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PINE CREEK GEOSYNCLINE FIELD EXCURSION GUIDE

FOR THE

TECTONICS AND GEOCHEMISTRY OF EARLY TO MIDDLE PROTEROZOIC FOLD BELTS, DARWIN, AUSTRALIA, AUGUST 7-14, 1985.

by

P.G. STUART-SMITH AND R.S. NEEDHAM

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ITINERARY

(refer to Fig. 1).

Day 1. Friday August 9

Leave Darwin, 0800

Stop 1-1 Beestons Formation/Archaean unconformity. 0920-0950

Stop 1-2 Crater Formation/Archaean unconformity. 1000-1040

Stop 1-3 Gerowie Tuff-Howley Anticline. 1155-1225

Lunch at Bridge Creek 1230-1330

Stop 1-4 Frances Creek iron mines, 1430-1530

Stop 1-5 Cullen Batholith 1620-1650

arrive Katherine (Springvale Homestead) 1740

Day 2. Saturday, August 10

Leave Katherine 0800

Stop 2-1 Tollis Formation 0830-0900

Stop 2-2 Katherine Gorge 0930-1130

Stop 2-3 Edith River Group section, 1240-1330

Lunch at Edith Falls. 1330-1430

Leave Edith Falls 1430

arrive Darwin 1800.

REGIONAL GEOLOGY

The Pine Creek Geosyncline is a roughly triangular area of about 66 000 km^2 south and east of Darwin, which contains Early Proterozoic fluviatile, shallow-water and intertidal metasediments, dolerite and granitoids interspersed with minor Archaean granitoid basement domes. It is surrounded by younger sedimentary basins from Middle Proterozoic to Mesozoic in age, and is mantled in many parts by Cainozoic deposits. It is a mineral province of significance, and currently produces mainly uranium and gold.

Up to 14 km of Early Proterozoic metasediments with interbedded volcanics and mafic sills are preserved in a layercake sequence which generally thins westwards (Fig. 2; Table 1). During the Top End Orogeny (1870 to 1780 Ma) the rocks were metamorphosed to mainly greenschist facies; however, amphibolite facies dominates in the northeast, in the Alligator Rivers region. Proven Archaean rocks are restricted to mainly granite-gneiss of the Rum Jungle, Waterhouse and Nanambu Complexes, which form mantled gneiss domes near the presently exposed western and eastern margins of the inlier.

In the northeast the higher-grade metasediments grade into the migmatitic Myra Falls Metamorphics, where in places sedimentary 'resisters' indicate the sedimentary parentage and allow correlation with the un-migmatised terrane. The intensity of folding increases generally towards the higher-grade terrane - tight to isoclinal folds with steep limbs in the central parts progress through overturned tight to isoclinal folds to polyphase isoclinal folds in the Alligator Rivers region. Also in the higher-grade terrane pre-orogenic granite was partly migmatised along with the surrounding metasediments.

During the Top End Orogeny many simple to composite granitoid plutons were emplaced (Fig 3). Granitoid intrusion overlapped with development of two unconformity-bound felsic volcanic-sedimentary sequences in small rifts in the southeast. The most striking feature of these sequences is an extensive red ignimbrite sheet which covered at least 6000 km^2 and which is closely related to a petrologically similar subvolcanic granite. The two sequences were separated by a mild fold event known as the Maud Creek Event.

A stable hiatus of about 150 Ma before the beginning of Middle Proterozoic deposition is marked by a 100 m-deep saprolitic weathered profile on the Early Proterozoic rocks. During this interval dolerite lopoliths were intruded about 1-2 km below surface at about 1690 Ma and subsequently partly exhumed.

The Middle Proterozoic rocks are mainly sandstone, with interbedded volcanics extruded about 1650 Ma ago. The rocks are little deformed and subhorizontal. Near-vertical faults are extensive but displacements are mainly along older fractures known to have been active during geosynclinal sedimentation or orogenesis, and are not known to exceed 600 m. The sandstone is cut by narrow dykes of dolerite emplaced about 1370 and 1200 Ma ago, and ~316 Ma phonolite dykes post-date, but are not seen to intrude, the sandstone.

Phanerozic seas partly or completely covered the region in Cambro-Ordovician, Permian and Mesozoic time in response to epeirogenic movements. Most denudation of Proterozoic strata was completed by about 150 Ma ago, as the present day cliffs at the edge of the sandstone plateau formed seacliffs to the Mesozoic ocean.

The tectonic history of the region and the main tectonic phases are summarised in Table 2.

EXCURSION

INTRODUCTION

Eight excursion stops have been chosen to represent the main stages of tectonic evolution in the Darwin-Katherine region.

Archaean basement-Early Proterozoic sequence relationships

Exposures of the Archaean-Early Proterozoic unconformity are found only in the west of the region, in the Rum Jungle area. **Stops 1-1 and 1-2** examine two exposures of the unconformity; similar granitic basement is overlain by different stratigraphic intervals of the basinal sequence at each stop. An onlapping relationship is indicated by clast lithologies in conglomerate resting on basement at **Stop 1-2**, where BIF pebbles, not seen elsewhere in the sedimentary sequence, were derived from Archaean basement and deposited in a formation about 700 m stratigraphically above the arkose of **Stop 1-1.**

Shearing is common at the unconformity and is well expressed at **Stop 1-2.** The shearing has been attributed by various workers to solid state movement of the basement resulting from magma emplacement at depth or differential movement during folding, or to shearing during decollement.

Elsewhere in the Pine Creek Geosyncline Archaean rocks are exposed 200 km west of Darwin as parts of the Nanambu Complex. Here the contact with younger rocks is known only from drillholes and excavations at the Ranger uranium mine. The contact is strongly sheared and involves medium grade schist and carbonate of the metamorphosed basinal sequence, and pegmatoid gneiss of the basement complex. The complex contains relatively unstrained granite, granite gneiss, and interlayered pegmatoid gneiss, schist and quartzite. The interlayered rocks are derived from the leucocratic lowermost part of the basinal sequence and were accreted to the granite and gneiss of the true basement during the Top End Orogeny (Needham & others; 1980) The contact exposed at the larger uranium mine therefore does not represent a true basement/cover unconformity.

Early Proterozoic pre-orogenic sequence (i.e. Pine Creek Geosyncline sequence)

Most of the stratigraphic elements of the Pine Creek Geosyncline are continuous with little thickness or facies variation between Rum Jungle and the South Alligator River, 180 km to the east. The most distinctive part of the sequence is the South Alligator Group, where airfall tuff conformable with chert-banded ferruginous siltstone indicate the essentially time-stratigraphic character of the succession. **Stop 1-3** examines part of the South Alligator Group in roughly the centre of the Pine Creek Geosyncline. **Stop 1-4** examines iron mineralisation developed over conformable breccias within pyritic carbonaceous sediments of the Mount Partridge Group. The breccias are possibly associated with thrust faults which developed early in the Top End Orogeny.

Granitoid intrusives

Granitoids were emplaced before, during and after the main folding events of the Top End Orogeny. **Stop 1-5** examines rock types typical of the more mafic (granodiorite) and more felsic (leucogranite) components of the Cullen Batholith, the largest granitoid body in the region. This body was in the main emplaced after the main deformation and is the source of most of the mineralisation in the central part of the Pine Creek Geosyncline.

Early Proterozoic post-orogenic sequence

The rift-controlled post-orogenic sequence is centred in the South Alligator Valley area around El Sherana, 100 km northeast of Katherine. The post-orogenic sequence around Katherine represents deposition beyond the main rifts onto bordering shelves, themselves probably parts of much wider, shallower rifts. **Stop 2-1** examines interbedded greywacke and siltstone typical of the El Sherana Group outside the South Alligator Valley (and of the uppermost part of the Group within the valley). Notably the rock types are very similar to those of the Finniss River Group which is the uppermost part of the pre-orogenic sequence, but the two can be distinguished by different structural style. **Stop 2-3** examines the Edith River Group sequence, which rests unconformably on the El Sherana Group. This same sequence extends with little change except greater thickness into the South Alligator Valley 85 km to the northeast. the ignimbrite sheet which is the main component of the sequence is probably coeval with the petrologically similar Grace Creek Granite about halfway between Katherine and El Sherana.

Middle Proterozoic cover sequence

The Middle Proterozoic McArthur Basin sequence rests disconformably or with slight angularity upon the El Sherana Group and with marked angular unconformity upon older rocks. The cover sequence is represented in this region by the Kombolgie Formation, sandstone deposited as a braided alluvial fan mainly from the north or northwest. **Stops 2-3 and 2-2** examines the basal contact and succession of the sandstone respectively. Interlayered basalt is present about 1000 and 150 m respectively. Stratigraphically above each stop but is not accessible for examination.

STOP DESCRIPTIONS

Stop 1-1 Beestons Formation/Archaean unconformity (Fig 4.)

Originally the Rum Jungle and Waterhouse "Granites" were thought to be concordant intrusions which had domed the Early Proterozoic metasediments of the Pine Creek Geosyncline (Sullivan and Matheson, 1952; and Malone 1962). However, no clear evidence of contact metamorphism was recorded, though quartz-tourmaline veins cut both granites and metasediments.

In 1962 B.P. Ruxton and J. Shields discovered an outcropping unconformity (Rhodes, 1965) which showed beyond dispute that the Beestons Formation, lowest stratigraphic unit in the western Pine Creek Geosyncline, is unconformable on what Rhodes defined as the Rum Jungle Complex. Since then, French (1970) and Johnson (1974) have described several further exposures of the unconformity between the granitic basement and Early Proterozoic metasediments.

At most exposures the unconformity contact is sheared and dips greater than 70° (Stephannson and Johnson, 1976). At this locality however the contact is relatively shallow, dipping south at about 40°, and deformation is absent. The unconformity is exposed in three outcrops and can be traced for about 150 m through scattered outcrops (Fig 4). The unconformity surface is irregular and undulating, broadly concordant with the dip of the overlying sediments.

Here the 'basement' is jointed massive pink, leucocratic coarse equigranular granite of the ~2500 Ma old Rum Jungle Complex (Richards and others, 1966). The granite consists of microcline, quartz, plagioclase, biotite, sericite and minor fluorite. Thin irregular fine grained leucogranite dykes and quartz tourmaline veins are common, and the quartz has a characteristic pale blue opalescent colour.

The sediments in contact with the granite are poorly sorted coarse to gritty arkose of the Beestons Formation. The arkose contains thin quartz pebble beds and lenses up to 3 m thick of chaotic clast supported conglomerate composed of angular white vein quartz fragments ranging up to 30 cm across in a gritty arkose matrix (Fig 5). Grains of blue opalescent quartz, like those in the granite basement, are common in the arkose. The sediments represent transgressive shallow water, possibly shoreline deposits, largely derived from the underlying granitic basement (French, 1970).

NOTES

Stop 1-2. <u>Crater Formation/Archaean unconformity</u> (Fig. 6)

In places the Crater Formation transgresses the underlying Namoona Group (Beestons Formation and Celia Dolomite) to rest directly on the Rum Jungle Complex. Whereas the Beestons Formation was unconformable on the complex at the previous stop, at this locality about 5 km further north, the Crater Formation (usually about 700 m higher in the section), overlies the complex.

The contact between the Crater Formation and the Rum Jungle Complex at this stop is typical of the relationship found along most of the unconformity. Within a few metres of the contact both the coarse to medium granite and the overlying hematite boulder conglomerate are strongly foliated parallel to the contact which here dips about 45° to the south-southwest (Fig. 7). The axes of small isoclinal folds and the prominent stretching lineation in the conglomerate lie on the foliation plane and plunge steeply (80-90°) to the southwest (Fig. 8). About 10 m north of the contact less foliated massive granite is exposed at the base of the hill. Relatively undeformed conglomerate is exposed at the contact about 20 m east of the hill crest, here the matrix is less foliated and consists of weathered granitic material and gritty BIF clasts. The clasts of banded iron formation are unique to the base of the Crater Formation around the southern margin of the Rum Jungle Complex. The only known sources for them are similar rocks exposed in the Rum Jungle Complex 14 km to the northeast, and 8 km to the southeast.

The domal structure of the Archaean complexes has been interpreted as the product of fold interference (Williams, 1963; Rhodes, 1965), or solid state diapirism whereby uplift of the Archaean Complexes was driven by underlying post orogenic granitoids (Stephannson and Johnson, 1976). Johnston (1984) considered these hypotheses and a third possibility (buckling around prexisting basement highs), and concluded that the doming was the product of fold interference modified by late faulting.

