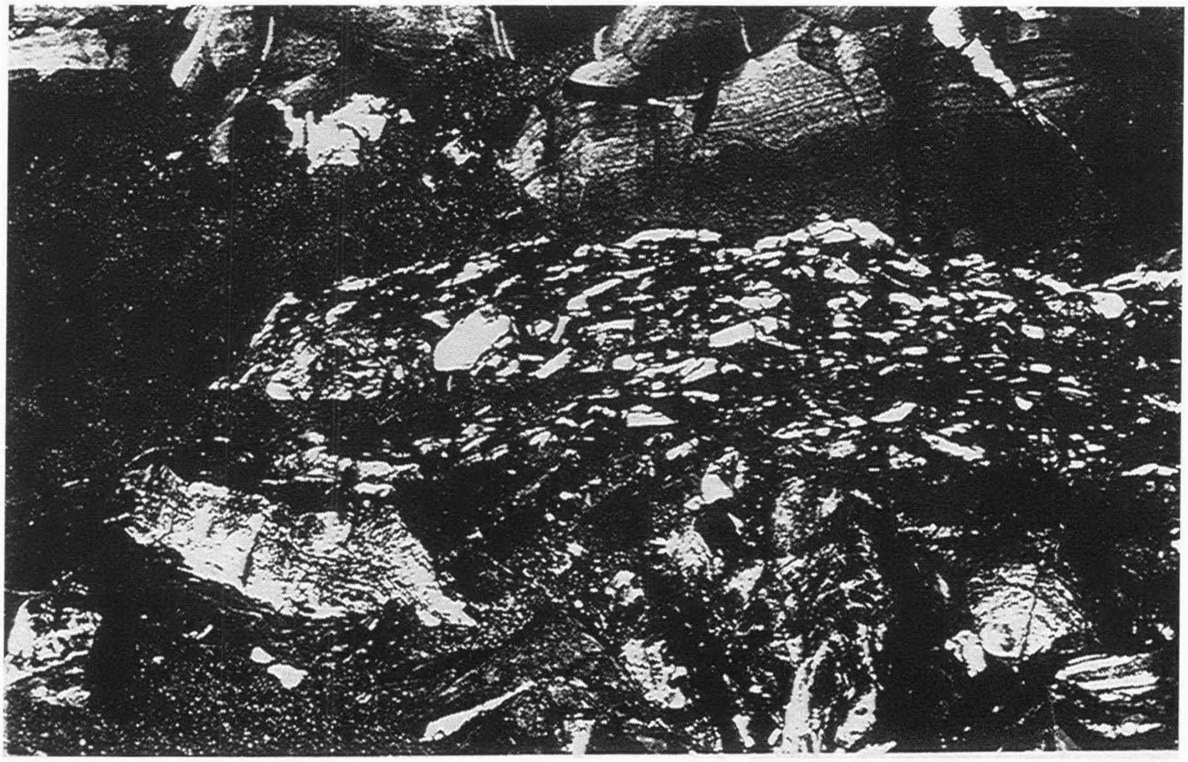

Fig. 6 Reworked material, derived locally from the upper laminated chert-carbonate facies of the Maude Headley Volcanic Member, exposed in the bed of of the Panton River. Note facing at hammer is right-way-up.

was rapid, and transport was only over a short distance. The source of the sediments clearly was not the underlying formations of the Halls Creek Group. Though the Olympio Formation is predominantly green, analyses show moderate Fe^{2+}/Fe^{3+}. The purple or red matrix that is found in turbidites high in the unit suggests an increased contribution from an oxidised source later in the deposition.

The succession is considered to have been deposited below wave-base, as no evidence of disturbance by wave action was recognised. The only evidence for emergent conditions was found at the top of the Maude Headley Volcanic Member in the Panton River section, where cobbles of the laminated layer at the top of the Member are enclosed in the basal upper Olympio Formation (Fig. 6). The boulder bed in the Ord River section contains rounded pieces of the Olympio Formation, but these may be the result of sub-aqueous channel erosion. The sandstone layer, northeast of Grants Peak, which consists of rounded quartz grains in a clay matrix, appears to be a lens within the turbidites, not a beach deposit. No evidence was found to show that these are marine turbidites. A possibility is that the Olympio Formation was deposited in a fault-bounded rift basin. This is supported by the presence of the coarse boulder bed exposed in the Ord River section and by the form of clast in the coarser turbidites. Whether the turbidites are marine or non-marine, winnowing of sediments across a continental shelf did not precede deposition. Hancock (*in* Plumb et al. 1985) stated that the Olympio Formation was deposited in an extensive submarine fan. Therefore the true thickness of the Olympio Formation may be less than the apparent thickness, estimated at about 4 km by Hancock. Possible interpretations that "reduce" the true thickness are that the fan grew outwards towards the east or that the Olympio Formation was deposited over a prolonged period in a set of overlapping ramp basins.

(Hancock *in* Plumb et al. 1985) stated that the sediments were sourced from a greenschist terrain to the north and west. To this should now be added that the source area contained granite and/or granitic gneiss, microgranite, red jasper, and limestone. Geochemistry of the lower Oympio Formation in the Maude Headley area shows high levels of elements that characterise A-type felsic units, and K, U and Th are high throughout the Olympio Formation. A study of detrital zircon populations should provide indications of the units that supplied these elements. That the source for the late Olympio Formation was at least in part different from the remainder, is shown by its magnetic signature. Moreover, this magnetic signature also shows that a magnetic unit was exposed in the source region. Since the Halls Creek Fault system is considered to be left-lateral in its overall movement (e.g., Plumb et al. 1985), the source area proposed by Hancock (op.cit.) would now be, relatively, some distance south from its original position.

An implication of the structural chronology, particularly the D_2 folding, discussed below is that the unit is younger in the east, where the layers having a purple matrix occur. A similar young stratigraphic position for the units with a purple matrix in the head of Osmond Creek (north of Dixon 1:100 000 Sheet area) was suggested by Dow & Gemuts (1969).

Maude Headley Volcanic Member ⱣHom

South of the Sophie and Saunders Creek domes, an A-type volcanic unit (formally, the Butchers Gully Member, informally referred to as the Brockman Volcanics - e.g., Ramsden et al. 1993, Taylor et al. 1995), occurs about 50-100 m above the base of the Olympio Formation (Griffin & Tyler 1992). Zircons from this unit give an age of 1870±4 Ma (Taylor et al. 1995), but SHRIMP zircon analysis of zircons extracted from a pillow lava within the Butchers Gully Member gives a much younger age of 1848±3 Ma. It is inferred that the unit was formed circa 1848 Ma but contains a substantial detrital contribution in the tuffaceous beds, of similar age to those found in the lower Olympio Formation. In the area covered by this report, an A-type volcanic unit occupies a similar stratigraphic position above the base of the Olympio Formation, but contains zircons giving ages of 1856±5 Ma (Page & Hancock 1988), 1857±2 Ma (Page & Sun 1994, Page unpublished data). It therefore is different in age to the Butchers Gully Member, and has been named the Maude Headley Volcanic Member.

The Maude Headley Volcanic Member extends over an area of about 700 km^2 in the north of Gordon Downs and southern Dixon Range 1:250 000 Sheet areas (Fig. 3). It can be subdivided into four extrusive units. A related sill, that is part of the igneous complex, intrudes the Biscay Formation south of Dry Creek camp.

The lowest unit, *ⱣHom₁*, is made up of thinly-bedded siliceous volcanic rocks, which tend to crop out poorly. Recessive layers in this unit may have been originally glassy, but are now clay. Towards the top of the thinly layered unit, pillows in thicker rhyolite indicate sub-aqueous deposition. The thinly layered unit was followed by a unit of fragmental volcanics cemented by a carbonate matrix, which forms prominent dark outcrops. From their "limestone" appearance, these have been described as *dolomite* in some older reports. The fragmental pieces are commonly porphyritic, flattened and bent, and the matrix contains cream-coloured clays, the product of recent weathering, as well as carbonate. Calcite also infills vesicles in pillow lavas at the top of *ⱣHom₁*. Massive, light-coloured rhyolite, *ⱣHom₃*, forms large hills southeast of Maude Headley. At the top of the Member, there is a laminated unit of chert and carbonate, *ⱣHom₄* (Fig. 7), or, in weathered outcrop, chert and ferruginous clay. *ⱣHom₄* forms prominent outcrops along the crests of anticlinal axes north of the Panton River and in the Dry Creek area. Similar banded chert-carbonate rocks are present northeast and northwest of Grants Patch. Northwest of Grant Peak, the laminated unit is capped by about 20 m of black carbonate rock and a thin crystal tuff. In the Panton River section, the laminated unit has been partly eroded, supplying cobbles to the basal upper Olympio Formation. The fifth facies unit, *ⱣHomᵢ*, consists of minor intrusive rocks. A sill, a few hundred metres thick, containing fluorite and abundant zircon euhedra, intrudes Biscay Formation south of Dry Creek camp. This may be compositionally layered. The northern margin has a granophyric texture, suggestive of the upper part of a layered sill, and mineralogy (including abundant zircon euhedra and fluorite), indicative of affinity to the Maude Headley Volcanic Member. An analysis of a sample of the sill, compared to the data from the rest of the Maude Headley Volcanic Member, shows no noticeable deviation from geochemical trends for the other units of the Member. Rocks containing feldspar euhedra up to a centimetre in length are probably

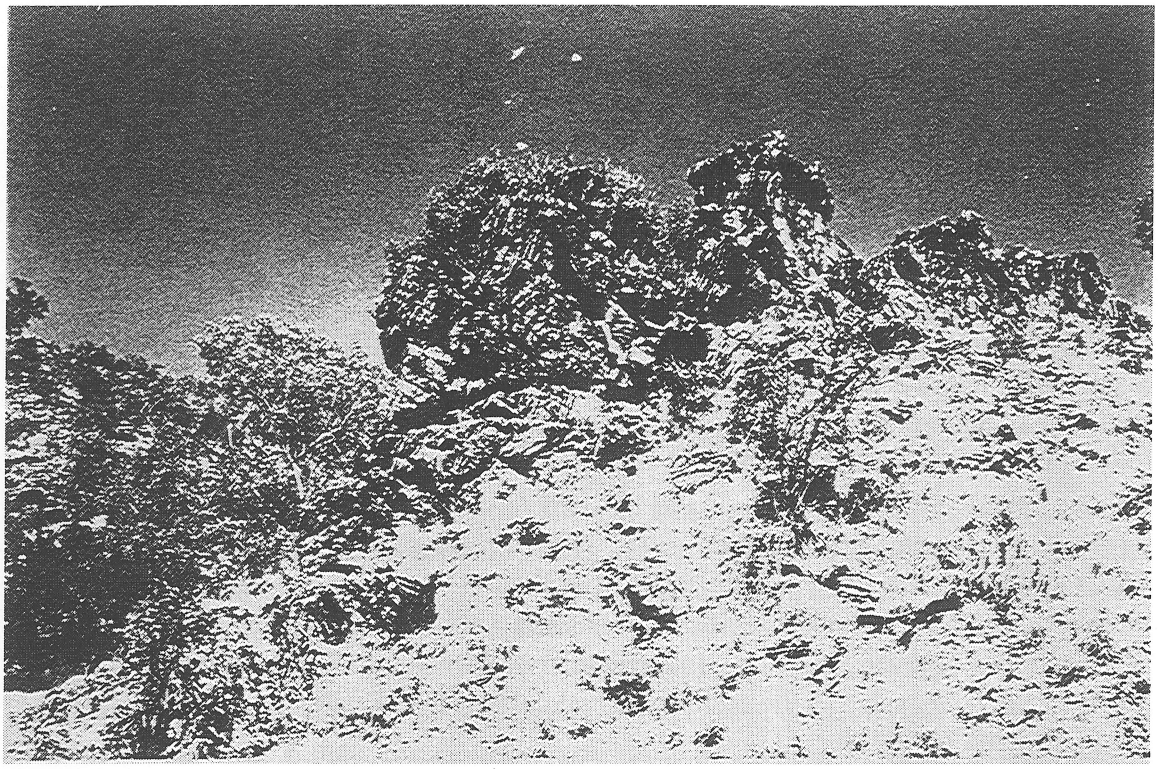

Fig. 7 Outcrop of the laminated chert-carbonate unit at the top of the Maude Headley Volcanic Member. The rough, topographically prominent outcrop is typical of this unit. Tumbled blocks in the lower right of the photograph show the thinly laminated character of the unit.

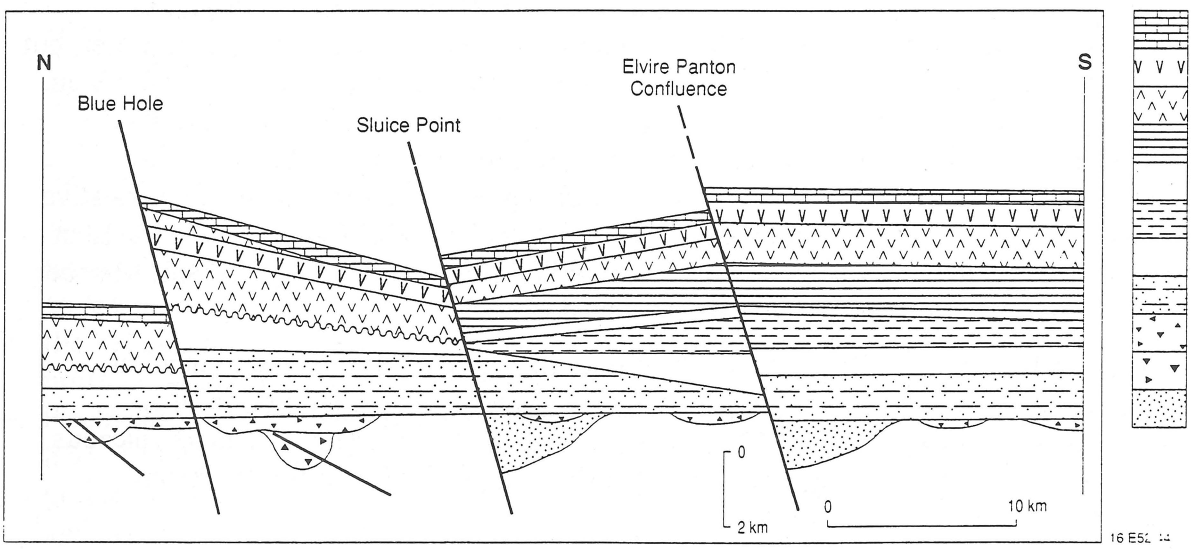

Fig. 8 Schematic block diagram showing the effect of D_4 faulting on the stratigraphy of the cover succession, from the Mount Parker Sandstone to the Headleys Limestone, from north to south along the Albert Edward Range. Datum, base of the Ranford Formation.

proximal intrusions within the volcanic complex. Thick rhyolites and large pillows visible in creek sections may indicate a nearby eruptive centre southeast of Maude Headley.

Commonly, the presence of the unit is shown by prominent dark outcrops of the carbonate-cemented fragmental rocks of *ЕHom₂*. These were not recognised as volcanic in previous mapping but were described simply as carbonate rocks (e.g., Dow & Gemuts 1969). Investigation of the surrounds to these carbonate ridges usually reveals poorly exposed chert-like rocks that are the thinly layered felsic volcanic rocks of *ЕHom₁*. Analysis of material collected from one such ridge, immediately to the north east of the Dry Creek road crossing over Woodward Creek showed high levels of Zr, REE, and TiO_2, confirming that it belongs to the Maude Headley Volcanic Member.

