DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1972/1

PROGRESS REPORT, ALLIGATOR RIVER PARTY N.T., 1971

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R.S. Needham and P.G. Smart

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(b) Dragfold in limb of major fold with low angle shears developing along the axis of the dragfold in escarpment 11 km northeast of Koongarra

(c) Brecciated and quartz-veined sandstone within north-trending fault in Kombolgie Formation, 2 km west of Koongarra

PLATES

SUMMARY

This Record describes the results of field work by the Alligator River Party during 1971. 1:50 000 scale geological maps of the Cahill and East Alligator 1:100 000 Sheet areas accompany the text.

The Lower Proterozoic metamorphics have been tentatively divided into three units: basal arkose, quartzite and interbedded carbonate rock, and schist with minor quartzite. The arkose is correlated with the Mount Partridge Formation, the quartzite sequence with the Koolpin Formation, and the schist with the Fisher Creek Siltstone. Metamorphic grade ranges from lower to upper greenschist facies, generally decreasing southwards and locally increasing towards the Nanambu Complex. The Lower Proterozoic metamorphic rocks are believed to be continuous with the Myra Falls Metamorphics further to the east, previously regarded as Archaean age.

The Nanambu Complex consists of a wide range of metamorphic rocks and some igneous rocks: leucogneiss, augen gneiss, migmatite, lit-par-lit gneiss, garnet gneiss, granitoid rock, amphibolite, pegmatite, schist, and quartzite. Metamorphic grade of these rocks has advanced to the almandine-amphibolite facies.

Structural affinities between the Complex and the surrounding Lower Proterozoic rocks, a gradual change in metamorphic grade through the Lower Proterozoic rocks towards the Complex, and the absence of an unconformity around the Complex suggest that it is a product of migmatization, i.e. remobilization caused by high-grade regional metamorphism with localized igneous activity. The Complex was probably formed from a thick sequence of immature sediments deposited in a foredeep at the western margin of the Eastern Trough of the Pine Creek Geosyncline. The Nimbuwah Complex is a large migmatite complex which may represent the orogenic centre of the geosyncline.

Basic intrusive rocks of the Cahill and East Alligator 1:100 000 Sheet areas are subdivided into pre- and post-deformation/migmatization types. Two distinct mineralogical groups are recognized in the first type: one derived from a tholeiitic parent magma, the other from an alkali basalt parent. The post-deformation/migmatization type is composed of relatively unaltered peralkaline phonolite rock (sodic microsyenite) occurring as undeformed dykes in the Nanambu Complex.

Two small exposures of acid volcanic rocks at Mount Basedow are considered to be remnants of flows on a re-exhumed surface. These volcanics, which appear to be slightly metamorphosed, could be older, however, and are possibly interbedded with the Lower Proterozoic rocks.

The Kombolgie Formation is composed mainly of medium to coarse quartz sandstone, with conglomerate beds (up to 30 m thick) and thin siltstone interbeds. Basal conglomerates commonly contain pebbles of Lower Proterozoic rock types. The orientation of widespread cross-bedding and ripple-bedding suggests a predominant depositional current from the north. Basalts within the formation are correlated with the Nungbalgarri Volcanic Member named in the Milingimbi 1:250 000 Sheet area.

Cainozoic sediments form a mantle over physiographic units called the Northern and Estuarine Plains. Other superficial deposits are talus cover on colluvial hill-slopes and patchy sand accumulations on and adjacent to the Arnhem Land Plateau. Marine deposits extend up to 80 km inland along the major river systems.

The area is structurally complicated: the Nanambu Complex is located in a broad anticline in Lower Proterozoic strata; it appears to be contiguous with these rocks, which dip 40°-50° away from the Complex and are isoclinally folded east of Jabiru; and the Munmarlary and Jim Jim Masses appear to form subsidiary folds on the western flank of the main Magela Mass.

The Kombolgie Formation is gently folded in the Mount Brockman and Mudginberri Massifs, but steeper dips are apparent adjacent to major faults. Depositional dips (drape structures, etc.) are also evident. The overall 5° dip in the main plateau is ascribed to a general tilt to the south-east.

Faulting is widespread but is obvious at the surface only in outcrops of the Kombolgie Formation, where vertical displacements are as much as 60 m.

The Alligator River and adjoining 1:250 000 Sheet areas are being extensively explored by several mining companies. The genesis of the uranium mineralization in the Cahill and East Alligator 1:100 000 Sheet areas is briefly discussed: a syngenetic origin is favoured by the authors, with hydrothermal/mesothermal effects (possibly contemporaneous with migmatization), and groundwater movements influencing the concentration of mineralization at a later date.

A survey of part of the base of the Kombolgie Formation in the Cahill 1:100 000 Sheet area was completed; the nature of the unconformity is masked by local irregularities.

Results of gamma-ray spectrometry of hand specimens suggest that significant uranium values occur within a favoured stratigraphic horizon in the Lower Proterozoic metamorphics, adjacent to the quartzite sequence.

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INTRODUCTION

Aims and methods of the survey

Following the discovery of uranium in the Alligator River region in 1970, the Alligator River Party was formed in April 1971 to map in detail the region covered by the Alligator River 1:250 000 Sheet. The project included a study of the genesis of uranium mineralization and the stratigraphic and structural control of the ore. Also included was a study aimed at investigating the possibility of a relation between the distribution of ore and the unconformity between the Kombolgie Formation and the underlying Lower Proterozoic rocks.

During the 1971 season, mapping of the Cahill and East Alligator 1:100 000 Sheets was almost completed; 1:50 000 scale compilation sheets for these areas are included in this report. Reconnaissance traverses to surrounding areas were also made. Following the completion of field checking, and a rotary drilling program in 1972, 1:100 000 scale preliminary editions will be produced (Fig. 1).

The purpose of this report is to provide a progress account of the party's activities, with notes on the geology of the areas mapped in detail.

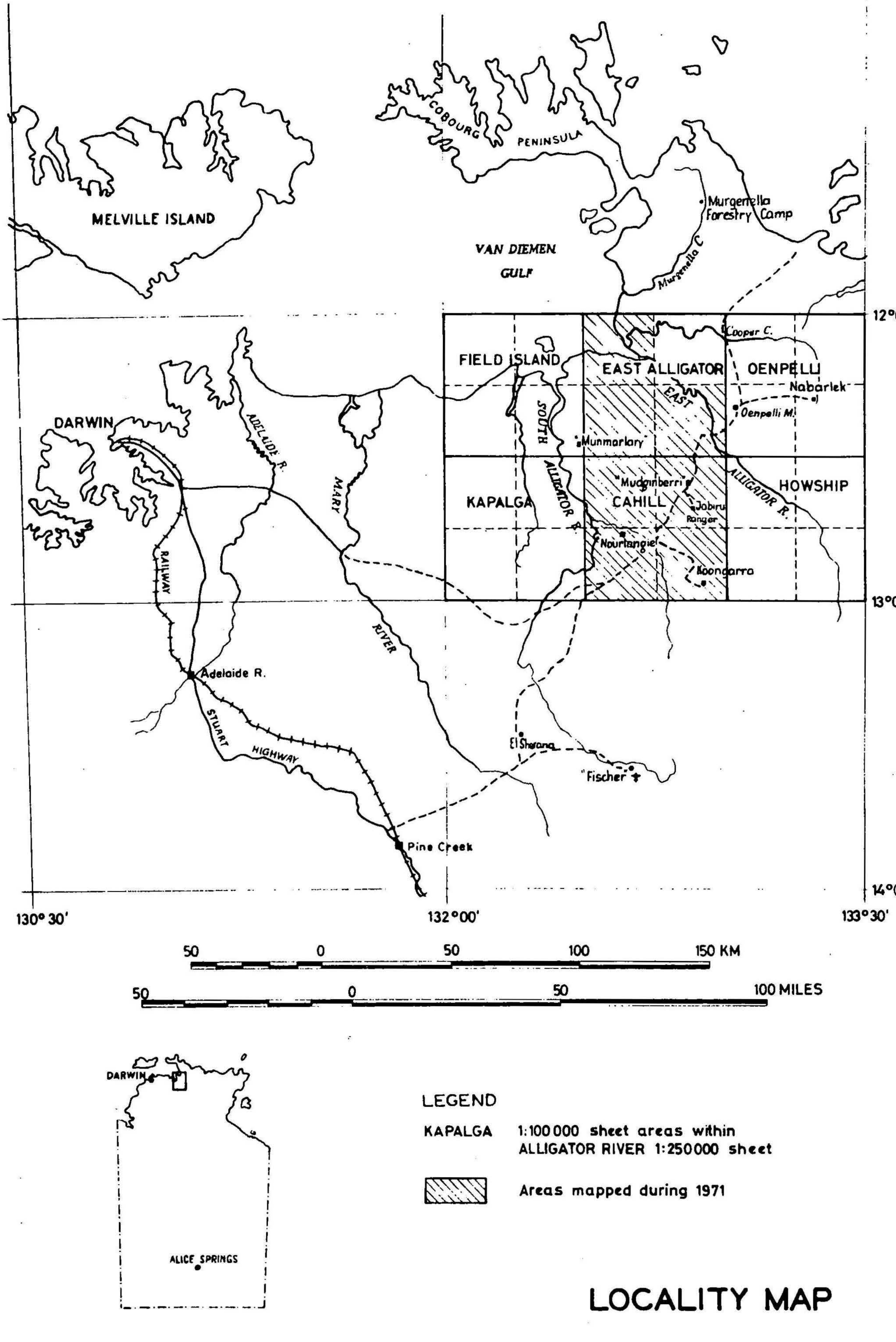
The party was in the field from mid-June to the end of October. Traverses were made by Landrover and on foot from a camp on the East Alligator River, 1 km upstream from Cahill's Crossing. Four traverse lines were drilled in the Cahill Sheet area by a trailer-mounted Gemco auger drill.

Field observations were plotted on RC9 (1:83 000 scale) aerial photographs, and later onto RC8 (1:16 000 scale) photographs, which were received towards the end of the field season. Detailed interpretation on RC8 photographs was made after the field season and was then transferred to 1:50 000 scale corrected bases drawn from the R.A.S.C. topographic bases.

Location and access

The Alligator River uranium province is centred on Mudginberri homestead, 225 km east of Darwin, and covers the Alligator River 1:250 000 Sheet area and parts of the surrounding Mount Evelyn and Cobourg Peninsula 1:250 000 Sheet areas; its northeasterly extent is not yet delineated.

FIG. 1



LOCALITY MAP

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To accompany Record 1972/1

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Access is provided by the Darwin-Oenpelli road which crosses the centre of the Cahill 1:100 000 Sheet area and the southeast corner of the East Alligator 1:100 000 Sheet area. Tracks leading off this road to Munmarlary and Mudginberri homesteads, and to mining camps and prospects, give reasonable access to all areas. Buffalo shooters' tracks give access to major watercourses throughout the area.

Previous investigations

Investigations prior to the 1950s are listed by Walpole et al. (1968). Bureau of Mineral Resources geologists made reconnaissance surveys of the Darwin-Katherine region between 1953 and 1957. Exploration of the South Alligator River area, mostly by United Uranium N.L., followed the discovery of economic uranium deposits there in 1953-4.

A second intensive phase of exploration centred on the Alligator River Sheet area followed the discovery of the uranium deposits of Nabarlek, Ranger, and Koongarra. Numerous companies are at present involved in active uranium exploration in the region.

PHYSIOGRAPHY

The Sheet areas lie between the South and East Alligator Rivers and contain three main physiographic units: the Northern Plains, the Arnhem Land Plateau, and the Estuarine Plains, (Dunn 1962). The Northern Plains consist of the remnants of a Middle Tertiary peneplaned and lateritized surface, the Koolpinyah Surface, partly covered by younger colluvial and outwash sands. It is underlain by deeply weathered rocks of the Nanambu Complex and Lower Proterozoic metamorphics. Consequently outcrop is sparse and rarely fresh.

The central part of the Northern Plains is occupied by the Nanambu Complex, whose outcrop is typically limited to creek banks, and to the headwaters of creeks, where schist and gneiss may be exposed below laterite breakaways up to 10 metres high. Owing to their slightly more resistant nature, rocks of the Nanambu Complex form slightly higher ground and consequently are characterized by well defined dendritic drainage. Outcrop of the Lower Proterozoic metasediments is mostly confined to creek banks and rare ferruginized or silicified exposures protruding through the superficial deposits.

Towards the south and east margins of the Northern Plains, above an elevation of 80 metres, the Cainozoic sand cover has been stripped and rock is exposed. Structural trends are more easily recognized on aerial photographs.

The scarp of the Arnhem Land Plateau is mostly sheer, and up to 200 metres high. Along the main scarp, and along the northwestern margin of the Mount Brockman Massif, the base of the Kombolgie Formation (Plate i) is exposed discontinuously. Owing to the obvious difficulty of access, few observations were made on the plateau surface.

The Estuarine Plains are seasonally inundated low-lying areas, where coastal to brackish estuarine conditions extend for up to 80 km inland (as far as the Leichhardt Billabong in the South Alligator River system). Pre-Quaternary outcrops are almost absent in this physiographic unit. Near the South Alligator River a few isolated exposures of in situ boulders and low, exfoliated domes of gneiss and granitoid rock have been recorded on these plains.

STRATIGRAPHY

The results of mapping during 1971 agree generally with the geology shown on the existing Alligator River 1:250 000 Geological Series Sheet (Dunn, 1962). However, the discovery of many more small exposures has led to a more complete understanding of the geology of the area.

The Nanambu Complex is a poorly exposed migmatite dome surrounded by metamorphosed Lower Proterozoic sediments, for which tentative correlations are proposed with the sedimentary units of the South Alligator River region, and the Myra Falls Metamorphics. All were deposited in the Eastern Trough, now tentatively regarded as the orogenic central trough of the so-called Pine Creek Geosyncline.

The Complex and the metamorphics are intruded by numerous basic rocks and their differentiates. Small isolated occurrences of acid volcanic rock at Mount Basedow are probably flow remnants on a re-exhumed pre-Kombolgie land surface, and are tentatively correlated with the Edith River Volcanics. Basalts interbedded with the Kombolgie Formation arenites are correlated with the Nungbalgarri Volcanics of the Milingimbi 1:250 000 Geological Series Sheet (Rix. 1965).

(a)

(b)

PLATE i

Typical exposures of the Lower Proterozoic/Carpentarian unconformity: (a) foliated quartz-mica schist under Kombolgie Formation, 4 km south of Ranger 1 (b) isoclinally folded schist below Kombolgie Formation, 9 km east of Mudginberri homestead.

(a)

(b)

PLATE ii

(a) Lower Proterozoic quartzite, 2 km west of Mount Cahill

(b) Deformed micaceous metapsammite, typical of the lower-grade metamorphics at Mount Basedow

Cainozoic sand and alluvium form an almost continuous veneer over older rocks in the lower areas of the Northern Plains and the Estuarine Plains.

Lower Proterozoic

Earlier workers considered that metasediments of the South Alligator Group in the central part of the Mount Evelyn 1:250 000 Sheet area continued north and east to the vicinity of Magela Creek, where they abutted against the more structurally complex and higher grade Myra Falls Metamorphics, tentatively assigned to the Archaean.

Field work during 1971 has shown, however, that there is a progressive metamorphic gradation from slightly altered sediments in the South Alligator River area to medium-grade metamorphic rocks in most of the Cahill and East Alligator 1:100 000 Sheet areas. The Myra Falls Metamorphics are of similar grade to the medium grade metamorphics of the Cahill and East Alligator Sheet areas.

Easterly structural trends within Lower Proterozoic rocks 14 km north of Mudginberri homestead are continuous with structural trends of the Myra Falls Metamorphics across the Bulman Fault.

Therefore the two reasons cited by Walpole et al. (1968) (the contrasting metamorphic grades and structural patterns) are no longer regarded as evidence of unconformity between Myra Falls Metamorphics, which they describe as Archaean, and the Lower Proterozoic rocks. We believe that the Myra Falls Metamorphics are continuous with the Lower Proterozoic strata, and that Lower Proterozoic deposition extended much farther to the east; the main trough of the Pine Creek Geosyncline is situated to the east (see Structure).

Little is known of Lower Proterozoic deposition in the areas mapped, since the rocks are largely covered by superficial deposits; in the Nanambu Complex, they have been migmatized. However, three broad stratigraphic units have been recognized: a basal sequence of arkose, succeeded by quartzite (with minor schist and dolomite), succeeded by schist (with minor quartzite). Paucity of outcrop, however, has allowed only a very poor definition of the boundaries between these units.

The arkose is best exposed in the southwest of the Cahill 1:100 000 Sheet area at Mount Basedow and near Patonga homestead. The arkose is a pink, grey or yellow (depending on the feldspar colour), ill-sorted rock, generally consisting of angular and irregular grains of microcline (sometimes perthitic), subrounded to angular quartz, and flakes of muscovite, with albite, rare chlorite, and magnetite, in a groundmass of cryptocrystalline quartz (chert) and incipient talc (or sericite?). Quartz feldspar ratio varies widely. Individual feldspar crystals are less than 1 cm across and are often recrystallized. The quartzite is exposed at Mount Cahill and at the Koongarra and Ranger uranium deposits. Because of greater resistance to erosion, the quartzite forms more prominent outcrops such as strike ridges (Plate iia). Two such ridges form part of a belt of Lower Proterozoic rocks which separate the Magela and Munmarlary Masses of the Nanambu Complex. A part of the quartzite in the Cahill 1:100 000 Sheet area appears on the aerial photographs as a distinctive smooth light photopattern which can be traced from Mount Cahill to Mount Basedow (Plate 8; Blw). It may prove useful as a marker horizon in tracing the quartzite south into the Jim Jim 1:100 000 Sheet area.

