AUSTRALIA

1:100 000 GEOLOGICAL MAP COMMENTARY

EAST ALLIGATOR

NORTHERN TERRITORY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

DEPARTMENT OF NATIONAL DEVELOPMENT AND ENERGY

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R.S. NEEDHAM

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INTRODUCTION

EAST ALLIGATOR* (Sheet 5473) covers the area between latitudes 12°00′ and 12°30′S and longitudes 132°30′ and 133° E, centred 210 km east of Darwin (Fig. 1). It contains the major Jabiluka uranium deposit at its southern edge, and part of the Kakadu National Park, an area of diverse scenery, wildlife, and native flora, containing many important archaeological sites, several of which include examples of Aboriginal art.

Geological fieldwork took place in 1971–72 and has been described in unpublished BMR Records by Needham & Smart (1972) and Needham & others (1975).

Settlement is very sparse: the 'Border Store' near Cahills Crossing in the southeast and the nearby Kakadu National Park headquarters (not shown on the map) are the only permanent buildings. Temporary structures include demountable rangers' camps and, from time to time, exploration company camps. The permanent population is less than 50. In CAHILL, to the south, a mining town, Jabiru, is being built near the crossroads of the Arnhem Highway and Oenpelli road, to service the Ranger uranium mine and any other mines, including Jabiluka, that may be developed in the vicinity.

Climate, physiography, vegetation, soils

The climate is monsoonal, with an average annual rainfall at Oenpelli (10 km to the east) of 1350 mm; the wet season lasts from November to March. Mean maximum and minimum temperatures in October, the hottest month, are 38°C and 22°C respectively, and in June and July, the coolest months, are 32°C and 18°C. Mean annual evaporation is about 2200 mm. The climatological and physical features of the region, and the fauna and flora, are summarised by Christian & Aldrich (1977). The three major physiographic divisions (Fig. 1) are (1) the Lowlands, dominated by an undulating plain of Cainozoic sand (the 'Koolpinyah Surface' of Story & others, 1969) and laterite; (2) the Floodplains, consisting of Quaternary estuarine and alluvial deposits; and (3) the Arnhem Land Plateau, developed on subhorizontal Carpentarian sandstone.

The Lowlands extend over more than half the Sheet area. Eucalypt-dominant woodland and tall open forests are common, but savannah and grassland, scrub, and paperbark communities fringing watercourses reflect a wide variety and depth of soils. Much of the vegetation is burnt annually.

The Floodplains are extensive along the coast and major rivers, and extend along tributaries for up to 30 km from the East Alligator River, where they may contain perennial swamplands, such as the Magela Plain and Didygeegee Swamp. Soils are mostly impermeable clays with thin bands of lighter soils. Vegetation type indicates the duration of flooding: sedges dominate areas that are flooded for periods of between two and six months, and herbaceous swamp vegetation covers areas wet for between six and nine months. Some permanently wet areas carry almost pure stands of paperbark, and various *Pandanus* and freshwater mangrove communities fringe lagoons and occupy perched aquifers in the plains.

The Arnhem Land Plateau rises 100 m above sea level in the northeast, and 200 m in the southeast; it is dissected into many small low mesas adjacent to the Floodplains. The plateau supports mainly heath-like shrubs and spinifex on shallow soils, and sandstone woodland and tall open forest dominated by evergreen eucalypts on deeper soils. Rainforest grows in deeply dissected parts and along the escarpment where permanent springs are tapped; these areas support specialised biological habitats and the region's greatest variety of plants and wildlife.

History of investigations

Geological surveys covering the area are summarised by Needham & others (1973b). EAST ALLIGATOR was mapped as part of a BMR reconnaissance geological survey of the Katherine-Darwin region in the 1950s (Dunn, 1962; Walpole & others, 1968), but received little further attention until the late 1960s, when prospecting for uranium began. Radiometric anomalies that led to the discovery of the Ranger 1 and Koongarra uranium deposits in CAHILL were detected by airborne surveys in 1969, and ground investigations in 1970 indicated the probability of substantial mineralisation (Eupene & others, 1975; Foy & Pedersen, 1975). Jabiluka 1 was discovered in 1971 by ground reconnaissance; Jabiluka 2 was found in 1973 during drilling of favourable host rocks along strike beneath the covering sandstone of the Kombolgie Formation (Rowntree & Mosher, 1975).