The Maude Headley Volcanic Member is variable in thickness, from several hundred metres southeast of Maude Headley to a few tens of metres in the northwest. Over part of its area of outcrop, the basal part of *ЕHom₁* and the lower Olympio Formation are missing, and the Member rests, with a faulted contact, on the upper Biscay Formation (Warren 1994b, also see Structure). Immediately west of Maude Headley, the D_1 detachment may be higher in the section, so that carbonates of *ЕHom₂* are faulted against lower Olympio Formation.

The four extrusive units suggest the volcanic complex evolved through a cycle of volcanic activity that began with small scale eruptions of highly mobile felsic tuff and thin flows, moved into an explosive, vapour-rich stage, and, after most of the vapour had been released, ended with the growth of domes of viscous rhyolite and slow discharge of fluids enriched in SiO_2 and CO_2.

The Maude Headley Volcanic Member is at least partly, possibly substantially, sub-aqueous. The lower beds contain bomb-like siliceous nodules enclosed in turbidites. Pillows occur south of Maude Headley and in the westernmost outcrops. The carbonate-rich matrix to the fragmental rocks also suggests deposition in water, utilising CO_2 supplied by the volcanic activity. The calcium may have been extracted from seawater, but equally may have had a magmatic origin. The upper chert-carbonate layer is probably an exhalative deposit, formed from sub-aqueous discharge of hot, siliceous and CO_2-rich fluids in the waning stage of volcanic activity. The carbonate rocks above the chert-carbonate rocks near Grant Peak provide supporting evidence for a submarine exhalative origin. The cobbles in the Panton River section are indicative of erosion during transient emergent conditions, but the turbidites that overlie the Maude Headley Volcanic Member show deep-water conditions were re-established (Fig. 6).

The available chemical data (see Geochemistry) show the Member has the chemical characteristics of A-type felsic rocks. The volcanics formed by fractionation of an intraplate mafic magma modified by a small crustal input. The Member is more siliceous and less enriched in REE, Zr, and Y than the Butchers Gully Member (Brockman volcanics), about 25 km to the south.

KIMBERLEY BASIN SUCCESSION

The outcrop of the Kimberley Basin succession is confined to a narrow corridor between faults along the Halls Creek Fault. Only two units are present. The King Leopold

Sandstone forms topographically prominent outcrops; the overlying Carson Volcanics are recessive. The Carson Volcanics were previously mapped as Fishhole Dolerite but Griffin & Tyler (1992) equated the Fishhole Dolerite to the Carson Volcanics of the Kimberley Group. Outcrops are generally dark green, medium- to fine-grained, and some retain amygdaloidal texture. Coarser-grained rocks may be sub-volcanic intrusive rocks. Carbonate rock is present locally. Two samples from the Carson Volcanics were collected for whole-rock analysis. Both are green rocks, somewhat fractured, but without any superimposed fabric, and appear to be extrusive volcanic rocks, metamorphosed to prehnite-pumpeyllite grade.

YOUNGER COVER SUCCESSIONS

The cover succession, from the Mount Kinahan Sandstone to the Mahony Group, is exposed in the east of the Dixon Sheet area. Lower units, up to the base of the Antrim Plateau Volcanics, are preserved in fault blocks, and there are several unconformities within the succession (Fig. 8). Non-deposition or removal of units by erosion, was controlled by differential movement on D_4 faults.

The Osmond Range succession of Dow & Gemuts (1969) contains only the Mount Parker Sandstone and the Bungle Bungle Dolomite, as the Fishhole Dolerite has been moved to the Kimberley Basin succession (Griffin & Tyler 1992). Previously the Osmund Range succession was considered to be present in the mapped area, but the units are now ascribed to the late Proterozoic Ruby Plains Group which crops out in the central and south parts of the Dixon Sheet area, in two blocks (probably garbens controlled by D_4 faults during glaciation) and a thrust sheet. The Mount Kinahan Sandstone (and the Eliot Dolomite, which is not preserved in the Sheet area) were partly stripped by the Late Proterozoic glaciation. Tillites, mainly the Moonlight Valley Tillite with its distinctive cap of flaggy dolomite, form a thin discontinuous layer resting on the glaciated surface over either the Mount Kinahan Sandstone or Olympio Formation. The recessive shales of the Ranford Formation rest on tillite or on the glaciated surface. Though the contact between the Olympio Formation and cover units is locally faulted, the glaciated surface and the Moonlight Valley Tillite are more extensive than was indicated in the first edition of the Dixon Range 1:250 000 geological map. Immediately east of Sluice Point, the lower Mount Forster Sandstone lenses out and the upper Sandstone becomes much thicker.

A major unconformity at the base of the Antrim Plateau Volcanics is also controlled by D_4 faults. From the southern Dixon Sheet boundary north to Sluice Point, the Antrim Plateau Volcanics rest on Timperley Shale. At the southern end of the McIntosh Creek section, the Volcanics overlie a thinned (probably eroded) lower Mount Forster Sandstone, but, north of McIntosh Creek, rest on the upper Mount Forster Sandstone. The Blackfella Rockhole Member, composed of breccia and scoria with potassium-rich cement, occurs from the Ord River southwards. Immediately to the north of the Ord River, also in a half-graben controlled by a D_4 fault, the Member is locally overlain by a basalt unit, which is apparently not found elsewhere.

RUBY PLAINS GROUP

Mount Kinahan Sandstone ꟼPk

The Mount Kinahan Sandstone consists of massive ridge-forming orthoquartzite, previously mapped as Mount Parker Sandstone. Minor revision to the distribution of "Mount Parker" Sandstone have been made. The prominent ridge south of Sluice Point is overlain by Moonlight Valley Tillite, and so is Mount Kinahan Sandstone, not Mount Forster Sandstone as shown on the first edition 1:250 000 map. Investigation of a ridge south of Blue Hole, shown on the first edition as Mount Parker Sandstone, showed this consisted of weathered Olympio Formation with a purple matrix.

DUERDIN GROUP

Fargoo Tillite ⱣEf

Lenses mapped previously as Fargoo Tillite occur north and south of Blue Hole (Dow & Gemuts 1967). Both are in locations where sedimentation may have been controlled by basement faults. Only the southern lens was visited as part of this survey. It is poorly exposed. Most of its area of outcrop is covered by a veneer of poorly sorted rounded cobbles to boulders, almost exclusively of quartzite. The basal unit, characterised by a dark photo-tone, consists of gritty sandstone cemented by calcite, and a brown to cream carbonate bed.

Moonlight Valley Tillite ⱣEm

The Moonlight Valley Tillite is a recessive discontinuous layer, resting for the most part on Olympio Formation. A fragment of glaciated pavement was found south of McIntosh Creek, where a fault had previously been inferred (e.g., Dow & Gemuts 1967). Similarly, to the north of Blue Hole on the Ord River, there was no evidence for a faulted contact between basement and cover.

The unit is poorly exposed, and its presence is commonly shown by a veneer of rounded cobbles of quartzite. In the photointerpretation, the unit has been picked out from the distinctive white band formed by the marker dolomite, a cream or pale pink flaggy dolomite, less than 10 m thick, at the top of the Tillite. North of Blue Hole, sandstone with a calcareous matrix occurs, apparently in place of the marker dolomite. Where the Tillite crops out, usually in creek banks, it has a clay matrix containing dispersed clasts. As well as the predominant quartzite clasts, other rock types occur, including a large (several metres) boulder of the Olympio Formation north of McIntosh Creek.

Ranford Formation ⱣEs

The Randford Formation is a recessive flaggy sandstone to shale unit. Good outcrops are restricted to creek beds and banks. Exposures in the valley south of McIntosh Creek are red-brown silty sandstone. It is extensively involved in the thrust complex south of the Panton River.

ALBERT EDWARD GROUP

The Albert Edward Group consists of Mount Forster Sandstone, the recessive Elvire Formation, Boonall Dolomite and recessive Timperley Shale. From McIntosh Creek northwards, only the Mount Forster Sandstone is present.

CAMBRIAN

Antrim Plateau Volcanics Єa

The Antrim Plateau Volcanics form a dark-toned unit on the air-photographs. Casual inspection from tracks suggest several flows are present. A very dark-toned layer, better defined on B&W RC9 photographs, almost everywhere underlies the Headleys Limestone, except southeast of Blue Hole Yard, where a thin lighter-toned unit, probably a basalt, occurs between the dark-toned layer and the Limestone. The dark-toned layer has been correlated with the Blackfella Rockhole Member (Mory & Beere 1988, following Sweet et al. 1974, who reported the Member as being exposed in regions bordering the Hardman Basin), the reference section of which is east of the area mapped. A thin lighter-toned unit, perhaps a sandstone, occurs within the sequence in the section along McIntosh Creek. In the southern part of the Dixon 1:100 000 Sheet area the Antrim Plateau Volcanics rest on the recessive Timperley Shale, but from about 1.5 km south of McIntosh Creek northwards, the Volcanics either rest directly on, or are separated by a thin recessive layer from, the Mount Forster Sandstone.

Headleys Limestone ЄNh

The Headleys Limestone is a pale grey flaggy limestone exposed in dip slopes above the Antrim Plateau Volcanics.

TERTIARY AND QUATERNARY UNITS

The Tertiary and Quaternary units include both depositional units and weathering profiles. Although some outcrops were seen in the course of work on the basement, most of the comments are based on photointerpretation. Letter symbols are those used on the 1:25 000 compilation sheets. Symbols that have replaced these, and are currently in use (late 1996) are placed in brackets.

Unit *Czf* corresponds to Unit *Tf* as used by Mory & Beere (1988) for a dark red photogeological unit overlying Nelson Shale south of Turner Outstation. Similar material overlies Nelson Shale and Panton Shale between the Ord River and the southern edge of the Dixon Range. It is characterised by dark rounded outcrops, probably covered by low dark-green shrubs, and lacks any trace of the layering in the underlying Shales. In both the areas where Unit *Czf* occurs, a pallid zone does not appear to be exposed, and the unit passes directly down into red shales (Nelson or Panton Shale), which are exposed in the bottom of drainage channels. It is therefore not a trizonal weathering profile, but may be either a ferruginous palaeosol or a ferruginous crust (ferricrete) developed on red shales. the unit *Czf* unit probably formed during development of the Ord Plain in the late Tertiary or Pleistocene in low-lying, flat-lying areas during episodes of marked seasonally variation in rainfall. *Czf* is overlain by *Ts* sediments and by *Qs*. It is being dissected by present drainage.

Unit *Ts* has been used for thin sediments that infill topographic lows in the Bay of Biscay Hills, and valleys in the Albert Edward Range and are spread over the Ord Plain. These were seen at Blue Hole, adjacent to the Panton River in the Albert Edward Range, and in the Grants Patch area. Unit *Ts* rests on Biscay Formation, Olympio Formation, on cover units of Proterozoic-Mid Palaeozoic age, and on Unit *Czf*. It is overlain by sheet sands of

Unit *Qs*. Topographic considerations indicate two separate units of Tertiary sediments. Those sediments in the Ord Plain and in the Elvire valley are at a lower topographic level and considered to be younger than the sediments which infill topographic lows in the Lamboo Hills.

The (older) *Ts* sediments at the higher topographic level include pockets of sediments capped by black soil near Katys Yard and east of Alice Downs airstrip, and light-coloured clays near Blue Hole Yard. Some sheet sand (Unit *Qs*), which covers flat-lying areas between the Dixon and Bungle Bungle Ranges may belong to the same episode of sediment deposition. The older *Ts* sediments may have been deposited early in an episode of north-directed tilt and ponded drainage, proposed by Warren (1994a) as the time when the Lawford Beds infilled drainage in the Sturt Plateau and the north-flowing Ord system was initiated.

Near Blue Hole, flat-lying grey to pale brown sediments cap steep banks to the north of Blue Hole and vary from 2-5 m thick. The upper surface of the unit is at about the same topographic level as the planar surface on the Olympio Formation to the west. In the vicinity of Blue Hole Yard the sediments infill a valley and ridge topography over steeply-dipping cover rocks. As a photogeological unit, it is readily delineated because of its tendency to be very poorly vegetated. The sediments are poorly lithified, and are being etched into a bad-lands topography by modern drainage. They are fine-grained, very poorly stratified and somewhat calcified. Carbonate minerals have precipitated around organic structures, preserving fragments of tree roots. North of Blue Hole Yard, the strike ridge terrain of the steeply dipping Late Proterozoic to Palaeozoic succession is infilled by a thin veneer of sediments, probably of similar age.

The *Ts* sediments at the higher topographic level may be correlates of the White Mountain Formation in the east of Dixon Range 1:250 000 Sheet area.

The White Mountain Formation consists of nearly 30 m of non-marine and marine sediments, which have been faulted, tilted and uplifted. The marine sediments contain foraminfera which cannot be older than Miocene (Lloyd, 1968a), and Lloyd (1968b) reasoned for a Miocene age for this unit. The most probable ages would correspond to the periods of high sea-stand which occurred in the early Miocene, between 25 and 21 Ma or in the mid Miocene, between about 18 Ma and 14 Ma, when sea level was approximately 150 m above present levels (Haq et al. 1987). The White Mountain Formation is now at an elevation of 270-300 m, and the marine beds are at the top of the Formation. Dow & Gemuts (1967) suggested the present elevation of the White Mountain Beds was partly the result of uplift along a nearby fault to the east, and their present elevation must in part be due to regional tectonic uplift, of approximately 150 m. The base is about 25 m higher than the sediments near Blue Hole Yard. The difference in elevation between the White Mountain Beds and *Ts* sediments may represent a component of west-directed tilt in the episode that created the depositional environment in which the younger *Ts* sediments were deposited. (As a test this hypothesis, the younger *Ts* sediments should be thicker in the west of the Ord Plain, and thin eastwards.)

The younger *Ts* sediments probably were deposited soon after the episode of weathering represented by Unit *Czf*. Photointerpretation suggest thin sediments are widely distributed over the Ord Plain. The Ord and Panton channels are cut down through these to bedrock, allowing their thickness to be estimated as about 10 m. They are pale orange to cream, grading upwards to cream and capped by a flat surface (*Czr/Qb*) which lacks trees or shrubs. They appear to have a much-gullied bad-lands surface close to incised stream channels. (This was used to delineate the unit relative to other units in the Ord Plain.) They probably were deposited in an episode of ponded drainage, infilling a subdued landscape on a precursor to the present Ord Plain.

In the floodplain of the Elvire River, sediments infill a strike-ridge terrain on the edge of the Albert Edward Range, and are presently being incised by the main streams. Their thickness is about 20 m. Some large boulders were removed in a trenching operation near the confluence of the Elvire and Panton Rivers (apparently to assess their gold content), but for the most part, the sediments are fine-grained. They appear to form low cliffs adjacent to the Elvire River, and are poorly vegetated. These sediments are at a similar topographic level to, and may be correlates of, the thin clays in the Ord Plains.

Sheet sand, mapped as Unit *Qs*, occurs east and west of Piccaninny Creek on a plateau surface at 240-260 m. This may be windborne sand brought by southeast winds in the Quaternary and deposited against the higher hills of the Dixon Range. However, it may be older, a correlate of the Lawford Beds and/or of the White Mountain Formation, derived from erosion of the nearby Devonian sediments, and deposited during an episode of ponded drainage in the Tertiary (cf. the Lawford Beds, Warren 1994a). Sheet sand between the Dixon Range and the Panton River is at a lower topographic elevation and overlies both the *Czf* unit and the younger *Ts* unit. It predates the present incised drainage, and is therefore either latest Tertiary or early Quaternary.

Black soils, *Qb*, occur south of Katys Yard and in small areas between Katys Yard and Grants Patch. These have been locally incised to bedrock by present drainage, and are only a few metres thick, formed over either thin sediments or bedrock. They are poorly vegetated, dark soils which become swampy during wet spells. They occupy topographic lows in the landsurface above the present drainage and so are developed over the older unit of *Ts*. Small areas of poorly vegetated soils, with the "fingerprint" appearance of black soil on the airphotographs, occur east of the Albert Edward Range, to the north of McIntosh Creek.