The quartzite sequence includes clayey quartz sandstone north of Mount Basedow, banded and cross-bedded fine-grained sandstone near Patonga homestead, quartz-pebble conglomerate west of Mount Cahill, and banded hematite quartzite and hematite-quartz breccia at Mount Cahill and 2 km west of Koongarra. The quartzite is distinguished from the Kombolgie Sandstone by its higher degree of recrystallization and strained quartz grains. It is, however, indistinguishable from quartzite in the Nanambu Complex as the higher grade of metamorphism has not changed the mineralogy or texture.

Silicified dolomite (Plate iii) crops out close to the quartzite, and sometimes is present as discrete lenses in it, forming discontinuous strike ridges up to 10 m high. The silicified dolomite outcrops are generally ferruginized and are recognizable by the presence of a white fibrous talcose mineral.

Other silicified sediments outcropping in the Lower Proterozoic are usually strongly brecciated and may show two stages of veining: quartz followed by hematite. Rock fragments of all Lower Proterozoic rock types have been found in the breccias, which are believed to occupy the sites of quartz-filled faults (Plate iv).

A similar rock type occurs in the Nanambu Complex; the lithic fragments are typically gneissic, although they superficially resemble arkose.

The schist sequence is a thick, fairly homogeneous succession of schist with some phyllite and minor quartzite. Outcrop is almost completely confined to exposures of the Lower/Middle Proterozoic unconformity in the Arnhem Land scarp. Deeply weathered schist also crops out in creek banks, and ferruginized horizons occasionally form low strike ridges on the Koolpinyah Surface. Micaceous laterite rubble with schistose texture is frequently the only evidence of underlying Lower Proterozoic schist (mapped as El under thin cover). Although the sequence generally displays planar dips, there is evidence of isoclinal folding in the eastern portion of the Cahill 1:100 000 Sheet area, where the schist is strongly deformed, and crenulations, kink folds, and overturned folds are widespread. Bedding is frequently obliterated although it can generally be recognized where quartzite crops out with the schist.

The schist typically consists of quartz and one or more of the phyllosilicates. Quartz-muscovite-chlorite schist is the most common rock type in the sequence. Some of the finer-grained rock could be more accurately described as phyllite (e.g. quartz-sericite phyllite) because of its grainsize and the high content of minute chlorite or sericite flakes, or both. Although grain size is variable the rocks are otherwise texturally similar displaying strong compositional banding: narrow micaceous layers alternate with layers of recrystallized elongate quartz lamellae, defining the most prominent foliation of the schist.

Less commonly other minerals occur in the schist giving it a distinctive appearance: amphibole schist is flecked with black acicular prisms of actinolitic hornblende; biotite flakes are usually randomly oriented in the plane of the foliation. Garnet schist contains porphyoblasts of garnet less than 1 cm in diameter. Frequently fibrous minerals and mica surround the garnet giving the rock a knotted appearance. Garnet is commonly pseudomorphed by iron oxides. Talc, graphite, and feldspar (unidentified) appear to be rare constituents in the schist. Carbonaceous (graphitic) schist is rarely exposed but has been intersected below ground level in drill holes in the Ranger and Koongarra deposits, and at the 7E prospect of Pan Continental Ltd.

A poorly exposed foliated serpentinite is present in the Lower Proterozoic schist 8 km northeast of Jabiru. It is an extremely fine-grained strongly sheared blue-green talcose rock stained by iron oxides. Its ultra-basic nature was confirmed by atomic absorption analysis of trace element concentrations (Co, Ni, Cr, and V). Relict igneous minerals are absent and the rock is completely altered to talc-serpentine schist. Its relation with the other Lower Proterozoic rocks is not clear, but its shattered outcrop and numerous slickensides suggest that it may have intruded along a thrust in the Lower Proterozoic schist.

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Grade of Metamorphism. In the Cahill and East Alligator Sheet areas the metamorphic grade of the Lower Proterozoic sequence ranges from almost unmetamorphosed sediments (Fig. 3) to upper greenschist facies. Of the Lower Proterozoic rocks, the schist best reflects the regional metamorphic grade by changes of mineralogy and texture. Arkose and quartzite merely show a variation in degree of recrystallization and grainsize: the mineralogy is not affected by greenschist facies conditions. Variation in grainsize may not be a function of metamorphic grade, but may be dependent on the amount of volatiles present or the original grainsize of the sediment.

Commonly, the schist consists of quartz, together with chlorite or muscovite, or both, (but sericite in lower-grade rocks) with minor amounts of talc and graphite. In higher-grade schists (those adjacent to the Nanambu Complex) biotite is a common constituent (Plate v). Porphyroblasts of garnet, actinolite, and staurolite(?) are rare. In the Lower Proterozoic metamorphics at Koongarra (near the southern margin of the Magela Mass of the Nanambu Complex) metamorphism has proceeded to the upper grade of the greenschist facies (the quartz-albite-epidote-almandine subfacies of Winkler, 1967). The assemblage in these schists is quartz-muscovite-biotite-garnet-feldspar. Retrograde metamorphism in these rocks is indicated by chlorite replacement of ferromagnesian minerals and widespread saussuritization of the feldspars. The grade may therefore have been as high as the almandine amphibolite facies. These rocks are thought to represent part of the Transitional Zone which borders the Nanambu Complex. Although our knowledge of metamorphic facies variation within the Lower Proterozoic sequence is restricted by poor outcrop and lack of subsurface information, certain regional patterns have emerged. The regional grade appears to increase subtly from south to north through the Jim Jim and Cahill Sheet areas, and also increases towards the Nanambu Complex. Another trend is an increase in grade to the Myra Falls area, suggesting an orogenic centre in this region. It is hoped that further work (including drilling) will provide sufficient information for isograds to be drawn over the Lower Proterozoic metamorphics.

Correlation. The metamorphic rocks surrounding the Nanambu Complex appear to be continuous with the Lower Proterozoic metasediments of the Jim Jim and Mundogie 1:100 000 Sheet areas. A tentative correlation of the three divisions of the Lower Proterozoic metamorphics is therefore proposed:

> Petrologically and spatially the arkosic sequence bears a close resemblance to the Mount Partridge Formation; its deposition was probably confined to an area near the Yemelba Ridge. The sediments which have since been subjected to migmatization and associated granitization to form the Nanambu Complex are probably equivalent to the Mount Partridge Formation.

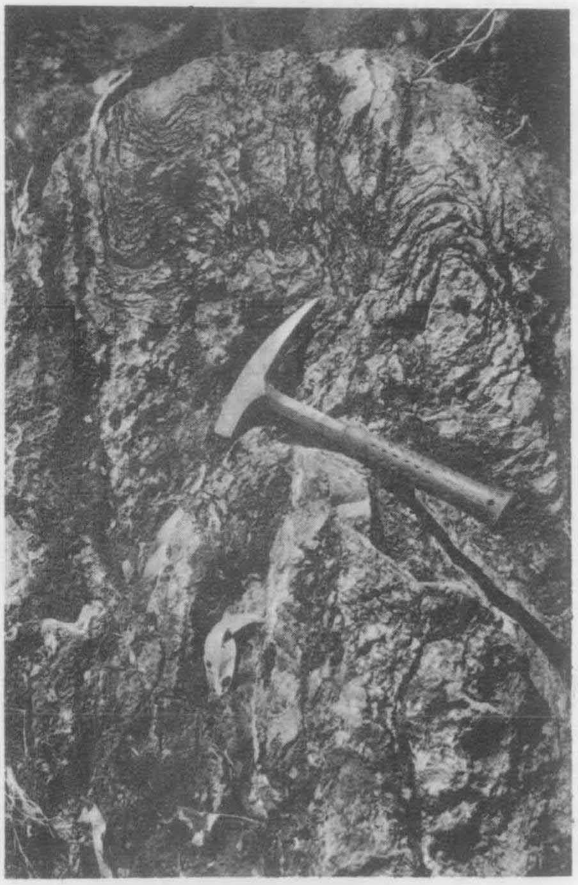

PLATE iii

Concentric lamellar algal(?) structures within steeply dipping ferruginized silicified dolomite, north of Woolwonga Swamp

PLATE iv

Brecciated silicified sediment, with lithic fragments of red shaly material, rebrecciated and hematite-veined, 7 km east of Patonga homestead

PLATE v

Strongly kink-folded crenulated biotite schist and quartz-chlorite schists. Exposure below the Lower Proterozoic/ Carpentarian unconformity at Nourlangie Rock. (Height of exposure 3 m)

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The quartzite and the carbonate rocks are believed to be the products of sedimentary conditions similar to those of the Koolpin Formation or Gerowie Chert, or both. Mapping of the Mundogie and Jim Jim 1:100 000 Sheet areas may show the Koolpin Formation to be continuous with the quartzite around the southern end of the Mount Partridge Range.

The schist, together with phyllite, is continuous with the Fisher Creek Siltstone. In the southeast of the Cahill Sheet area it appears to be finer grained to the east. Further correlations to the east are complicated by an increase in metamorphic grade.

Nanambu Complex

The name Nanambu Granite was used by Condon & Walpole (1955) to describe rocks exposed near Nanambu Creek, which flows into the Woolwonga Swamp at about 12°42' S, 132°41' E. Dunn (1962) described the Nanambu Granite as a garnetiferous and gneissic granite: a medium-grained grey rock with very little dark mineral, and weathered brown garnet 'scattered throughout'.

We have modified the name to Nanambu Complex since it has been found to include gneissic, schistose, and granitic rocks, despite a sparseness of exposure. It crops out between the South Alligator and East Alligator Rivers in three areas (Fig. 2). The two western masses may be continuous across the Woolwonga Swamp, but are separated from the Magela Mass by a belt of north-trending Lower Proterozoic schist and quartzite. The northern part of the Munmarlary Mass is masked by a cover of Tertiary laterite, and its extent is not known.

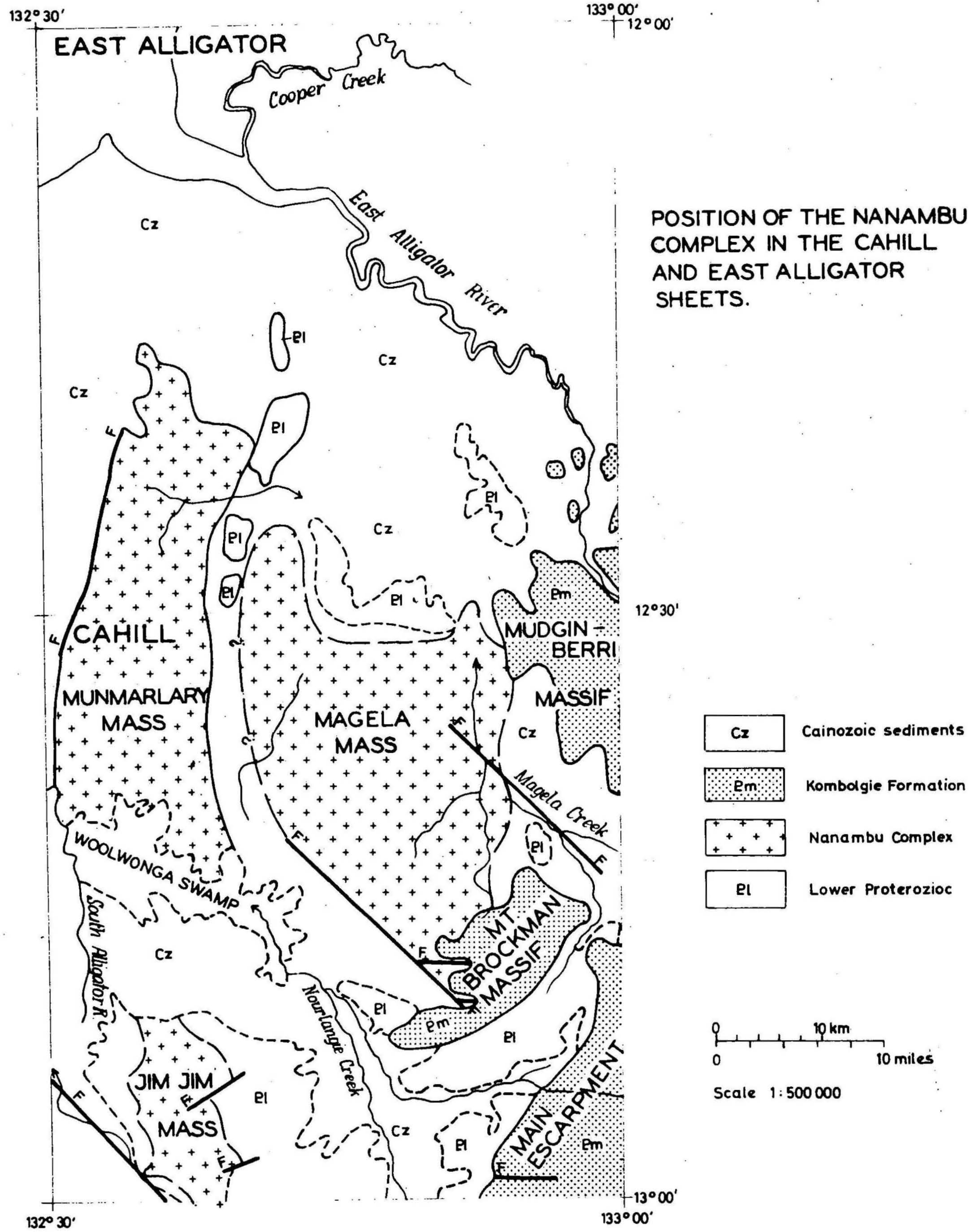
The most common forms of exposure of the Nanambu Complex rocks are:

Below laterite scarps in the fan-shaped head-waters (amphitheatres) of most creeks.

Deeply-weathered outcrop along the upper reaches of creeks.

Low, rounded platforms and in situ boulders of granitic and augen gneisses.

FIG. 2



POSITION OF THE NANAMBU COMPLEX IN THE CAHILL AND EAST ALLIGATOR SHEETS.

Adjacent to the Arnhem Land escarpment, as conical hills overlain unconformably by feldspathic sandstone of the Kombolgie Formation.

Low hills composed of basic amphibolite.

Rugged hills of tough, resistant sheared feldspathic quartzite.

Many metamorphic rock types and some igneous rock types occur within the Nanambu Complex. Owing to so few exposures, their relative abundance in decreasing quantities can be only roughly estimated:

Leucogneiss.

Other gneisses (including biotite gneiss, augen gneiss, lit-par-lit gneiss, and garnet gneiss (Plate vi).

Granitoid rocks (foliated granite, syenite, monzonite, adamellite and diorite) (Plate vii).

Amphibolite (including metadolerites and metapelites).

Pegmatite and quartz veins.

Schist (Plate v).

Quartzite (Plate viii).

Mylonite.

At this stage, our petrological knowledge of the Complex is based on hand-specimen and thin-section examinations of surface samples. Some fresh rock chips from water bores at Mudginberri and Munmarlary have also been examined. Smaller cuttings of recognizable weathered rock have been recovered from auger-holes.

Leucogneiss. The term leucogneiss has been applied to a diverse group of non-layered rocks consisting essentially of quartz, alkali feldspar, and plagioclase. Accessory muscovite or biotite or both, (altering to chlorite) may also be present as subparallel plates sometimes giving the rock a weakly foliated appearance. Relations with other rocks in the Complex are seldom apparent. However, at some exposures, particularly in the Jim Jim Mass, they form layers which are conformable with other gneiss, schist and quartzite. Rock cuttings from boreholes near Munmarlary and

Mudginberri indicate that leucogneiss contains minor amphibolite, which suggests that the former may represent either part of a metamorphosed sedimentary sequence or the 'leucosome' of a migmatite (leucocratic part of a migmatite, generally rich in quartz and feldspar, Mehnert, 1968, p. 355). (Plate vi).

The relative abundance of the migmatitic and metamorphic types is uncertain. We consider that the bulk of the leucogneiss was formed during migmatization. Some of the so-called leucogneiss, especially the coarser-grained variety may even be of hydrothermal origin (i.e. pegmatite). Only where discrete veins, dykes, or pods of coarse quartz-feldspar rock occur has the term pegmatite been applied.

Other gneisses. Leucogneiss grades through a continuous textural and mineralogical series of rock types into other strongly foliated gneisses. The foliation is attributed largely to the alignment of mica flakes and, to a lesser degree, the orientation of potash feldspar (c-axis parallel to foliation). The essential mineralogy of the other gneisses is fairly constant, consisting of clear quartz, and either potash feldspar or plagioclase, or both, with generally lesser amounts of biotite or muscovite, or both. Garnet, probably almandine, is a rare accessory. Potash feldspar (microcline) is generally far more abundant than plagioclase, but the latter may predominate. Biotite appears to be the dominant mica in the Magela Mass, but in the Munmarlary and Jim Jim Masses the micas occur in approximately equal amounts, or muscovite may even be dominant. The gneisses generally display alteration effects. Frequently the only minerals which have entirely escaped the effects of alteration and retrograde metamorphism are quartz and muscovite. The feldspars are moderately altered to sericite or clays, and biotite is usually partly altered to chlorite. Measurements of the extinction angle of plagioclase twins perpendicular to 010 indicate that its approximate range of composition is oligoclase to andesine.

These gneisses typically display a granuloblastic texture (defined by Joplin, 1968, P. 28), characteristic of the almandine-amphibolite facies. Some distinctive textural features such as compositional banding, augen structure, and migmatitic folding are also commonly developed.

Banded gneiss in which granuloblastic quartzo-feldspathic bands are separated by schistose biotite-muscovite bands is most common in the Magela Mass of the Complex. These mafic bands may be preserving original sedimentary layering even at this advanced stage of metamorphism, although they are more probably 'melanosome' (Mehnert, 1968, p. 356). (the melanocratic part of a migmatite rich in mafic minerals) or 'palaeosome' (remnants of the migmatite parent rock).