Following the first announcement of the discovery of uranium mineralisation in the Alligator Rivers region in 1970, BMR began a semi-detailed (1:100 000-scale) investigation of the area, which later became known as the Alligator Rivers Uranium Field. Because of the generally poor exposure of the Archaean to Early Proterozoic units, the fieldwork included a program of shallow core-drilling to reach fresh bedrock; the drillhole locations and the bedrock types encountered are plotted on the map. Later work in surrounding areas has helped to establish the stratigraphy of some units which extend into EAST ALLIGATOR

* The names of 1:100 000 Sheet areas are printed in capitals.

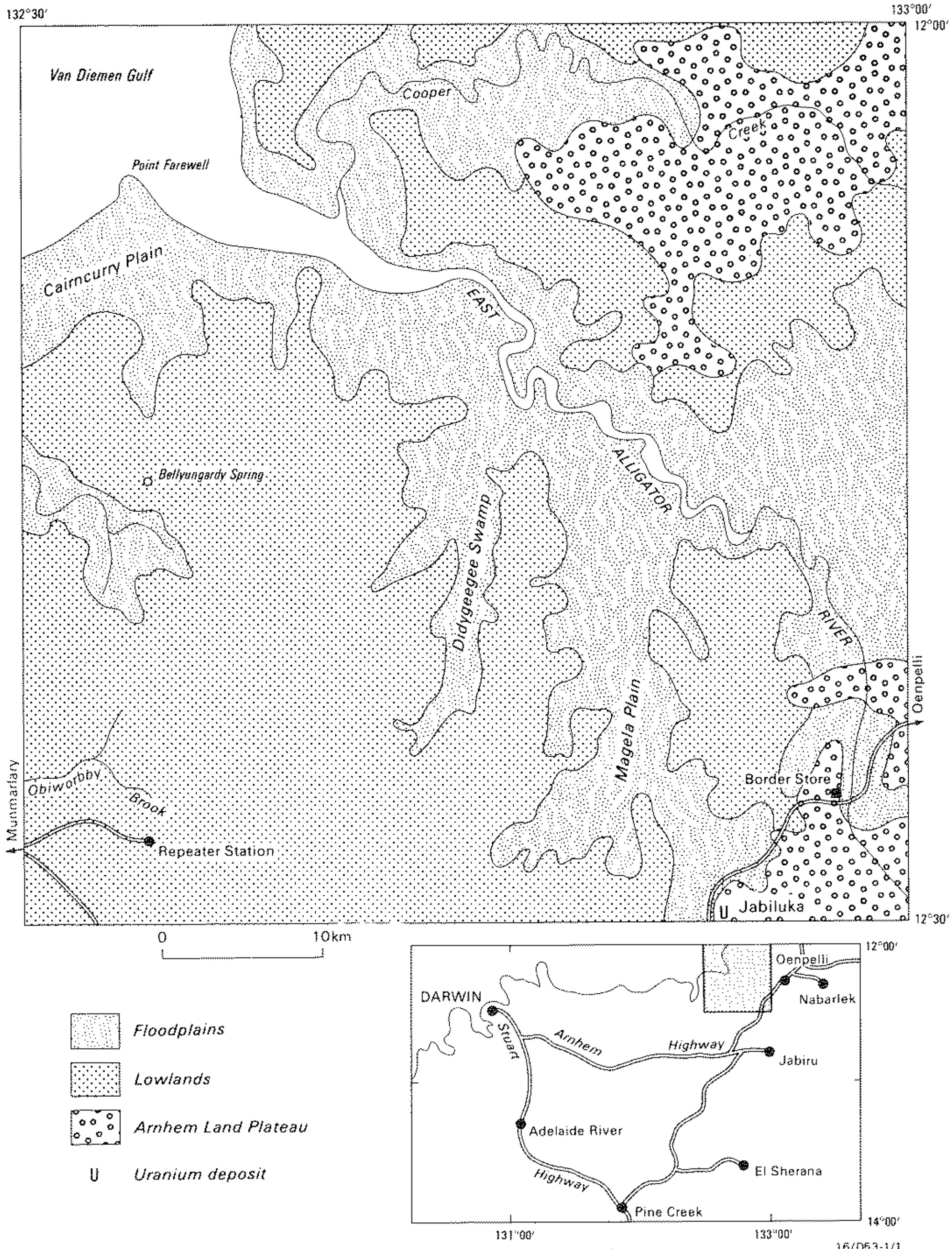

Fig. 1 Location and physiography

(Stuart-Smith & Hone, 1975; Stuart-Smith, 1977). An airborne magnetic and gamma-ray spectrometer survey of the Alligator Rivers region was flown by BMR in 1971–2 (Horsfall & Wilkes, 1975), and most of EAST ALLIGATOR has been covered by more detailed airborne and ground geophysical work by exploration companies. A Preliminary (uncoloured) Edition of the EAST ALLIGATOR geological map was issued in 1974.

Acknowledgements

P.G. Smart did most of the fieldwork on which this map and commentary are based. Pancontinental Mining Ltd, Geopeko Ltd, Esso Minerals Ltd,