The Ord Plain is generally described as being covered by black soils (e.g., Mory & Beere, 1988). On airphotographs, the plain lacks the "fingerprint" pattern that characterises the black soils developed on the Lawford Beds in Antrim and Nicholson, but it is grassed, without any shrubs or trees. It is covered by thin soils developed over the redbeds of the Panton Formation and Nelson Shale and over the younger *Ts* sediments. In the early stages of photointerpretation, the surfaces in the Ord Plain were designated *Czr*, as *young relict surfaces*, following Mory & Beere (1988), but have now been moved to the more general category of black soil plains.

STRUCTURE

The structural evolution east of the Halls Creek Fault can be simplified into four phases. D_1 and D_2 are single, short-lived stages. However D_3 and D_4 are more complex. D_3 may

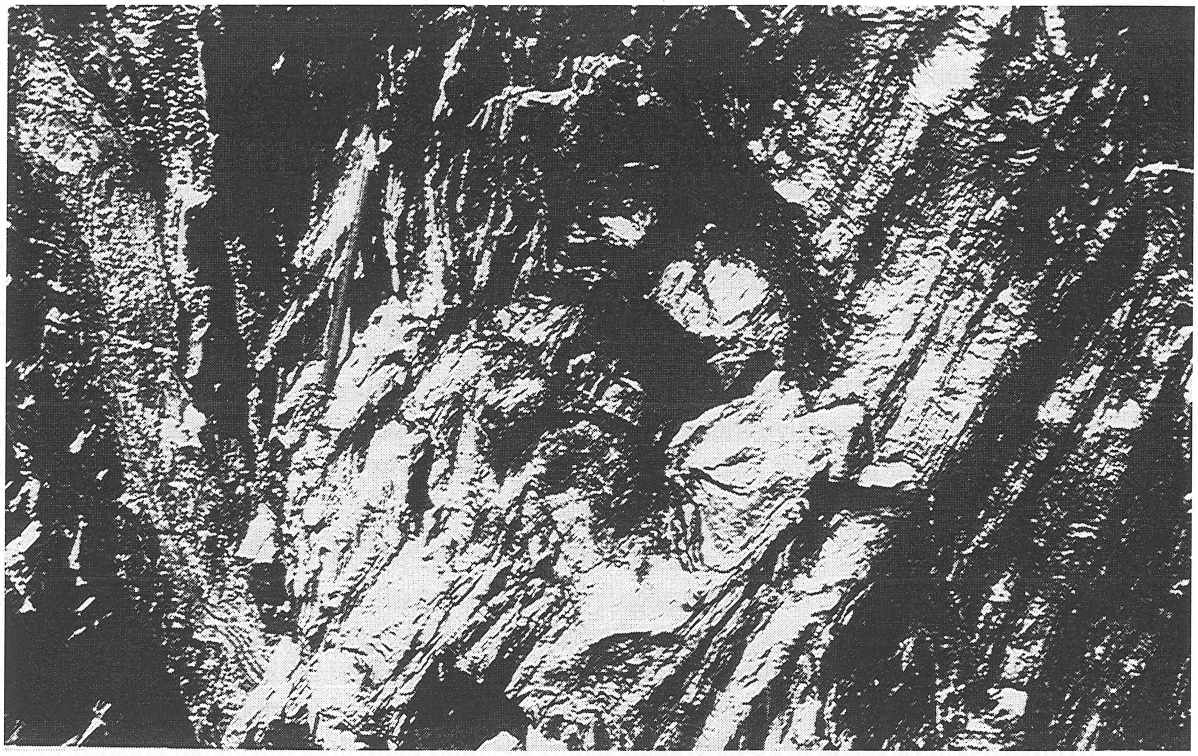

Fig. 9 Refolded D_1 lineations in deformed Maude Headley Volcanic Member, exposed in the bank of Woodward Creek.

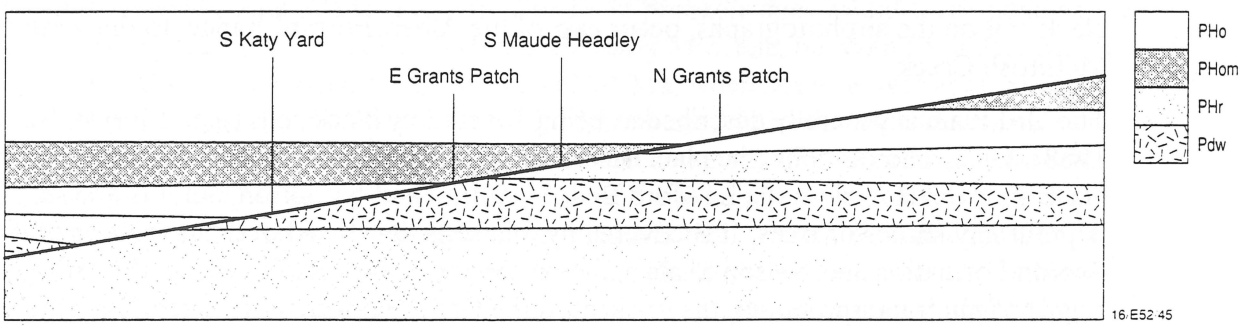

Fig. 10 The stratigraphic sections (see Appendix, locations shown in Fig. 3) arranged to delineate a low-angle normal fault.

be multi-stage. D_4, as deduced from its relationship to Late Proterozoic-Early Palaeozoic sedimentation and deformation, certainly was multi-stage, involving both compression and extension at different times.

D_1 detachment: *Narrow (3m) zones of laminated rocks, corresponding to excised section.*

The stratigraphic section from the upper Biscay Formation to the Olympio Formation above the Maude Headley Volcanic Member is reasonably well-established (e.g., Griffin & Tyler 1992, also see above). However, regional mapping revealed gaps in the expected stratigraphic continuity (see Appendix structure). The discontinuities were found to correspond to thin (~ 3 m) zones of laminated or Brecciated rock. These zones are commonly recessive, cropping out poorly, but where siliceous Maude Headley Volcanic Member is involved, they form excellent outcrop (see Fig. 9). Examples of representative sections are described in Appendix structure, and their locations are shown in Fig. 3.

The faults are not mylonitic, but formed through brittle deformation (e.g., Fig. 11). In the section south of Katys Yard (locality A in Figure 3, Fig. A1), lower Olympio Formation has been faulted against dolerite. Close to the D_1 fault, the dolerite is Brecciated and calcite infills tension gashes (Fig. 11). Quartz may have also infilled gashes, as fragments of lineated quartz occur in float. The Olympio sediments take on a close-spaced fracture cleavage parallel to the fault. In thin section, sample 93525131, from the D_1 surface in the Maude Headley Volcanic Member (locality B in Fig. 3, Fig. A2), has very fine layering. The surface lineation shows that this is not a syn-depositional fabric, but it is consistent with subsequent metamorphism of a fine-grained tectonically-laminated protolith to upper greenschist facies. Lineations are common on D_1 surfaces where the Maude Headley Volcanic Member has been involved, and are refolded by later structures. These lineations may have been slickensides before metamorphism, and offer potential for determining direction of movement in detailed studies.

The zone of missing section at each locality, considered by itself, approximates a bedding-parallel fault. Appraisal on a regional scale shows that the discontinuities can be can be translated into segments on a detachment surface that is geometrically a low-angle normal fault (Fig. 10). Apart perhaps from the D_1 detachment inferred in the Dry Creek area, all observed and inferred D_1 deformed surfaces can be integrated into a single detachment surface that cuts progressively down-section, from north to south and from east to west. The D_1 surface can be traced or inferred from elision of section over an area stretching about 35 km north to south and 17 km east to west. (N.B. D_2 folding caused east-west shortening.)

Brittle-style deformation is consistent with the probability that this D_1 detachment formed under a thin cover, of no more than a few kilometres (that is, beneath no more than the probable thickness of the Olympio Formation, estimated at 4 km, see above). Though the timing of D_1 is not known, observation of overprinting by later structural stages shows that the detachment occurred early in the structural evolution. It may have been contemporaneous with mid-crustal extension and deposition of the younger, coarse-grained turbidite unit in the late Olympio Formation in a ramp or extensional basin some time after 1847 Ma. Alternatively, the D_1 surface may be the root-zone of a gravity slide

Fig.11 Deformed dolerite close to the D_1 detachment surface in the area south of Katys Yard. Calcite fills small tensional voids within the deformed dolerite.

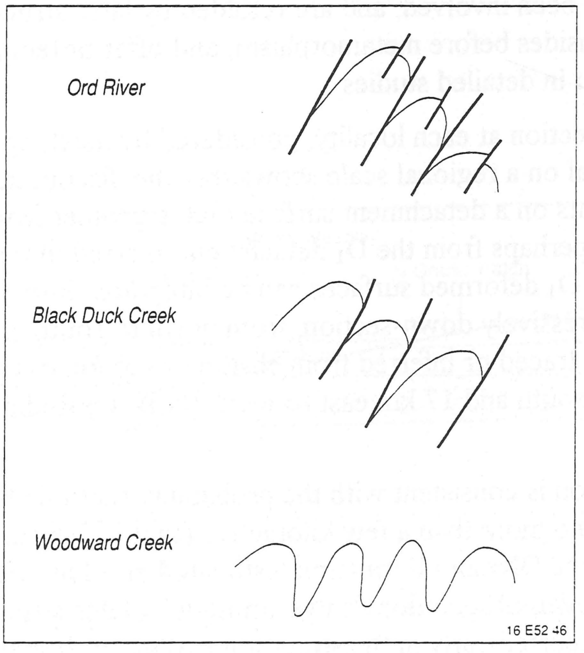

Fig. 12 Schematic cross sections showing the change in style of D_2 faults from south to north.

translated towards a rapidly deepening trough to the west (e.g., the trough in which the Koongie Park succession was deposited).

Subsequently, this D_1 low-angle detachment has been folded as part of the sequence, and behaved as a stratigraphic horizon locally; though its nature is obvious at the regional scale. Similar faults may be present higher and lower in the succession, but are less unlikely to be recognised, as disruption of the section would be less obvious.

The stratigraphic discontinuity caused by this early detachment has reduced the prospectivity of a considerable portion of the Grants Patch-Maude Headley-Dry Creek gold district. From empirical observations, Warren (1994c) proposed that gold was mobilised by fluids moving along D_3 faults, and precipitated by mafic rocks in the uppermost Biscay Formation in areas where the stratigraphic section from the mafic upper Biscay Formation through the lower Olympio Formation to the Maude Headley Volcanic Member was complete. Dolerite played the same role as the mafic upper Biscay Formation in the Katys Yard - Grants Patch area. The effect of the D_1 surface has been to destroy the stratigraphic continuity, removing the turbidites of the lower Olympio Formation, and placing Maude Headley Volcanic Member against mafic rocks of the upper Biscay Formation northeast of Grants Patch and south and southwest of Maude Headley; leaving these areas barren.

D_2 compression : *Upright to overturned folds which become tighter northwards (and higher in the section)*

The second stage of deformation was compressional, marked by the formation of upright to overturned folds. This folding affects the coarse-grained turbidites in the upper Olympio Formation, but is not present in the overlying cover succession. The area of outcrop of the Olympio Formation has an airphoto pattern dominated by tight to open folds whose axial traces trend slightly east of north. Ground traverses show these to be upwards-facing north-plunging anticlines.

The D_2 folds change character from south to north. In the southern outcrops, there is no axial-plane fabric present in D_2 folds. Farther north, axial-plane fracture cleavage serves as a plane of weakness for compression. In the area south of Maude Headley, probable D_2 folds have shallow plunges to both north and south, and tight synclines are preserved between more open anticlines. The Biscay Anticlinorium and the Grants Patch Anticline (see Fig. 3) are both regional scale D_2 folds. Their form and shallow plunge to the north are typical of D_2 anticlines in this area.

North from Black Duck Creek to McIntosh Creek, the synclines are sliced out, the anticlines are overturned to the east and plunge shallowly northwards. In the main, beds dip westwards at about 70°. Less commonly, overturned beds, dipping westwards at approximately 70°, are exposed in creek sections. Synclinal structures are rarely found, and are very tight. Small-scale structures suggest that the main fold pattern can be represented by overturned folds whose axial planes dip west at about 70°, in which the synclines have been tightened and transformed into small-scale thrust zones (Fig. 12).

In the section along the Ord River, the crests of outcrop-scale anticlines are breached by incipient east-directed thrusting (Fig. 12).

The implications of the observations are that, firstly, the D_2 folding has caused a considerable amount of shortening across the Biscay Anticlinorium, which has been enhanced by east-directed thrusting; and, secondly, that overall, the Olympio Formation youngs from south to north and also from west to east.

The timing of D_2 falls between 1845 Ma and deposition of the Kimberley Group; as no structural difference was noted in the field between the coarse-grained magnetic unit containing zircons of this age and the remaining Olympio Formation.

D_3 compression and extension: *N to NNE faults and upright folds*

D_3 faults are narrow zones, trending near north-south. They are poorly exposed, but appear to be steeply-dipping. On their east side, there are zones of folds that have axial traces parallel to the faults and have variable plunge. These folds are tight close to the faults, but on a regional scale become more open away from each fault. Their effects can be recognised in outcrop for distances up to a kilometre. They overprint the regional fabric elements, refolding lineations and creating intersecting cleavages. Overprinting of D_2 by D_3 is recognisable from the presence of slate pencils, and in the Black Duck Creek section, where there are no D_2 synclines, the presence of D_3 synclines. D_3 folds are accompanied by an increase in grain size and probably a slight increase in metamorphic grade.

Metamorphism accompanying this phase of folding produced silky phyllites from finer-grained sediments. South of Katys Yard, the D_3 folds are accompanied by an increase in grain size and probably a slight increase in metamorphic grade. In the Mount Slinkey district, a zone of Qtz-Chl-Cal veins occurs adjacent to a D_3 fault, and pyrite crysts (or cubic voids or iron oxide pseudomorphs) are common in outcrop.

Near Grants Peak, D_3 appears to have involved a component of near-horizontal transport, which has formed sheath-type folds refolding D_1 lineations. This may be related to a change in direction in two near-parallel D_3 faults, from north-south near Monkey Yard (the abandoned yard about 9 km north-northeast of Grant Peak known locally by this name) to south-southwest trending near Grants Peak. The upper part of Grant Peak is deformed Maude Headley Volcanic Member, surrounded by Olympio Formation. The form of the outcrop may be due solely to interaction between D_2 or D_3 folding and topography. However, there are small-scale sheath folds in the felsic volcanics and the Olympio turbidites are locally sheared and deformed. Both these features suggest that the fold geometry may be more complex, and possibly there is a macroscopic D_3 sheath fold in this area.

The age at which the D_3 structures developed is not known. Major left-lateral movement on the Halls Creek Fault system is known to have occurred at the time that the Carr Boyd Group was deposited in the late Mesoproterozoic (Plumb et al. 1985). The northwards direction of transport shown by the sheath folds is consistent with this movement. D_3 may therefore be transpressive in a regional context, even though its effects seems to be simple compressional on a local scale.

Possible reactivation of D_3 faults

D_3 structures have been reactivated at several localities: Near Monkey Yard, the exposures on the west side of the fault are at a slightly higher metamorphic grade than those to the east, even though D_3 folding indicates west-directed thrusting. South of Maude Headley, where the D_3 folds are also on the east side of the fault, the section west of the D_3 fault is exposed at a deeper level than to the east. The inference is that D_3 faults were re-activated in a later, extensional, stage, probably related to development of D_4 faults. Warren (1994c) suggested that the D_3 faults formed the pathway for movement of gold-bearing fluids. Such fluid movement would have been more feasible in an extensional environment.