He found that the high strain zone, common at the basement/cover contact, and concordant with stratigraphy, has a consistent vergence and interpreted it to be the product of an early northwest-verging decoupling zone, possibly gravitationally induced. This high strain zone has within it in places, recumbent folds and widespread concordant foliation. It has been refolded by upright, tight to isoclinal, north-trending noncylindrical folds (dominant regional structures) and later east-west upright and polyclinal kink folds. The amount and type of strain varies considerably around the complexes and may reflect original heterogenous strain, superposition of later strains, or movement of the basal detachment surface across basement topography. Strains were probably highest over pre-existing basement highs (Johnston, 1984).

Formation of the high strain zones, early in the deformation of the Early Proterozoic strata is not consistent with the post-orogenic diapir-model as proposed by Stephannson and Johnson (1976). The abundance of quartz-tourmaline veins in basement and cover may reflect space accommodation of disharmonic deformation (Johnston, 1984) rather than fluids associated with subsurface post-orogenic granitoid intrusions.

NOTES

Stop 1-3. Gerowie Tuff - Howley Anticline

The Early Proterozoic geosynclinal sequence consists of mainly slate, siltstone, sandstone, conglomerate, carbonate rocks and greywacke, schist and gneiss (Needham and others, 1980). In the central part of the geosyncline the sediments are regionally metamorphosed to low grade and in places extensively contact metamorphosed by syn to post-orogenic granitoid intrusions. At this stop low grade rocks of the Gerowie Tuff are well exposed in the road cutting and exhibit the dominant structural features characteristic the central part of the geosyncline.

Rocks exposed in the cutting consist mostly of laminated to thinly bedded black crystal and vitric tuff with a spotted weathered surface (Fig. 9), and minor pelitic interbeds and thin bands of pyritic chert (silicified dolomite?). Here the tuffs commonly form graded beds up to 50 cm thick, with laminated and microlenticular crossbedded tops.

The tuffs are also present in the overlying Mount Bonnie Formation where they have yielded U/Pb zircon ages of about 1880 Ma (Page, 1983) dating deposition of the South Alligator Group and the 'sag phase' of the tectonic development of the geosyncline.

The central part of the geosyncline is dominated by one period of folding, characterised by regional northwest to north-trending tight folds with subhorizontal axes and a well developed axial plane cleavage. These folds are openly folded about widely spaced northwest or northeast-trending regional flexures and locally modified by granitoid intrusion. At this stop, the hinge of one such regional fold, the Howley Anticline, is exposed in the southeastern end of the road cutting (Fig. 10). Here the anticline plunges about 40° to the south (Fig. 11) and has a well developed axial plane cleavage striking 175° and dipping 78° to the west. Joints, commonly well developed in the relatively brittle tuff beds, form a prominent set striking 072° and dipping about 75° to the north-northeast. In places these joints are filled by quartz.

The Howley Anticline is an economically important structure in the region as it is the locus of gold mineralisation which is mostly stratigraphically controlled within the Koolpin Formation of the South Alligator Group. In places, quartz saddle reefs are present, however they contain only low-grade mineralisation and most mineralisation is in late stage quartz filled steeply dipping faults and shear zones concentrated in the hinge or adjacent limbs of the anticline.

NOTES

Stop 1-4 Frances Creek iron mines (Fig. 12)

Massive hematite lodes in the Frances Creek area were discovered in 1961 and mined by the Frances Creek Iron Mining Corporation Pty Ltd between 1966 and 1974, during which time about 8,000,000t of iron ore were produced. The lodes occur as lenses up to 600 m long and 20 m wide, which crop out as prominent discontinuous strike ridges up to 50 m high, over a strike length of about 25 km. The most important individual lenses are those in the Frances Creek group of mines which include from south to north: Helene, Thelma 2, Ochre Hill and Saddle; others are Elizabeth, Marion, Jasmine, Rosemary, Rosemary 2, Thelma-Frances, and Beryl. The excursion stop is at the Helene Leases in the southern part of the field, where the largest tonnages were produced from a group of ironstone lenses which appear to thicken within fold hinges in Early Proterozoic sediments of the Wildman Siltstone. The ironstones, which average 59% Fe consist of massive or brecciated iron and manganese oxides in a siliceous gossanous matrix, and grade into pyritic carbonaceous phyllite and siltstone breccia at depth. The ironstones probably formed by oxidation and enrichment of the permeable breccia zones prior to the deposition of flat-lying Cretaceous sediments which unconformably overlie the ironstone and locally contain pebbles of massive hematite in basal conglomerates.

The breccia forms an essentially conformable horizon within the enclosing sediments, locally cross-cutting in places, and is folded with them about the regional northwest-trending isoclinal folds, but truncates locally developed earlier tight to isoclinal folds with wavelengths of about 1 m (Johnston, 1984). The margins of the breccias are characterised by quartz slickensides and in the adjacent rocks quartz pressure shadows on pyrite cubes define a stretching lineation which is also folded by the regional folds. This elongation direction parallels the slickensides, except in disoriented breccia clasts, and unfolded indicates a tectonic transport direction to the southwest (Johnston, 1984). The earliest observed structures in the area are slaty and crenulation cleavages found only within the breccia clasts.

The breccia is interpreted as forming during the later stages of thust fault development at the onset of the Top End Orogeny. The southwest tectonic movement direction is similar to that of other known thrust faults to the east (Johnston, 1984) and is consistent with northeast-southwest compression during the Nimbuwah Event.

At the Helene open cut the breccia is well exposed on the top bench at the northern end of the pit and at the base of the pit in the southwest corner. Along the northern bench, between the two exposures of breccia, a sequence of bleached white and grey siltstone and phyllite is well exposed; at depth these rocks are dark grey, pyritic and carbonaceous. The sequence forms the basal part of the Wildman Siltstone which is about 750 m thick in the area. Thinly bedded fine to coarse feldspathic quartz sandstone, quartzite and rare dolarenite are interbedded with the pelitic sequence further up section and are exposed 1 km to the west.

The Wildman Siltstone is underlain by the Mundogie Sandstone which is exposed on the ridge about 200 m east of the pit and forms the core of a shallow north-plunging regional anticline (Fig. 12). The sandstone is interpreted as a fluvial deposit which is transitional with the shallow marine, possibly subtidal deposits of the Wildman Siltstone.

Pre-orogenic sills of Zamu Dolerite intrude most units in the Early Proterozoic geosynclinal sequence. One such body intrudes the Wildman Siltstone in the area and is exposed as deeply weathered, pale greenish yellow clay on the eastern and southern walls of the open cut.

NOTES

The Enterprise gold mine, Pine Creek

Although the Enterprise gold mine could not be included in this excursion, it is en route to Katherine and some features of the mine are visible from the road. The gold mineralisation at Pine Creek is representative of the widespread hydrothermal vein-type precious and base-metal mineralisation related to granitoid intrusions concentrated in this part of the region.

The Enterprise mine is the largest of the Pine Creek group of mines which has a total recorded production of nearly 3 t Au. The goldfield workings consit of numerous open cuts, shafts and adits which cover an area about 4 km long and 1 km wide centred on the western outskirts of Pine Creek Townshop. Most of the workings are above the water table, however major underground development up to 80 m deep was carried out in the larger Enterprise, Elsinore and Eleanor mines. Gold was first discovered in the early 1870s and production continued until 1915, by which time 124,960 t of ore had been treated with an average yield of 32g Au/t from the batteries and 8 Au/t from cyanide works (Hossfeld, 1936). Since 1915 the deposits have been worked sporadically by prospectors, and investigated by diamond drilling (Shields, 1965).

In 1985 Goldfields Exploration Pty Ltd commenced open cut operations at Enterprise on a 6,700,000 t ore body averaging 3.3g Au/t (Dann and Delaney, 1984). The open cut operations can be seen on the western flank of the ridge next to the Pine Creek turnoff. The mine lies adjacent to the western margin of the Pine Creek Shear Zone in contact metamorphosed phyllite and greywacke of the Mount Bonnie and Burrell Creek Formations. The presence of a thin carbonaceous shale bed containing chert nodules, defines the upper boundary of the Mount Bonnie Formation at the Enterprise Mine and outlines a southeasterly plunging, tight anticline as the dominant structure in the region which forms the main ridge immediately west of the highway. About 1000 m west of the mine the sediments are intruded by the Tabletop Granite. The gold occurs in quartz reefs and small irregular veins in association with arsenopyrite, pyrite, chalcopyrite, sphalerite, tetrahedrite, pyrrhotite, minor galena and native bismuth. The major reefs mostly follow near vertical sheared axial planes or follow the strike of the enclosing sediments where they show considerable thickening on fold crests; and have been interpreted as saddle reefs (Walpole and other, 1968; Van der Plank, 1965; and Dann and Delaney, 1984). However, recent detailed study of the geometry, mineralogy and geochemisty of the vein systems at Enterprise by P. Holyland (Gold Fields Exploration Ltd) and M.A. Etheridge (BMR) deomonstrated four separate episodes of veining. The bedded and saddle reefs formed during the earliest of these episodes, synchronous with folding and regional metamorphism. However, there is a close relationship between gold values and the second vein episode, which crosscuts all fold structures, and which was deposited from a higher temperature, higher salinity fluid approximately contemporaneous with contact metamorphism. Holyland and Etheridge interpreted this vein episode to be at least partly magmatic in character, and to have been a major influence on the development of ore grade mineralisation.

NOTES

Stop 1-5. **Cullen Batholith: Fingerpost Granodiorite/Driffield Granite contact** (Fig. 13)

Syn-to-post orogenic granitoids (1870-1780 Ma) intrude the Early Proterozoic geosynclinal metasediments and the felsic volcanic suites of the El Sherana and Edith River Groups. The Cullen Batholith (1840-1780 Ma) is the largest granitoid body in the Pine Creek Geosyncline, and is surrounded by an extensive hornfels aureole up to 10 km wide (Fig. 14). The batholith is overlain by Middle Proterozoic to Cambrian sediments in the west and by scattered residual cappings of Mesozoic sediments.

Twenty three plutons are defined (Fig. 14); sixteen of these coalesce at shallow depths and form a broad v-shaped mass, covering about 2800 km^2 centred on the Pine Creek township (Stuart-Smith and Needham, 1984). The other plutons of the batholith surround the main body and are probably interconnected at depths of less than 3 km (Tucker and others, 1980). Contacts are mostly smooth and discordant, and faulted in places. A major north-northwest trending shear zone, the Pine Creek Shear Zone, follows an embayment of Early Proterozoic metasediments which separates two major lobes of the batholith either side of Pine Creek township.

Ten granitoid types are distinguished by mineralogy and texture using the nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1973). As well as the ten granitoid phases, older bodies of monzonite (Bludells Monzonite), Early Proterozoic hornfels rafts, and post-granitoid dykes (Lewin Springs Syenite) have been distinguished. The granitoid phases are granodiorite (type 1), three types of granite (types 2, 3, 4), and six types of leucogranite (types 5, 6, 7, 8, 9, and 10). The distribution of these phases is shown in Fig. 14.

At this stop the contact between altered grey coarse porphyritic biotite hornblende granodiorite (type 1) of the

Fingerpost Granodiorite and pink fine to medium-grained equigranular leucogranite (type 9) of the Driffield Granite, is exposed. (Fig. 16).

The granodiorite is one of the most mafic and possibly oldest granitoid phase in the Cullen Batholith. It is strongly porphyritic, consisting of scattered tabular pink microcline phenocrysts up to 6 cm across in a medium to coarse grained groundmass of pale green saussuritised oligoclase, microcline, anhedral quartz and about 10 to 15 percent mafic minerals. Hornblende is the dominant mafic mineral, forming scattered prismatic dark green to pale brown crystals which are commonly altered to either chlorite and epidote or to pale and dark green amphibole aggregates. Pale to dark brown biotite is present and is also altered to chlorite and epidote in places. Accessory minerals include apatite, sphene, opaque minerals and zircon, the latter commonly occurring as inclusions in biotite.

Mostly the granodiorite is massive with very little textural or mineralogical variation. However at this locality the rock is in places compositionally banded, and mafic xenoliths, usually rare, are common (Figs. 17, 18).

The Pine Creek Shear Zone cuts the eastern part of the Fingerpost Granodiorite (Fig. 14) and is evident in outcrop as north-northwest trending fractures and ultracataclasite veinlets (Fig. 17). Within the zone the granodiorite shows microscopic evidence of deformation and alteration; undulose extinction and recrystallised grain boundaries are common and most minerals are partly or completely replaced by secondary products.

The Driffield Granite is one of five plutons characterised by broadly concentric transitional zones of granite and leucogranite. The fine to medium grained equigranular leucogranite exposed as low bouldery outcrops at this locality forms the outer western margin of the pluton and is transitional to the east and south into coarser grained equigranular to porphyritic leucogranite.