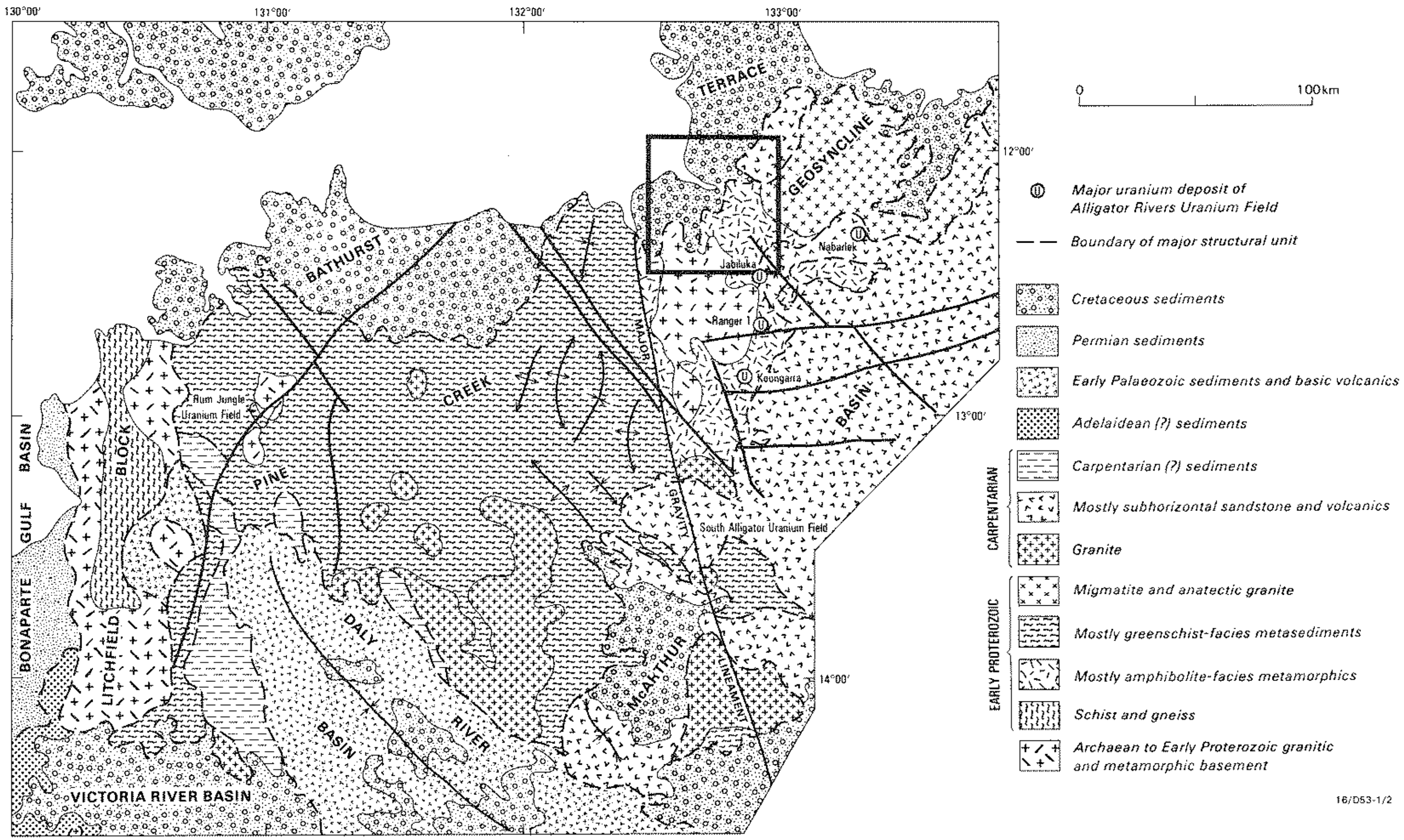

Fig. 2 Regional setting of the EAST ALLIGATOR Sheet area in the Pine Creek Geosyncline.

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The figures were drawn by L. Hollands

REGIONAL SETTING

EAST ALLIGATOR is in the Alligator Rivers Uranium Field in the northeastern part of the Pine Creek Geosyncline (Fig. 2). The geosyncline contains Early Proterozoic metasedimentary rocks (with local volcanics) resting on a gneissic and granitic Archaean basement which is exposed in the west in the Rum Jungle area and in the northeast in CAHILL and EAST ALLIGATOR. The metasediments have a preserved aggregate thickness of up to 14 km (Needham & others, 1980); between 1870 and 1800 m.y. ago the sequence was folded, and was metamorphosed to the greenschist facies in most areas and to the amphibolite facies in the Alligator Rivers Uranium Field; in the extreme northeast of the geosyncline the metasediments are locally migmatised. The low-grade Early Proterozoic metasediments are mainly shale, siltstone, slate, sandstone, conglomerate, carbonate rock, and greywacke, and the pelitic rocks are commonly carbonaceous; the medium-grade (amphibolite facies) rocks are schist and gneiss. These Early Proterozoic strata are extensively intruded by pre-tectonic dolerite sills, and by post-tectonic granite plutons and dolerite lopoliths and dykes; a syntectonic granite intrudes in the extreme northeast. Younger, mainly sandstone, units of Carpentarian, Adelaidean, and Cretaceous age rest on these rocks with marked unconformity.

STRATIGRAPHY

The stratigraphy is summarised in Table 1.