Augen gneiss is most common in the Munmarlary and Jim Jim Masses. It may be purely metamorphic, the augen representing porphyroblasts, or it may be migmatized rock in which the augen-shaped pods represent the development of 'neosome' (Mehnert, 1968, p. 356). It may instead be deformed magmatic rock, in which case the augen are porphyroclasts (i.e. their growth was determined by deformation). The augen are up to 3 cm long and are usually Carlsbad-twinned microcline, but some appear to be acid plagioclase. Some are idiomorphic - a characteristic of the advanced stages of migmatization.

Other gneisses display the vein, layered, dilation, folded, ptygmatic, augen and schlieren migmatitic structures described by Mehnert (1968). We consider these migmatitic rocks may be fare more abundant than is indicated by outcrop and may even form the bulk of the Complex. (Plate vi).

Granitoid rocks. The granitoid rocks include a variety of types ranging from a granitic to a dioritic composition; the granitic and adamellitic rocks are more abundant than intermediate types.

Outcrops of the granitoid rocks are strongly jointed and display some of the morphological features associated with igneous rocks such as exfoliation domes and tors. They are, however, rarely massive and their foliation is generally conformable with that of the surrounding gneiss and schist. Although they tend to occur as discrete small exposures (usually less than 400 m diameter), they never display sharp contacts, and a transitional zone of granitic gneiss is normally developed around them. This suggests that these rocks are plutonitic migmatites. (Plate vii).

Coarse pegmatite veins intruding the granitoid rocks are believed to represent a later hydrothermal phase. Massive quartz veins are less common. Phonolite dykes also intrude one of the granitoid rocks. Narrow aplitic dykes intersect one exposure of foliated granitoid rock in the Jim Jim Mass.

The essential mineralogy is the same as that of the gneisses (i.e. quartz, microcline, plagioclase, and biotite with accessory muscovite and opaque minerals). Clinopyroxene also occurs in some of the intermediate types. Several secondary minerals, resulting from retrograde metamorphism and possibly from some deuteric alteration, are also present. Microcline is generally more strongly sericitized than plagioclase. In some granitoid rocks, however, the plagioclase is saussuritized. Biotite is usually chloritized to some degree and clinopyroxene is invariably uralitized. Another alteration effect is the conversion of titanomagnetite to sphene. It is difficult therefore

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(a)

(b)

PLATE vi

(a) Migmatite showing typically folded granitic leucosome in biotite-rich melanosome, 18 km northeast of Munmarlary homestead

(b) Biotite-rich melanosome containing pods of, and inter-layered with, a quartz-rich pegmatoid leucosome, 10 km south of Nourlangie Camp

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to interpret the petrogenesis of these rocks from their mineralogy. Even the frequency of mineral inclusions, which Mehnert (1968) has cited as evidence for distinguishing migmatitic from magmatic rocks, is impossible to determine due to masking by alteration effects.

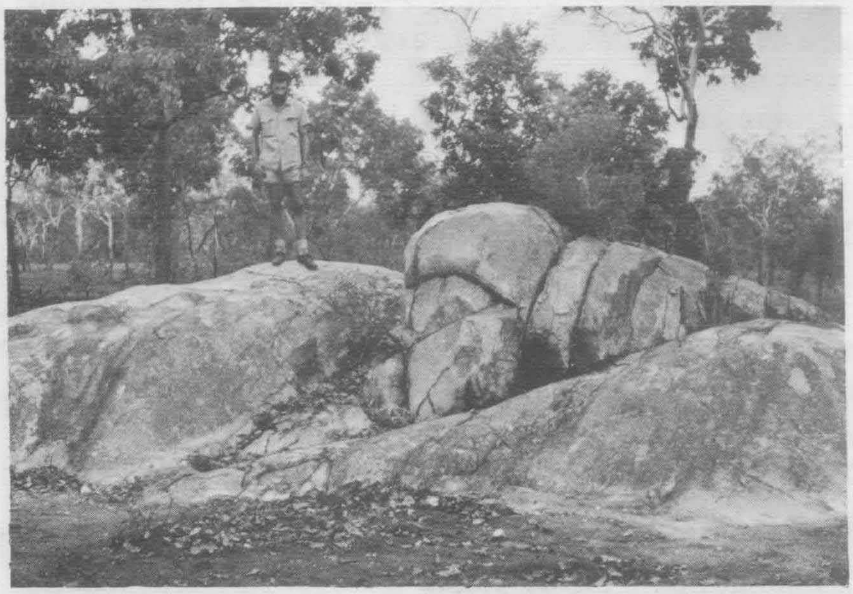
Plagioclase is generally idiomorphic and lacks more sodic rims. The plagioclase rarely occurs as the elongate laths typical of magmatic rocks but tends to be more equidimensional. Microcline and quartz are xenomorphic against plagioclase but are commonly idiomorphic against each other. These textural characteristics are fairly typical of plutonic migmatites. It is, however, possible that these rocks could be orthogneisses.

Amphibolite. Outcrop of amphibolite within the Complex is limited and as contacts with other rock types are rare their relations are uncertain: some of the amphibolites appear to represent mafic bands segregated during migmatization, while others appear to cut across the prevalent gneissic foliation and are therefore believed to be dolerite dykes intruded into the Lower Proterozoic sequence before migmatization. Some exposures range from foliated to massive.

The amphibolites are dark, generally strongly foliated rocks consisting of amphibole and plagioclase with minor quartz, potash feldspar, biotite, and chlorite. Sphene, epidote and opaque minerals are common accessory minerals. These rocks frequently have a well developed granuloblastic texture (consisting of a completely recrystallized mosaic of amphibole, plagioclase, and quartz) which is characteristic of the almandine-amphibolite facies. In some amphibolites, however, recrystallization appears to be incomplete, and idiomorphic hornblende crystals occur as porphyroblasts in a finer-grained matrix of plagioclase, epidote, chlorite, and quartz. The amphibole is commonly pale green pleochroic actinolitic hornblende, which should not be stable at almandine-amphibolite facies temperatures. A possible explanation for the persistence of this mineral, rather than common hornblende, is that the composition of the original rock was unsuitable for the formation of hornblende. Alternatively, the actinolite could be pseudomorphing hornblende as a result of retrograde metamorphism.

The origin of these rocks is problematical. Relict textures and minerals have not revealed whether they were derived from sediments or basic igneous rocks. The transition from dolerite in the Lower Proterozoic sequence to amphibolite in the Nanambu Complex appears to be traceable petrographically (i.e. in mineral assemblages and texture) from altered dolerite to metadolerite to basic amphibolite. Accessory chalcopyrite and pyrite in one of the amphibolites near Jabiru, also suggest an igneous origin. This does not exclude the possibility that at least some of the amphibolites are of sedimentary origin. Bryan (1962) recognized both igneous and sedimentary types in the Rum Jungle area.

(a)



(b)

PLATE vii

(a) Massive outcrop of foliated granitoid rock displaying near-vertical foliation, 10 km southeast of Nourlangie Camp

(b) Massive syenite surrounded by foliated granitoid rocks. 10 km east of Patonga homestead

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Pegmatites and quartz veins. Pegmatites are randomly distributed through the Nanambu Complex and appear to be most abundant in the Transitional Zone between the Complex and the Lower Proterozoic metamorphics. They rarely form continuous outcrops but normally appear as pegmatite rubble around milky quartz, suggesting that most pegmatites in the area are composite, with quartz cores. Quartz-tourmaline veins are also occur within the Complex.

The pegmatites are invariably barren and consist essentially of quartz, perthitic microcline, muscovite, and tourmaline. Some contain an unusual green amorphous feldspar. The perthitic feldspar and tourmaline tend to be idiomorphic; muscovite forms large books; and quartz is interstitial, or may form granophyric intergrowths with microcline.

These rocks obviously represent a late stage in the formation of the Complex. Some of the pegmatites may be a product of migmatization, as muscovite is more indicative of metamorphic rocks; others may be of magmatic origin, as granophyric intergrowths are more characteristic of igneous rocks.

Schist. Schist forms only a very minor portion of the Nanambu Complex. It is normally conformable with gneissic rock and quartzite, and may represent the pelitic members of an original sedimentary sequence rather than the product of metamorphic differentiation. Being the least competent rock the schist best reflects the deformation of the Complex (e.g. by kink folds, isoclinal folding, and crenulations).

The schist is composed mainly of biotite (altering to chlorite marginally or along cleavages), elongate clear quartz grains and xenoblastic feldspar (generally microcline). Variation in mineral content yields a range of rock types which become more gneissic as the feldspar content increases. The common varieties of schist are biotite schist, quartz-biotite schist and feldspar-quartz-biotite schist.

The distinctive mineralogy of these rocks provides a further possible basis for defining the Nanambu Complex/Lower Proterozoic boundary. The dominant phyllosilicate in the Nanambu Complex and transitional zone schists is bioite, while chlorite and muscovite (or sericite) are the dominant ones in the Lower Proterozoic schists, with biotite as a minor constituent. Some of the more altered biotite schists in the Complex in which alteration to chlorite is almost complete are, however, indistinguishable from the Lower Proterozoic chlorite schists.

Other schistose textured rock, superficially similar to the Lower Proterozoic schist, has been identified as sheared gneiss.

Quartzite. Quartzite, chiefly micaceous or feldspathic, or both, crops out extensively within the Complex and forms prominent strike ridges or rubbly rounded hills. The hills commonly represent the only surface expression of the Complex, giving a false impression of the abundance of quartzite in it. Where good continuous creek exposures occur, however, the quarteite is seen to account for only a very minor part of the succession. Typically the quartzite forms rare, narrow resistant bands (about 10 cm wide) interlayered with gneiss, pegmatite and schist.

Mapping of the quartzitic rocks is difficult. There is little evidence that these rocks are of sedimentary origin as current and normal bedding and other sedimentary structures are rarely seen. Although strike and dip are frequently measurable in ridge-like exposures, it is difficult to establish whether they represent bedding, or shearing in a quartz-filled fault, i.e. sheared quartzites closely resemble bedded ones (Plate viii).

Mineralogy and petrography of the quartzite identify the following types: recrystallized quartzite consisting entirely of a granuloblastic quartz mosaic; sheared muscovite quartzite in which the mica flakes have strong directional orientation; and feldspathic quartzite in which elongate blebs of feldspar (generally completely sericitized) are oriented parallel to a shear or an original bedding. Feldspar may constitute as much as 20% of the rock, but is normally interstitial between quartz grains.

The quartz is generally strained and fractured, and sutured boundaries are common. It occurs as elongate grains or lensoid lamellae, which give the rock a bedded appearance. Similar small quartz lamellae, elongated in the ratio of about 2.5:1, have however been recorded in sandstones by Pettijohn (1957).

Some quartzite is believed to be of sedimentary origin: relatively clean quartz sandstone with variable amounts of pelitic matrix. Microscopic examination suggests that others are sheared quartz rocks.

The banded hematite quartzite which is developed in the Lower Proterozoic sequence has not been recorded in the Complex.

Mylonite. The mylonitized gneiss in the Nanambu Complex is a highly deformed rock produced by dynamic metamorphism. The original gneissic texture is preserved to varying degrees giving a wide range of textures.

Some of the mylonites are only slightly deformed as shown by strained quartz grains. Ruptures of the fabric occur firstly along grain boundaries to produce interstitial stringers of granulated material. Where deformation has proceeded further, quartz grains are fragmented and the

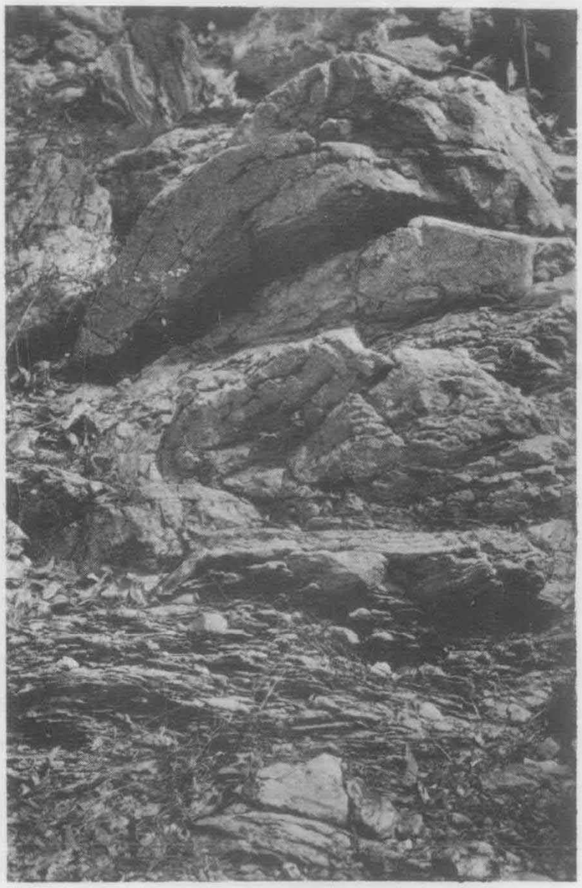

PLATE viii

Sheared quartzite (shearing more intense at base) which appears to be bedded, within the Nanambu Complex, northeast of Munmarlary homestead streaks and layers of granulated minerals are more extensive. With continued granulation the matrix is reduced to microscopic grain size. These rocks are true mylonites, which are hard and resemble indurated siltstone.

Moorehouse (1964) observed that mylonites and other microbrecciated and granulated rocks are liable to subsequent alteration or recrystallization. Alteration is not extensive in these mylonites and only some of the feldspar powder has been transformed to mica. Alteration of the ferromagnesian minerals with consequent release of iron oxide, plus extensive iron staining along fractures and in the fine-grained matrix, has occurred in most of the mylonite. Few of the rocks show evidence of recrystallization and only banding is considered to be relict. The rocks are significant for they are generally the only surface manifestation of faults within the Complex; their occurrence on a strong photo lineament is considered to be an indication of a major fault.

Quartz and feldspar, usually microcline microperthites, are the predominant minerals in the mylonitized gneisses. Frequently the only relict crystals fully preserved are large euhedral potash feldspar laths (less than 5 cm long); this is a characteristic of mylonites, because large feldspars are most resistant to granulation and become separated from each other in a fine-grained paste of ruptured and distorted quartz grains and clay. Mica is not abundant; biotite, when present, is usually distorted and iron-stained, and can be recognized only by its pleochroism and basal cleavage. Biotite and epidote, however, sometimes form unaltered inclusions in quartz grains. Other ferromagnesian minerals are absent. One mylonite contains less than 1% of a relict granular pale greenish mineral with a very high relief and a very low birefringence (almost isotropic); it is probably strained garnet.

Grade of Metamorphism. Mineral assemblages in the gneiss, granitoid rock, schist, and amphibolite of the Nanambu Complex indicate that regional metamorphism progressed to the almandine-amphibolite facies (Fig. 3).

The facies is divided by Turner and Verhoogen (1960), and Winkler (1967) into three subfacies of increasing metamorphic grade:

staurolite-almandine subfacies

kyanite-almandine-muscovite subfacies

sillimanite-almandine-orthoclase subfacies

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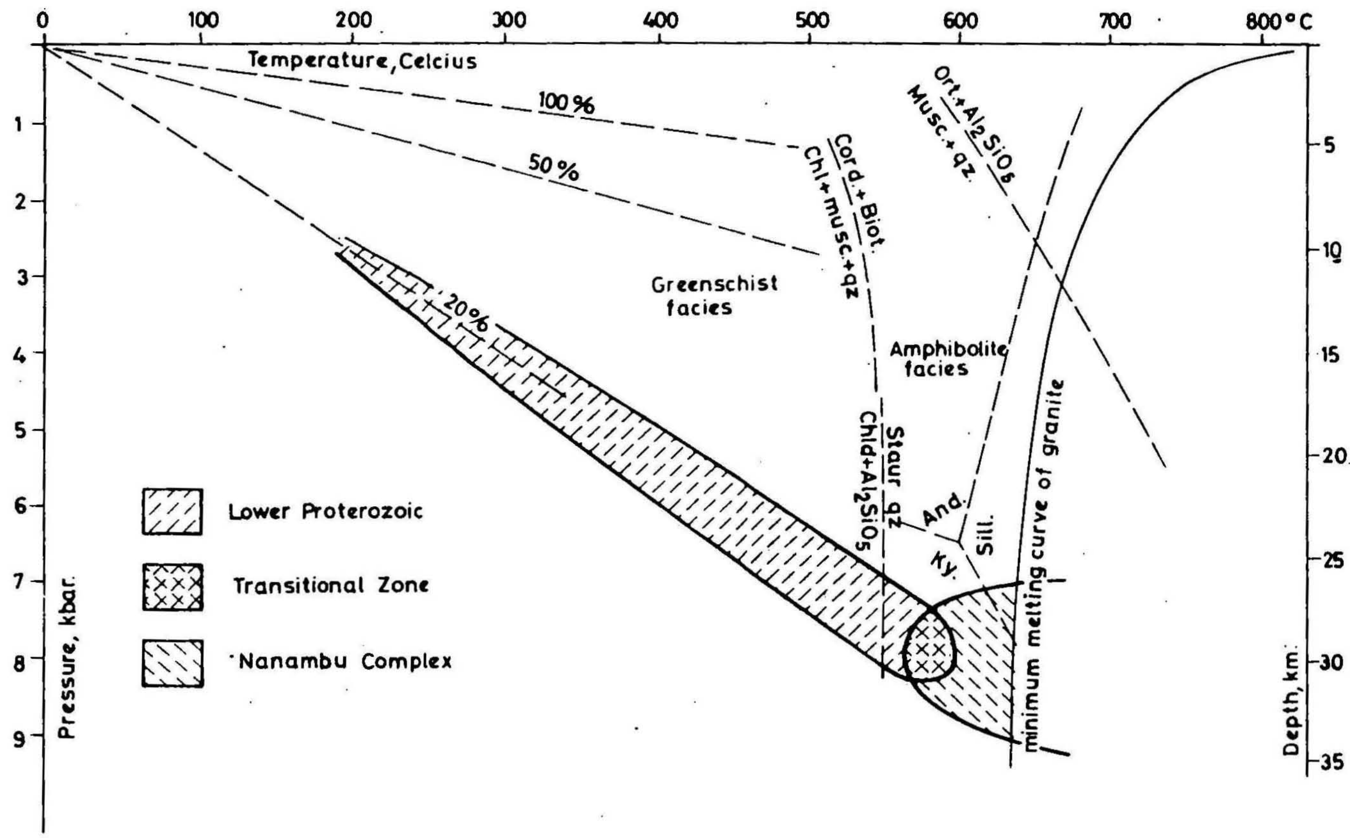
FIG. 3



P-T CONDITIONS OF THE NANAMBU COMPLEX AND LOWER PROTEROZOIC METAMORPHICS SIMPLIFIED AFTER WINKLER 1967

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The lack of orthoclase and sillimanite plus the presence of muscovite, some epidote, and microcline indicate that the grade of metamorphism is probably below the sillimanite-almandine-orthoclase subfacies.