D_4 extension and compression *Isolated structures: Major faults and minor structures (e.g., isolated folds, kink bands, quartz veins) with trends between 40° & 80°.*

D_4 faults can be traced into the cover sequence, where they influenced both sedimentation and erosion. They are therefore of Neoproterozoic to mid-Palaeozoic age, or were reactivated during this period. Extension during deposition of the cover sequence, and compression in the formation of the Albert-Edward Trust Complex, was transmitted through these faults. Some of the folding south from Maude Headley appears to be related to the major D_4 fault just to the north, and thus is D_4. Airphoto-interpretation shows that, a few kilometres east of Dry Creek, doubly-plunging drag folding produced through differential movement on parallel D_4 faults has near north-south axes. This folding is similar in form to the folds developed between faults in cover rocks north of old Flora Valley homestead (Antrim 1:100 000 Sheet area) and may be of similar age (mid-Palaeozoic?).

Though D_4 structures are seen to overprint D_3 locally, the possibility that D_3 and D_4 are related and overlap in time should be considered. The expression of D_3 suggests it may be a deeper version of the thrust-complex that affects the cover sequence in the Albert Edward Thrust Complex. Alternatively, D_3 structures may have been reactivated in the mid Palaeozoic.

GEOCHEMISTRY

Samples for geochemistry were collected from the mafic rocks in the Biscay Formation, the Olympio Formation, the Maude Headley Volcanic Member and the Carson Volcanics.

Olympio Formation

Five samples were collected from the turbidites of the Olympio Formation. The results show the sediments are mainly derived from a granitic source. However, they include a component from a mafic source, shown by moderate levels of Cr and Ni. U and Th contents are also moderate, accounting for the high levels of both recorded in the airborne spectrometric data.

Maude Headley Volcanic Member

A suite of samples from the Maude Headley Volcanic Member were analysed by Page & Hancock (1988). Additional samples were collected as part of the regional mapping program. The samples of the Maude Headley Volcanic Member are generally siliceous (69-78 weight percent SiO_2). The carbonate-rich rocks are weathered, and difficult to sample for fresh material. The data include three samples from the carbonate unit, one relatively fresh and the remaining two weathered to some degree. Of these, the freshest sample has high CaO and LOI, but also has high TiO_2 and low Zr (269 ppm) and thus low *zirconium number* (zr = 100Zr/[Ti + Zr]) -see below, and so is among the least chemically-evolved samples. The analyses show that the Maude Headley Volcanic Member is typically A-type (e.g., Eby 1990, Whalen et al. 1990), characterised by high Nb, REE, Zr, Y, Ga, Ga/Al and Zn. Sn and Ta contents are slightly elevated (Fig. 13). There are no data for F, but the common presence of accessory fluorite shows a significant F content. The unit is not exceptionally enriched in either Th or U. The average for both elements in the Volcanic Member is similar to Th and U contents in the two samples of turbidites from the lower Olympio Formation at Maude Headley. Th and U must be elevated locally, as the airborne spectrometric spectra over the Member shows some "bright" areas, probably corresponding to the massive rhyolites of PHom3, characterised by elevated K, Th and moderate U. However, both the basal siliceous unit and the carbonate-cemented unit have low Th and U, and will be "dark" areas on spectrometric images.

There is good correlation of some elements with TiO_2 (Fig. 14, Note TiO_2 decreases with increasing SiO_2 in felsic suites, and either TiO_2 or zr can be used to study element variation and magmatic evolution in place of SiO_2). Zr reached a maximum at about TiO_2 0.2-0.3 weight percent and total Fe reached a maximum at TiO_2 of 0.3 weight percent. Nb shows a main trend which peaks at TiO_2 about 0.2 weight percent, and a second trend, defined by a few samples, about 200 ppm higher than the main trend. In general, the samples for which analyses are available are not stratigraphically controlled, and cannot be directly correlated to facies. However, two samples, known to come from the basal unit, show that this has low TiO_2 and Zr, but high zr, and is therefore evolved. The fragmental unit has high TiO_2 and moderate Zr, and thus very low zr numbers, and therefore is least evolved. Also, the trends in the elements plotted against TiO_2 suggest that the Member formed from discreet pulses of magma released from a chemically differentiated magma chamber. This hypothesis could be tested by more detailed, stratigraphically controlled sampling.

Values for $K_2O + Na_2O$ are high throughout, but the unit falls partly into alkaline and partly into sub-alkaline classes (Fig. 15). K/Na (expressed as k = molecular $K_2O/[K_2O + Na_2O]$, not shown in this report) is erratically variable. Some samples have very low k and some very high k. This probably indicates metasomatism, through alteration of feldspars. Very high normative corundum in some samples probably also indicates alteration.

The two samples that can be placed in the lowest part of the Member are both very siliceous and have high zr numbers (highly fractionated). This indicates that the magma chamber became chemically stratified and formed a siliceous, highly fractionated cap, prior to initial eruption, in a manner similar to the Brockman Volcanics where a highly evolved,

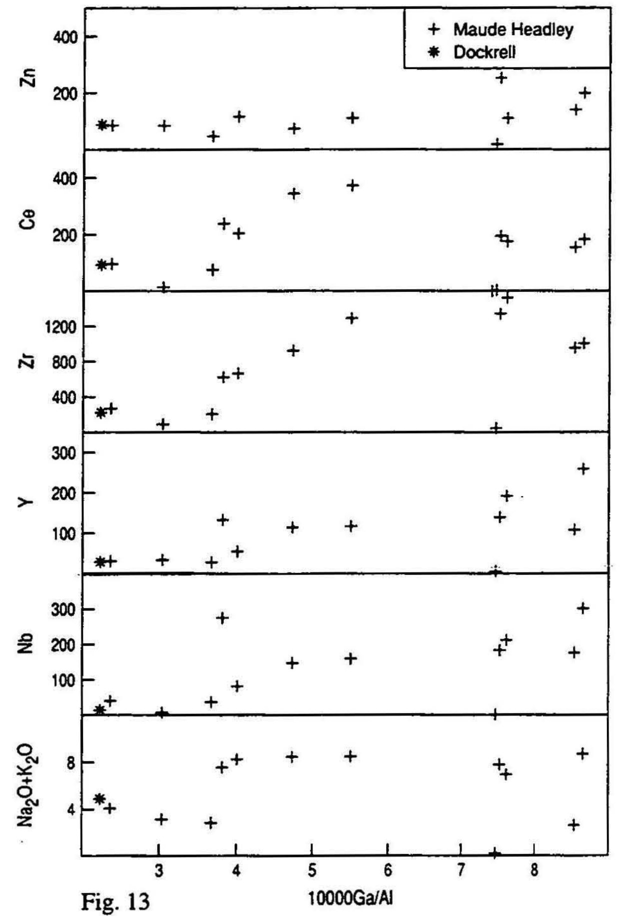

Fig. 13

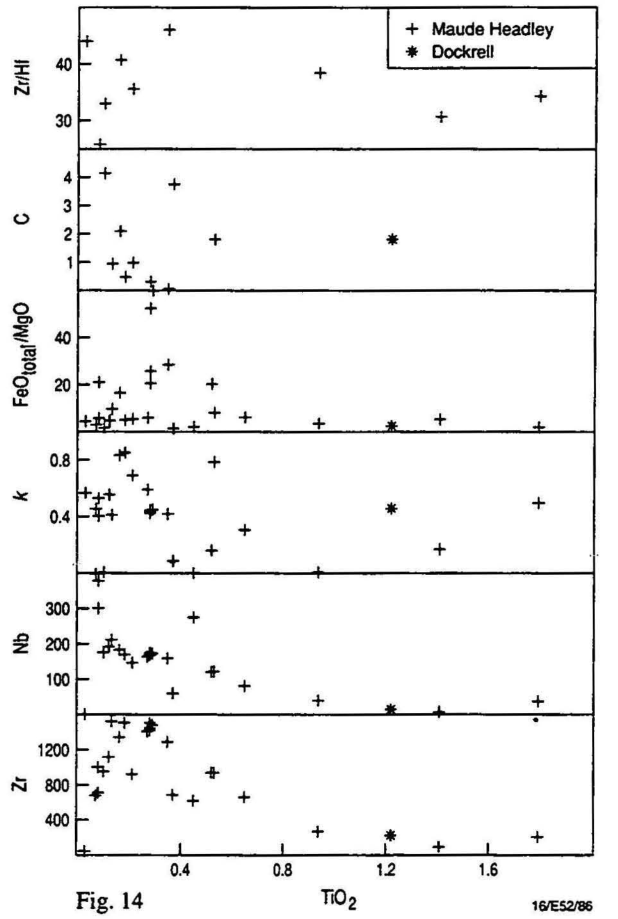

Fig. 14

Fig. 13 Plots of Zr, Ce, Zn, $N_a2O + K_2O$, Nb and Y against 10000Ga/Al, showing the elevated Ga/Al in the Maude Headley Volcanic Member. Limits for unfractionated I & S type granitoids from Whalen et al (1990) are shown.

Fig. 14 Plots of Zr, Nb, k, FeO_{total}/MgO and norm corundum against TiO_2 (Note, samples with more evolved compositions have lower TiO_2)

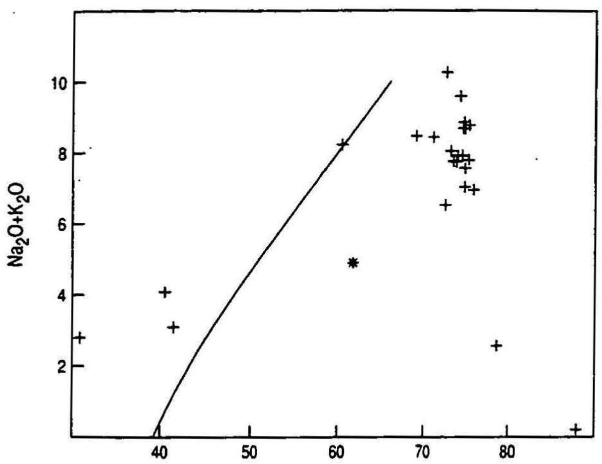

Fig. 15

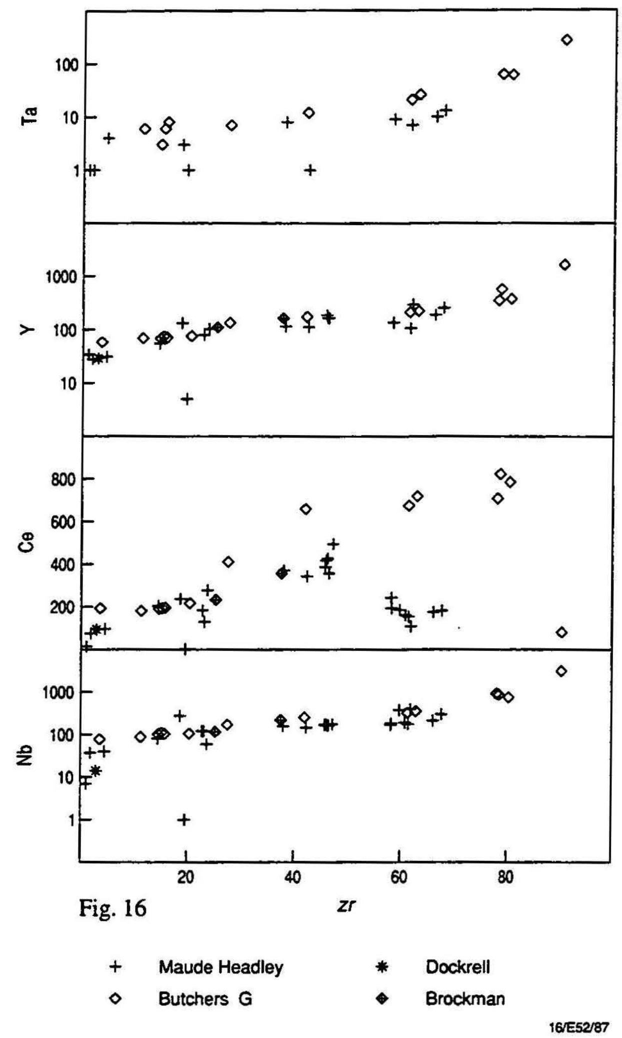

Fig. 16

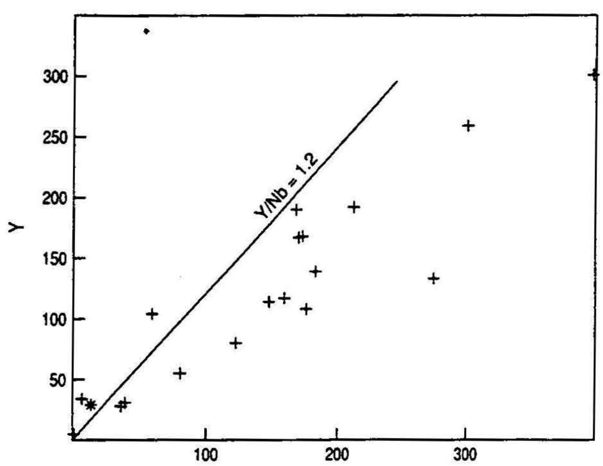

Fig. 17

Fig. 15 Plot showing total alkalis against SiO_2 for the Maude Headley Volcanic Member. Note that the Maude Headley samples are siliceous and also most are too low in total alkalis to be classified as alkaline.

Fig. 16 Plots for Nb, Ce, Y and Ta against *zr* for the Maude Headley Volcanic Member (+) compared to the Butchers Gully Member (Brockman Volcanics) (◊). Specimens collected from the Brockman area (Page & Hancock 1988), but having the characteristics of the Maude Headley Volcanic Member are shown separately (Δ).

Fig. 17 Plot of Y against Nb for the Maude Headley Volcanic Member. Only three samples, all from the carbonate-cemented fragmental unit, plot in the field for Y/Nb > 1.2.

somewhat siliceous suite of lavas was erupted during the earliest phase of activity (Ramsden, 1993). No equivalent of the Niobium Tuff has been found at the base of the Maude Headley Volcanic Member, though the possibility that such a layer exists cannot be dismissed. However, as the Maude Headley Volcanic Member is more siliceous than the Butchers Gully Member, less enriched in Nb (also in REE, Y, Zr, Zn, and Ta, Figs 16), and the base is removed by D_1 over much of the outcrop-area, the prospectivity is low.

Taylor et al. (1995a&b) presented evidence showing the Butchers Gully Member formed in an intraplate setting. For the diagnostic parameters, Zr/Nb and Nb/La, the Maude Headley Volcanic Member has Zr/Nb of 1.7-11.5 (average for 17 samples is 7.0), and Nb/La of 0.8-5 (average of 10 samples is 1.6). These values are similar to those reported by Taylor et al. (1995b) for the Butchers Gully Member, which they considered showed affinity to ocean island basalt (OIB) rather than to MORB, and interpreted as showing an intraplate origin. Also, Eby (1990) stated that A-type suites, in which $Y/Nb < 1.2$ (see Fig. 17), are derived from sources chemically similar to OIB, whereas those having $Y/Nb > 1.2$ are derived from sources similar to island arc or continental margin basalts.

The zircon age of the Maude Headley Volcanic Member is identical to that of major mafic bodies, the Panton, Toby and Springvale intrusions, and felsic activity, west of the Halls Creek Fault (Page et al. 1995). The chemical signatures of these mafic magmas resulted from large-scale partial melting of lithospheric mantle (Sun et al. 1991). The mafic contribution to the Maude Headley Volcanic Member would have had the element enrichment characteristic of late granophyric segregations from a large fractionating mafic body (cf. Turner et al. 1992) or of very small-scale partial melts of mantle peridodite (cf. Baker et al. 1995, Carlson 1995).