The leucogranite is the most felsic phase within the pluton and consists of an equigranular mosaic of K-feldspar, quartz and plagioclase. K-feldspar is the predominant constituent, comprising up to 50 percent of the rock. It occurs as anhedral grains of microcline and less commonly orthoclase, and rarely as rims around plagioclase. Quartz contents range from 20 percent up to 50 percent and occur as anhedral grains or as graphic intergrowths with K-feldspar. Albite-oligoclase comprises 5 to 25 percent of total feldspar; it is mostly anhedral but in places it forms subhedral zoned crystals. Minor amounts (less than 1 percent) of pale dark reddish brown to greenish brown biotite are commonly present and are altered to chlorite, epidote and iron oxides in places.

NOTES

Stop 2-1. Tollis Formation

Two unconformity-bound groups of volcanic rocks and associated sediments (El Sherana and Edith River Groups) separate the older Pine Creek Geosyncline metasediments from Middle Proterozoic platform cover of the McArthur Basin. The lower El Sherana Group developed during an extensional phase at about 1860-1850 Ma centred on the South Alligator Valley where rift valleys were filled with rhyolite flows, ignimbrite, and ill-sorted arenite and rudite, and flyschoid sediments spread onto adjacent lands (Needham and Stuart-Smith, 1985).

The Tollis Formation is the most widespread unit of the El Sherana Group and consists of about 2200 m of interbedded greywacke, siltstone, slate, argillite, cherty tuff and crystal tuff, and minor altered mafic to intermediate volcanics. The volcanic rocks include pitchstone and chloritized and carbonated mafic lavas and chloritized porphyritic andesite. The andesite contains phenocysts of plagioclase, augite, and minor magnetite and apatite in a fluidal devitrified groundmass. The basal part of the formation is devoid of distinctive volcanic rock types, and consists of greywacke, siltstone and argillite. Rock types typical of the basal part are exposed in the first road cutting at this stop (Fig. 19) and those more typical of the upper part of the formation are exposed in the second road cutting 500 m further east. At the second road cutting rare carbonate breccia is present and dark green volcanic agglomerate, and deeply weathered greenish grey altered mafic flows and tuff, are the only volcanic rocks present.

Metamorphic grade of the sediments is low and folding is mostly open to tight and upright (Fig. 20). An associated near vertical axial plane slaty cleavage is common in pelitic rocks and a spaced fracture cleavage may be present in psammitic rocks (Fig. 19). In the second road cutting the relatively simple regional folds typical of the unit are locally disrupted by extensive shearing and faulting. The deformation and accompaning low grade metamorphism of the El Sherana Group took place before deposition of the Edith River Group, and together with associated granitoid intrusion represent a discrete event termed 'the Maud Creek Event'; this deformation was also superimposed on the older pre-orogenic sequence in the southern part of the geosyncline.

NOTES

Stop 2-2. Katherine Gorge

The spectacular Katherine Gorge is developed in the plateau-forming Kombolgie Formation where the Katherine River cuts the plateau along major joints, and faults (Figs. 21 and 22). The formation is the basal unit of the Middle Proterozoic platform cover of the McArthur Basin which forms the eastern margin of the Pine Creek Geosyncline.

The Kombolgie Formation comprises a sandstone sequence punctuated by two layers of intermediate to basic volcanics (Walpole and others, 1968). It is about 900 m thick on the Arnhem Land Plateau but is much thicker (up to 2000m) in locally developed basins in the Katherine-El Sherana area. The gorge is cut into 250 m of the west sandstone unit; the lower volcanic horizon (the McAddens Creek Volcanic Member) is about 150 m up section and is preserved on the top of the plateau 2 km from the gorge.

The Kombolgie Formation overlies Edith River Group rocks generally disconformably or paraconformably, and in places, with slight angularity. It oversteps onto El Sherana Group and older Early Proterozoic rocks with high angular unconformity. The unconformity is located at the entrance of the gorge but in this area is covered by talus.

Sandstone makes up 80% of the formation and is mainly medium to coarse-grained, moderately rounded, moderate to well sorted, and clayey or feldspathic in the basins, but mature to slightly clayey in the plateau sequences. Labile conglomerates are common at the base, and are up to 10 m thick in the plateau increasing to 25 m thick in places in the basins. Vein quartz and quartzite are the commonest clasts, although in the basins volcanic clasts are also common and indicate a largely local provenance. The formation also contains minor siltstone. The sandstone is extensively cross-bedded and ripple-marked (Figs. 23 and 24) and was deposited as braided alluvial fans from a northwesterly provenance (Ojakangas, 1979) on a relatively stable, peneplaned, mostly metamorphic basement.

The age of sandstone deposition is about 1650 Ma as indicated by the age of interlayered basalt (Page and others, 1980).

The greater thickness of the formation locally in basins indicates considerable subsidence during sedimentation, probably by reactivation of bounding faults. The interbedded volcanics were mainly fissure-fed flood basalts, which were in places extruded subaqueously (Needham, 1978) and spread over at least 10 000 km^2.

Except for a suite of Precambrian dolerite dykes intruded along and parallel to ENE trending faults there is no evidence of geological processes in the region for about 1500 Ma after Kombolgie Formation deposition. The region may have been subject to erosion for much of this time. By the Mesozoic, the Proterozoic rocks were exhumed almost to their present extent, at which time extensive continental to shallow sea sediments were deposited; the present sandstone scarps of the area possibly formed sea cliffs. Faulting continued to be periodically active from the Middle Proterozoic onwards, and resulted in local folding adjacent to larger faults.

NOTES

Stop 2-3 Edith River Group section, Edith Falls

The Edith River Group is the younger (~1850 Ma) of the two Early Proterozoic felsic volcanic sequences. It overlies the El Sherana Group and older geosynclinal metasediments with a marked angular unconformity and is unconformably overlain by the Kombolgie Formation and flat-lying Cretaceous sediments, mostly with a moderate to shallowly angular contact. In many places the contact with the Kombolgie Formation is disconformable or sheared near basin bounding faults.

At this excursion stop a section along the Edith Falls road through the Edith River Group is examined, commencing near the base of the sequence and ending at the contact with the overlying Kombolgie Formation near Edith Falls (Fig. 25).

At the first road cutting (2.5km from the falls) massive boulder conglomerate, part of a 300 m thick section of the Phillips Creek Sandstone, is exposed. The conglomerate is clast supported, consisting of subrounded boulders up to 40 cm across of greywacke, phyllite, and minor vein quartz, and tuffaceous sediment in a sandy matrix (Fig. 26). The clasts are similar to rocks types in the underlying Tollis Formation which are exposed in a road cutting about 50 m to the west. The Phillips Creek Sandstone forms lenses at the base of the Edith River Group which elsewhere consist of purple medium sandstone, conglomerate, shale and tuffaceous sediments up to 300 m, thick (Needham and Stuart-Smith, 1985). The contact with the Tollis Formation is not exposed in the road cutting, but elsewhere is seen to be unconformable and can be readily traced on aerial photographs (Fig. 27).

Between this road cutting and Edith Falls a variety of felsic volcanics and minor mafic volcanics and clastic sediments of the Plum Tree Creek Volcanics is exposed along the roadside. Here the formation forms an easterly dipping sequence about 1000 m thick, and forms part of a continuous sheet of volcanics which extends over 6000 km^2. Locally the unit rests conformably on basal sandstone units such as the Phillips Creek Sandstone but oversteps them to rest unconformably on the El Sherana Group and older Early Proterozoic metasediments. Outliers of the volcanics in the Fergusson River area are intruded by the Cullen Batholith and in the Eva Valley area NE of Katherine the volcanics appear to be comagmatic with porphyritic microgranite of the Grace Creek Granite (Needham and Stuart-Smith, 1985).

Massive glassy red or pink ignimbrite of rhyodacitic to andesitic composition with a distinctive weathered pitted surface and common flow banding and columnar jointing is the predominant rock type. The best exposure at this stop is a road cutting 1.3 km from the falls (Fig. 28); where the ignimbrite is cut by carbonate-quartz-chlorite-epidote veinlets and contains rare lithic fragments. Typically the rock has corroded phenocrysts of microcline, andesine and minor quartz and chloritised hornblende which are set in a fluidal to layered fragmental altered groundmass of quartz, sericite, chlorite, carbonate and trace amounts of apatite, zircon, sphene, leucoxene and biotite. Other rock types exposed along the road include massive and amygdaloidal mafic flows and minor thin interbeds of lithic tuff and graded pebble and cobble conglomerate. The mafic rocks are poorly exposed and extensively altered to carbonate, chlorite and iron oxides. Andesine laths and minor feldspar crystals are commonly preserved. Mafic minerals where preserved, are either hornblende (outcrop 1.9 km from falls) or clinopyroxene and minor biotite (outcrop 0.6 km from falls).

The unconformable contact between the Kombolgie Formation and the Plum Tree Creek Volcanics is exposed at the top of the scree slope on the north side of the falls. The unconformity surface is irregular and displaced by a small reverse fault (Fig. 29). Boulder conglomerate, composed mostly of clasts derived from the underlying volcanics and minor quartz, forms the base of the Kombolgie Formation and grades rapidly upwards into polymictic cobble conglomerate and coarse poorly sorted quartz sandstone. The sandstone dips about 35° to the east and forms the western margin of the Edith Falls Basin sequence which includes two volcanic members (Fig. 27).

A 150 Ma period separates deposition of the Plum Tree Creek Volcanics and the Kombolgie Formation. During this time lopoliths of Oenpelli Dolerite were intruded (Stuart-Smith and Ferguson, 1978) at about 1690 Ma (Page and others, 1980) in the eastern part of the geosyncline, and were subsequently partly exhumed.

Local high angularity of the unconformity between the Kombolgie Formation and the Edith River Group indicates minor faulting and associated local folding during this time. Beneath the unconformity the volcanics are intensely altered to a hematite-sericite-quartz rock, a distinctive saprolite developed on all rock types beneath the unconformity and indicative of a prolonged period of chemical weathering during the erosional interval prior to deposition of the Kombolgie Formation.

NOTES

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TABLE 1. SUMMARY OF ARCHAEAN TO MIDDLE PROTEROZOIC STRATIGRAPHY OF THE PINE CREEK GEOSYNCLINE

	Unit	Lithology	Thickness (m)	Age (Ma)
MIDDLE TO LATE PROTEROZOIC	MINOR DOLERITE	quartz dolerite dykes and small plug-like bodies		1200 $\pm$ 35
	MUDGINBERRI PHONOLITE MUNMARLARY PHONOLITE	phonolite dykes	1	1316 $\pm$ 50
	TOLMER GROUP	sandstone, dolomite, siltstone	1000	
	KATHERINE RIVER GROUP	sandstone, conglomerate, minor greywacke, siltstone. Interbedded basalt-andesite volcanics and pyroclastics	1200	1648 $\pm$ 29 (basalt)
late EARLY PROTEROZOIC TRANSITIONAL IGNEOUS ACTIVITY ~1870-1650 Ma	OENPELLI DOLERITE	layered tholeiitic dolerite lopoliths	<250	1688 $\pm$ 13
	EDITH RIVER GROUP	ignimbrite, microgranite, rhyolite, minor basalt and cherty sediments; basal sandstone, arkose	1200	1850 (ignimbrite)
	POST-OROGENIC GRANITE EMPLACEMENT	biotite granite, adamellite, syenite, granodiorite (numerous plutons)		1780 - 18[illegible]0
	EL SHERANA GROUP	rhyolite, greywacke, siltstone, sandstone, basalt		1860
	MYRA FALLS METAMORPHICS & NOURLANGIE SCHIST	layered schist, gneiss (metamorphosed and partly migmatised Early Proterozoic sediments)		1800
	NIMBUWAH COMPLEX	granitoid migmatite, granite, gneiss, schist (anatexis of Early Proterozoic granite)		1803 - 1870
	ZAMU DOLERITE	layered tholeiitic dolerite sills and minor dykes	<2500	1914 $\pm$ 170
EARLY PROTEROZOIC SEDIMENTATION ~1870-2400 Ma	FINNISS RIVER GROUP (flysch)	siltstone, slate, shale, greywacke, arkose quartzite, schist, minor interbedded volcanics	1500-5000	
	SOUTH ALLIGATOR GROUP (shallow marine chemical, volcanic)	pyritic black shale and siltstone, chert-banded and nodulated hematitic siltstone and black shale, algal carbonate, banded iron formation, jaspilite, tuff, greywacke near top	<5000	1884 $\pm$ 3 (dacite)
	MOUNT PARTRIDGE GROUP (fluviatile, near-shore chemical, supratidal)	sandstone, siltstone, arkose, shale, conglomerate, quartzite, carbonaceous siltstone & shale, dolomite, magnesite; minor interbedded volcanics	<5000	
	CAHILL FORMATION (supratidal, fluviatile)	quartz schist, pelitic and partly carbonaceous near base with lenses magnesite	3000	
	NAMOONA GROUP (shallow marine, chemical, detrital, supratidal)	pyritic carbonaceous shale and siltstone calcareous in places, calcareous sandstone, tuff, agglomerate; arkose, sandstone and massive dolomite in west.	<3500	
	KAKADU GROUP (fluviatile)	sandstone, arkose, siltstone, conglomerate, quartzite, schist, gneiss	~1000	
ARCHAEAN BASEMENT	NANAMBU COMPLEX	granite, augen gneiss, leucogneiss, minor quartzite and schist (includes accreted Early Proterozoic metamorphics)		1800 (gneiss) ~2500 (granite)
	RUM JUNGLE COMPLEX WATERHOUSE COMPLEX	coarse, medium, and porphyritic adamellite, biotite-muscovite granite, migmatite, gneiss, schist, pegmatite, meta-diorite, banded iron formation		2500