Since the critical index minerals for the remaining subfacies, staurolite and kyanite, have not been identified in Nanambu Complex rocks, it is impossible at this stage to equate the metamorphic grade to a single subfacies. It is hoped that further petrographic studies will reveal the existence of one of these index minerals in an equilibrium assemblage (e.g. the critical kyanite-almandine-muscovite assemblage).

The extensive migmatization and regional lit-par-lit injection within the Complex provide sound evidence that at least the kyanite-almandine-muscovite subfacies conditions were reached. Kennedy (1949) showed that in the Moine schists of the Western Highlands of Scotland the 'central area of regional injection and migmatization' extended throughout the sillimanite and kyanite zones (i.e. the sillimanite-almandine-orthoclase subfacies and the kyanite-almandine-muscovite subfacies) but did not extend into the garnet zone. Winkler (1967) suggested that under the high pressures of the Barrovian-type kyanite-almandine-muscovite subfacies sufficient temperature (about 600°C) could have been generated for migmatization involving part melting of gneisses.

The absence of chlorite, except as an occasional alteration product of biotite; the absence of epidote or zoisite except where it occurs with calcic plagioclase in amphibolite; and the presence of hornblende and plagioclase in the amphibolite, indicate a higher metamorphic grade than the greenschist facies.

The granuloblastic texture of the gneisses, amphibolite and the quartzite provides further evidence that almandine-amphibolite facies conditions were reached.

It is unlikely that the Nanambu Complex is of uniform metamorphic grade. Typically, concentric zones of progressively higher grade are developed towards the granitic core of such migmatite massifs. But, although the migmatites occur centrally in the Munmarlary Mass, they are located towards the eastern margin of the Magela Mass and in the western part of the Jim Jim Mass. Detailed petrographic studies of fresh core to be obtained by drilling during the 1972 field season may reveal the existence of such metamorphic zoning.

The Origin of the Nanambu Complex. Petrological and mineralogical studies of the Nanambu Complex have to date been only brief, but they clearly suggest that the Complex is of migmatic origin, and possibly forms a mantled dome structure. Features indicating the migmatite origin are:

The occurrence throughout the Complex of migmatitic gneiss in which the microfabric of the new part (neosome) is distinct from that of the parent gneiss (palaeosome).

The progressive increase in regional metamorphic grade from the Lower Proterozoic rocks into the Complex.

The kyanite-almandine-muscovite subfacies, which is considered minimal for the Nanambu Complex, is sufficiently high grade for extensive migmatization.

The frequent occurrence of injection gneisses (i.e. gneiss with lit-par-lit granitic and biotite-rich layers).

The occurrence in the Complex of some granitoid rocks which appear to grade into gneiss.

Where exposed, boundaries of granitic rocks appear to be concordant.

The absence of contact aureoles adjacent to the granitoid rock.

Even where granitoid rocks display local discordant boundaries with the country rock, the foliation of the granite grades into the regional structure of the Lower Proterozoic sequence.

The existence of pegmatite veins in the Transitional Zone between the Complex and the Lower Proterozoic schists.

The boundary of the Complex, which is transitional through extensively pegmatite-veined, biotite-rich schist, indicates that the Complex was formed by migmatization of Lower Proterozoic sediments. Evidence to suggest an Archaean age for the Complex has not been found and the existence of an angular unconformity between Lower Proterozoic metamorphics and the rocks of the Complex seems unlikely. It is possible that the granitoid rocks within the Complex may represent the remnants of an Archaean basement, although their concordance with the gneiss suggests that they too are a product of migmatization.

Another possible origin for the Complex is that of an intrusive granite causing extensive metamorphism of the Lower Proterozoic rock pile. Such a possibility is discredited by the absence of metamorphic aureoles adjacent to the granitoid rocks of the Complex.

Basic Intrusive Rocks

Stewart (1959) introduced the name Zamu Complex to describe the sills and dykes of dolerite and gabbro and their differentiates, which intrude Lower Proterozoic sediments in the Zamu Creek area. Dunn (1962) extended the use of the name to some of the basic intrusives of the Alligator River 1:250 000 Sheet area (Ɇdi), which intrude the Lower Proterozoic sediments. He tentatively distinguished them from those intruding the Myra Falls Metamorphics (Ɇdo). As we regard the Lower Proterozoic and the Myra Falls Metamorphics as continuous we no longer make this distinction. However, with further work we may be able to subdivide the basic intrusives of the uranium province on geochemical grounds.

In describing the Zamu Complex, Dunn noted that 'the granophyres form the greater proportion of the outcropping intrusives and have a dioritic or granodioritic composition'. In the Cahill and East Alligator 1:100 000 Sheet areas, however, the rocks are largely of doleritic composition; acidic differentiates form only a minor proportion of the intrusives. In decreasing order of abundance the rock types represented are:

Dolerite and porphyritic gabbro.

Diorite, microdiorite and phonolite.

Syenite, sodic syenite, monzonite, and granophyre as rare intrusions.

To date no agreement has been reached on the age and nature of the dolerities in the region. Dunn (1962) concluded that the discordant dolerite intrusives west of the East Alligator River 'were intruded after the folding of the sediments but before granite intrusion' (which occurs in neighbouring areas). Bryan (1962), however, noted that the basic intrusives in the Jim Jim Creek area were 'elongated and follow the Lower Proterozoic trends' and probably intruded before Lower Proterozoic folding. Walpole (1962) regarded some of the sills as folded with the sediments, but considered that most of the dykes were intruded after folding, and before the intrusion of the granite.

Bryan also noted that, in the Katherine-Darwin area, the principal intrusive types are sills and subhorizontal sheets; he recognized sills of two distinct Lower Proterozoic ages with no geographic overlap, the rocks being predominantly dolerite derived from a tholeiitic magma. He recognized contact aureoles in adjacent sediments (less than 20 feet wide). In the Cahill and East Alligator Sheet areas these contact effects are masked * by the overall regional metamorphism which reaches the albite-epidote-amphibolite or the upper greenschist facies in the Lower Proterozoic rocks and the almandine-amphibolite facies in the Nanambu Complex.

It is possible that several phases of igneous activity are represented by these rocks. Since no geochemical data are available a subdivision based purely on petrographic and field evidence has been made. Two distinct phases are recognized:

(Pdo_1) basic intrusives and their differentiates which antedate Lower Proterozoic folding and migmatization.

(Pdo_2) phonolite (or micro alkali syenite) dykes which postdate migmatization.

Pre-deformation intrusives (Pdo_1). These intrusives occur throughout the Lower Proterozoic sequence and the Nanambu Complex. Those intruding the Complex, are altered to amphibolite (described earlier). They are granuloblastic-textured and only rarely retain relict igneous textures. They are considered to be true amphibolites; their normal mineral assemblage of actinolite-plagioclase-quartz is believed to be a product of subsequent retrograde metamorphism. The metamorphic grade of those intruding the Lower Proterozoic rocks generally increases towards the Nanambu Complex. Some display only an extensive deuteric alteration, but most are extensively altered by the combined effects of deuteric alteration and greenschist regional metamorphism, and, in places, by retrograde metamorphism. Relict ophitic texture is identifiable in these rocks.

Deuteric alteration, regional metamorphism, and retrograde metamorphism tend to mask, or at least minimize, differences in the composition of the original intrusions. However, variations in the quartz content, the K-feldspar/plagioclase ratio, grainsize, texture, and the percentage of opaque minerals indicate that these rocks were predominantly dolerite and gabbro, but included some microdiorite, monzonite, syenite, sodic syenite (including pegmatite), and granophyre. These rocks almost certainly represent several phases of igneous activity.

*Note: except in the case of the phonolites which do display contact effects.

Outcrop is usually so poor that relations with adjacent rocks are rarely apparent. However, when dolerites are foliated or have a marked lineation they are usually conformable with the Lower Proterozoic aerial photograph trends. Some appear to be locally discordant although contacts are not exposed. Others appear to form narrow sill-like bodies which rarely exceed 100 metres in thickness and a k lometre in length, but usually appear to be much smaller. One intrusion in the Howship 1:100 000 Sheet area is apparently zoned. It ranges from olivine gabbro to granophyre, and includes dolerite, porphyritic saussuritized dolerite, sodic syenite, and sodic pegmatite. The outcrop of this intrusion is approximately 1 km across, but boundaries between the various phases are indiscernible. Its size and age are uncertain. It crops out just below the Arnhem Land escarpment, forming a topographical basement high on which the Kombolgie Formation sandstone was deposited.

So far, two distinct mineralogical groups can be recognized within the basic intrusives: one derived from a tholeiitic parent magma, the other from an alkali basalt parent.

Intrusives derived from a tholeiitic parent magma commonly consist of granophyric quartz dolerite, quartz dolerite, and differentiates. These rocks are characterized by groundmass quartz, the absence of biotite (sometimes present as a minor accessory) and olivine, and the interstitial development of a granophyric texture and rare development of myrmekite. Primary plagioclase may remain unaltered, but normally it is albitized, sericitized, or even saussuritized; in metadolerites it is recrystallized and occassionally untwinned. Clinopyroxene is generally uralitized or chloritized, but in metadolerites it is converted to coarse, granular, hypidiomorphic pleochroic green amphibole, probably a low-alumina or actinolitic hornblende. Sphene partly replaces the titanium-bearing opaque minerals.

Rocks from an alkali basalt parent magma are characterized by the absence of quartz, the presence of granular olivine phenocrysts, and the almost ubiquitous occurrence of biotite plates in the groundmass. The olivine is altered along fractures and marginally to iddingsite or serpentine, or both; in extremely altered varieties the olivine crystals are completely pseudomorphed by an unidentifiable platy amorphous green-brown mineral. The biotite content of the intrusive is believed to indicate an alkaline affinity.

We consider that this subdivision of Pdo_1 is justified on petrographic evidence even though some of the quartz could be derived from the saussuritization of plagioclase. Chemical analyses may help in identifying many of the altered dolerites.

A problematical ultrabasic/basic intrusion crops out near Nourlangie Rock in the Transitional Zone of the Nanambu Complex. Petrographic evidence is inconclusive. One thin section examined contained green spinel, hypersthene, anthophyllite, forsterite, and corundum(?). If the parent magma had been alkaline the intrusion could represent an ultramafic rock which has been subjected to a high grade of metamorphism. Hence the outcrop could be a differentiate of an alkali basalt magma. Alternatively, if the parent had been tholeiitic, the rock could be a pyrometamorphosed aluminous xenolith.

Post-migmatization types (Edo$_2$). These are exclusively peralkaline phonolitic rocks which intrude the Magela Mass of the Nanambu Complex. They are typically dark greenish grey, fine-grained, generally porphyritic rocks forming dykes less than 10 metres wide and rarely exceeding 400 metres in outcrop length. The dykes are straight, parallel-sided, apparently steeply dipping, and occasionally bifurcate. West of Mudginberri, a dyke swarm intrudes a garnetiferous leucogneiss but no contacts are exposed. On the eastern margin of the Magela Mass a phonolite dyke (about 2 metres wide) intrudes foliated granitoid rocks. It is clearly discordant and has narrow chilled margins, but no contact aureole is apparent.

These rocks are unmetamorphosed and relatively free from alteration. The phenocrysts are laths and glomeroporphyritic aggregates of sanidine and sanidine-anorthoclase; moderately acicular, zoned, idiomorphic aegirine-augite; and nepheline. The nepheline is rarely zoned. The phenocrysts display resorption effects and reaction rims; e.g. some aegirine-augite is rimmed by a pleochroic green sodic amphibole, which also occurs as fine needles in the groundmass. Accessory amounts of biotite, sphene, ilmenite needles, and large skeletal grains of opaque minerals also occur. The groundmass is generally fine-grained or even glassy, with only incipient development of amphibole and biotite crystallites.

Acid Volcanic Rocks

Acid volcanic rocks, occurring as rubble in valleys at Mount Basedow, are probably flow remnants and correlatives of the Edith River Volcanics, which unconformably overlie Lower Proterozoic strata in the South Alligator River area. The nearest confirmed outcrop of Edith River Volcanics is 45 km to the southwest, in the vicinity of Shovel Billabong.

The volcanics at Mount Basedow are generally pink or grey and contain phenocrysts of resorbed quartz and highly sericitized and chloritized sanidine crystals up to 5 mm in diameter in a ground mass of quartz and feldspar. Chlorite commonly contains magnetite, and the rock displays blotchy hematite staining. One specimen contained minor epidote. The alteration of feldspar and pyroxene(?) may be due to regional metamorphism, which would indicate that the volcanics were part of the Lower Proterozoic sequence metamorphosed to the lower greenschist facies grade.

Of the descriptions given by Stewart (1965) of the Edith River Volcanics, the Pul Pul Rhyolite bears closest resemblance to the volcanics at Mount Basedow, which are tentatively regarded as porphyritic alkali rhyolites. The possibility of a pyroclastic origin cannot be excluded.

Kombolgie Formation

The Kombolgie Formation forms the Arnhem Land Plateau, the edge of which is marked by a sheer scarp up to 200 m high, and is the most prominent relief feature in the Alligator River Sheet area. In the areas mapped, two large outliers of Kombolgie Formation (the Mount Brockman Massif and the Mudginberri Massif) lie adjacent to the main escarpment. Most observations of the formation were made at the base of the scarp, as in most places it proved unscalable; the underlying Lower Proterozoic rocks are sometimes well exposed when not masked by talus covering the foot slope (Plate i).

In the Cahill 1:100 000 Sheet area the formation comprises lower and upper sandstone units, separated by a basalt sill, which appears to be related to the Nungbalgarri Volcanic Member. The sandstones are composed mainly of medium to coarse (0.25-1.0 mm), moderately well sorted, sub-rounded to sub-angular quartz grains; matrices range in composition from amorphous and fibrous clay minerals to opaque iron oxides. Friable varieties are devoid of a matrix and quartzitic varieties may contain either interlocking grains or a fine quartz cement.

The sandstone displays a range of rock types from fine ferruginous siltstone, to conglomerate containing well rounded quartz cobbles up to 20 cm. Conglomerate beds range from 20 cm to over 30 cm thick and are more common below the volcanic member. Basal conglomerates directly above the underlying Lower Proterozoic strata generally consist of subangular quartz and quartzite (often feldspathic) pebbles (up to 80%), up to 20% shards of Lower

Proterozoic schist, rodded quartzite, and psammitic shale, and highly angular chunks of vein quartz (up to 2%). Distribution of the conglomerates is sporadic, and may have been controlled by relief of the pre-Kombolgie surface; thus, basal conglomerate is missing at Nourlangie Rock, which probably formed a small hill prior to Kombolgie sedimentation.

Accessory minerals may be locally related to the parent rock at the onset of Kombolgie deposition. Biotite, pyroxene, and chlorite are present as accessory minerals in sandstone overlying a hill of granite on the north-western flank of the Mount Brockman Massif. Quartz grains in a specimen collected near the base of the formation 15 km east of the Koongarra Deposit contained inclusions of minor epidote(?) as euhedral laths.

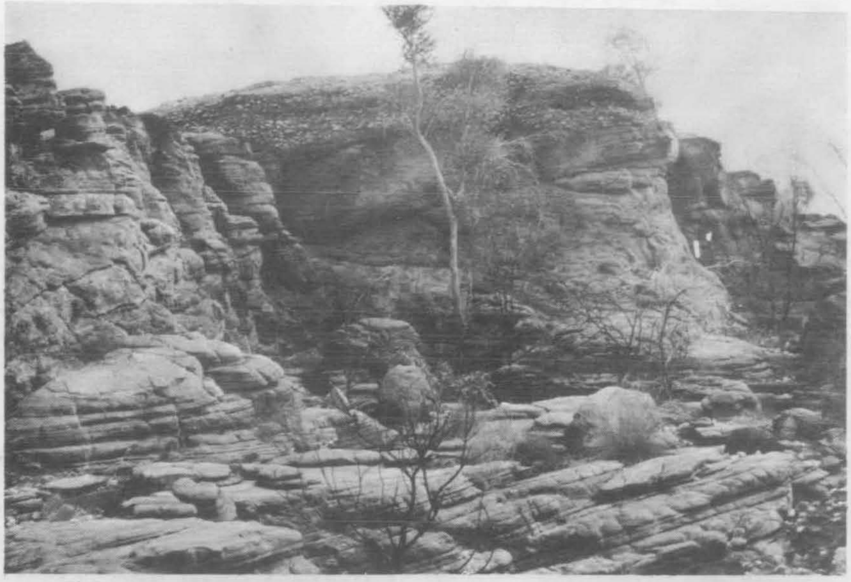
Sandstone above the volcanic member was not visited in the field, but aerial inspection suggested that it is generally more homogeneous, the absence of thick conglomerate beds being apparent.