A model for formation of the Maude Headley Volcanic Member, like the Butchers Gully Member, in an intraplate setting through hot-spot or mantle plume activity (introduction of IOB) is probable. Hot mantle-derived material fractionated to provide source material enriched in REE, Zr, Y and Nb, which interacted with siliceous crust. Two pieces of supporting evidence for a young mafic source are the high ε_{Nd} values found in the Maude Headley Volcanic Member (S.-s. Sun, AGSO, pers comm. 1996) and the co-temporal mafic units to the west. However, there is no evidence of a large mafic body at depth (e.g., no gravity high) in the area of the Maude Headley Volcanic Member. One possibility is that the Maude Headley Volcanic Member is in an upper-crustal detachment moved eastwards from above the large mafic bodies to the west, and that the volcanics formed initially as a cap above one of these. (As the Halls Creek Fault is supposed to have substantial left-lateral displacement, a large mafic body well to the south should be considered, rather than the obvious bodies of similar age, such as the Panton or Springvale intrusions to the present west.) If the Butchers Gully Volcanics are similarly related to a fractionated mafic intrusion, there is, as yet, no dated mafic of this age, though there is evidence of a major thermal event contemporaneous with the Butchers Gully Volcanics. Neither the Maude Headley nor Butchers Gully A-type magmas are likely to be high-temperature melts of old volatile-depleted crust, as both have young ε_{Nd} ages.

Gold mineralisation occurs in the district in which the Maude Headley Volcanic Member also occurs, and the possibility of a genetic relationship should be considered. As gold is known to concentrate with incompatible elements during crystallisation of mafic magmas under some circumstances (Zentilli et al. 1985), elevated gold values may be present in the parts of the unit that carry the highest Zr and Y. If the chert-carbonate unit were deposited by discharge of volatile-enriched fluids in the late stages of volcanic activity, then this unit may also carry high Au. Sampling for Au has not been carried out systematically. A single grab sample of weathered chert-carbonate contains 177 ppb Au, which is anomalous but well below economic grades. A sample of ashstone from within ḆHom$_2$, in the Panton River section, contains 5 ppb Au. If the A-type magmas were fractionated from mafic bodies then the parent mafics must have been sulphur-undersaturated in order for gold to concentrate in the felsic cap.

Empirical observation shows gold mineralization in the Grants Patch-Dry Creek districts is localized in the uppermost Biscay Formation, but only occurs where the stratigraphic interval from the upper Biscay Formation to the Maude Headley Volcanic Member remains complete. Thus, gold workings are absent from the north of the Grants Patch anticline where the Member is faulted out, and also from the region south of Maude Headley, where the lower Olympio Formation is faulted out. This observation is taken to indicate that the source of the gold is in the Member, but the lithological change from felsic turbidite to mafic Biscay Formation precipitated gold during later fluid circulation (Warren 1994c).

The extreme levels for REE, Zr, Y and Nb found in the Butchers Gully Member were not reached in the Maude Headley, either because the mantle component was less enriched or because a greater input of crustal material diluted the precursor magma chamber to the Maude Headley Volcanic Member.

Arsenic in water supplies

Some whole-rock analyses show anomalously high As (in the range 5-40 ppm). The As may have been introduced by the same fluids that mobilized the gold. There is no apparent co-incidence between samples containing high As and gold mineralization, though most high-As samples were collected near D_3 faults.

Generally, the most common mineral that contains As is the sulphide, arsenopyrite, which breaks down during weathering. Possible leaching of As from weathered rock has implications for the quality of both groundwater and surface water. No groundwater is extracted in the area covered by the survey, but surface water is used for human and stock supplies. During the wet season, when run-off is high, As should be diluted to low levels. However, when run-off ceases and evaporation is intense, As levels will be enhanced in ponded water supplies and may reach dangerous levels. The Guidelines for Australian Water Quality, issued by the Australian Health and Medical Research Council and the Australian Water Resources Council give the recommended maximum level for As in drinking water as 0.007 mg/litre. *Arsenic cannot be removed by boiling the water. The use of surface water supplies in the region during the dry season is not recommended without testing.*

GEOLOGICAL AND TECTONIC EVOLUTION

The geological history of the area covered by this report began with deposition on an ensialic basement, consisting of the Ding Dong Downs Volcanics and Sophie Downs Formation, with an age of 1920-1900 Ma (Page & Sun 1994), which is exposed in domes to the south. The oldest rocks exposed in the area are mafic volcanics and pelitic and psammitic sediments of the Biscay Formation, which was intruded by dolerite, probably during or soon after deposition.

A period followed during which there was perhaps volcanic activity nearby (cherts at the base of the Olympio Formation) and some minor erosion. Renewed deposition began circa 1857 Ma. A thick (to 4 km) succession of turbidites, the Olympio Formation, was deposited. Deposition was interrupted soon after it commenced, by an episode of A-type volcanism forming the Maude Headley Volcanic Member, dated at 1857±5 Ma (Page & Sun, 1994). The turbidites were derived from the northwest (Hancock *in* Plumb et al. 1985) from a largely felsic (granitic) terrain. This terrain contributed detrital zircons with ages of 1868-1873 Ma, but is presently not exposed. A second cycle of turbidite deposition, which included the Butchers Gully Volcanics, occurred at about 1848 Ma. A still-later cycle of turbidite deposition which produced the late Olympio Formation, which contains zircons with an age of 1847±6 Ma. The turbidites were derived from a near-by terrain, through rapid erosion of a source area containing both granite and a magnetic unit, and apparently deposited in (or merely preserved in) fault-controlled troughs. Though the zircon population is similar in age to the Butchers Gully Volcanics, the source was granitic and the zircon population provides the age of the source, not the age of sedimentation. (Also, that the "magnetic" turbidites are separate from the Butchers Gully Volcanics, is shown by the distribution of the two units in Halls Creek 1:100 000 Sheet area.) A low-angle detachment fault, D_1, which disrupts the stratigraphic continuity in the southwest of the area, may have been involved in development of the depositional sites to accommodate the late Olympio turbidites (see Appendix 1). Alternatively, the detachment may be the root-zone of a west-directed gravity slide into a deep basin. The most likely time when this may have formed is during deposition of the Koongie Park succession (at about 1840 Ma, Page & Sun 1994).

Deposition of the late Olympio Formation was followed by east-directed compression, D_2. This produced folds that are upright to overturned-to-the-east, and plunge shallowly north. The Biscay Anticlinorium and the Grants Patch Anticline are typical regional scale D_2 folds. D_2 folds become tighter in the northern part of the area, as synclinal axes, and, in the north and east, also anticlinal axes, become small-scale thrust planes. Metamorphism in the south (the most deeply buried region) reached greenschist grade, with Bt-Mu assemblages in felsic volcanics. In the north and east, the effects of metamorphism on the Olympio Formation are minimal.

Deposition of the Kimberley Basin succession (at about 1800 Ma, Page & Sun 1994) may have extended over the area, but the sediments are now preserved only in fault-bounded blocks along the Halls Creek Fault Zone. Two units are present, the mature quartzites and pebble conglomerates of the King Leopold Sandstone, and basalts and minor carbonate rocks of the Carson Volcanics. The basalts of the Carson Volcanics have been metamorphosed to prehnite-pumpellyite grade.

A period of erosion preceded deposition of the Mount Parker Sandstone, which overlies the Olympio Formation to the north. Plumb et al. (1985) considered that the Mount Parker Sandstone, and the Bungle Bungle Dolomite, correlate with the succession in the Birrindudu Basin with an age of about 1680-1600 Ma.

The north-south D_3 faults and associated folds may have developed during left-lateral movement on the Halls Creek Fault during deposition of the Carr Boyd Group. Plumb et al. (1985) placed the Carr Boyd Group in the interval 1200-900 Ma, though the age data are not well-constrained.

The Mount Kinahan Sandstone and the now-eroded Eliot Dolomite are equated with the Heavitree Quartzite and Bitter Springs Formation of the Amadeus Basin. Their maximum age is 1080 Ma, given by the Stuart Dyke Swarm beneath the Heavitree Quartzite, but a considerable time-gap may have elapsed before deposition. Minimum age of the Bitter Springs Formation is circa 800 Ma (Zhao et al. 1995).

D_4 structures (mainly faults) came into existence before the Late Proterozoic glaciation. They bound the fault blocks in which the Mount Kinahan Sandstone escaped glacial erosion, and controlled two small troughs (north and south of the Ord River) where thicker glacial sediments are preserved. The D_4 faults controlled both deposition and erosion from the end of glaciation to the eruption of the Antrim Plateau Volcanics at the base of the Ord Basin succession. Especially, the D_4 faults controlled the erosion that preceded the Volcanics, and the deposition of the Volcanics.

Deposition of the Devonian Mahony Group marked the beginning of renewed tectonic activity in which D_4 and probably D_3 structures were reactivated. During the Devonian and possibly, the early Carboniferous (cf. the effects of the Alice Springs Orogeny in the Ngalia, Amadeus, Georgina and Officer Basins), uplift resulted in supply of sediments to a trough which extended from north to south across the Dixon 1:100 000 Sheet area, east of the present Albert Edward Range. The zone of complex basement-cover interaction, marked by low-angle west-directed thrusts within the Range, developed towards the end of this tectonic activity, as the faults that control the thrusting also enclose narrow slivers of the Mahony Group sediments in the Hardman Range. For simplicity, the structural regimes along the Range can be subdivided into two. North of the Panton River, large-scale folds formed on the east side of D_4 faults. These folds are large open structures plunging shallowly to the north-northeast. (The aeromagnetic signature of the Antrim Plateau Volcanics shows the sub-surface form of the fold structures well.) Photointerpretation indicates the D_4 faults themselves flatten in the Headleys Limestone or near the base of the overlying Nelson Shale, and there is south-directed thrusting along the D_4 faults over the folds. South of the Panton River, asymmetric folds, with axial planes parallel to the basement-cover contact, developed in the cover sequence beneath the Antrim Plateau Volcanics, and locally within the Volcanics. As the folds tightened, they developed into low-angle thrust faults, mainly propagating within the Ranford Formation. On a regional scale, the asymmetric folds are controlled by southeast- to east-southeast-striking faults that cause minor displacement in the flat-lying Antrim Plateau Volcanics and

Headleys Limestone east of the Albert-Edward Range. West of the Range, these faults refract into the northeast-trending D_4 faults. Drag-folding between subparallel D_4 faults within the Olympio Formation may have occurred in the Devonian.

There is gap in the geological record from the mid Palaeozoic until the Tertiary. By the Tertiary, a surface with little relief, the Sturt Plain (or Canning Surface of Plumb & Gemuts, 1976) extended across much of northwestern Australia. Some of the resistant sandstones formed a line of low flat-topped hills along the present Albert Edward Range. A plateau had formed north of the present Dixon Range, and a tableland occurred over the Antrim Plateau Volcanics in the south. West of the Albert Edward Range, there were low hills within the plain, and a discontinuous low ridge of King Leopold Sandstone along the trace of the Halls Creek Fault. Warren (1994a) suggested that drainage across the area covered by this report, was to the south, into the Sturt Creek system. Most streams crossed through the Albert Edward Range through breaks in the ridges of resistant sandstone created by faults. West of the Range, the streams have maintained much their same courses to the present. Trizonal laterite is preserved in the Sturt Plain, but appears not to have extended as far north and west as the preserved outliers of the Sturt Plateau in this area.

The Late Eocene collision of the Australian plate with continental crust to the north (e.g., Pigram & Davies 1987) probably initiated changes to the landscape. In the Sturt Plain, incision by south-flowing drainage into the laterite due to slight tilt to the south preceded deposition of the Lawford Beds (Warren 1994a). Reversal of tilt to the north then had the effect of ponding south-flowing drainage so that the calcareous Lawford Beds were deposited as a very extensive veneer over Antrim Plateau Volcanics in the Sturt Plain. However, in the Dixon 1:100 000 Sheet area, the early southwards tilt is not apparent and the earliest event is equated with tilt towards the north in the Sturt Plain. Deposition in low-lying areas adjacent to drainage channels has left small thin pockets of sediments (the older *Ts* unit), as, for example, near Blue Hole on the Ord River. The small area of White Mountain Beds in the east of the Dixon Range 1:250 000 Sheet area probably was deposited in this same episode of northwards tilting, and is capped by marine or estuarine sediments. There is no evidence that the marine incursion reached farther inland. However, this northwards tilt also started the headwards erosion of the north-draining Ord system, which etched out the less resistant sediments of the Ord Basin to form the Ord Plain, and captured the headwaters of the Sturt Creek system. West of the Albert Edward Range, the captured streams were rejuvenated and began to cut down into the plain, forming the Bay of Biscay Hills. The streams maintained their routes through the Albert Edward Range. For some (e.g., Ord, Panton, Castle Creek), the structural breaks continue down to the present level of erosion. Some streams (McIntosh, Elvire) cut gorges as they eroded down through the quartzite ridges. The Ord River incised gorges through the western end of the Dixon Range and into Antrim Plateau Volcanics southeast of Blue Hole. McIntosh Creek cut a gorge through a ridge of Mount Forster Sandstone and through Antrim Plateau Volcanics to the east.

A second period of sediment deposition, once more as the result of ponded drainage, occurred after the Ord Plain had formed. Sediments were trapped upstream of the gorge cut by the Panton River through the Antrim Plateau Volcanics. A thin veneer of clays was deposited in the Ord Plain. Renewed incision of the major river channels into the Ord Plain has cut down through this veneer, and an underlying ferruginous duricrust, to bedrock, which is exposed in the base of the present-day channels.

GOLD: MINING ACTIVITY AND MINERALIZATION

Production figures are poorly known and records of mining activity are incomplete. There seem to have been three, perhaps four, periods of mining activity. The first followed immediately after discovery, circa 1890, and waned when the far-richer Coolgardie and Kalgoorlie fields were discovered. A second period may have occurred either (or both) in the 1930s or after the Second World War. Archaeological traces of this activity remain, but no records. The Grants Patch field was abandoned at the time of Finucane's (1939) study. Another phase of activity followed the increase in the gold price and introduction of metal detectors in the late 1970s. Traces of this activity, costeans and drillholes, and the abandoned camp and bulldozed scrapings at Maude Headley are visible, but weather-beaten. The current, and continuing activity consists of alluvial workings in the Grants Patch area and the Dry Creek district. Alluvial mining was being carried out in the Mount Slinkey district in 1992, but the area had been abandoned in mid-1993. Exploration permits in the Grants Patch area held by Dominium Mining in 1992-3, had passed to Precious Metal Australia in 1994-5. Some prospecting, using metal detectors to obtain nuggets for jewellery and for specimen material, continues, but on an informal basis and no records are kept.

Most gold is alluvial, taken from lag deposits. Two episodes in the development of the current landscape are very important in producing workable concentrations. The prolonged levelling and weathering of the Stuart Surface allowed the release of the gold from the primary source and formation of coarse secondary gold. Incision of the Ord drainage has released the secondary gold and concentrated it in lag and stream-bed deposits.

Mount Slinkey district Workings in the area, known locally as Mount Slinkey (Also called Slinkey Hill or Slinkey Ridge), consist of a line of alluvial scrapings made in 1992 (possibly 1991-2). The line of scrapes follow a near north-south D_3 fault zone in the Olympio Formation. There is an abundance of quartz veins close to the fault trace, and voids or iron oxide cubes after coarse disseminated pyrite are common in the Mount Slinkey district. Unweathered quartz veins generally contain pockets of chlorite and calcite. Oral tradition reports that small patches of coarse-grained alluvial gold were extracted from the workings. The area was abandoned in 1993.