TABLE 2. Summary of Early to Middle Proterozoic geological history

PLATFORM COVER	1650 Ma.	Continental to shallow marine deposition of sandstone and minor siltstone. Extrusion of andesite and basalt flows. (Katherine River and Tolmer Groups).
	1690 Ma.	Intrusion of dolerite lopoliths and sills (Oenpelli Dolerite).
	Shoobrige Event. ~1780 Ma	Northwest to north-trending shear zones and associated localised low grade regional metamorphism.
	1840 Ma -1780 Ma	Granitoid intrusion.
TOP END OROGENY	Rifting phase 1850 Ma	Fluvial deposition of sandstone, Felsic and minor mafic volcanism. (Edith River Group).
	unconformity	
	Maude Creek Event	Low grade regional metamorphism and upright folding in south.
	Rifting Phase 1860 Ma	Valley-fill felsic and mafic volcanism and fluvial sandstone deposition, followed by widespread turbidite facies deposition. (El Sherana Group).
	unconformity	
	Nimbuwah Event 1870 Ma.	Low to medium grade regional metamorphism, polyphase deformation and granitoid intrusion.
	Pre-orogenic Phase	Intrusion of dolerite (continental tholeiite) sills Turbidite deposition (Finniss River Group), felsic volcanism outside area.
	Sag Phase 1880 Ma	Shallow marine subtidal, partly evoporitic deposition of pelites, felsic volcanism (South Alligator Group).
PINE CREEK GEOSYNCLINE	unconformity	
	Rift Phase	Deposition of basal paralic arkosic sandstone, 2200-~2000 Ma subtidal carbonaceous and dolomitic pelites, marginal massive stromatolitic, partly evaporitic supra-to intertidal carbonate, deltaic supratidal to subtidal conglomeratic sandstone and siltstone. Minor mafic to felsic volcanism. Numerous transgressive-regressive cycles. (Kakadu, Namoona and Mount Partridge Groups).

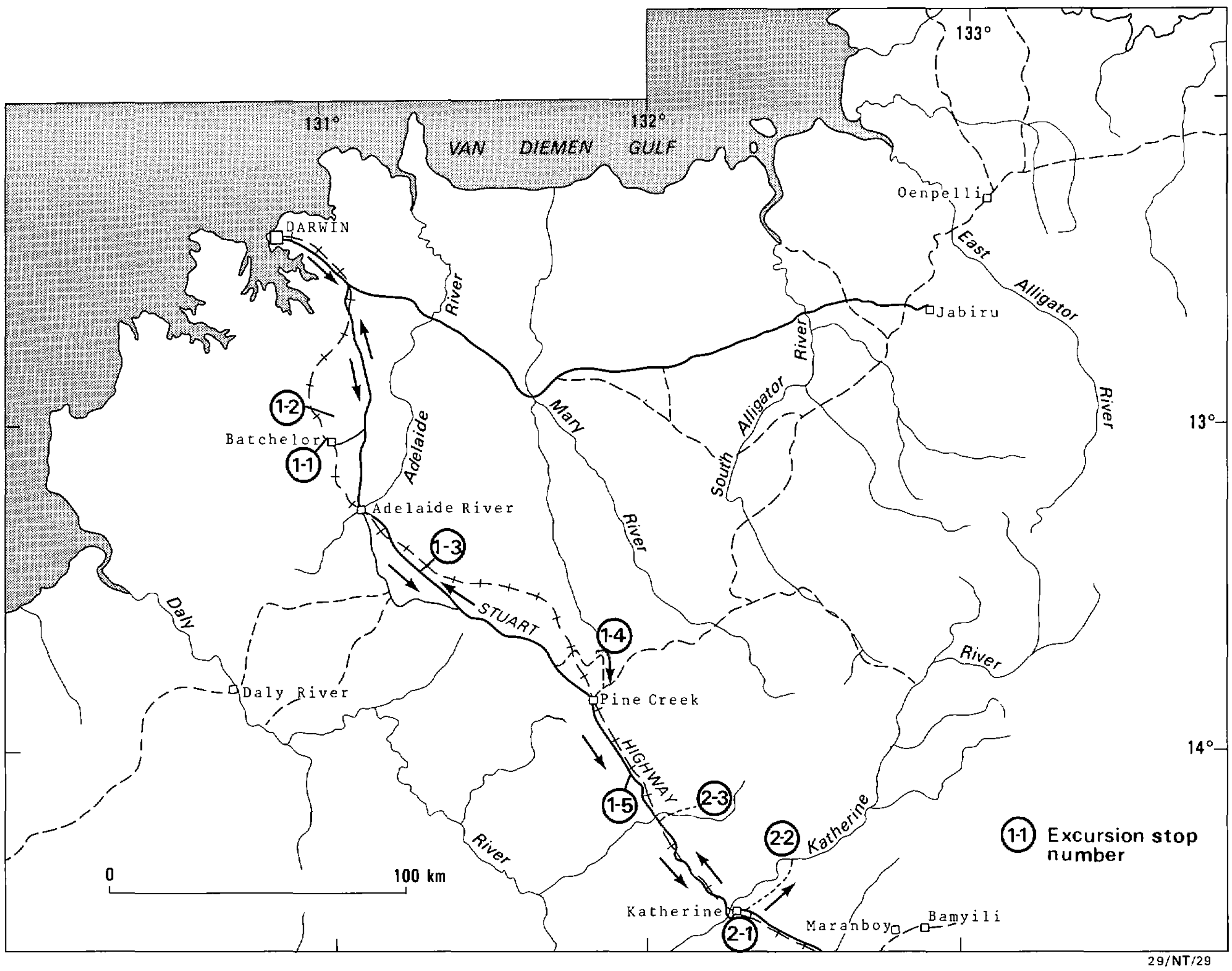

Fig. 1 Route map

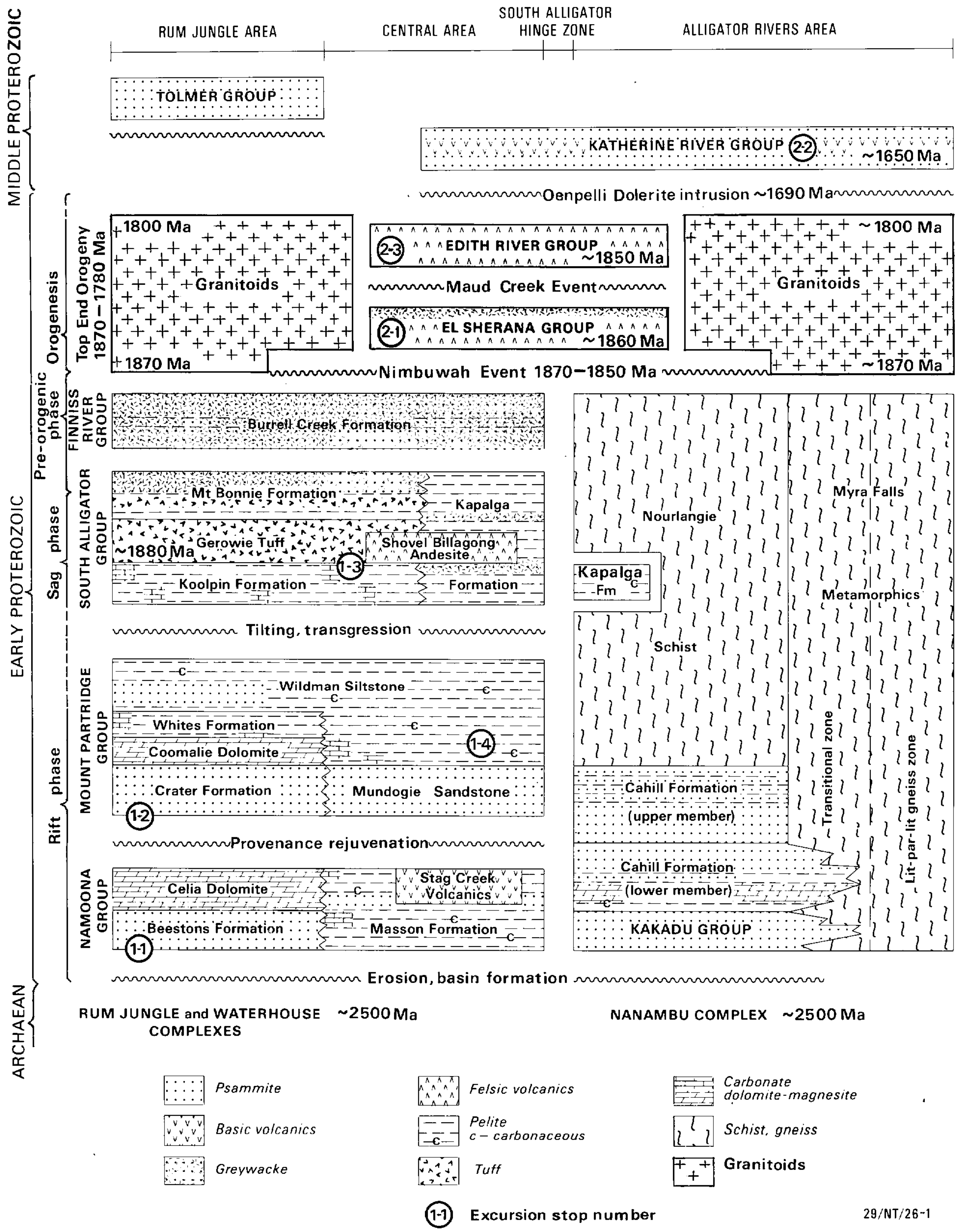

Fig. 2 Diagrammatic stratigraphy of the Pine Creek Geosyncline.

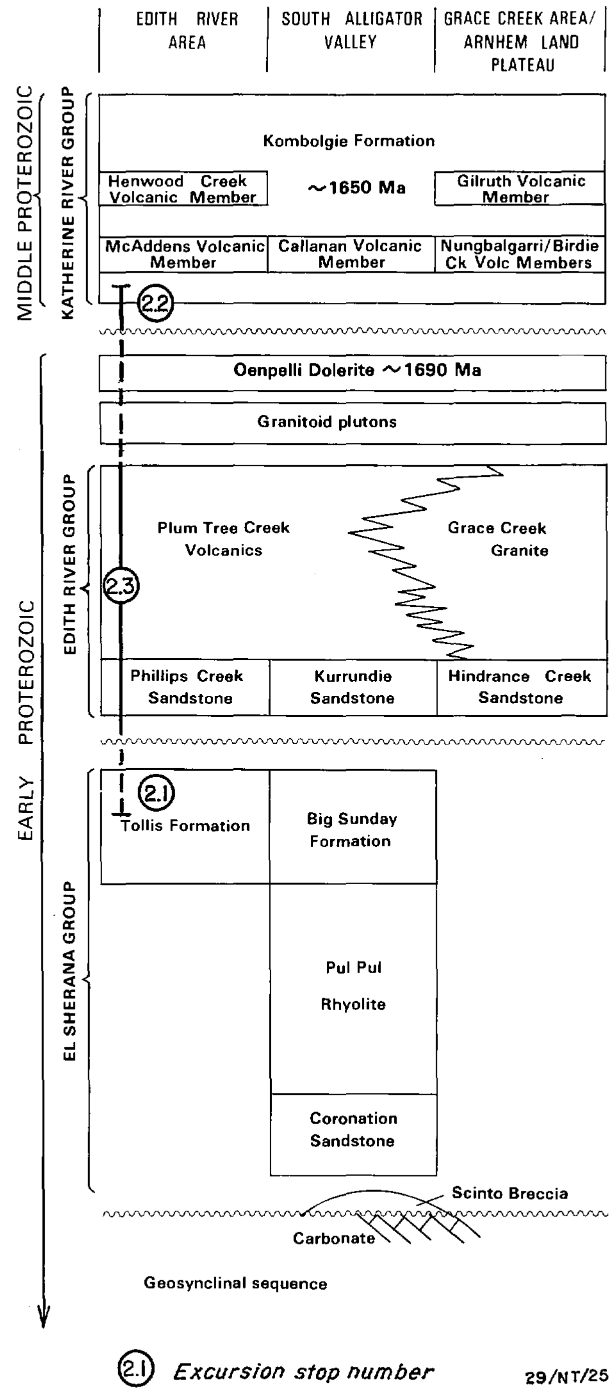

Fig. 3 Diagrammatic stratigraphy of the late Early Proterozoic felsic volcanic suites and basal Middle Proterozoic platform cover.