The sandstone throughout the formation is commonly cross-bedded and ripple-marked. The cross-bedding varies from medium (5 cm - 2 m) to large-scale (2 m - 8 m) and is of the 'alpha' type described by Allen (1963) as being suggestive of a shallow freshwater origin. The few measurements recorded of directional sedimentary structures in the Cahill 1:100 000 Sheet area generally fall within the southern quadrant, suggesting a prevailing current of deposition from the north (Plate ix a).

The Northern Plains are in part a re-exhumed pre-Kombolgie Formation land surface, and display a similar terrain to the exposed unconformity surface at the base of the Kombolgie Formation, with local relief up to 20 m and isolated hills up to 120 m above the general surface. Local drape structures over re-exhumed basic intrusive bodies and small hills of foliated granites are obviously depositional in origin, although the low dips in the main scarp probably resulted from an overall tilt to the southeast. Basinal dips in the Mount Brockman and Mudginberri Massifs have been modified by tectonism, producing dips of up to 70° in places, and faulting (see Structure, and Barometric levelling of the base of the Kombolgie Formation).

At one locality visited in the Howship Sheet area the volcanic member consists of microcrystalline massive basalt. Although it is generally more amygdaloidal at the top of the sequence (with vesicles of quartz, and a pale green chlorite), intercalated hornfelsic sediments suggest the possibility of more than one flow. The basalt is ophitic-textured and composed of sericitized feldspar laths, pyroxene, and skeletal magnetite.

(a)



(b)

(c)

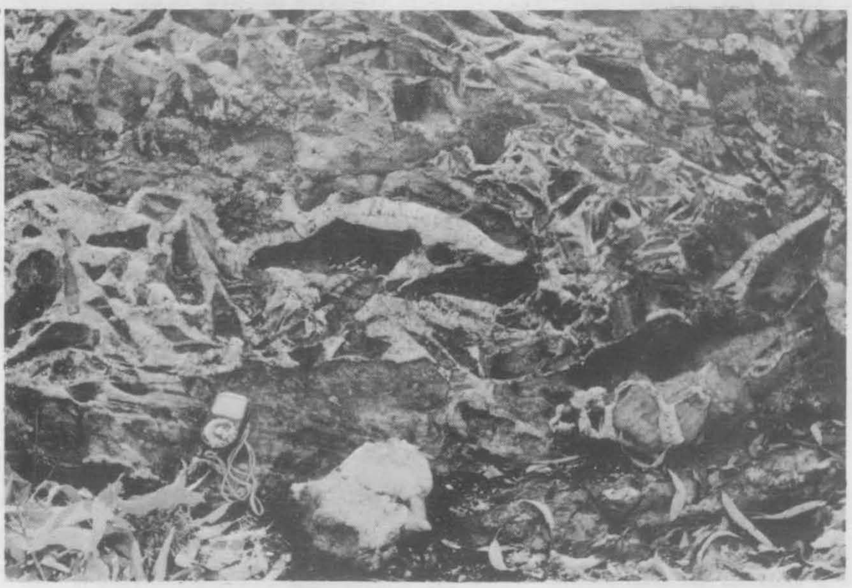


PLATE ix

(a) Extensive large-scale cross-bedding in Kombolgie Formation, 4 km north of Koongarra
(b) Dragfold in limb of major fold with low angle shears developing along axis of dragfold in escarpment, 11 km northeast of Koongarra
(c) Brecciated and quartz-veined sandstone within north-trending fault in Kombolgie Formation, 2 km west of Koongarra

Cainozoic Sediments

Cainozoic sediments form a veneer over the Northern and Estuarine Plains, and talus slopes and colluvial sand cover adjacent to and over the Arnhem Land Plateau.

The deposits have been divided into the following units: Laterite, Late Tertiary Sands, Talus, and Quaternary Continental and Marine Sediments.

Laterite. Generally, the profiles seen in the Cahill and East Alligator 1:100 000 Sheet areas are either detrital or are truncated remnants of the standard laterite profile described by Whitehouse (1940).

Of the laterite types described by Williams (in Story et al, 1969) as occuring in the Adelaide River-Alligator River area, the following types have been recognized:

Detrital laterite is formed mainly from reworked material cemented in a ferruginous matrix. It generally forms blocks (up to 1 m in size), and pavements on low hills or breakaways over the Nanambu Complex. It also forms bare pavements and benches of laminated laterite in the Cannon Hill area.

Pisolitic laterite-primary or detrital-consists mainly of cemented ovoid ironstone pisoliths between 0.25 and 1.0 cm in diameter, often case hardened or varnished. It occurs as blocks or pavements, and is often exposed at the margins of the Estuarine Plains, where the Koolpinyah surface is being actively eroded at its edges.

Mottled-zone laterite is the middle part of the standard laterite profile, and consists of deeply weathered bedrock grading up into a ferruginous zone of generally pisolitic laterite, and down into a pallid zone. It commonly occurs over the Nanambu Complex in the bottom of amphitheatres at the head of creeks, and is usually surrounded by a breakaway of pisolitic or detrital laterite.

Concretionary laterite is pedogenetic in origin and, unlike the laterites already described, is actively forming, rather than being in an erosional or stable environment. It occurs as ferruginous mottles in poorly drained alluvial soils, or as ironstone nodules in situ in the soil profile, and has been noted in the active flood plains of Magela and Nourlangie Creeks.

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Late Tertiary Sands (Czs). Coarse unconsolidated quartz sands, often with a hematitic clayey matrix, form the remnants of the Koolpinyah Surface. This surface remains stable only in the eastern half of the East Alligator Sheet area and in small scattered localities throughout the Cahill Sheet area. The greater part of the rest of the area mapped is covered by a dissected Koolpinyah Surface (i.e. dissected Czs).

Where the sands have been almost completely removed, structures within the underlying weathered rocks become apparent on aerial photographs. In costeans at Koongarra undisturbed structures can be measured in weathered schists and quartzites (mapped as Blc) within 1 m of the surface.

The late(?) Tertiary sands of the Northern Plains are probably fan deposits (Story et al), derived from the Mesozoic sand, silt, and claystone, the Kombolgie Formation sandstone, and the Lower Proterozoic metamorphics. Hooper (pers. comm.) however noted that water worn pebbles within the late(?) Tertiary sands have been recorded only east of Magela Creek, and therefore the unconsolidated sands may be aeolian. Clean, unconsolidated quartz sand developed in situ on the Arnhem Land Plateau from the Kombolgie sandstone has developed continuously since the early Tertiary.

At the margins of the Estuarine Plains, erosion of Czs and redeposition have produced a narrow but distinct photogeological unit, (Cza), which is characterized by a relatively steep slope of 5°; winnowing of the sands by erosion has resulted in the development of a sandy veneer on the slope. Because they are a direct product of erosion of unconsolidated sands and not part of the open drainage system, the clay and silt deposits found in isolated 'swallow holes' developed on the Koolpinyah Surface are also included in the Cza unit; their formation has probably been continuous since the early Tertiary.

Talus Material and Rubble (Czt). Large talus slopes are commonly developed adjacent to the Arnhem Land Plateau where the base of the Kombolgie Formation is above ground level. The scree sometimes conceals the contact between the Kombolgie and the underlying strata, but often a bench is developed at the top of the talus slope, and the unconformity is exposed below an overhang of sandstone formed by preferential erosion of the Lower Proterozoic rocks. The talus is composed mostly of large blocks (up to 20 m) of Kombolgie sandstone, but pebbles or shards of the underlying rocks are commonly present.

Laterite, quartz, quartzite, and dolerite rubble are widely scattered over the Northern Plains. The quartz and quartzite rubble is developed adjacent to strike ridges of Lower Proterozoic rocks or other similar strata close to the surface.

Dolerite is an extremely common constituent of rubble in almost every part of the area mapped. Notably, it occurs adjacent to outcrops of quartz, quartzite, and the more massive varieties of gneiss on which 'grinding hollows' are seen. Aboriginals commonly used it for making artifacts; they transported he dolerite to suitable 'workshops' where they ground it against the quartz or gneiss to make tools. It is assumed that most of the dolerite rubble seen has been transported by man; therefore only definite outcrops of basic intrusives have been shown on the maps.

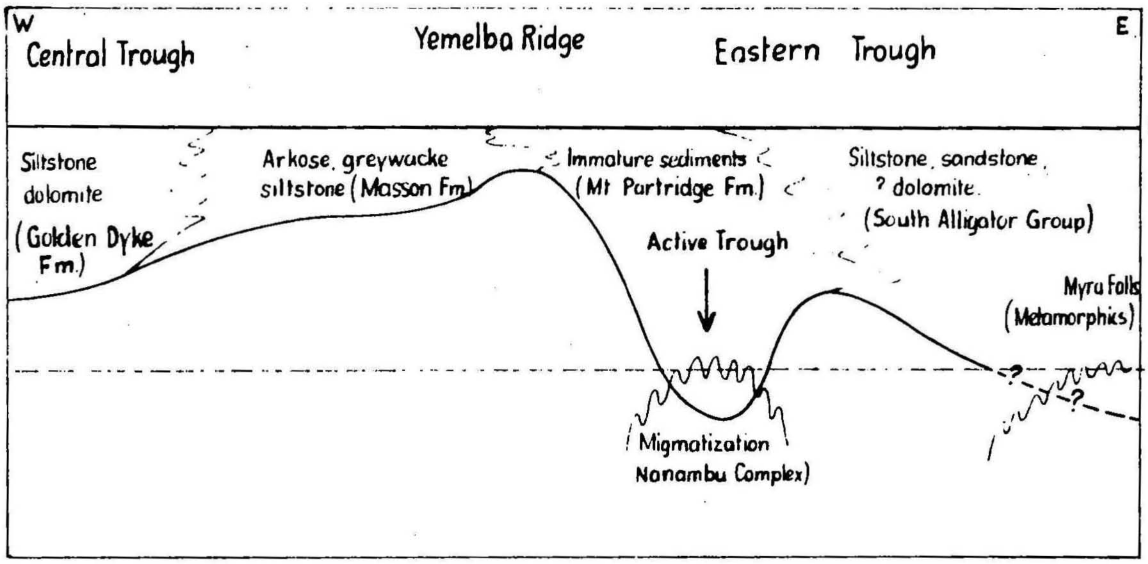
Quaternary Continental Deposits. Deposition in a continental environment during the Quaternary is represented by a variety of alluvial types.

Alluvial silt, sand, and clay (Qa) occurs in the courses and flood plains of active rivers. The large bodies of unconsolidated quartz sand (Qs) within the courses of major creeks and rivers, and the outwash deposits (Qs) over the adjacent flood plains, consist mostly of material derived from the Kombolgie Formation or late Tertiary sands, and are mostly deposited during floods. The sediments of abandoned river courses (Qas) consist mostly of silt and mud. The oxbow lakes developed prior to the late Pleistocene to Recent coastal emergence, are shallow depressions in the surface of the flood plain, into which the present drainage system is incised. Silty levee deposits (Qal) are developed on the banks of the main channel of the South Alligator River, and are also preserved along some of the abandoned river courses. Black humic soils and clays (Qf) are commonly developed in poorly drained depressions within the drainage systems. Those adjacent to the Arnhem Land Escarpment often display anomalous radio-activity.

Quaternary Marine Deposits. During the wet season (November to April) marine conditions strongly influence deposition in the major river courses for a considerable distance inland. In fact brackish conditions extend as far inland as the Leichhardt Billabong in the South Alligator River system.

Coastal alluvial deposits (Qca) are comparatively well drained silt and clay deposits with sparse vegetation cover, such as sedge or samphire, and stand above the poorly drained black soil plains and mud pans (Qcp), which are also developed adjacent to, and within, estuarine channels. Salt pans are developed in some mud pans. The pans are generally devoid of vegetation except in areas bordered by Czs which are perenially waterlogged and support paperbark and waterweed growth (e.g. Woolwonga Swamp).

FIG. 4



RELATIONSHIPS BETWEEN SEDIMENTARY UNITS OF THE CENTRAL TROUGH AND THE (EXTENDED) EASTERN TROUGH

The coastal sand ridges (Qcr) are generally within 2 km of the present coastline and parallel to it, or are adjacent and parallel to the edge of Czs. The latter type represent strand lines prior to the recent drop in sea level; the former represent stages in the current progradation of the coastline. Ridges were not visited during the 1971 field season, but Williams, Hooper & Story (in Story et al.) reported that the dunes are commonly composed of shelly sand and support a woodland of non-eucalypts or semi-deciduous types.

STRUCTURE

The Pine Creek Geosyncline is regarded as a shallow intercratonic structure rather than an orogenic belt (Walpole et al., 1968; Walpole & Smith, 1961). We believe, however, that the Nimbuwah Complex represents an orogenic centre within the geosyncline, and, with the Nanambu Complex, was produced by extensive migmatization of Lower Proterozoic strata.

Accumulation of a thick sedimentary pile in a deep marginal trough on the western flank of the Eastern Trough could have resulted in P/T conditions suitable for migmatization of the Nanambu Complex without involving regional orogenic processes. If the sediments were immature feldspathic sandstone and arkose similar to those of the Mount Partridge Formation it would explain the leucocratic nature of the Nanambu Complex (Figure 4).

The Magela Mass of the Nanambu Complex occupies a dome structure within Lower Proterozoic metamorphic rocks. The Jim Jim and Munmarlary Masses are subsiduary elongate domes or folds on the western flank. The Jim Jim Mass appears to be overturned, its axis dipping about 50° west.

Structurally the Complex is continuous with the surrounding lower-grade rocks, which generally dip 40°-50° away from it; there is evidence of isoclinal folding east of Jabiru. The schists are often crenulated parallel to strike; there is no conclusive evidence for more than one phase of tectonism.

Photo-lineaments suggest that the pre-Carpentarian rocks of the area are extensively faulted, but lack of exposure makes it hard to relate structural disconformities suggested by photo-interpretation. At Mount Cahill and Mount Basedow, where exposures are relatively good, complex fault patterns have been discerned: the gradational boundary of the Nanambu Complex is offset by faulting along Magela Creek and near Mount Cahill; in the Munmarlary area the boundary coincides with a continuous fault trending about 020°; faulting appears to follow the boundary along the southwest and southeast (concealed by Kombolgie Formation) edges of the Magela Mass, where it may be controlled either by the margin of the Complex, or by the interface between quartzite and dolomite (?Koolpin Formation) and schist (?Fisher Creek Siltstone) in the Lower Proterozoic succession.

The fault along the southeast edge of the Magela Mass also affects the Carpentarian Kombolgie Formation, along the southeast flank of the Mount Brockman Massif, where dips of up to 70° are locally developed. Brecciated sandstone and widespread quartz-veining are also visible near Koongarra (Plate ix b, c).

Generally, faults affecting the Kombolgie Formation have vertical displacements of less than 60 m, and apparently little or no horizontal displacement. The major faults and joints within the formation are tensional features, with minor vertical displacements, apparently controlled by older basement features. Many such faults can be traced from the Kombolgie Formation, through the Lower Proterozoic metamorphics, and into the Nanambu Complex. The predominent trends of major faults are northwest, and approximately east.

The Mount Brockman and Mudginberri Massifs are wide flat basinal features with steeply dipping (25°-70°) margins. The shapes of the basins closely coincide with the present outline of the massifs, suggesting that the basins were formed tectonically. However, away from the margins, dips soon shallow to less than 5°.

The basinal outliers present an interesting regional trend heading approximately north in the Cahill 1:100 000 Sheet area and swinging east in the Oenpelli 1:100 000 Sheet area. This trend is duplicated by the corridor of Lower Proterozoic exposure which lies between the outliers and the main escarpment, and in which the Myra Falls Window (Alligator River 1:250 000 Sheet) is situated; the coincidence of this trend with the spatial distribution of uranium mineralization has been noted.

ECONOMIC GEOLOGY

Uranium

To date the current intensive exploration program in the Alligator River uranium province has resulted in the discovery of three major uranium deposits. Dodson (1971) has briefly described some of the deposits, and further information has since become available in relevant press statements made by exploration companies.

Dodson also discussed likely origins of the mineralization (viz: syngenetic, concentration from a massive source rock, and hydrothermal/ mesothermal deposition).

There appears to be a spatial relation between uranium mineralization in the Alligator River uranium province, and the quartzite sequence of the Lower Proterozoic succession. The quartzite sequence, correlated with the Koolpin Formation or Gerowie Chert, or both, also lies adjacent to the margin of the Nanambu Complex. Characteristically, pegmatite dykes are extensively developed in this zone.

Therefore there is no straightforward relation between the mineralization and the regional geology, but we suspect that the mineralization is of a relocated syngenetic origin, and believe that uranium was present in above normal concentrations in the Lower Proterozoic sedimentary pile, as a result of erosion and deposition of material from a uranium-enriched Archaean provenance; the uranium was later concentrated along a preferred horizon within the sedimentary pile by either (a) ground water circulation, concentrating uranium adjacent to carbonate horizons in the quartzite sequence, or (b) the 'sweating out' of volatiles and mineralized solutions containing uranium, from the sediments during migmatization, and their subsequent concentration in the Transitional Zone of the Complex. Ground water circulation may have further concentrated the uranium after deposition.