At the location, there are traces of a long-abandoned rough hut, but there is no record of the earlier activity, though Dow & Gemuts (1969) showed a gold occurrence at this locality on the East Kimberley 1:500 000 geological map. During the 1980s, the area was investigated for alluvial deposits and hard-rock lodes. Sampling showed "only creeks in the vicinity of the Slinkey workings and draining the Slinkey Fault carried significant gold values" (Thiele 1987).

Dry Creek The Dry Creek district is entirely an alluvial mining field, where there is continuing extraction of unconsolidated material from stream beds and adjacent slopes. This extraction has obscured most of the evidence of earlier activity. Drill collars from an earlier exploration program were visible in 1992. The Dry Creek field was mentioned by Smith (1898), but apparently not visited. The main areas of alluvial workings either overlie the uppermost Biscay Formation or are in streams draining off such outcrops. A D_3 fault passes through the eastern part of the field. A major D_2 fold (part of the core of the Biscay Anticlinorium) is present, and is displaced by a D_4 fault north of the area of alluvial workings (cf. Maude Headley district). Maude Headley Volcanic Member forms topographically prominent ridges in the Dry Creek district.

Maude Headley Maude Headley (spelling uncertain) is the name used locally to refer to an area of alluvial workings southwest of the Dry Creek district. There are traces of very old habitation. The main alluvial scrapings appears to date from the last decade.

The workings at Maude Headley are entirely alluvial. They consist of several small areas of bulldozed scrapes east of the track leading to Dry Creek. The scrapings have removed superficial cover overlying the upper Biscay Formation immediately below the base of the Olympio Formation. The sequence exposed in the district extends from the upper Biscay Formation to the Maude Headley Volcanic Member. The D_1 detachment crops out to the southwest. In the Maude Headley area, it may fault the fragmental unit in the Member against the lower Olympio Formation. The Biscay Formation is exposed in the core of a D_2 anticline, which is cut by D_3 faults and locally refolded by D_3. The dominant structure is a major D_4 fault, which passes north of the workings, cuts the D_2 folds, and places upper Olympio Formation to the north against the more diverse exposures in the Maude Headley area. At the northernmost workings, the colluvial material was extracted from above poorly exposed vein quartz.

There are faint tracks southwest and northeast of Maude Headley which may lead to additional old alluvial workings.

Grants Patch (including the Katys Yard workings) is situated in a triangular area north of the Panton River, between the Halls Creek fault and an unnamed fault to the east. Previous descriptions have referred to the area as the Panton River field (Smith 1898) and Grant's Creek (Finucane 1939). Most of the activity was in the earliest episode when both alluvial and hard-rock mining were carried out. Several small shafts were sunk, but did not locate minable primary mineralization. The field was less productive than the Halls Creek district to the south, but accessible, as the telegraph line and original track from Wyndham to Old Halls Creek passed through the field. The field was abandoned at the time of Finucane's (1939) investigation. Small-scale alluvial mining has been carried out intermittently since the 1940's, and still continues. Exploration in the field has involved drilling and surface sampling, both in the late 1980's and in 1993 (late 1992-1994?).

The sequence exposed in the Grants Patch district extends from the upper Biscay Formation to the upper Olympio Formation. Alluvial mining has been almost entirely in superficial material overlying the Biscay Formation. Shafts have been sunk in the Biscay Formation and the lower Olympio Formation. D_1, D_2 and D_3 structures are all prominent in the district, D_4 structures are of minor significance. The Grants Patch Anticline is a regional D_2 fold. Virtually all the activity in the Grants Patch workings has been along the west limb of this major fold, between Grant Creek and the Halls Creek Fault. The line of workings also follows closely a prominent quartz vein, which may fill a D_3 structure.

Along this part of the fold limb, the succession is from dolerite to lower Olympio Formation, juxtaposed by the (inferred) D_1 fault. Maude Headley Volcanic Member is present, but is poorly exposed and may be only a few metres thick. North of Grant Creek, where there has not been any mining activity, the lower Olympio Formation and the Maude Headley Volcanic Member are not present, and the upper Olympio Formation is faulted against dolerite.

Costeans in the Katys Yard area cross a vein of blue quartz filling a D_3 fault, which separates mafic rocks (probably dolerite) from poorly exposed sediments, which appear to be Olympio Formation. Alluvial workings occur only to the east of this quartz vein.

In the Grants Patch district, there are numerous tracks suggestive of exploration activity, including one leading to the exposures of Maude Headley Volcanic Member, northwest of Grant Peak, where there is an inclined drill hole Many of the tracks lead to outcrops of the Member. These tracks and the drillhole suggest that initial favourable prospecting was followed by unsatisfactory results from additional testing, but there is no documentation. de Havilland (1985) states that gold nuggets have been found south of the Panton River. The area to which he referred may correspond to an area with faint tracks and a few, very small, bulldozed scrapes about 6-7 km south of Katys Yard, where lower Olympio Formation overlies meta-dolerite, separated by a D_1 fault (see Appendix 1).

Other areas Maitland (1900) listed *Mount Coghlan* as a gold locality in the Kimberley Goldfield. He probably referred to a separate area of alluvial workings near Mount Coghlan. Fragments of tracks are visible on airphotographs in the area south of Mount Coghlan (in Antrim 1:100 000 Sheet area). *Saunders Creek* seems sometimes to refer to an area near the ruins of Ding Dong Downs homestead in the Halls Creek 1:100 000 Sheet area or, alternatively, to the area along Saunders Creek near where it enters the Panton River east of Dry Creek. Although there is a local tradition that the latter was also an alluvial area during the earliest phase of gold mining, no records of any gold extracted are available.

The Sluice Point Prospect, about 3 km south of McIntosh Creek, at the eastern margin of the Olympio Formation, contains significant alluvial gold (Zas et al. cited in Theile 1987).

Alluvial flats (in the younger *Ts* sediments) at the junction of the Panton River and Elvire Creek were sampled for alluvial gold, possibly in the late 1980s, and a washed-out track, leading towards the area where the Panton River passes out of the Olympio Formation, suggest this area was also investigated at the same time. Theile (1987, citing Zas et al.) reported alluvial gold at Hardmans Bend on the Panton River, though it is not clear to which locality this refers.

Distribution of gold mineralisation

The distribution of gold workings strongly indicate that both stratigraphy and D_3/D_4 structures were important in localising primary gold mineralization. Cainozoic events produced the enriched secondary concentrations.

Despite revisions of the stratigraphy, the observation of Dow and Gemuts (1969) that gold mineralisation occurs close to the Biscay-Olympio interface remains valid. Most areas where alluvial gold has been extracted overlie the uppermost Biscay Formation immediately below lower Olympio Formation. The line of small shafts and alluvial diggings at Grants Patch follows closely the faulted contact between dolerite and lower Olympio Formation (below the Maude Headley Volcanic Member). An exception to this generalisation is in the southwest of Grants Patch, where Moodys Shaft was sunk in lower Olympio Formation, between a prominent quartz vein and dolerite. Maude Headley Volcanic Member crops out north of the quartz vein.

Costeans north of Katys Yard were cut across a quartz vein which separates Olympio Formation from Biscay Formation, but the alluvial workings are east of the costeans, over Biscay Formation. Katys Yard, and the unnamed alluvial prospect about 7 km south of there, are near a D_1 faulted contact between dolerite and lower Olympio Formation.

Maude Headley and most of the Dry Creek alluvial scrapings are near the normal stratigraphic contact of mafic Biscay and lower Olympio turbidite, and the productive alluvium more commonly overlies Biscay Formation. The more recent workings at Dry Creek follow stream channels draining north towards the Panton River over Olympio Formation. Both Maude Headley and the Dry Creek workings are on the southeast side of a prominent D_4 fault.

Mount Slinkey is in Olympio Formation, the geophysical characteristics of which indicate it to be the upper Olympio Formation, and therefore above the Maude Headley Volcanic Member.

Duffers Mine is outside the area covered by this report. However, a report of investigations in its vicinity includes mention of anomalously high Zn, indicative of the presence of Maude Headley Volcanic Member. Similarly, anomalous levels of zinc reported to the northwest of the abandoned Ding Dong Downs homestead (the southern Saunders Creek area) suggest that the Member, probably the lowest unit, occurs here also.

Most workings are located close to D_3 and/or D_4 faults. Most of the alluvial workings at Dry Creek are close to a D_3 fault. A similar fault lies to the east of Maude Headley. The quartz vein at Grants Patch trends north-northeast, but probably occupies a D_3 tensional structure within steeply dipping dolerite without any significant displacement. The similar quartz vein north of Katys Yard occupies the junction between Olympio Formation and dolerite. The Slinkey Fault is a D_3 structure, and the numerous quartz-chlorite-calcite veins suggest tension fills related to the fault. The Mount Coghlan locality is close to northeast-trending D_4 and to approximately north-south D_3 faults.

The D_1 faulted contact of mafic Biscay Formation against Maude Headley Volcanic Member, even if close to either D_3 or D_4 faults, appears to be unfavourable as a stratigraphic setting for mineralization.

Empirically, both late tensional faults and the change in lithology from mafic (basalt or dolerite) in the Biscay Formation to immature turbidite seem to have been important in precipitating gold. The exception, the small workings at Mount Slinkey, is within the Olympio Formation.

No correlation between high As values (whole-rock samples) and alluvial gold workings is apparent. Quite high As levels occur in areas that are not known gold areas.

Primary mineralisation, alteration and the fluid phase

Primary mineralisation was reached in shafts at Grants Patch, where Finucane (1939) reported pyrite, chalcopyrite and galena. Pseudomorphs after pyrite are widely distributed, but there are few traces of copper to be found in the area that contains evidence of mining activity. It seems sulphur activity was high enough to preclude siderite, but not high enough (or buffered) to stabilise bornite. Though oxygen fugacity was high enough to stabilise carbonate, neither magnetite nor hematite have been noted in the vicinity of the gold workings.

Mafic rocks collected near gold workings have characteristic carbonate alteration, in which calcite-chlorite assemblages take the place of epidote-actinolite. Ilmenite is partly replaced by sphene, and biotite (or hydrobiotite) by chlorite. Albite is present in some samples, but has been removed from the most thoroughly altered specimens. Phengite is a rare component of less altered rocks.

This chlorite-carbonate alteration required an H_2O-CO_2 mixed fluid, which contained minor F, because traces of F are present in chlorite and up to 0.5 weight percent in hydrobiotite. Chlorite also contains trace amounts of Cl. As Cl partitions into the fluid phase (Mora & Valley, 1989), the fluid that caused the alteration must have also contained some Cl. The textural evidence shows that the fluid removed both K and Na from the mafic rocks. Some samples of the Maude Headley Volcanic Member have chemical signatures consistent with alteration, as both Na/K and Mg/Fe are erratically variable.

Sources and origin (Warren 1994c)

Possible gold-source-rocks include the mafic volcanics in the Biscay Formation, the interlayered dolerite, the mafic Carson Volcanics (previously Fishhole Dolerite) in the Kimberley Basin succession, the lower Olympio Formation and the A-type Maude Headley Volcanic Member.

Little testing has been done of possible source rocks. Unaltered dolerite from north of Katys Yard carries 2 ppb Au. Altered mafic rock at Maude Headley also contains 2 ppb Au. The Maude Headley Volcanic Member merits special attention as a source-rock for both gold and chemically active fluids. Three samples of the Maude Headley Volcanic Member have been analysed for gold content. A siliceous nodule from near the base of the Panton River section (high *zr* number) had 2 ppb Au, and an ashstone, also having a high *zr* number, had 5 ppb. A grab sample of weathered chert-carbonate at the top of the member contains 177 ppb Au. As gold shows a high positive correlation with incompatible elements such as Y and Zr (Zentilli et al. 1985), those parts of the Maude Headley Volcanic Member carrying the highest levels of these elements have enhanced potential to carry elevated gold values. The heavily carbonated fragmental facies carried low levels of incompatible elements, but appears to have been derived from a volatile-rich part of the magma chamber. Moreover, the uppermost part of the Maude Headley Volcanic Member, exposed in an arcuate region, from northwest of Grants Patch to Dry Creek, consists of interlayered thinly banded chert and carbonate, suggestive of sinter or hot-spring deposits, potentially linked to epithermal enrichment. In addition, the A-type chemistry of the Maude Headley Volcanic Member could have provided (or buffered) the fluids enriched in CO_2, F, and, perhaps, Cl, which were involved in later alteration.

Carbonate alteration is common to many gold mining districts. In the Archaean gold-districts of the Yilgarn Block, this has been interpreted (e.g., Phillips 1993) as the result of interaction between wallrock and hydrous fluids of low salinity, with T > 200°C, reduced sulphur and modest CO_2, which were expelled by metamorphic reactions at greater depths. Such fluids would be syn- or late metamorphic. The distribution of workings indicates that the combination of proximity both to late faults and to the interface between mafic rocks and feldspathic sediments were required to precipitate gold. This would place the primary mineralisation in the class of unconformity-related deposits. Available data gleaned from mineral assemblages and mineral analyses indicate the fluid phase composition resembled the Archaean type described by Phillips (1993), with low oxygen fugacity, low salinity and low CO_2.

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APPENDIX 1

REFERENCE LOCALITIES FOR THE D_1 DETACHMENT

The evidence for the existence of the D_1 detachment has been assembled from the distribution of localities where part of the stratigraphic section in the interval from the upper Biscay Formation to the Olympio Formation above the Maude Headley Volcanic Member is absent. This appendix contains maps and descriptions of the individual localities, and thus provides details of the supporting evidence for the abstract presented by Warren (1994b). At most of the localities where part of the expected section is absent, it is replaced by a thin layer of laminated rock with a layer-parallel fabric. This is particularly true for the area south and southwest of Maude Headley, where the siliceous Maude Headley Volcanic Member is involved. The exposures south of Katys Yard, where lower Olympio Formation overlies deformed dolerite (Fig. 11), show deformation occurred in the brittle zone. In a regional context, the sections can be arranged as segments on a low-angle extension fault (Fig. 10).

Prospect Creek - Katys Yard - western Grants Patch: Lower Olympio Formation/dolerite (Reference area; 6-7 km south of Katys Yard, point A in Fig. 3)

In the area immediately east of the Halls Creek Fault, north from approximately where the original track from Wyndham to Old Halls Creek crossed Prospect Creek to the vicinity of the track from Grants Patch to Alice Downs, the lower Olympio Formation abuts the dolerite unit Ƀdw. There is no evidence of an intrusive contact (no chilled margin to the dolerite, no crosscutting relationship and no hornfels in the Olympio Formation). The boundary between the dolerite and turbidites, interpreted as the D_1 surface, is folded about a D_2 regional anticline and appears in the appropriate position in parasitic folds on the west limb of the fold within the Olympio Formation between the abandoned track and the Halls Creek Fault. The reference area is within this zone of parasitic folds, some 6 kms south of Katys Yard (Fig. A1, see also Fig. 3).

In the Grants Patch district, exposure is poor, as the area is essentially an old land surface, which is only lightly etched by the recent drainage to expose fresh bedrock. The stream channels draining into Prospect Creek are more active, and exposure is better. The reference area is in a low amphitheatre etched by a small side stream of Prospect Creek (GR813174, McIntosh 1:100 000 Sheet area). The locality shows evidence of investigation as a gold prospect with tracks and dozer scrapes, and probably corresponds to the locality south of Katys Yard recommended by de Havilland (1985) as a site for collecting gold nuggets.

Even in the reference area, the D_1 surface is generally recessive. However, exposures are sufficiently good to demonstrate that there is no chilled margin to the dolerite, that the edge of Ƀdw is deformed and that calcite infills tension structures close to the deformed edge (Fig. 11). The upper margin of lower Olympio Formation, exposed in a bulldozed scrape, is converted into thinly laminated rock.