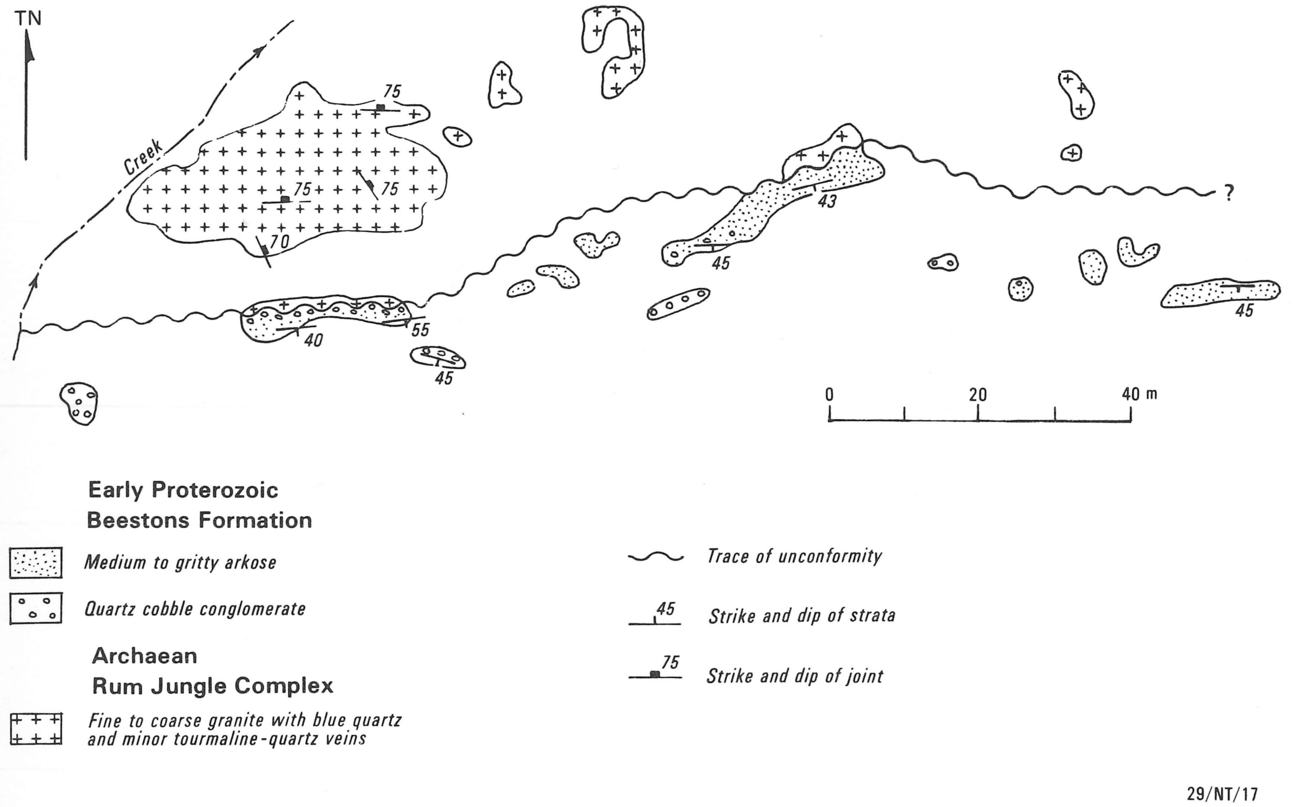

Fig. 4 Stop 1-1 Geology of the Early Proterozoic Beestons Formation/Archaean Rum Jungle Complex unconformity (after Eupene, 1985)

Fig. 5 Stop 1-1 Early Proterozoic/Archaean unconformity. Basal conglomerate of the Early Proterozoic Beestons Formation, containing angular quartz clasts, rests unconformably on massive leucocratic coarse equigranular granite of the Archaean Rum Jungle Complex.

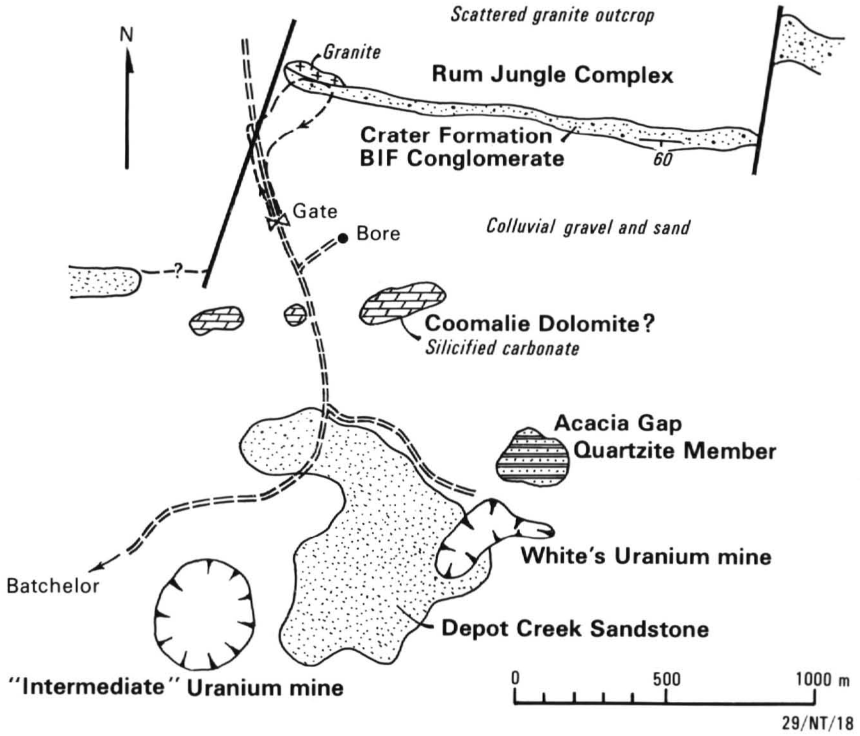

Fig. 6 Stop 1-2 Geology of the Early Proterozoic Crater Formation/Archaean Rum Jungle Complex unconformity.

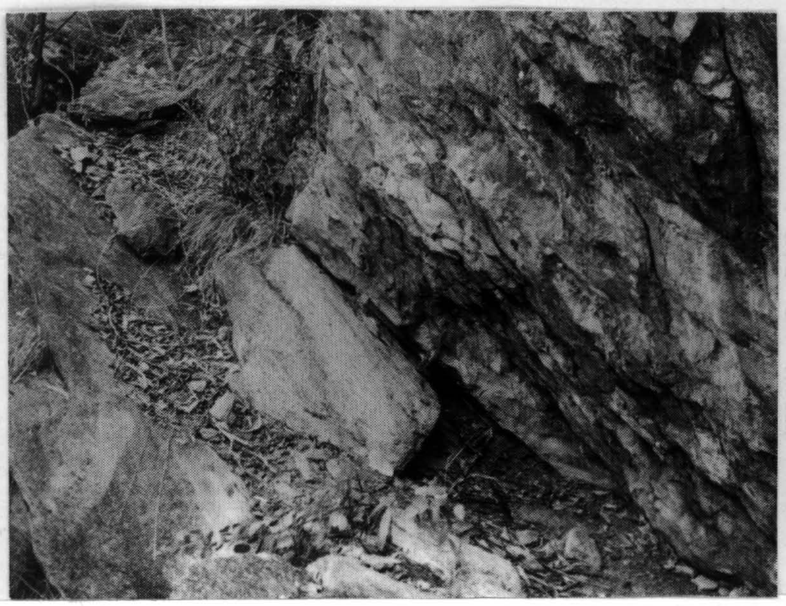

Fig. 7 Stop 1-2 Unconformable contact between overlying sheared BIF conglomerate of the Crater Formation and Rum Jungle Complex granite.

Fig. 8 Stop 1-2 Strongly sheared hematite boulder conglomerate, Crater Formation, showing deformed BIF clasts and prominent lineation.

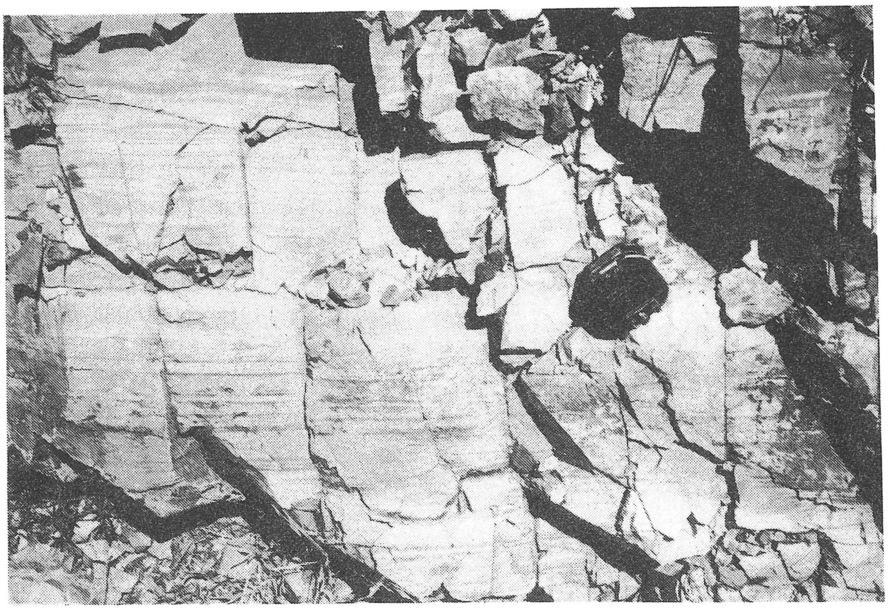

Fig. 9 Stop 1-3 Jointed, laminated black glassy crystal and vitric tuff, Gerowie Tuff.

Fig. 10 Stop 1-3 Howley Anticline (Stuart Highway 34.6 km from Adelaide River).