The oldest rocks belong to the Archaean to Early Proterozoic Nanambu Complex, which forms scattered small exposures in the southwest. In the west, Early Proterozoic gneiss of the complex grades into the Munmarlary Quartzite of the Kakadu Group, the earliest sequence of recognisable sedimentary rocks. The Cahill Formation overlies the Kakadu Group, and in places appears to rest directly on the Nanambu Complex. The Cahill Formation consists principally of quartzofeldspathic and micaceous schists which, near the base, are carbonaceous and interbedded with carbonate rocks. The Nourlangie Schist, a monotonous sequence of quartz schist, overlies the Cahill Formation in the east. Some partly ferruginous and siliceous rocks near Cannon Hill in the southeast are possible equivalents of the Koolpin Formation, and carbonaceous schist and phyllite in the northeast are possible equivalents of the Koolpin Formation or Fisher Creek Siltstone. All of these units grade into banded schist and gneiss of the Myra Falls Metamorphics in the northeast; in addition, they are intruded by predeformation Zamu Dolerite, as mainly sill-like bodies of amphibolite but possibly as dyke-like bodies in the Nanambu Complex. The post-tectonic Oenpelli Dolerite intrudes most of the metasedimentary units as broadly concordant bodies west of the East Alligator River, and as an extensive undulating sheet northeast of the river. Carpentarian plateau-forming sandstone of the Kombolgie Formation rests with marked regional unconformity on all older rocks, and Cretaceous sandstone, siltstone, and conglomerate commonly underlie Cainozoic sand plains throughout the area, and form small scattered mesas.