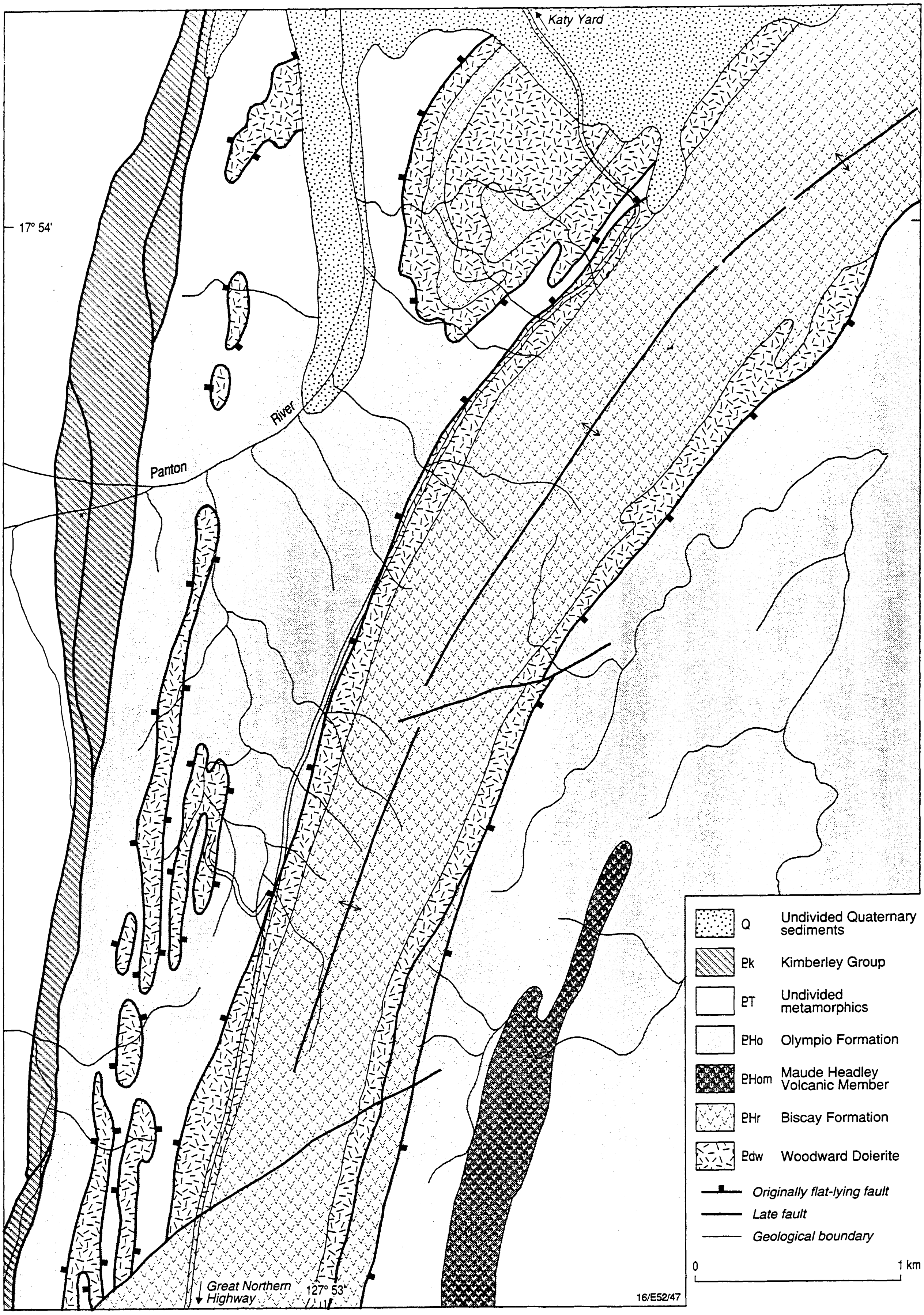

Fig. A1 Map showing area south of Katys Yard where lower Olympio Formation overlies dolerite.

Prospect Creek and its tributaries provide a section across the regional D_2 anticline. On the steeply dipping east limb, the D_1 surface occurs in a creek bank at GR815129, McIntosh 1:100 000 Sheet area. There is no chilled margin to Ƥdw, and a zone of rubbly deformed rock marks the trace of the D_1 surface. The D_1 surface is also exposed in a gully just to the north of the Panton River (GR858218), where there is a recessive zone of mylonitic rocks about 2 m wide.

South and southwest of Maude Headley: *Maude Headley Volcanic Member/Biscay Formation* (Reference area: Adjacent to the intersection of the Dry Creek road and Woodward Creek, Fig. A2, point B in Fig. 4)

In the area south and southwest of Maude Headley, the Maude Headley Volcanic Member is juxtaposed against the Biscay Formation. Here, the D_1 surface is better exposed, as the strain has mainly been taken up in the siliceous basal Maude Headley Volcanic Member. Deformed rocks are exposed in a zone, up to 3 m thick, of laminated and lineated rock. Later deformations commonly refold the D_1 lineations (Fig. 9).

A thin section cut from the laminated material (specimen 93525131, collected at GR867076, Halls Creek 1:100 000 Sheet area, in the reference area) has a finely layered texture predating regional metamorphism (Bt-Mu grade: upper greenschist facies). The hand-specimen shows this fabric has been crenulated by one, possibly two later events.

In the reference area, the D_1 detachment places the lowest unit of the Maude Headley Volcanic Member, the thinly layered felsic volcanics, over Biscay Formation (Fig. A3). However, at Maude Headley, the detachment may have removed the lower, thinly-bedded part of the Maude Headley Volcanic Member. The contact of the lower Olympio Formation with the Member is obscured by alluvium, but the carbonate-cemented fragmental unit appears to "overlie" the turbidites.

Northeast Grants Patch district: *upper Maude Headley Volcanic Member/dolerite* (Reference area 3 km southwest of Grants Peak, point C in Fig. 3)

The Maude Headley Volcanic Member is exposed in low ridges between Grants Patch and Grant Peak (Fig. A4), where it is faulted against mafic material, which from its coarse-grained recessive outcrop, is considered to be dolerite rather than mafic volcanics. As in the area south of Maude Headley, most of the D_1 strain has been taken up in the felsic rocks, but the mafic rocks close to the dislocation surface (e.g., GR927305, 923295, McIntosh 1:100 000 Sheet area) also show the effects of the deformation.

These outcrops show a strongly developed lineation, plunging shallowly to the north, which is related to tight upright regional folding. In the northernmost outcrops of the Volcanic Member, there are small sheath folds indicating north-directed transport The sheath folds appear to have been refolded by the upright folds. The area is cut by D_4 structures. Several interpretations are possible. The sheath folds may be late D_1 and the upright folds are D_2, implying that transport in D_1 was northwards.(The overview of D_1 presented below is more consistent with westerly transport of the upper plate.)

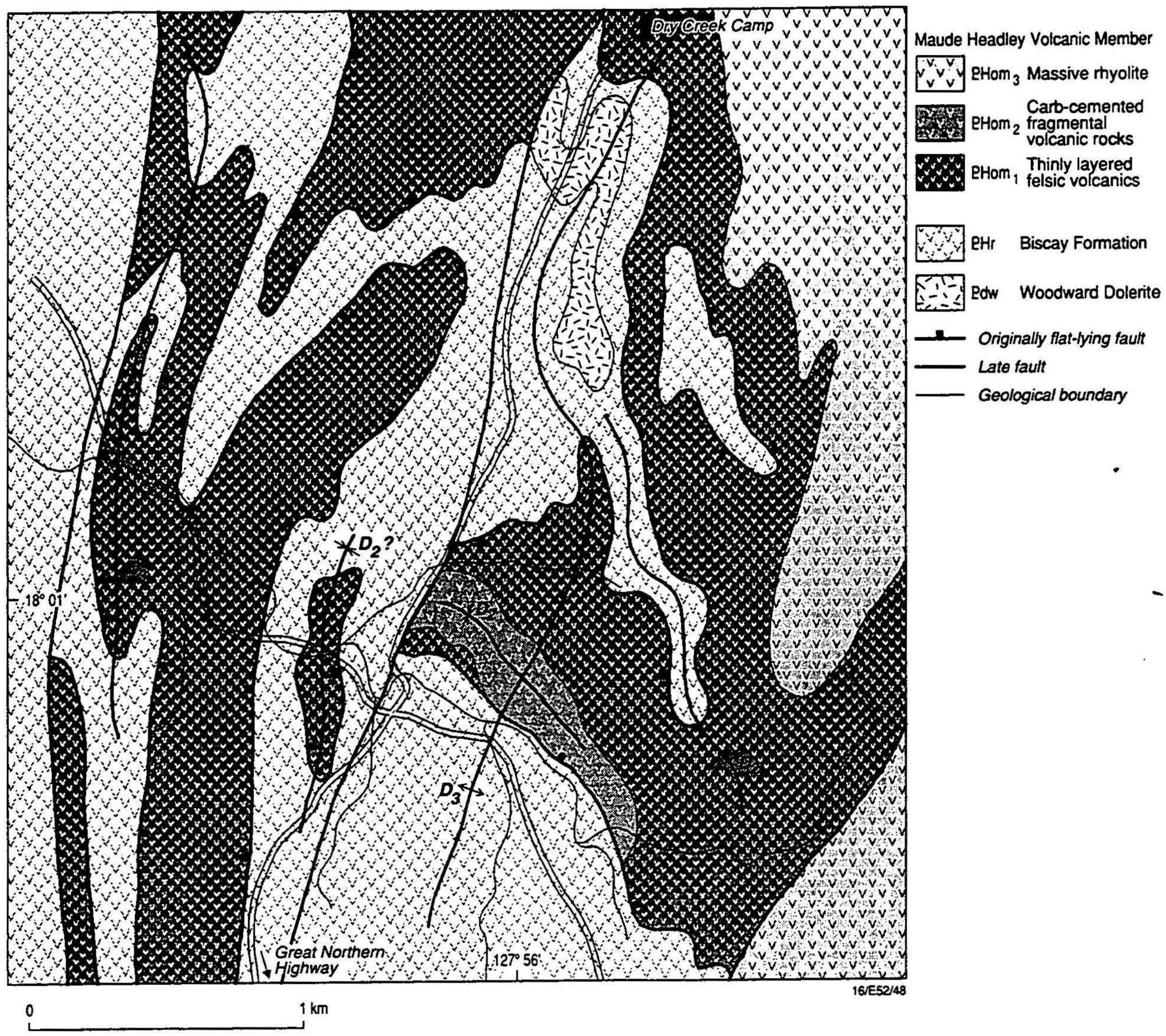

Fig. A2 Map at 1:25000 of reference area south of Maude Headley, where Maude Headley Volcanic Member overlies Biscay Formation.

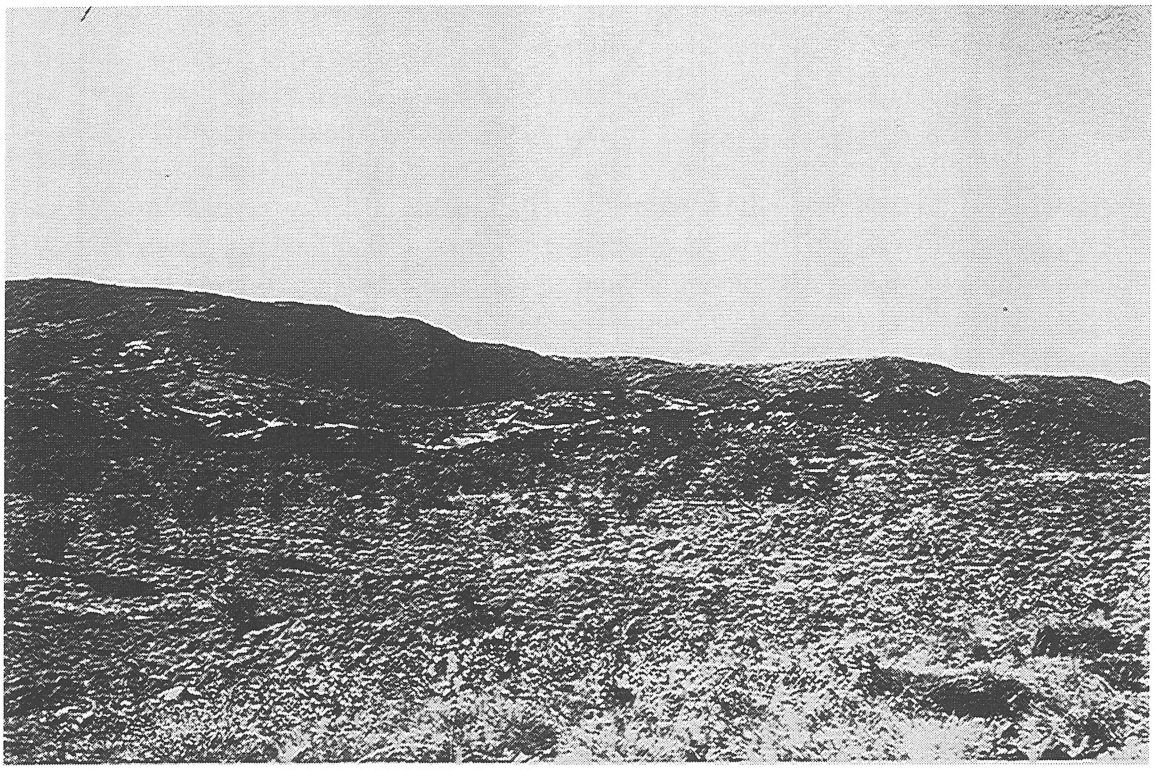

Fig. A3 View, about 6 km south of Maude Headley, looking east from an inlier of Biscay Formation in the foreground, separated from Maude Headley Volcanic Member by a D_1 fault. (Note absence of lower Olympio Formation.) East of the D_1 surface, there is, in order, low lying recessive ꝒHom$_1$, dark, rough rises of ꝒHom$_2$, and higher hills of massive rhyolite, ꝒHom$_3$.