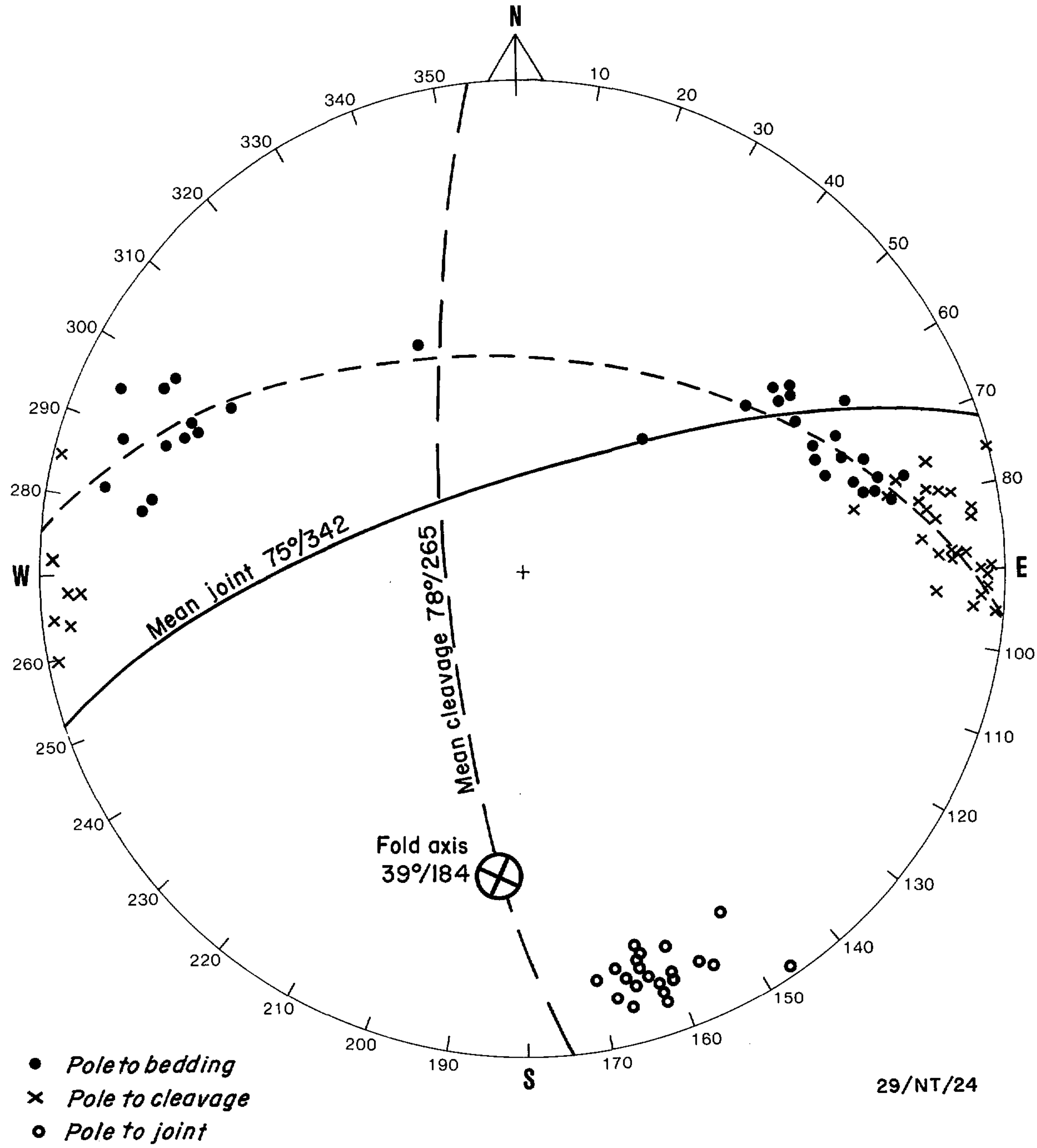

Fig. 11 Stop 1-3 Howley Anticline, structural elements (Stuart highway 34.6 km from Adelaide River).

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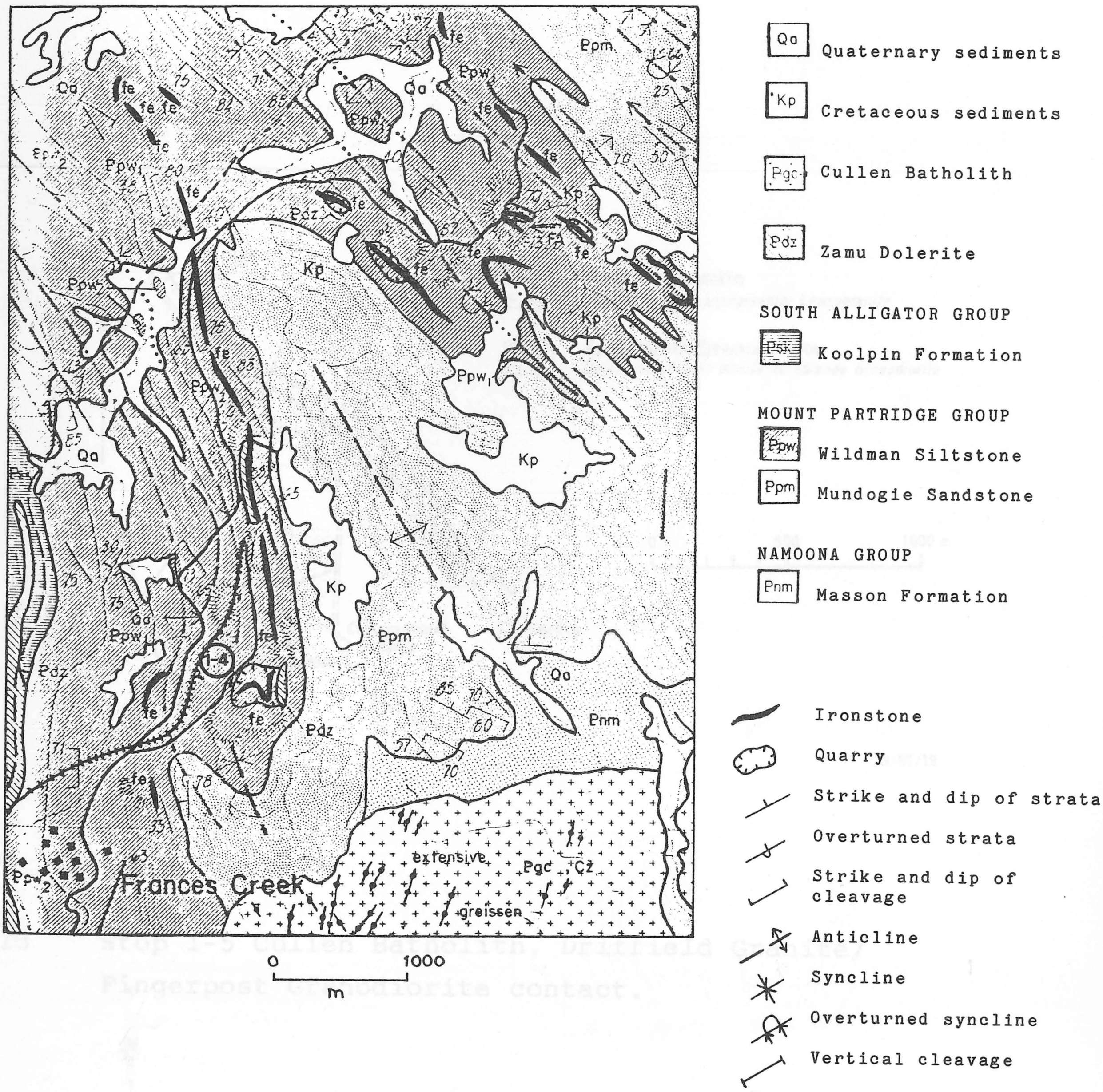


Fig. 12 Stop 1-4 Generalised geology of the Frances Creek iron mines.

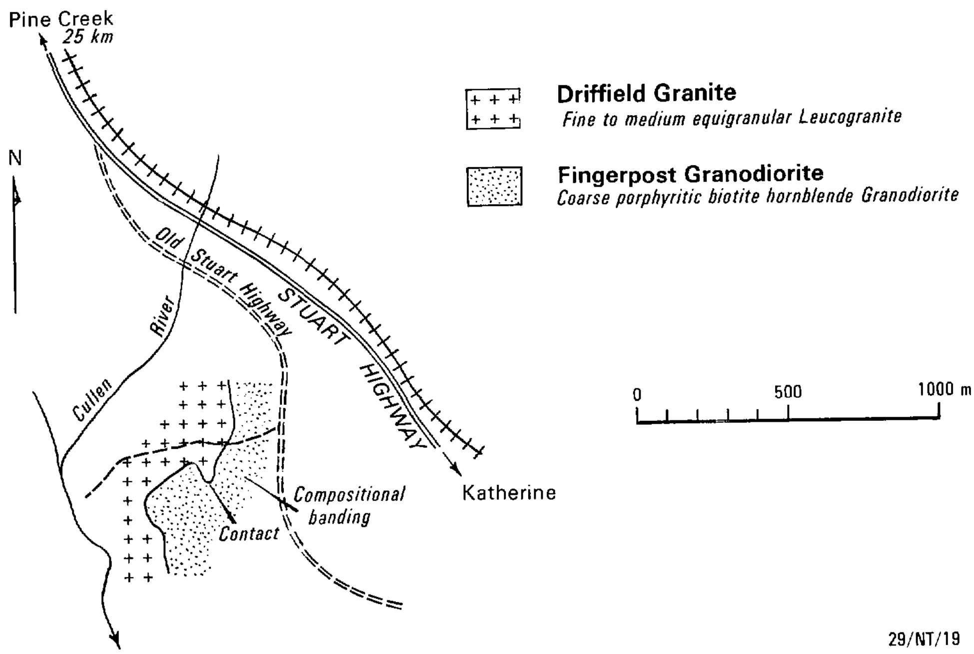
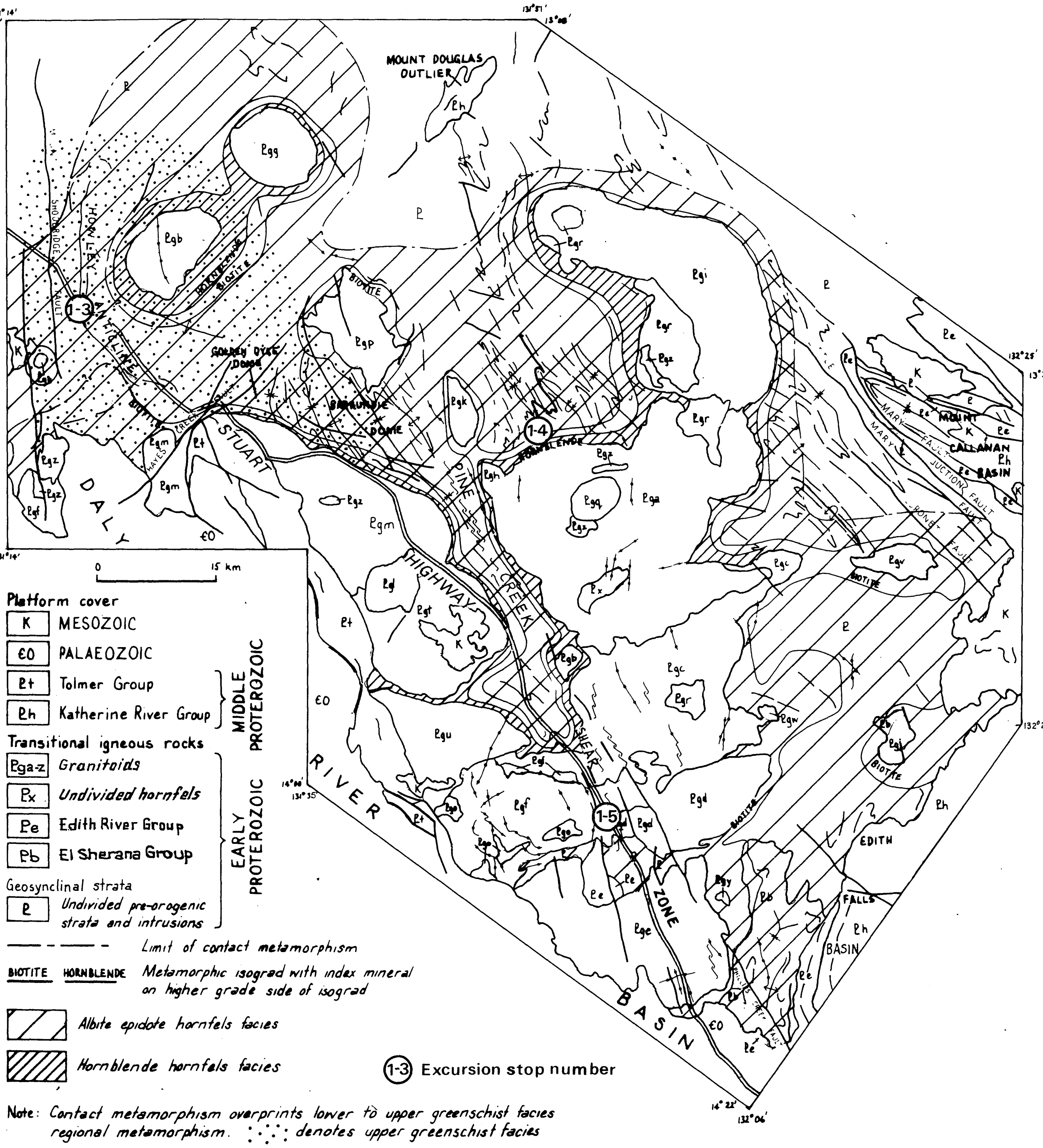


Fig. 13 Stop 1-5 Cullen Batholith, Driffield Granite/ Fingerpost Granodiorite contact.