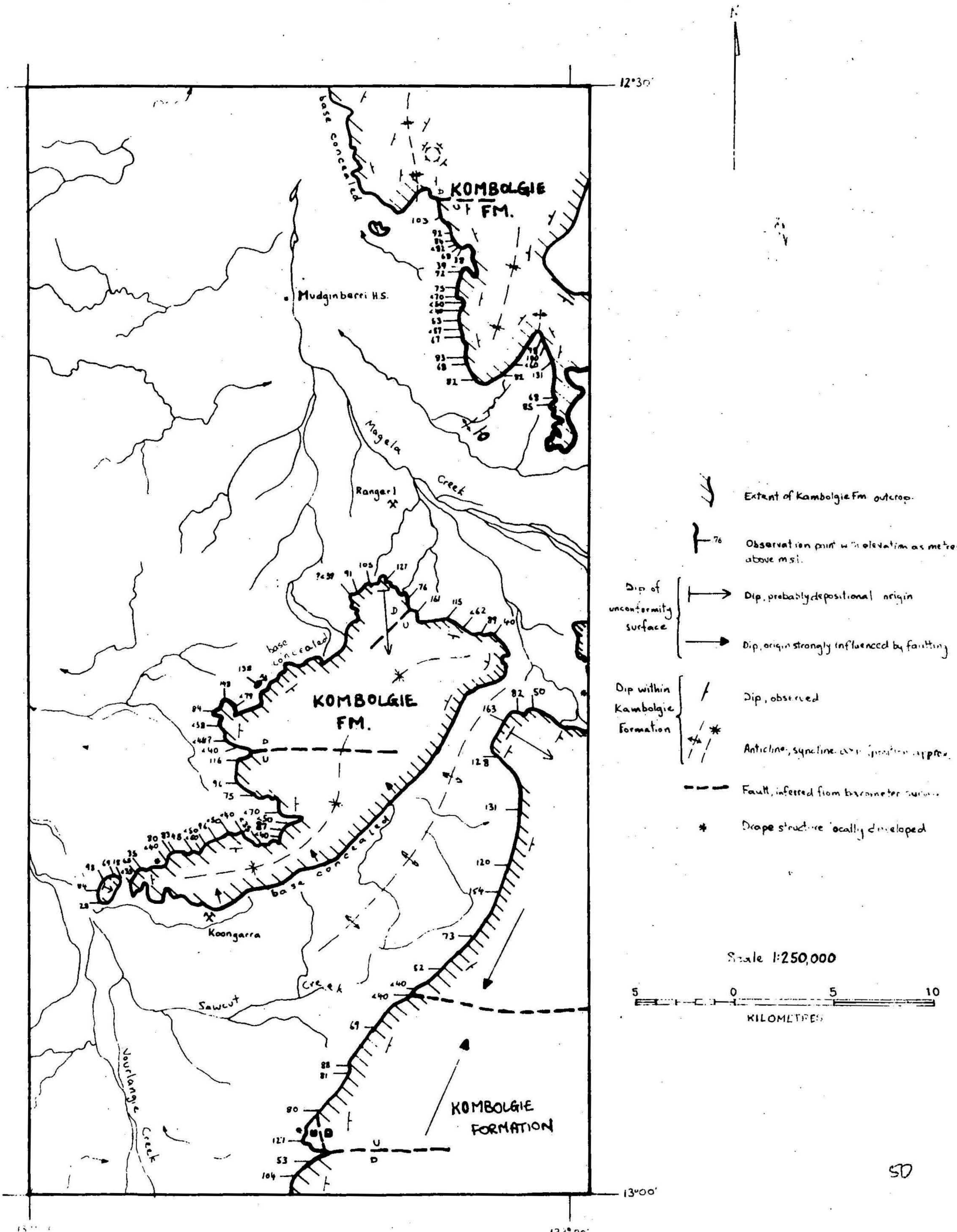
A suitable structural trap was probably necessary for concentration of deposits of economic proportions. We believe that the interface between the more competent 'quartzite sequence' and the less competent Fisher Creek Siltstone may have acted as a plane of stress release during tectonism, the resultant shearing and brecciation thus providing a suitable environment for the secondary concentration of uranium.

The compact quartzose nature of the Kombolgie Formation sediments and the absence of uranium in unweathered rock tend to dismiss the Kombolgie as a possible massive source for uranium concentration. Small roll fronts observed in the formation rarely show anomalous radioactivity; however, thorium appears to be present within minor heavy-mineral concentrations in some beds. The Kombolgie Formation may have played an important role in the concentration of the uranium nonetheless; a change in the physicochemical environment may have prevented mobility of uranium-bearing groundwaters

FIG. 5

BAROMETRIC LEVELLING OF THE BASE OF THE KOMBOLGIE FORMATION
CAHILL SHEET AREA

Elevations shown in metres above mean sea level.



above the Kombolgie/Lower Proterozoic unconformity, thus concentrating mineralization below it. To date mineralization has been found to extend to about 200 m below surface at Ranger 1.

Secondary uranium minerals occur in a boulder train within the Kombolgie Formation in the Mudginberri Massif. They were probably introduced along a shear or fault transgressing the unconformity at the base of the formation. Alternatively, they may have been deposited by circulating mineralized groundwater. Secondary mineralization has also been seen in the matrix of Kombolgie Sandstone boulders, in the soil profile above the Nabarlek orebody.

Minor galena and copper are associated with the uranium deposits at Ranger 1 and Koongarra; a trace of vanadium has been reported from Ranger 1. Variable gold values (trace to 5 dwt) also occur at Ranger 1, and Pan Continental has reported gold values from conglomerates developed at the base of the Kombolgie Formation.

Water

A high seasonal rainfall supplies most water requirements in the Cahill and East Alligator Sheet areas. Now that Woolwonga Reserve is being fenced, and stations are conducting extensive fencing programs to enable domestication of buffalo, water bores are being drilled to augment the water supply in paddocks devoid of perennial water holes - especially over the Nanambu Complex. Usual sites for the water bores are at the intersections of photolineaments, or in sheared quartzite outcrops and quartz veins. Results are variable, but yields of up to 11,000 litres per hour have been obtained.

BAROMETRIC LEVELLING OF THE BASE OF THE KOMBOLGIE FORMATION

In order to investigate the possibility of a relation between the unconformity at the base of the Kombolgie Formation and the uranium mineralization, the unconformity surface in the Cahill Sheet area was systematically levelled by G. Lau, NT Mines Branch. Using R.A.S.C. 1:50 000 contoured topographic bases, a position easily identified on the ground was selected (e.g. the junction of a creek bed) and its elevation was calculated from the contour map. The elevation difference between this point and the unconformity was measured using a pocket aneroid barometer. Values were compensated for drift by rechecking readings at the selected base after the measurement at the unconformity. As the operation generally took less than 30 minutes the amount of drift encountered was negligible. The results are included in Figure 5.

A series of outliers of Kombolgie Formation, namely the Mount Brockman, Mudginberri, and Oenpelli Massifs, lie parallel to, and a few kilometres from, the main Arnhem Land Scarp. The outliers are divided from the main scarp by Lower Proterozoic metamorphic rocks which are low-lying and covered mostly by Cainozoic sediments to the southwest of the Bulman Fault. Northeast of the fault, in the Myra Falls Window, the metamorphics are being eroded, forming extremely rugged terrain.

Dips in the main escarpment are generally to the southeast, but in the outliers the strata dip towards their centres. Characteristically, the shapes of the basins closely follow the present outcrop shape of the outliers. By inference, therefore, a long sinuous anticlinal axis runs between the main escarpment and the outliers.

Measurement of the unconformity surface indicated that the original pre-Kombolgie surface was irregular, with a relief comparable with that of the Northern Plains. The surface was disrupted by post-Kombolgie faulting. Isolated hills such as Mount Cahill rose above the level of the original surface, and steep dips at Nourlangie Rock, and the northern tip of the Mount Brockman Massif appear depositional, indicating the position of topographic highs on the Lower Proterozoic surface during Middle Proterozoic deposition. Irregularities of a smaller scale are evident as pebble-filled valleys along the unconformity, and as drape structures over resistant basic intrusive bodies (e.g. 4 km northwest of Koongarra) (Fig. 5).

The barometric survey showed that several of the larger fractures vertically displace the unconformity surface by up to 70 m. Hinged downfaulting along Sawcut Creek has resulted in spurious dips of the unconformity along the main escarpment. So far the survey has not revealed any relation with the uranium mineralization.

The barometric survey will be continued, as it is hoped to gain an understanding of the regional structure of the Kombolgie Formation, including the relations of the outliers to the main escarpment and the Mount Borradaile/Wellington Range outcrops. Such a survey may provide useful information about the Bulman Fault, and the westerly striking faults through the Arnhem Land Plateau.

GAMMA-RAY SPECTROMETRY

Thirty-six whole-rock samples representative of the Cahill and East Alligator Sheet areas were analysed by Geophysical Branch, using the gamma-ray spectrometer in the Darwin office; the results are tabulated below:

Lower Proterozoic	Field No.	percent eU	percent eTH	percent eK
(a) Arkose	CA75H	-	.0018	1.9
"	CA201	trace	.0018	1.6
(b) Silicified dolomite	CA171	-	-	-
" "	CA184	trace	-	-
(c) Quartz-muscovite schist	CA28A	-	.0007	trace
" " "	CA59A	trace	.0036	1.9
" " "	CA1008D	-	.0011	trace
" " "	CA103B	-	.0012	-
" " "	CA1023	-	.0015	-
" " "	CA1096	.0058	.001	-
Quartz-muscovite-chlorite schist	CA1096A	.03	-	trace
Graphite schist	CA1096G	.012	-	-
Quartz-muscovite schist	CA1026A	-	-	-
Muscovite-amphibole schist	CA1020	-	.001	-
Quartz-biotite schist	CA75K	-	.0047	trace
Talc schist	CA1058	.0034	-	-
Carbonaceous shale	CA1008C	.0008	-	trace
Quartz-chlorite schist	CA1014	.01	trace	-
Biotite schist	CA14	-	-	-
Quartz-muscovite schist	CA14F	-	-	5.1
(d) Clayey quartzite	1049B	-	.001	1.9
Banded quartzite	1013A	-	.001	-
Feldspathic quartzite	CA227A	-	.001	trace
Fine banded quartzite	CA120	-	-	trace
Quartz siltstone	CA1151	-	.0009	-
Nanambu Complex				
Muscovite-quartz-feldspar gneiss	CA80	-	.002	trace
Muscovite leucogneiss	CA194	trace	.0004	1.9

Nanambu Complex	Field No.	percent eU	percent eTH	percent eK
Granitoid rock; foliated	CA212	trace	.0011	1.6
"	CA179I	trace	.0009	2.1
"	CA202	trace	trace	1.4
" chloritized	CA215	-	.0007	2.5
" altered	CA49	-	.0025	1.13
Syenite	CA179K	trace	.0020	3.0
Basic Intrusive				
Dolerite	CA30B	trace	trace	0.6
"	CA222	trace	.0014	1.0
Acid Volcanics				
Rhyolite	CA69F	trace	.0021	1.5

All measurable eU occurs in Lower Proterozoic schists. All the Lower Proterozoic units show low variable (or lack of) eTH and eK values.

The Nanambu Complex generally displays a trace of eU, an eTH content up to .0025%, and a relatively high eK content, consistent with rocks which have undergone potash metasomatism.

All those samples containing measureable eU fall along the strike of Ranger 1 and Pan Continental's prospects 7E and 7J. Samples CA1096, CA1096A, CA1096G are from the vicinity of 7E; CA1058 is from the BMR anomaly half way along an arc between prospects 7E and 7J; CA1008C is from the base of the escarpment directly south of Ranger 1; CA1014 is from southeast of Ranger 1 below the escarpment.

Twenty-four bottom-hole samples from auger holes showing anomalous (more than x 3 background) down-hole radioactivity were submitted for gamma-ray spectrometry. All yielded .0010 to .0050% eTH and 1.4 to 3.7% eK. Six contained a trace of eU and one sample, T4/28, taken along the strike from Ranger 1 at the A.P. boundary between the Geopeko and Pan Continental leases, contained .0019% e U. The remaining samples did not contain measurable uranium.

One sample of anomalous black humic soil (from the headwaters of Baroalba Creek) assayed 0.01% eU with a trace of eTH.

ACKNOWLEDGMENTS

We would like to thank the staff of the following companies for their assistance and hospitality during the field season. Geopeko Ltd, Pan Continental Ltd, Noranda Australia Ltd, Australia and New Zealand Exploration, and Queensland Mines Ltd.

We thank especially the field geologists of those companies, who helped us immensely by providing access and outcrop information, and by entering into many discussions concerning the detailed and regional geological aspects of the Alligator River uranium province.

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APPENDIX 1

ABREVIATIONS USED ON MAPS AND IN APPENDIX 2.

a	arkose
am, b/a	basic amphibolite
b	biotite
bif	banded ironstone
c	carbonaceous
chl	chlorite
cgl	conglomerate
dol	dolomite
dolr	dolerite
f	feldspar
fer	ferruginous
g	graphite
gi	griesen
gn	gneiss, gneissic
gr	granite, granitic
h, hem	hematite, hematitic
l	leucocratic
lat	laterite
lgn	leucogneiss
m, mic	mica, micaceous
mps	metapsammite
mqt	metaquartzite
ma	metaarkose
mig	migmatite
mu	muscovite
myl	mylonite, mylonitised

peg	pegmatite
ps	psammite, psammitic
ph	phonolite
q	quartz
qb	quartz breccia
qt, qzit	quartzite
sch	schist, schistose
sd	silicified dolomite
se	silicified sediment
ser	sericite
serp	serpentinite
sil	silicified
sy	syenite
sl	slate
slts	siltstone
sst	sandstone
w, weath	weathered
bdd	bedded
bndd	banded

ABBREVIATIONS USED IN APPENDIX 2 ONLY

c	coarse-grained
m	medium-grained
f	fine-grained
T.D.	total hole depth
T.P.D.	total probe depth
cps	radioactivity in counts per second
*	bottom-hole sample submitted for gamma-ray spectrometry.

APPENDIX 2

AUGER DRILLING DATA

Traverse 1

Origin: Jim Jim Crossing NE along the Oenpelli Road to Mount Cahill.

Spacing: 0.4 km (1/4 mile)

Hole No.	Depth (m)	Lithology	Max. Rad. (cps)	Depth Max. Rad. (m)	Remarks
1	24.4	chl m sch, clay	30	0.6	
2	24.7	"	50	3.7	
3	23.2	chl q m sch	55	1.2	? some porcellaneou carbonate.
4	7.9	m q rock	60	7.9	max. rad. at T.D.
5	6.7	m q gn	90	4.3	* 80 cps at T.P.D.
6	14.0	dolr	38	0.6	
7	13.7	m q gn	52	9.1	
8	8.2	m q gn, sch	46	6.1	
9	4.6	c q f lgn, m sch	68	3.0	*
10	4.9	mu q gn, m sch	90	3.0	*
11	5.5	q mu sch	110	4.3	* max. rad. at T.P.D
12	13.4	chl m q sch	50	4.9	
13	11.0	q f gn, sch	54	7.9	
14	7.0	chl mu sch, q sch	38	1.8	
15	6.1	q f gn, some m	52	4.6	max. rad. at T.P.D.
16	7.3	chl mu sch	42	5.5	max. rad. at T.P.D.
17	6.1	m q ?kaolin rock	42	2.4	
18	8.2	m/q f gn, m sch	40	2.4	
19	14.3	am	30	3.7	

20	8.2	chl m sch	40	2.4	
21	4.6	mu q sch, b sch	72	2.4	*
22	12.8	b q sch	78	5.5	* 70 cps at T.P.D.
23	15.2	q mu b f gn & sch	52	4.3	
24	9.4	"	64	4.9	q augen
25	12.2	"	62	1.8	
26	5.2	mu q f sch	42	0.6	
27	11.6	c̲ q f gn	82	5.5	* f crystals/1.5 cm 68 cps at T.P.D.
28	10.4	c̲ m q f gn	72	4.9	* max. rad. at T.P.D.
29	5.8	granular f q rock	52	3.0	feldspathic qzite?
30	13.4	q f sch rock	64	3.7	
31	7.0	mu f sch	50	4.9	
32	22.9	chl m sch	38	18.2	
33	12.9	mu b q f sch, shaly	not probed		
34	6.1	mu sch, clayey	probe faulty		
35	19.9	m chl q shale	"		
36	3.7	hem qzite & siltstone	"		
37	6.1	clayey sst, qzite	"		
38	25.3	?mu chl q shale	"		
39	25.3	chl mu q slate	"		
40	23.5	q chl m shale	"		
41	11.9	q mu sch, qzite bands	"		

<u>Traverse 2</u>

Origin: 11 km northeast of Koongarra, adjacent to Kombolgie escarpment; SE across valley.

Spacing: 160 metres (0.1 miles)

Hole No.	Depth (m)	Lithology	Max. Rad. (cps)	Depth Max. Rad. (m)	Remarks
1	19.2	mu b sch	38	4.6	max. rad. at T.P.D
2	17.9	m sch	30	3.0	
3	19.5	?chl mu sch	30	4.9	
4	14.6	"	18	4.3	max. rad. at T.P.D.
5	15.2	mu clay	22	2.4	
6	13.4	mu mud	28	0	
7	19.2	"	16	2.4	max. rad. at T.P.D.
8	12.2	mu sch	12	1.8	"
9	14.3	"	20	1.8	"
10	11.0	chl sch, q bands	14	3.0	"
11	13.4	chl sch	18	1.8	"
12	1.2	mu sch	20	3.7	"
13	9.1	q b sch	20	4.9	"
14	10.7	chl sch	30	1.8	"
15	18.3	chl sch, ?c q sch	30	1.2	
16	18.9	chl b sch, c mu rock	40	2.4	
17	14.3	q mu sch	50	5.5	* 30 cps at T.P.D.
18	20.1	am mu sch	50	6.1	* 40 cps at T.P.D.
19	18.6	chl mu sch	46	6.1	* 38 cps at T.P.D.
20	14.6	q ?chl mu sch	30	0.6	
21	13.4	q ?mu sch	36	0.6	
22	21.6	am mu sch, b sch	46	3.7	38 cps at T.P.D.
23	14.3	q m sch	46	1.8	
24	18.3	q chl mu sch	44	3.0	32 cps at T.P.D.
25	23.5	chl mu sch	44	4.9	* max. rad. at T.P.
26	11.0	q mu sch	48	1.2	* 42 cps at T.P.D.