Exposure of the Archaean to Early Proterozoic rocks is sparse, and generally rocks are weathered to depths between 10 and 100 m. An early Tertiary laterite profile and a blanket of Cainozoic sand cover most of the lowland area. Outcrops are found mostly in the footslope to the Arnhem Land escarpment, in incised banks and actively eroding headwaters of creeks, and as small pavements near the edges of drainage flats and floodplains.

ARCHAEAN TO EARLY PROTEROZOIC

NANAMBU COMPLEX

Basement gneiss, granite, and schist form a mantled gneiss dome that occupies much of the southwest half of the Sheet area. The name 'Nanambu Granite' was used by Condon & Walpole (1955) and Dunn (1962) to describe gneissic and garnetiferous granite in CAHILL to the south; Needham & Smart (1972) modified the name to reflect the presence of a range of granitic and metamorphic rock types, and the definition was given by Needham & Stuart-Smith (1980). In EAST ALLIGATOR the complex crops out sporadically south from Bellyungardy Spring (428370). Geochronological studies (Page & others, 1980) have obtained ages of 2470–2400 and 1800 m.y., indicating formation in the late Archaean and the late Early Proterozoic. The 2470–2400 m.y. age is thought to represent the age of emplacement of the granite complex, wheras 1800 m.y. is the age of regional metamorphism of the Early Proterozoic sediments and of the accretion of arkosic basal members onto the Archaean granite of the complex (intermediate isotopic ages, e.g. 1980 and 1880 m.y., are interpreted by Page & others to represent incomplete isotopic homogenisation during the 1800-m.y. regional metamorphism). Rocks of the complex are subdivided on the basis of age and lithology into unmetamorphosed Archaean granite (An — not known in EAST ALLIGATOR), metamorphosed Archaean granite (APna — now mainly gneiss), and Early Proterozoic pegmatoid leucogneiss, schist, and migmatite (APnp). For the most part, however, rock exposure is too sparse to enable the complex to be subdivided, and large areas are mapped as APn — undivided Nanambu Complex.

The *gneiss and foliated granite sub-unit* (APna) has yielded dates of 1980, 1880, and 1800 m.y. and has a generally high initial $^{87}Sr/^{86}Sr$ ratio, indicating that minerals which crystallised in Archaean times have only partly responded to the 1800-m.y. regional metamorphism. Essential minerals are quartz, K-feldspar or plagioclase or both, and biotite. Muscovite may be present but is generally subordinate to biotite, and almandine is a rare accessory. Potash feldspar is usually microcline, and is generally more abundant than plagioclase (oligoclase to andesine), although in places plagioclase may predominate. Feldspar is moderately altered to sericite or clay minerals, and biotite is usually partly altered to chlorite. These gneisses typically have a granuloblastic texture characteristic of the almandine-amphibolite facies. In places augen textures are well developed.

The Early Proterozoic *pegmatoid leucogneiss, schist, and migmatite* (APnp) yield an 1800-m.y. age, consistent with the timing of late Early Proterozoic regional metamorphism; normal initial isotopic ratios indicate a metasedimentary origin. The term leucogneiss has been applied to a diverse group of massive rocks of pegmatoid texture, consisting essentially of quartz, alkali feldspar, and plagioclase. Accessory muscovite and lesser biotite (altered to chlorite) may also be present as subparallel plates, giving the rock a weak foliation. In particularly coarse specimens feldspar may form layers up to 12 cm thick. Muscovite and quartz commonly form differentiated layers up to 2 cm across that mark the foliation, although in places the muscovite flakes are randomly orientated. Almandine is a common accessory.