DOMINANTLY LEUCOGRANITE PLUTONS

- Ɛgb Burnside Granite
- Ɛgf Fenton Granite
- Ɛgl Douglas Leucogranite
- Ɛgu Umbrawarra Leucogranite
- Ɛgo Foelsche Leucogranite
- Ɛgw Wandie Granite
- Ɛgr Francis Creek Leucogranite
- Ɛgq Saunders Leucogranite
- Ɛgv Mount Davis Granite
- Ɛgj Wolfram Hill Granite
- Ɛgy Yenberrie Leucogranite
- Ɛge Tennysons Leucogranite

CONCENTRICALLY ZONED TRANSITIONAL GRANITE AND LEUCOGRANITE PLUTONS

- Ɛgs Shoobridge Granite
- Ɛgt Tabletop Granite
- Ɛgn Bonrook Granite
- Ɛgd Driffield Granite
- Ɛga Allamber Springs Granite

Ɛgz Bludells Monzonite

DOMINANTLY GRANITE PLUTONS

- Ɛgg Margaret Granite
- Ɛgm McMinns Bluff Granite
- Ɛgp Prices Springs Granite
- Ɛgk McKinlay Granite
- Ɛgx Fingerpost Granodiorite
- Ɛgc McCarthys Granite
- Ɛgh Mount Porter Granite
- Ɛgi Minglo Granite

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Fig. 14 Cullen Batholith, plutons and metamorphic aureole.

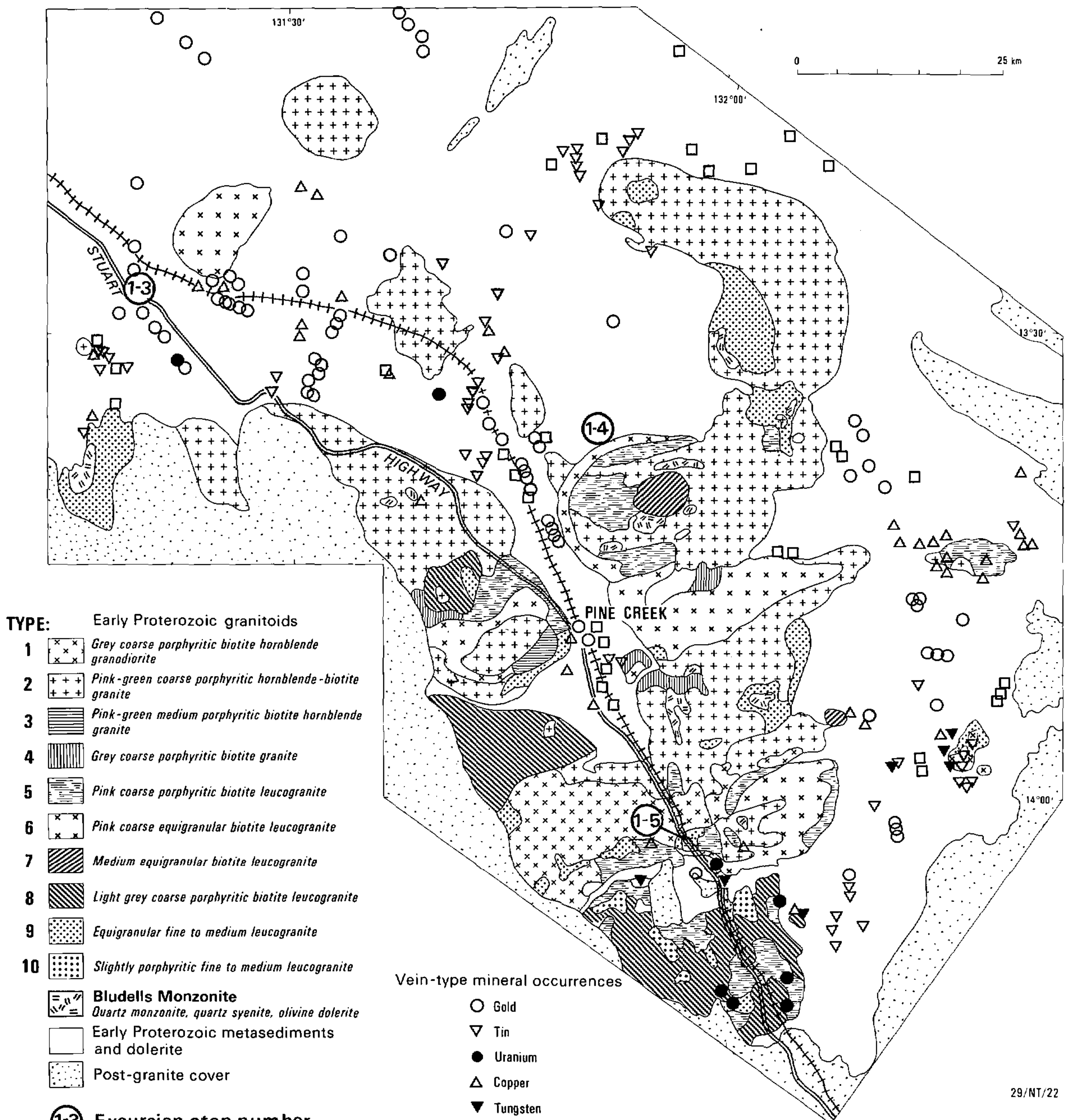

Fig. 15 Cullen Batholith, distribution of granitoid phases.

Fig. 16 Stop 1-5 Intrusive contact between altered grey coarse porphyritic biotite hornblende granodiorite of the Fingerpost Granodiorite (bottom of picture) and younger fine to medium equigranular leucogranite of the Driffield Granite.

Fig. 17 Stop 1-5 Massive porphyritic biotite hornblende granodiorite (Fingerpost Granodiorite) showing mafic xenolith and ultracataclasite veinlets.

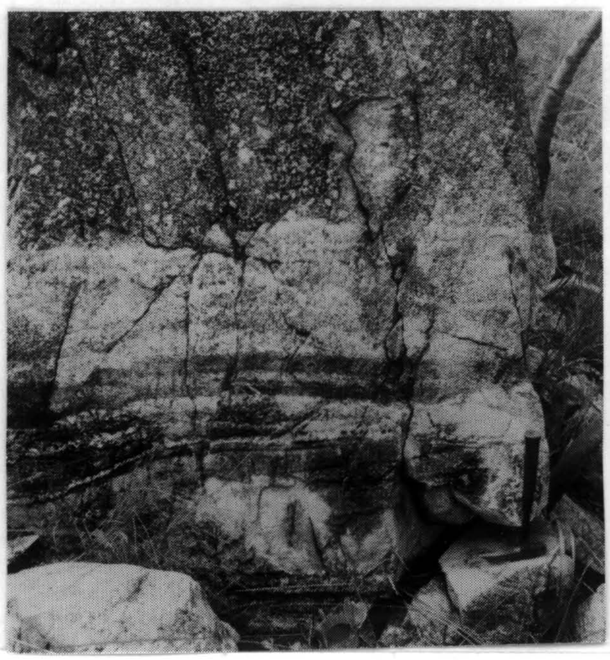

Fig. 18 Stop 1-5 Compositional banding in the Fingerpost Granodiorite.

Fig. 19 Stop 2-1 Interbedded greywacke and siltstone, typical of the basal part of the Tollis Formation (Katherine Gorge road 18.5 km from Katherine).

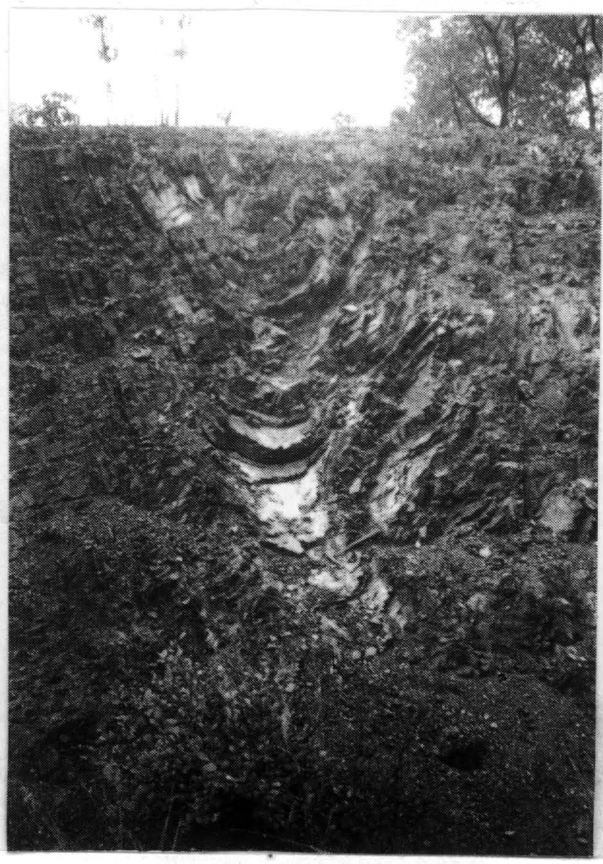

Fig. 20 Stop 2-1 Tight fold in Tollis Formation (Katherine Gorge road km from Katherine).

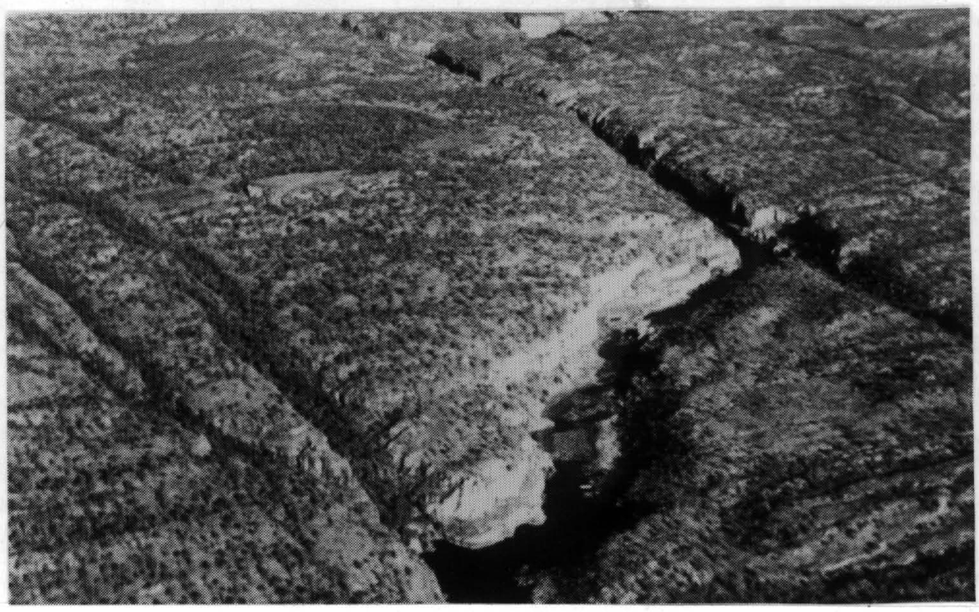

Fig. 21 Stop 2-2 Aerial view of Katherine Gorge. The gorge follows joints and faults in gently dipping sandstone of the Middle Proterozoic Kombolgie Formation.

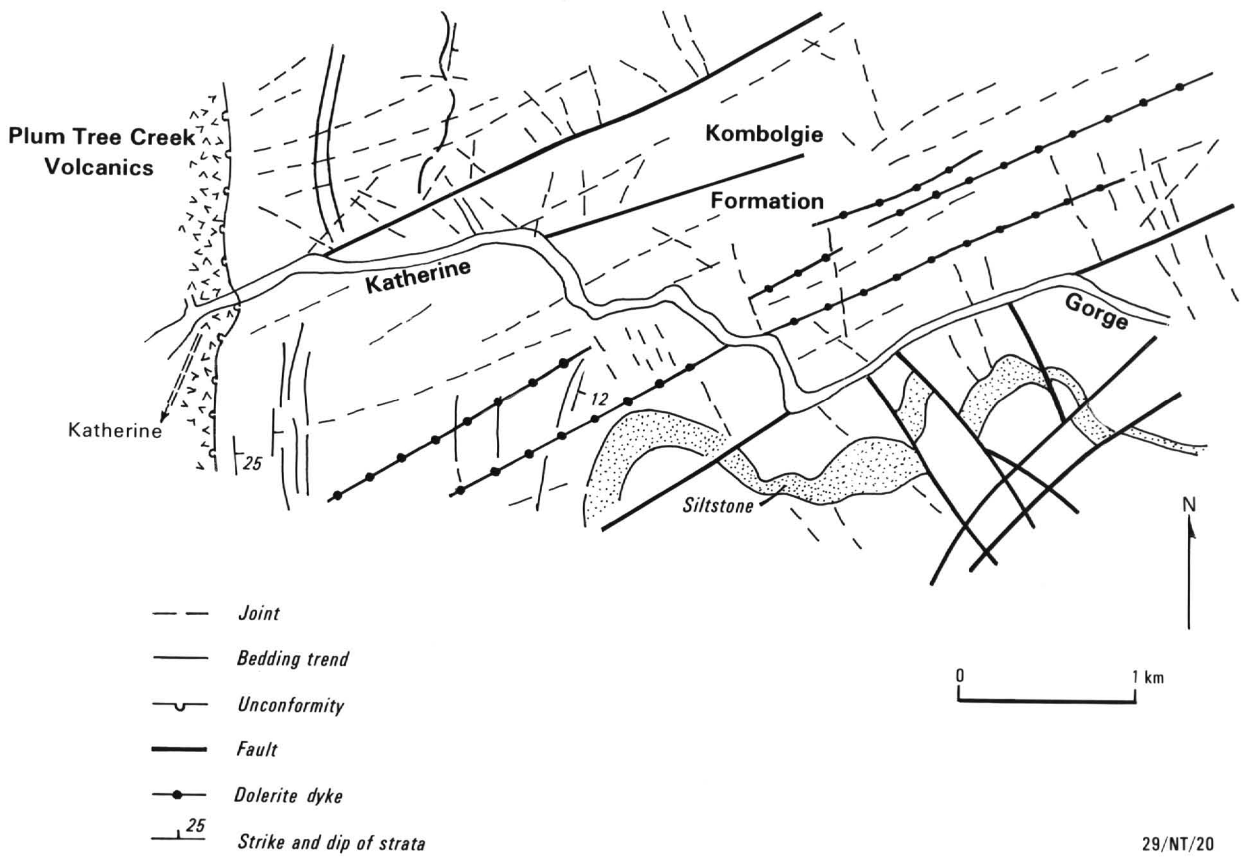

Fig. 22 Stop 2-2 Geology of the Katherine Gorge.