27	17.4	q m sch	50	4.3	*
28	13.1	mu sch, some ?b f sch	48	8.6	*
29	10.7	?chl sch	30	1.8	
30	19.8	chl ?mu sch	32	4.3	values increase with depth
31	6.1	q sand & silt	32	1.8	
32	15.8	hem ?chl sch	38	2.4	
33	4.6	fer sand & silt	32	2.7	values increase with depth
34	16.2	hem mu sch	44	4.9	values decrease with depth
35	10.7	chl sch	22	0.6	
36	17.7	m sand	40	7.3	values increase with depth
37	12.5	mu sch	35	6.4	
38	18.0	q mu sch	38	3.7	
39	19.2	"	50	7.9	*
40	19.8	"	50	10.4	* 28 cps at T.P.D.
41	14.3	mu mud	40	4.9	
42	21.6	mu sch	45	1.8	25 cps at T.P.D.
43	13.1	m q chl sch	30	4.3	
44	13.4	q m sch	28	3.7	

Traverse 3

Origin: billabong (with island) on Nourlangie Creek, 11 km SE of Koongarra; NE for 3 km

Spacing: 0.4 km (1/4 mile)

Hole No.	Depth (m)	Lithology	Max. rad. (cps)	Depth Max. Rad. (m)	Remarks
1	8.5	c q sand	40	1.2	
2	7.0	c q sand, hem clay	26	2.4	
3	7.6	c q sand, hem clay	24	1.8	

63

4	6.1	"	30	3.6	max. rad. at T.P.D
5	7.3	"	30	5.5	"
6	5.5	"	40	2.4	
7	6.4	"	20	3.7	max. rad. at T.P.D
8	4.6	"	22	3.0	"

Traverse 4/5 - Traverse 4

Origin: Intersection of Pan Continental/Geopeko lease boundary and Kombolgie escarpment, east of Mudginberri Homestead; WSW along boundary, (T4) then W to Magela Creek (T5).

Spacing: 160 m (0.1 miles)

Hole No.	Depth (m)	Lithology	Max. Rad. (cps)	Depth Max. Rad. (m)	Remarks
1	18.6	q m sch	60	12.2	
2	15.8	sch	24	1.2	
3	7.3	q m sch	22	0	
4	7.3	"	28	1.8	
5	16.5	q chl sch	34	1.2	values decrease with depth
6	15.2	q chl m sch	22	1.2	
7	14.6	sch	28	1.5	
8	19.8	m sch	38	6.1	
9	12.2	q m sch	44	0.6	
10	18.3	"	45	1.2	
11	12.8	" some chl	32	2.4	
12	12.8	q chl sch	40	3.7	
13	8.5	"	20	1.2	
14	5.8	" some f	20	3.7	
15	7.0	q m sch	30	3.7	values increase with depth

16	4.3	lat	25	1.5	
17	10.8	m sch, some q	28	4.3	
18	10.1	?chl m sch	44	3.0	
19	12.8	m am sch	50	1.8	
20	11.6	sch	24	0.6	possibly serpentinite
21	11.9	q chl ser sch, some f	32	1.8	
22	18.0	q chl sch	42	1.2	
23	3.7	"	42	1.8	
24	12.2	"	40	4.3	
25	3.0	sil & fer dol	42	1.8	
26	7.3	q m sch	38	4.0	values increase with depth
27	8.5	q ?chl m sch	60	1.8	*
28	4.6	lat, q	68	21.	*
29	13.7	q chl m ?ser sch	50	6.7	* values increase with depth; some epidote?
30	18.9	chl sch	100	6.1	*
31	14.3	q chl sch, dol	52	0.6	*
32	10.7	q ser sch, dol	45	3.7	* values decrease with depth
33	12.8	dol; green weath rock	50	6.7	*

Traverse 4/5 - Traverse 5

Hole No.	Depth (m)	Lithology	Max Rad. (cps)	Depth Max. Rad. (m)	Remarks
1	3.0	lat	24	0.9	max. rad. at T.P.D.
2	6.1	q ser sch, ?gn	42	4.2	"
3	11.0	"	32	2.4	
4	7.3	q b chl sch	40	1.2	
5	9.1	q m clay ?gn	30	4.9	max. rad. at T.P.D.; clay=weath f?

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6	12.8	q clay ser ?gn	40	1.8	values decrease with depth
7	8.8	q mu clay ?gn	40	0.6	
8	14.6	q m sch, gn; some ser & chl	40	1.2	
9	9.1	q clay m gn	38	0.6	
10	7.3	weath gn	48	4.3	
11	7.3	"	48	0.6	
12	8.5	"	40	2.4	
13	9.1	"	44	2.4	

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PLATE 1

Reference

CAINOZOIC	QUATERNARY		Qca	*Silt, mud, coastal alluvia*
			Qcp	*Coastal mud pans*
			Qcr	*Coastal sand ridges*
			Qa	*Silt, clay, sand: alluvium*
			Qs	*Unconsolidated alluvial sand: outwash and colluvial deposits*
			Qas	*Silt, clay: abandoned channel deposits*
			Qal	*Silt: levee deposits*
			Qf	*Black humic soil and clay deposits*
			Czt	*Sandstone boulders; sandstone and schist rubble, sand: talus deposits*
			Lat	*Laterite*
			Cza	*Sand, clay: partially stripped Czs*
			Czs	*Unconsolidated sand, clayey sand*
MESOZOIC	CRETACEOUS	Mullaman Beds	Klm	*Sandstone ferruginous sandstone, siltstone, basal conglomerate, radiolarian chert*
PROTEROZOIC	CARPENTARIAN	Kombolgie Formation: Upper Kombolgie Sandstone	Ehk$_2$	*Massive quartz sandstone, quartz greywacke, minor siltstone*
		Kombolgie Formation: Nungbalgarri Volcanic Member	Ehn	*Fine to medium basalt, amygdaloidal basalt*
		Kombolgie Formation: Lower Kombolgie Sandstone	Ehk$_1$	*Massive quartz sandstone, quartz greywacke, minor siltstone conglomerate, hematitic sandstone and brown ferruginous sandstone*
		Edith River Volcanics	Ehe	*Acid volcanics; rhyolite?*
			Edo$_2$	*Phonolite dykes: post deformation*
	LOWER PROTEROZOIC	Nanambu Complex	Nac	*Migmatite, leucogneiss with thin soil cover*
		Nanambu Complex	Na	*Migmatite, leucogneiss, gneissic granite, augen gneiss, schist, basic amphibolite, quartzite*
			Edo$_1$	*Dolerite, diorite, syenite and differentiates: pre deformation*
		South Alligator Group: Fisher Creek Siltstone	Els	*Quartz mica schist, chlorite mica schist, amphibole schist, garnet schist, Quartz sericite phyllite and minor quartzite bands*
		South Alligator Group: Koolpin Formation	Elq	*Quartzite, micaceous quartzite, banded hematitic quartzite some conglomerate and schist*
			Else	*Silicified sediments*
			Elsd	*Silicified dolomite*
			Elw	*Quartzite*
		Goodparla Group: Mount Partridge Formation	Ela	*Pink, grey and yellow arkose, sometimes micaceous*
			Elc	*Schist, arkose, quartzite, with thin soil cover*
			El	*Undivided quartzite and schist*

Geological boundary
Anticline, showing plunge
Syncline
Where location of boundaries and folds is approximate, line is broken, where inferred, boundaries and folds are queried, where concealed line is dotted
Plunge of minor syncline
F.A. *Plunge of fold axes*
Dome
Fault, showing relative horizontal movement
U D *Fault (D, U indicate relative movement down, up)*
Low angle reverse fault (T, indicates upper plate)
Fault with slickenside
Where location of fault is approximate line is broken where inferred faults are queried, where concealed faults are shown by short dashes
qb *Fault containing brecciated quartz or silicified sediments*
Fault zone
35 *Strike and dip of strata*
Prevailing strike and dip of strata
Prevailing strike and dip of strata, facing not known
Vertical strata
30 50 *Curving dip*
5 *Dip slope*
Dip 5°-15°
Dip 15°-45°
Trend line — *Air-photo interpretation*
L L *Lineament*
Joint pattern
20 *Prevailing dip of strongly deformed strata*
30 *Generalised strike and dip of undulating strata*
Prevailing strike and dip of joint
25 *Strike and dip of foliation*
Prevailing strike and dip of foliation
Vertical foliation
55 35 *Foliation with plunge of lineation (crenulation)*
Foliation with plunge of lineation (undifferentiated)
Foliation with horizontal lineation (crenulation)
30 *Strike and dip of cleavage*
Prevailing strike and dip of cleavage
Vertical cleavage
42 65 *Strike of bedding and cleavage coincident*
40 *Strike and dip of bedding with vertical cleavage*

Direction of sedimentation 'x' denotes cross bedding 'r' denotes ripplemark
Direction of sedimentation, sense unknown
q *Quartz vein*
Direction of shearing
Prospect
Mine, scheduled for production at present under evaluation
Cu *Copper*
U *Uranium*
Bore
W.H. *Water hole*
Spring
Waterfall on stream
Escarpment
Road and vehicle track
Landing ground
"Potonga" H.S. *Homestead*
Building
Fence
Trigonometrical station
22 *Photo centre point*
Aboriginal Reserve boundary
Extent of auger traverse

SCALE 1: 50000
0 1 2 3 4 5 km
0 1 2 3 miles

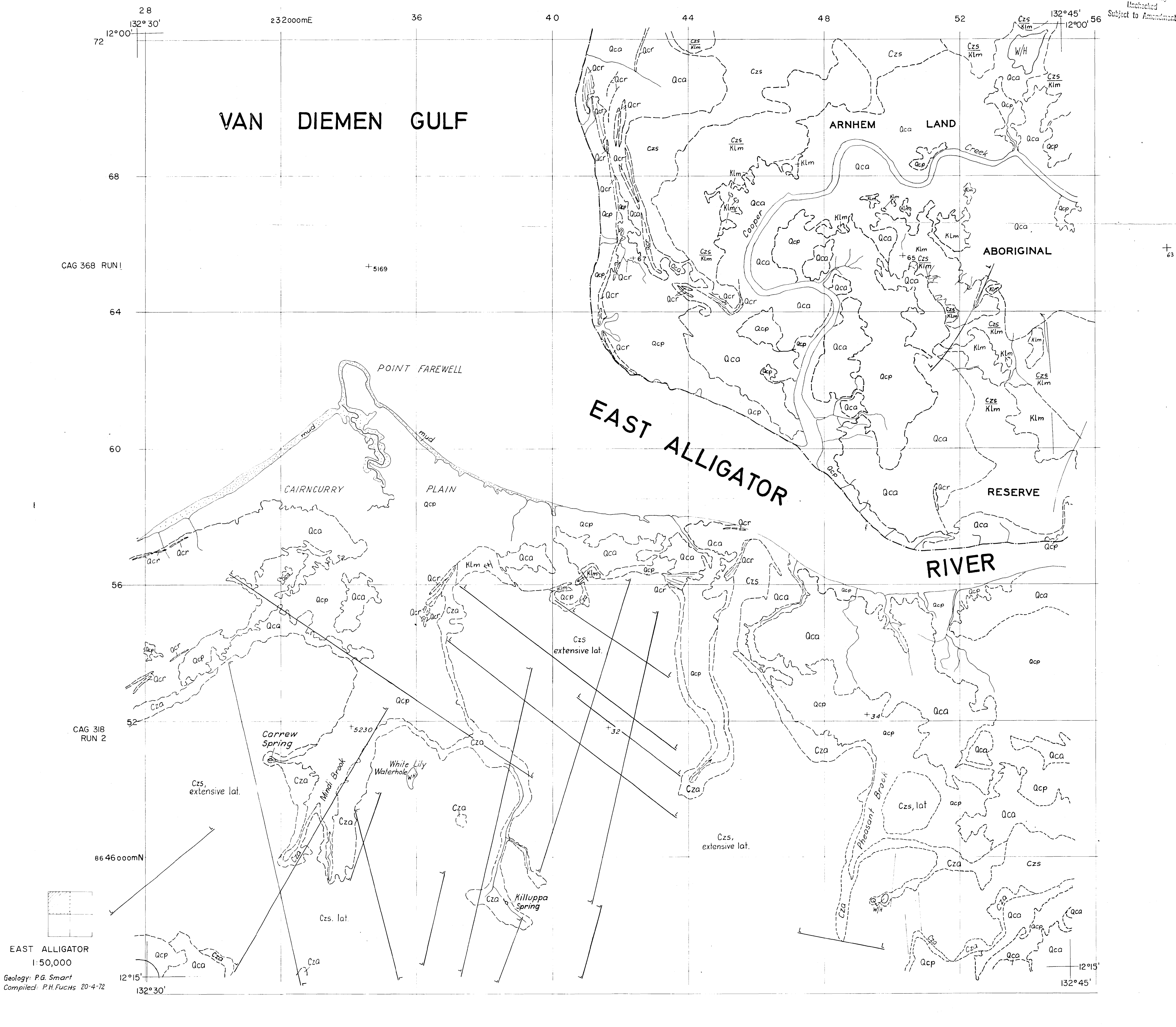
IV		I
	EAST ALLIGATOR 5473	
III		II
IV		I
	CAHILL 5472	
III		II

1:100000 SHEET AREA

EAST ALLIGATOR AND CAHILL 1:100000 SHEET AREAS NORTHERN TERRITORY

Record 1972/1

PLATE 2



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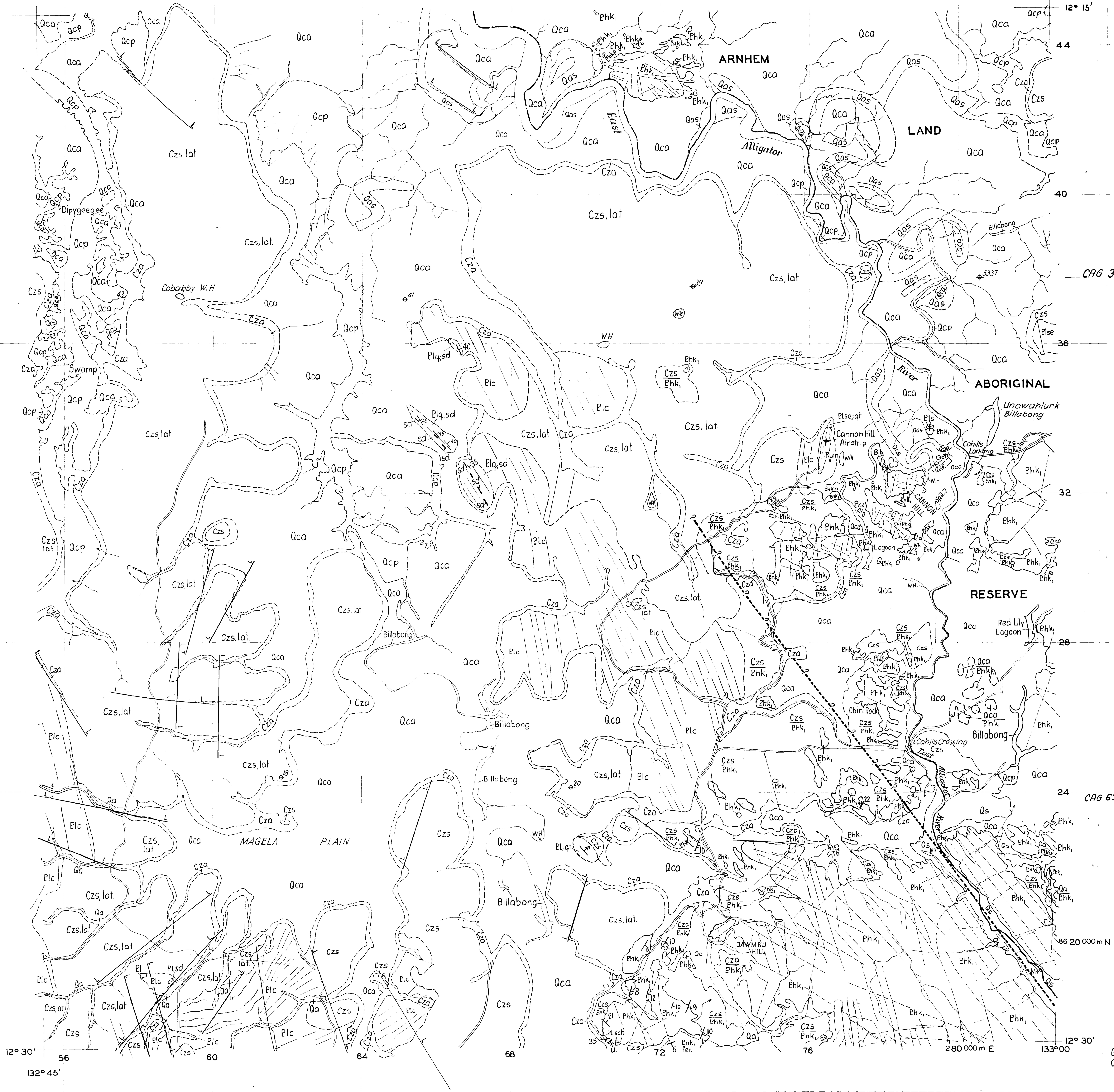
Unchecked
Subject to Amendment
VAN DIEMEN GULF
ARNHEM LAND
ABORIGINAL
RESERVE
EAST ALLIGATOR RIVER
POINT FAREWELL
CAIRNCURRY PLAIN
Cooper Creek
Carrew Spring
Mindi Brook
White Lily Waterhole
Killuppa Spring
Pheasant Brook
mud
Czs, extensive lat.
Czs extensive lat.
Czs. lat.
Czs, lat
Qca
Qcp
Qcr
Czs
Cza
Klm
Czs/Klm
W/H
CAG 368 RUN 1
CAG 318 RUN 2
232000mE
8646000mN
132° 30'
132° 45'
12° 00'
12° 15'
EAST ALLIGATOR
1:50,000
Geology: P.G. Smart
Compiled: P.H. Fuchs 20-4-72