Biotite schist, quartz-biotite schist, feldspar-quartz-biotite schist, and muscovite-biotite schist are commonly interlayered with the gneiss in bands rarely more than 5 cm wide. Kink and isoclinal folds and crenulations reflect a complex deformational history. Biotite is commonly partly altered to chlorite and marks the foliation. With increasing proportions of elongate quartz grains and xenoblastic feldspar (generally microcline), the schist grades into fine leucogneiss.

In the extreme southwest of the Sheet area, migmatites show the vein, layered, dilation, ptygmatic, augen, and schlieren structures described by Mehnert (1968); these rocks, which probably represent a progression of metamorphic differentiation from layered leucogneiss and schist, are composed of granuloblastic quartzofeldspathic layers up to 40 cm across, separated by subordinate layers of biotite ± muscovite, quartz, and feldspar up to 30 cm across.

EARLY PROTEROZOIC

KAKADU GROUP

Munmarlary Quartzite (Pkm)

Quartzite, feldspathic quartzite, and minor meta-arkose of the Munmarlary Quartzite flank and overlie the Nanambu Complex in the west, and are in places transitional, where substantially feldspathic, into pegmatoid gneiss of the complex. These rocks are the oldest recognisable Early Proterozoic metasediments in the Sheet area, and were probably deposited on Archaean basement.

The quartzite forms scattered exposures along strike ridges or on rubbly rounded hills. It is similar to quartzite of the correlative Mount Basedow Gneiss in CAHILL, and consists entirely of a granuloblastic quartz mosaic, in places sheared and muscovitic or feldspathic. Feldspar may constitute up to 20 percent but is usually only interstitial. The quartz is mostly strained and fractured, and forms elongate grains or lensoid lamellae giving rise to a weak foliation resembling bedding. The quartzite is in places surrounded by gneiss of the Nanambu Complex, suggesting that the quartzite was orginally sandstone in a dominantly arkosic sequence, the arkose having been metamorphosed to granitoid gneiss and hence into Nanambu Complex. The quartzite remains a mappable unit as it forms relatively prominent and continuous outcrops. At this scale some gneiss (metamorphosed feldspathic sandstone and arkose) has had to be mapped with the quartzite.

CAHILL FORMATION (Pc)

The Cahill Formation has been informally subdivided into upper and lower members; the lower member grades upwards into the more psammitic, and much thicker, upper member. The upper member is not known to be exposed in EAST ALLIGATOR. The formation is poorly exposed, and its stratigraphy has been mainly defined from drill traverses in CAHILL (Needham & Stuart-Smith, 1976). The lower member contains the major uranium deposits and most uranium prospects in the Alligator Rivers Uranium Field.

Lower member (Pc_1)

The lower member ranges in thickness from 300 to 600 m, and is characterised by frequent abrupt