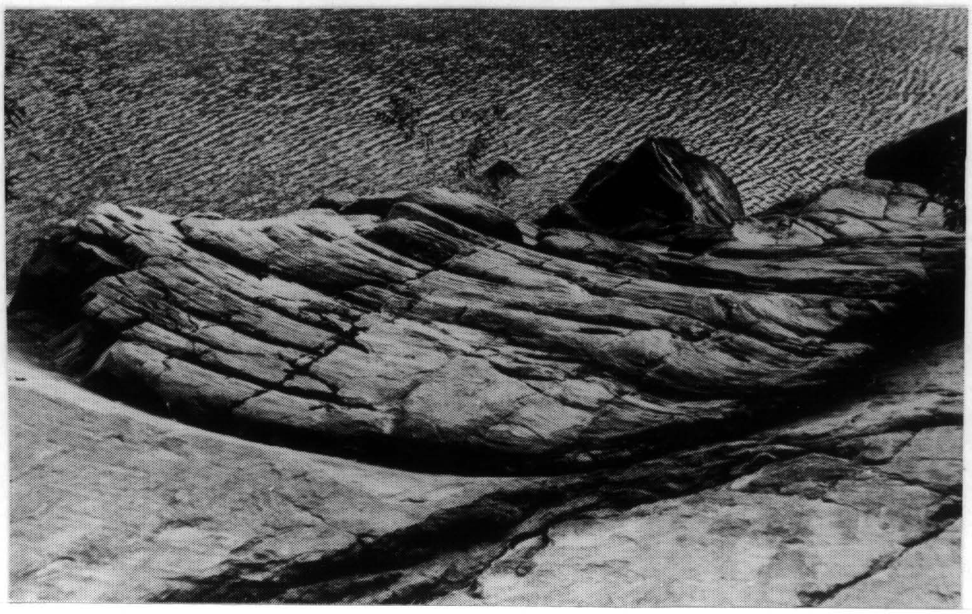

Fig. 23 Stop 2-2 Crossbedded quartz sandstone, Kombolgie Formation (Katherine Gorge).

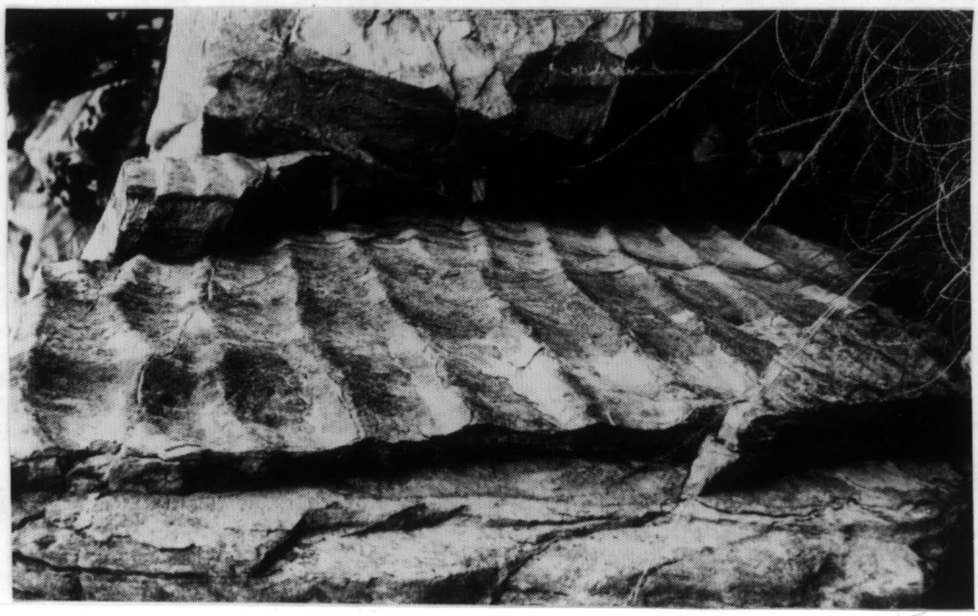

Fig. 24 Stop 2-2 Ripple marked quartz sandstone, Kombolgie Formation (Katherine Gorge).

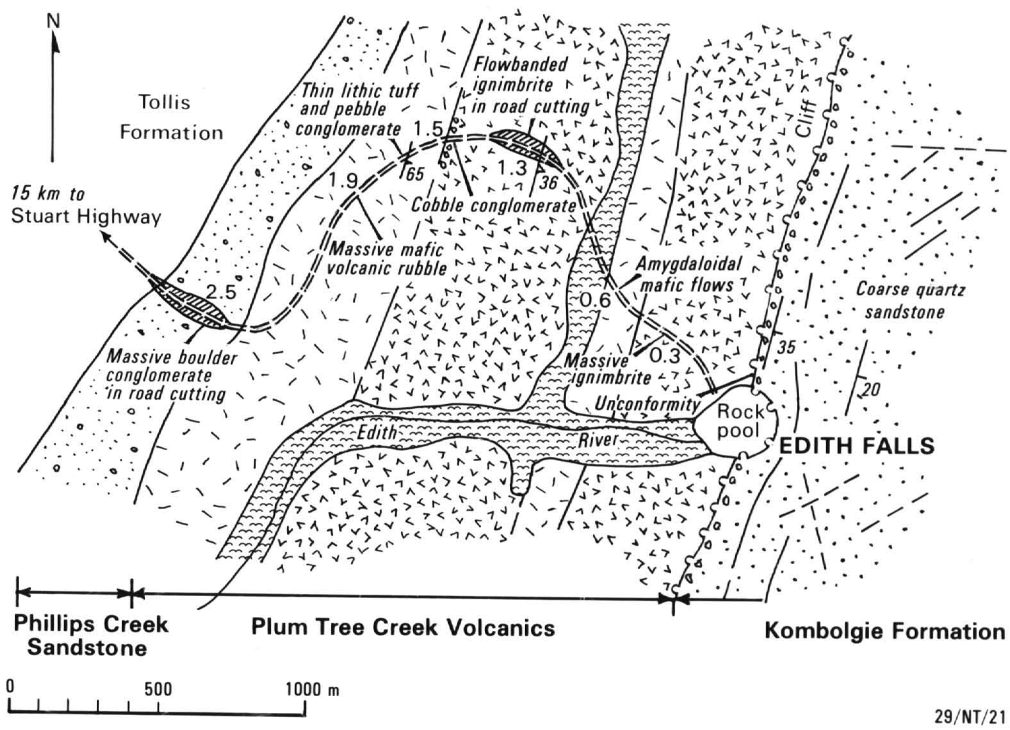

Fig. 25 Stop 2-3 Section through the Edith River Group and the Middle Proterozoic unconformity, Edith Falls.

Fig. 26 Stop 2-3 Massive boulder conglomerate of the Phillips Creek Sandstone (roadcutting 2.5 km from Edith Falls).

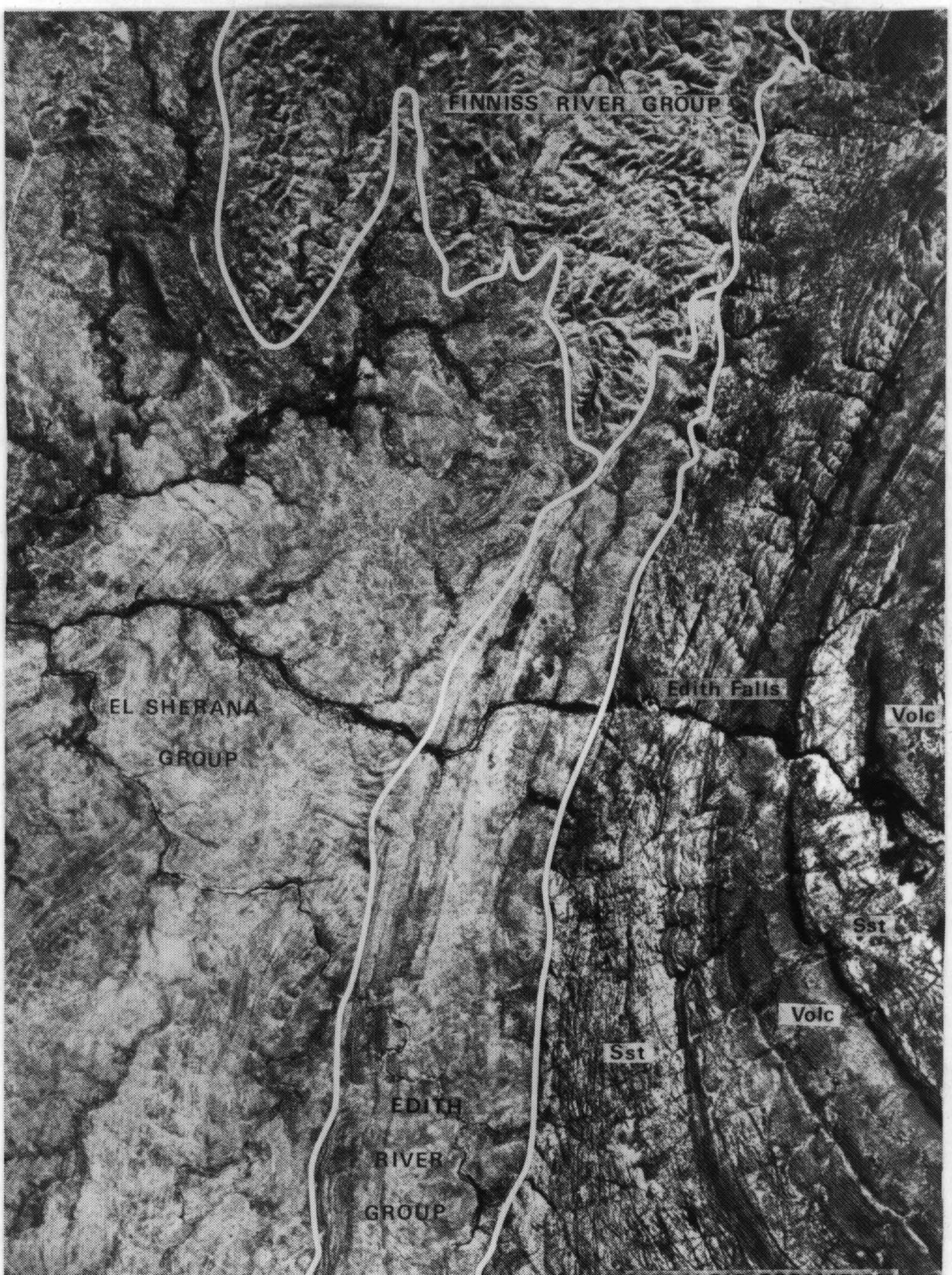

Fig. 27 Stop 2-3 Aerial photograph of the Edith Falls area.

Fig. 28 Stop 2-3 Massive flow banded ignimbrite of the Plum Tree Creek Volcanics (roadcutting 1.6 km from Edith Falls).

Fig. 29 Stop 2-3 Edith Falls: Unconformity between basal conglomerate of the Middle Proterozoic (1650 Ma) Kombolgie Formation and underlying highly weathered Early Proterozoic (1850 Ma) Plum Tree Creek Volcanics. Note small reverse fault in centre of picture.