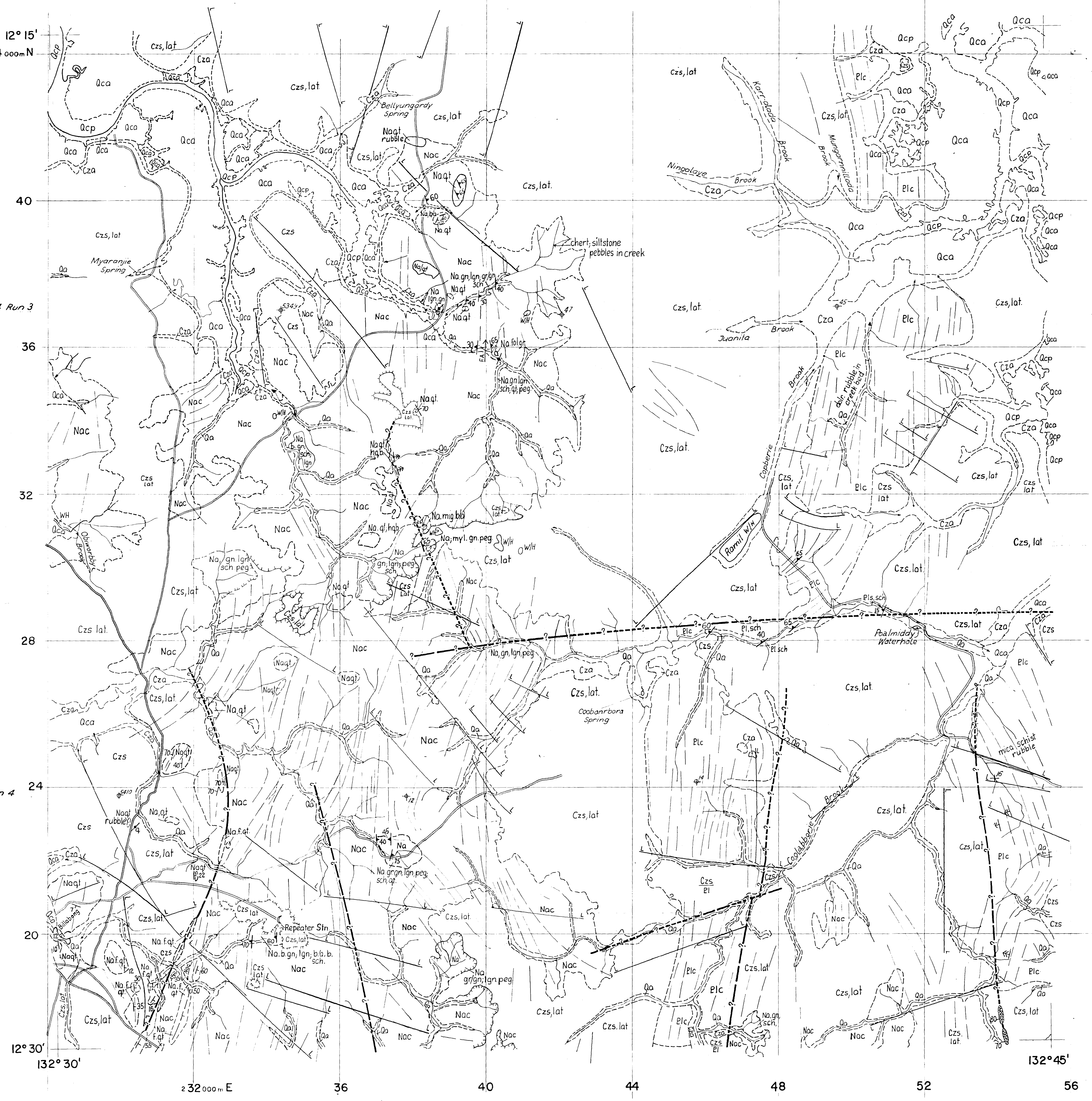
PLATE 3



EAST ALLIGATOR
1:50 000

Geology: P.G. Smart
Compiled: P.H. Fuchs 19-5-72

PLATE 4



EAST ALLIGATOR
1:50 000

Geology: P.G. Smart
Compiled: P.H. Fuchs 15-5-72

PLATE 5

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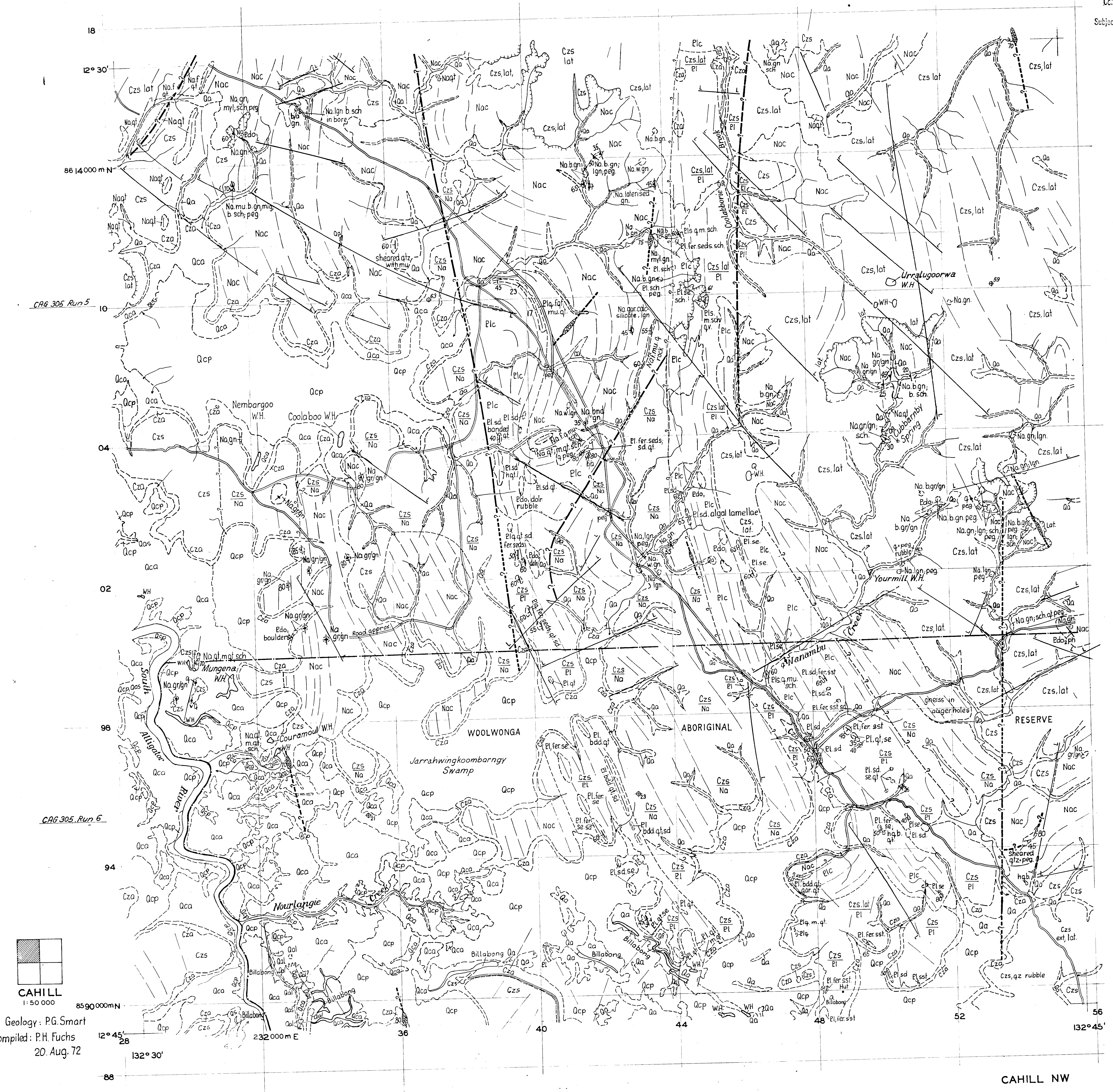

CAHILL NW

41

Original

PLATE 6

CAHILL
1:50 000

Geology: P.G. Smart
Compiled: P.H. Fuchs
20. Aug. 72

Original

42

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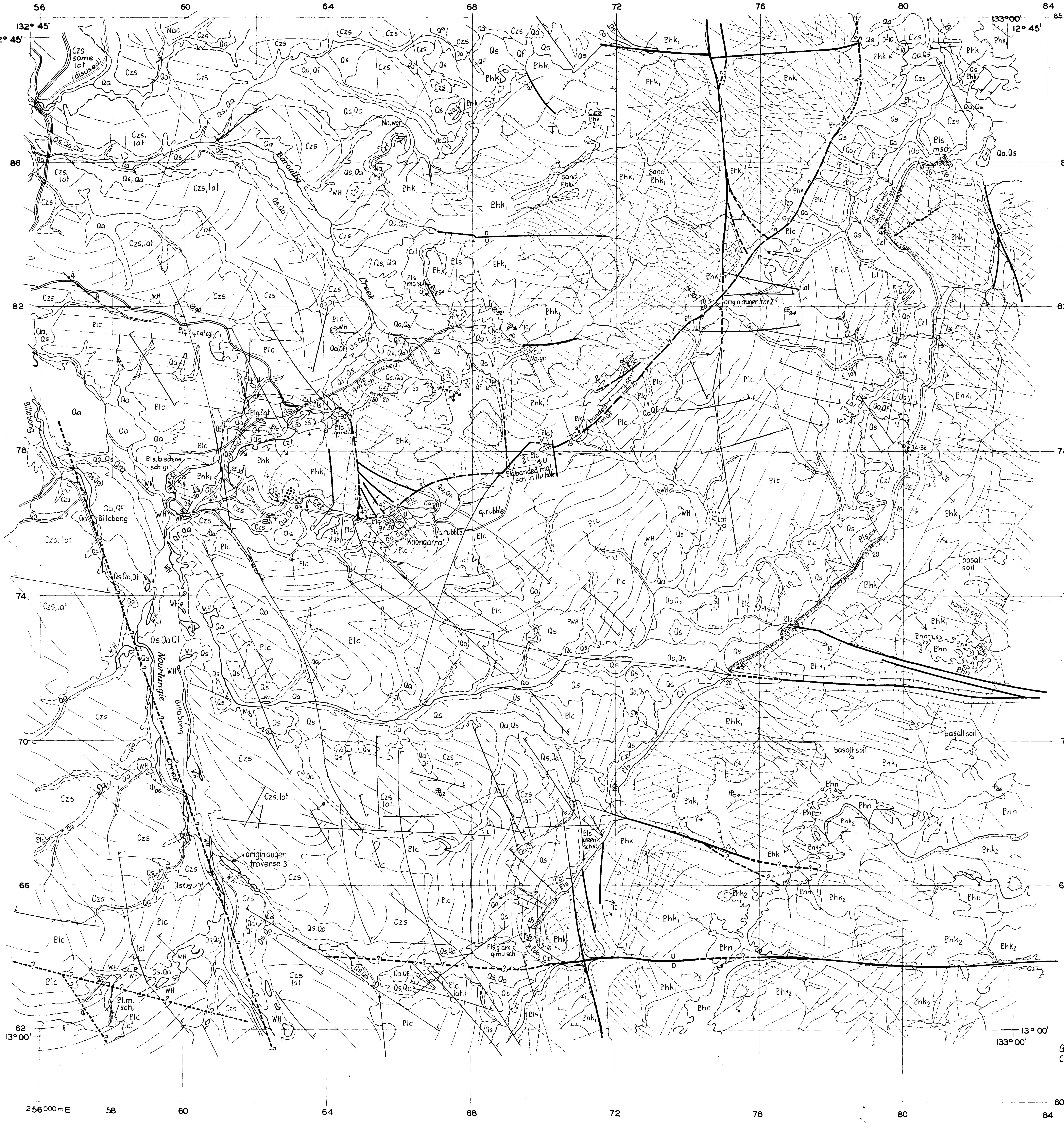
PLATE 7

CAG 306 Run 7

CAG 307 Run 8



CAHILL
1:50 000

Geology: R.S. Needham
Compiled: P.H. Fuchs 10-5-72

Camb

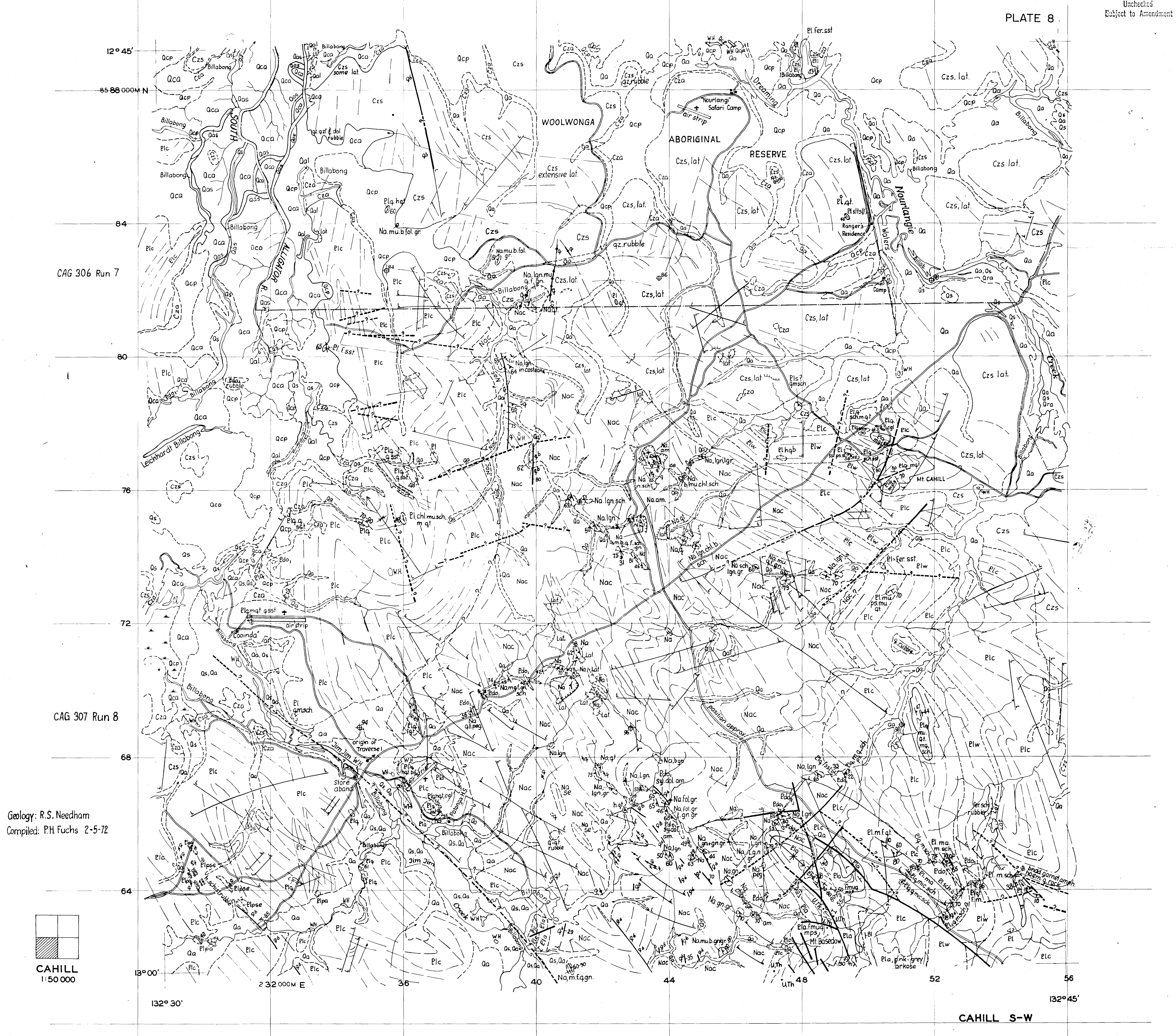


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PLATE 8
12° 45'
85 88 000M N
WOOLWONGA
ABORIGINAL
RESERVE
"Nourlangi" Safari Camp
air strip
SOUTH
ALLIGATOR R.
Nourlangie
Creek
Dreaming
Waters
Ranger's Residence
Camp
Leichhardt Billabong
Billabong
Mt. CAHILL
"Cooinda"
air strip
Jim Jim W.H.
origin of Traverse I
Store aband.
Jim Jim
Creek
Mt. Basedow
position approx.
CAG 306 Run 7
CAG 307 Run 8
84
80
76
72
68
64
13° 00'
2 32 000M E
36
40
44
48
52
56
132° 30'
132° 45'
Geology: R.S. Needham
Compiled: P.H Fuchs 2-5-72
CAHILL
1:50 000
CAHILL S-W
Canb.