TABLE 1. SUMMARY OF STRATIGRAPHY

	Unit and map symbol	Thickness (m)	Main rock types	Relationships	Isotopic dates (Page & others, 1980) (m.y.)	Principal references
QUATERNARY	(Qcm)		Mud, silt	Intertidal muds transitional with Qcp, Qcr, Qca		This Map Commentary
QUATERNARY	(Qca)		Silt, mud	Coastal and estuarine alluvium transitional with Qcp, Qcr, Qcm, Qa		" " "
QUATERNARY	(Qcp)		Clay, silt, mud	Mud pans in coastal and estuarine plains, transitional with Qca		" " "
QUATERNARY	(Qcr)	<5	Sand, shelly sand, coquina	Transitional with Qca, Qcp		" " "
QUATERNARY	(Qa)	<3	Silt, sand, clay, sandy siltstone	Creek and river alluvium transitional with Qs, Qas, Qf, Qca		" " "
QUATERNARY	(Qs)	<3	Unconsolidated sand	Outwash and colluvium transitional with Qa		" " "
QUATERNARY	(Qas)	<10	Silt, clay	Abandoned channel deposits in estuarine plains		" " "
QUATERNARY	(Qf)	<2	Black and brown humic soil and clay	Transitional with Qa at headwaters of some stable streams		" " "
TERTIARY TO QUATERNARY	(Cza)	<3	Sand and clay	Winnowed edges of, and depressions in, Czs		Story & others (1969)
TERTIARY TO QUATERNARY	(Czs)	<75	Unconsolidated sand, ferruginous and clayey in places	Overlies early Tertiary laterite		" "
TERTIARY TO QUATERNARY	(Czl)	<3	Nodular, concretionary, pisolitic and vermicular laterite	Developed mainly on deeply weathered Cretaceous and Early Proterozoic rocks; minor pedogenic and transported types		" "
CRETACEOUS — Bathurst Island Formation	(Kb)	<60	Undivided			
CRETACEOUS — Bathurst Island Formation	Marligur Member (Kla)	<25	Poorly consolidated, poorly sorted fine to very coarse quartz sandstone, minor siltstone and conglomerate	Unconformable on Ꝑhk$_1$ and older units; interfingers with Kld		Hughes (1978)
CRETACEOUS — Bathurst Island Formation	Darwin Member (Kld)	<35	Fine argillaceous sandstone, siltstone, micaceous mudstone, radiolarian shale, basal conglomerate	Unconformable on Ꝑhk$_1$ and older units; interfingers with Kla		" "
CRETACEOUS	(Kl)	<10	Sandstone, siltstone	Contemporaneous with Kla, Kld; unconformable on AꝐn, Ꝑc; strongly lateritised		
	REGIONAL UNCONFORMITY					
CARPENTARIAN — KATHERINE RIVER GROUP	Kombolgie Formation (Ꝑhk$_1$)	300	Sandstone, pebbly sandstone, conglomerate, minor siltstone; local unconformable ferruginous sandstone (Ꝑhk$_{1f}$)	Markedly unconformable over AꝐn, Ꝑc, Ꝑo, Ꝑdz, Ꝑdo		Needham & Stuart-Smith (1978)
	REGIONAL UNCONFORMITY					
CARPENTARIAN	Oenpelli Dolerite (Ꝑdo)	Unknown	Porphyritic and ophitic olivine dolerite, minor serpentinite	Intrudes AꝐn, Ꝑo, Ꝑc	1688	Smart & others (1976); Stuart-Smith & Ferguson (1978)

TABLE 1. (continued)