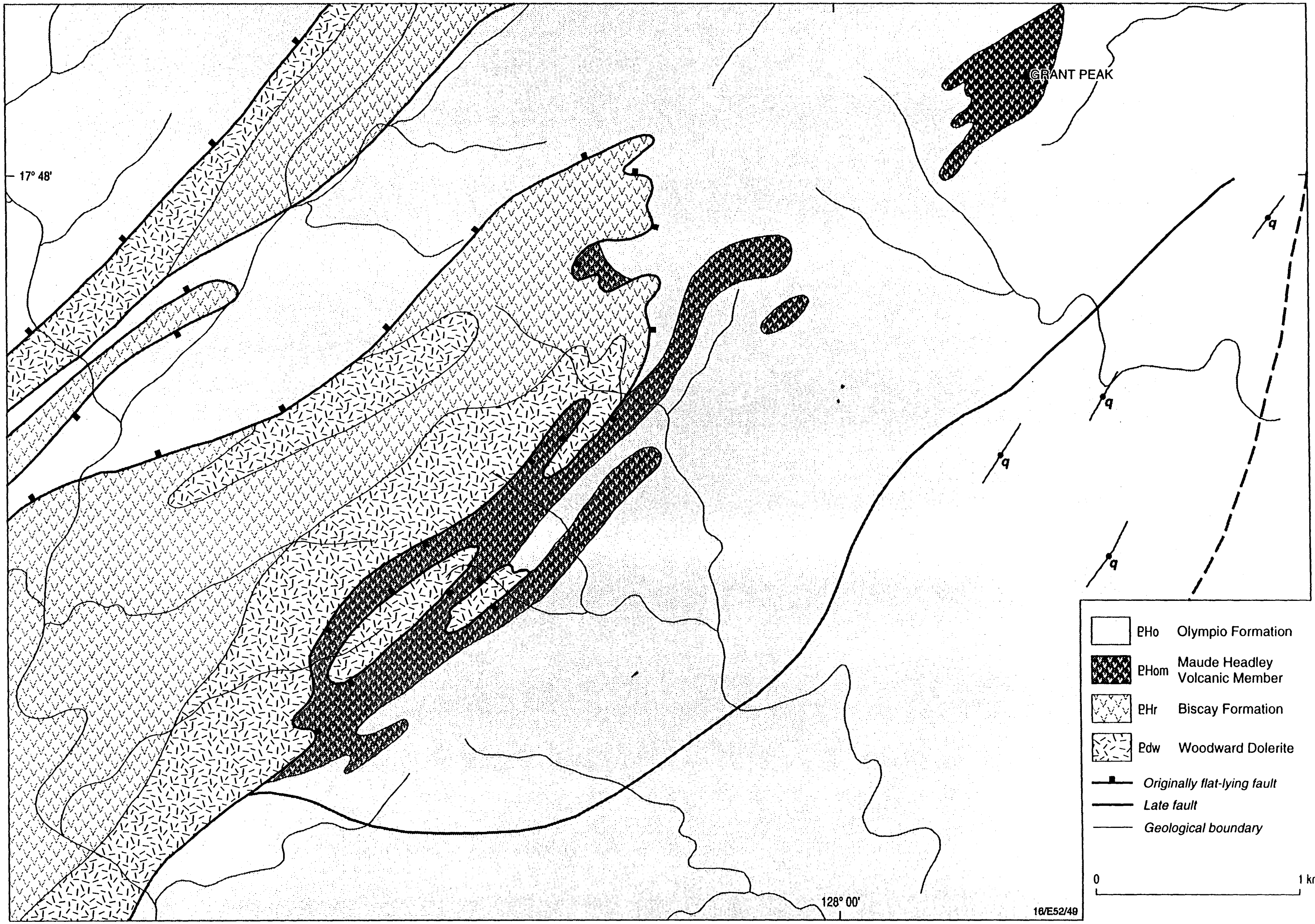

Fig. A4 Map of area south west from Grant Peak, where Maude Headley Volcanic Member overlies dolerite.

Alternatively, both the sheath folds and the upright folds may be related to a north-south fault of D_3 type, which changes direction in the area east of Grants Patch (see Figs 3, A4). This hypothesis is considered the more feasible interpretation, but this area merits additional, more detailed, study of its structural complexities.

Northern Grants Patch, Dry Creek district *Upper Olympio Formation/Lower Olympio Formation* (Figs A5, A6, points D and E respectively in Fig. 4)

In the area to the north of Grants Patch, there are no outcrops of Maude Headley Volcanic Member around the nose of the Grants Patch Anticline. It is unlikely this is due to non-deposition, as Maude Headley Volcanic Member occurs to the west and northwest of the Anticline, as well as to the east. The Member on the west limb of the Grants Patch Anticline does crop out poorly south of Grant Creek, where it appears to be thin and lacking the upper fragmental carbonate-cemented unit and the laminated chert-carbonate band. Both the carbonate-cemented fragmental unit and the upper laminated chert-carbonate unit occur in the outcrops northwest of Grants Patch, but only the carbonate-cemented fragmental unit is present in the fault-bounded sliver against the Halls Creek Fault north-northwest of the tip of the Grants Patch Anticline. West-facing Maude Headley Volcanic Member occurs to the east of the northernmost Grants Patch Anticline. The chert marker at the Biscay-Olympio disconformity occurs on both limbs of the Anticline. The D_1 surface was not recognised in outcrop, but can be extrapolated from where it occurs about a km to the south (Gr926337, McIntosh 1:100 Sheet area), separating Olympio Formation from Biscay Formation (Fig. A5). An alternative suggestion, that local erosion of the Maude Headley Volcanic Member in that part of the district that now is exposed in the rim of the Grants Patch Anticline followed broad warping, is possible. No indication of an erosion surface was noted in the field; and this alterative explanation supposes that the D_2 folding was initiated during deposition or it requires fortuitous co-incidence of warping and the later regional fold axis.

Maude Headley Volcanic Member forms very prominent thick outcrop in the Dry Creek area. However, just to the east of Dry Creek camp, it is missing or reduced to minor volcaniclastic rocks (Fig. A6). At this locality, the chert layer is present at the Biscay-Olympio disconformity, which is undisturbed. Airphotographs show the Maude Headley Volcanic Member re-appears and gradually becomes thicker along strike to the southeast. The same strictures apply here as for the interpretation in the northern Grants Patch Anticline: Non-deposition of PHom_1, PHom_2 and PHom_4 in the Maude Headley Volcanic Member is unlikely. Removal by erosion could be considered, as there is evidence for limited erosion of the upper laminated chert-carbonate unit, PHom_4, in the Panton River section a few kilometres to the north (Fig. 6). At the stratigraphic level where the D_1 surface might be expected, there is a recessive valley and poorly exposed layered rocks. Also, in this area, the lowest part of the upper Olympio Formation forms a more distinctly layered sequence than anywhere else. An erosional break and non-deposition of the basal part of the upper Olympio Formation might be considered in detailed sedimentary and structural mapping in this area, but removal of section through movement on a low-angle D_1 detachment fault provides the simpler explanation.

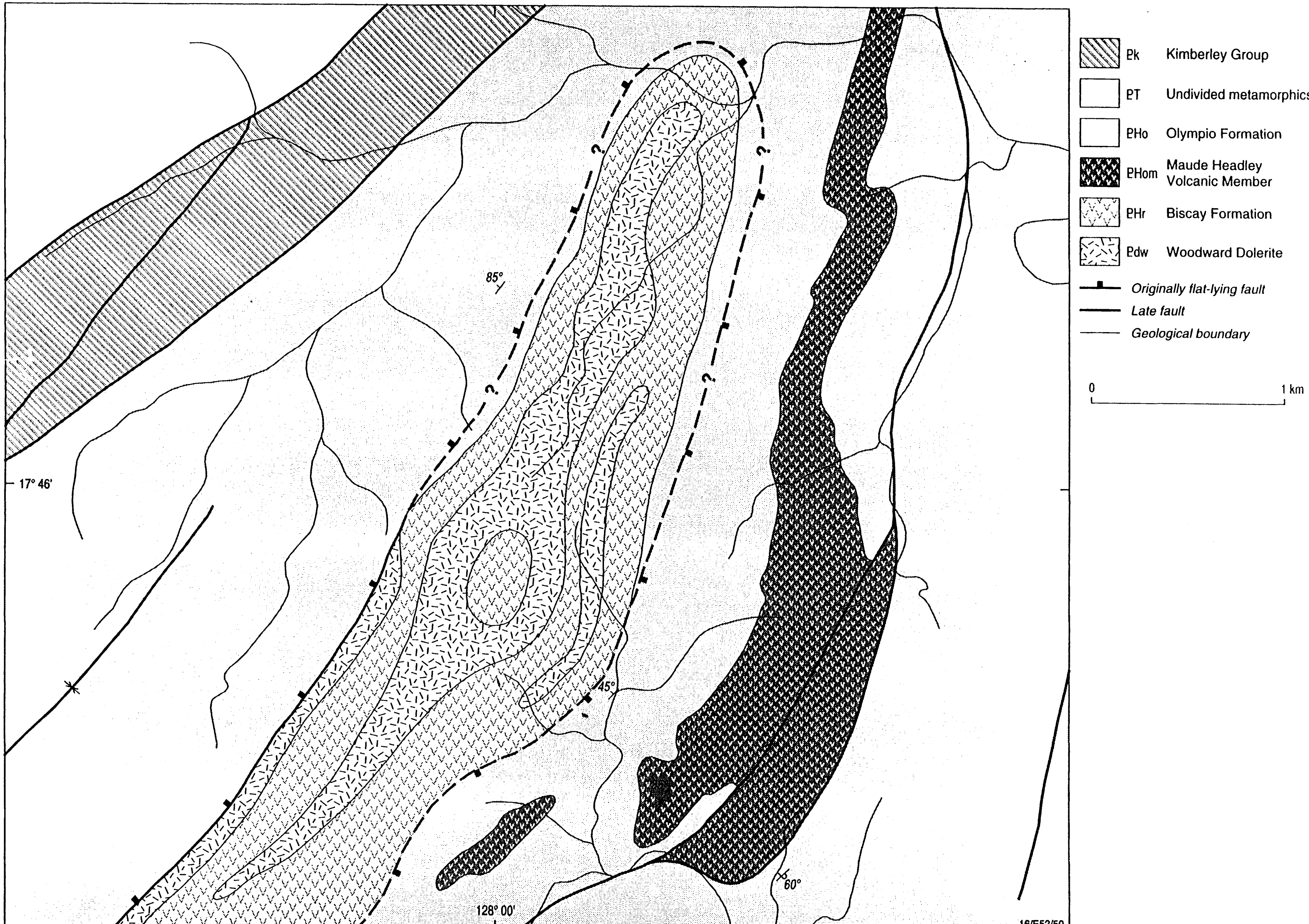

Fig. A5 Map showing the northern Grants Patch Anticline, where a D_1 detachment appears to have placed upper Olympio Formation over lower Olympio Formation, and removed the Maude Headley Volcanic Member.

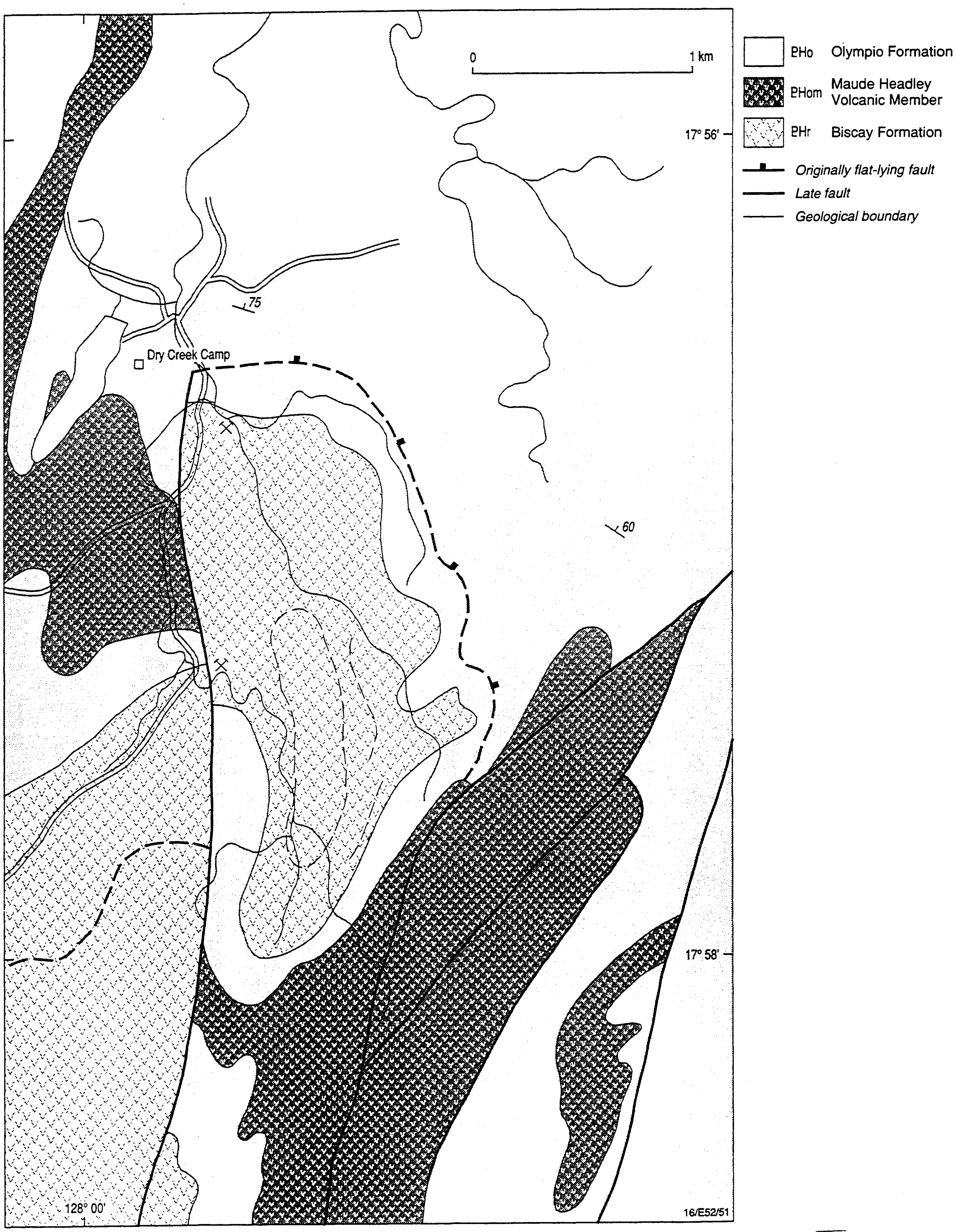

Fig. A6 Map showing the area east of Dry Creek camp, where a D_1 detachment appears to have placed upper Olympio Formation over lower Olympio Formation, and removed the Maude Headley Volcanic Member.

Overview

At most of the localities where part of the expected section is absent, it is replaced by a thin zone of laminated rock with a layer parallel fabric. This is particularly so for the area south and southwest of Maude Headley, where the siliceous Maude Headley Volcanic Member is involved. The exposures south of Katys Yard show that faulting occurred in the brittle zone.

If the sections are considered in their regional context, they can be arranged as a segments on a low-angle extension fault (Fig. 10). This fault progresses down section from north to south and east to west. The simplest view is that the upper plate moved to the southwest.

Models to account for the formation of the D_1 structure are hampered by the lack of information on its timing and the lack of continuity across the Halls Creek Fault. This is compounded by the knowledge that the area where D_1 is recognised was formerly tens of kilometres to the south, relative to outcrops west of the Halls Creek Fault. Two possible ways in which the detachment may have formed can be suggested.

Near horizontal extensional faults at shallow crustal levels are known from large sedimentary basins. Such faults are commonly part of larger structural regimes (e.g., flower structures) that control sedimentation. Therefore, this fault may be related to formation of sites in which deposition of the younger Olympio Formation took place. A variant of this theory is to propose that the Olympio Formation was deposited in a series of ramp basins that developed and overlapped eastwards in response to mid-crustal extension (cf. the Cobar Basin in the Lachlan Fold Belt - Drummond et al. 1992). This hypothesis would account for the younging of the Olympio Formation towards the east and the detachment of the Maude Headley Volcanic Member through extension from a mafic source. This model would also account for the gravity profile across the Olympio Formation. However, it would also imply that old basement (as old as or older than the Ding Dong Downs Volcanics) should exist to the west, especially as country rock to the older large mafic bodies. No such old basement has yet been recognised; units that have been dated contain detrital zircons similar in age to the mafics that intrude them. The most obvious test of the hypothesis would be a deep-seismic reflection profile across the region, from the Kimberley Basin to the edge of the Antrim Plateau Volcanics.

An alternative view is that the detachment is the root-zone of a large-scale gravity slide or nappe that slid towards a trough in the west, such as the trough in which the Koongie Park succession was deposited. Very large nappe structures of this type are known in many mobile belts. The Queanbeyan nappe in the Lachlan Fold Belt (Stauffer & Rickard, 1966), and the Black Rock Antiform (Hancock *in* Plumb et al. 1985) in the Halls Creek Mobile Belt are two such structures whose dimensions are comparable, though both resulted in large recumbent folds with inverted limbs. However, such slides generally are sourced over rising domal regions which are cored by granite intrusion and slide into related sag-ducted basins. Such an environment does not fit the formation of the D_1 detachment, as the there are no granite intrusions recognised east of the Halls Creek Fault. However, a slide related to regional uplift might be considered. Around the perimeter of the Castle