Age	Group/Formation	Unit and map symbol	Thickness (m)	Main rock types	Relationships	Isotopic dates (Page & others, 1980) (m.y.)	Principal references
		REGIONAL METAMORPHISM 1870–1800 m.y.			MAJOR UNCONFORMITY		
EARLY PROTEROZOIC	Myra Falls Metamorphics	(Ꝑxm)	Unknown	Undivided			
		(Ꝑxm$_2$)	Unknown	Quartz schist ± feldspar ± mica ± garnet ± chlorite, banded biotite gneiss, leucocratic gneiss, feldspathic and micaceous quartzite	Gradational with Ꝑo, Ꝑc, Ꝑxm$_1$	1800	This Map Commentary
		(Ꝑxm$_1$)	Unknown	Lit-par-lit gneiss, banded gneiss, garnet-biotite and muscovite-quartz schist, banded gneiss, leucogneiss, hornblende gneiss, minor quartzite, feldspathic schist, amphibolite, rare augen gneiss	Gradational with Ꝑxm$_2$		" " "
		Zamu Dolerite (Ꝑdz)	< 300	Ortho-amphibolite	Sills folded and metamorphosed with enclosing sediments	1940	Ferguson & Needham (1978)
	S. ALLIGATOR GROUP	Koolpin Formation(?) (Ꝑsk)	Unknown	Siliceous ferruginous schist and quartzite with magnetite, graphite, and garnet in places; minor amphibolite	Not clear; may overlie Ꝑc		Swingler (1977); Stuart-Smith & others (1980)
		Nourlangie Schist (Ꝑo)	Unknown	Quartz-mica schist, quartz schist, mica schist, commonly garnetiferous	In places unconformable over Ꝑc		This Map Commentary
	Cahill Formation	(Ꝑc)	3000	Undivided			
		(Ꝑc$_2$)	2500	Feldspathic quartzite and schist, quartzite, mica schist ± garnet, minor conglomerate; commonly magnetitic, chloritised in places	Gradationally overlies Ꝑc$_1$		Needham & Stuart-Smith (1976)
		(Ꝑc$_1$)	300-600	Interbanded pyritic carbonaceous mica schist, chloritised feldspathic quartzite, quartz schist, calc-silicate gneiss and amphibolite, commonly with garnet, magnetite, hematite, and chlorite; lenses of massive dolomite-magnesite	Not clear; probably unconformable on Ꝑkm and AꝐnp, onlapping AꝐna		" "
	KAKADU GROUP	Munmarlary Quartzite (Ꝑkm)	200	Quartzite, feldspathic quartzite, minor meta-arkose	Oldest definite metasedimentary unit; transitional with AꝐnp		Needham & Stuart-Smith (1978)
ARCHAEAN–EARLY PROTEROZOIC	NANAMBU COMPLEX	(AꝐn)		Undivided			This Map Commentary
		(AꝐnp)		Pegmatoid leucogneiss, schist, migmatite	Transitional with Ꝑkm	1800	" " "
		(AꝐna)		Foliated granite, augen gneiss (metamorphosed Archaean granite)		2470-1800	" " "

changes in rock type. Generally it can be distinguished geochemically from the upper member by lower Fe/Mg ratios and higher Mg, F, and Th values. The uranium content of unmineralised rocks is low, with highest values in carbonaceous rocks (Table 2).

TABLE 2. AVERAGE GEOCHEMICAL ANALYSES, CAHILL FORMATION, IN AREAS NOT KNOWN TO BE MINERALISED. The number of samples analysed for each rock type is shown in parentheses.

	LOWER MEMBER				*UPPER MEMBER*	
	Quartzite (8)	*Schist (3)*	*Carbonaceous schist (6)*	*Carbonate (2)*	*Quartzite (4)*	*Schist (8)*
Oxides (wt%)						
SiO_2	71.94	60.90	57.28	26.13	76.04	66.08
TiO_2	0.40	0.50	0.61	0.02	0.43	0.59
Al_2O_3	13.71	17.52	18.17	0.41	11.15	15.97
Fe_2O_3	0.90	1.46	1.76	0.55	0.56	1.24
FeO	1.58	3.57	4.02	n.d.	2.49	4.04
MnO	0.05	0.06	0.05	0.04	0.04	0.07
MgO	2.71	5.56	4.31	27.60	1.26	2.29
CaO	1.04	0.39	3.13	15.97	1.24	0.70
Na_2O	1.49	1.43	0.86	0.04	1.25	1.29
K_2O	2.69	2.95	4.24	0.09	2.68	4.17
P_2O_5	0.13	0.11	0.08	0.06	0.11	0.11
loss	2.87	5.18	4.59	28.97	1.49	3.03
Total	99.51	99.63	99.10	99.88	99.74	99.58
Trace elements (ppm)	(*)	(**)	(**)			
F	760	1250	920	n.a.	450	650
Co	10	15	18	n.a.	6	18
Ni	15	44	54	3	25	43
Cu	42	15	48	n.d.	8	82
Zn	51	44	109	6	59	109
Pb	14	7	14	2	12	17
Th	21	15	17	n.d.	12	12
U	5	3	7	n.d.	4	4
Fe:Mg	1.14	1.13	1.68	.03	3.06	2.90

* one sample only; ** two samples only; n.d. — not detected; n.a. — not analysed.

Carbonaceous rocks

Carbonaceous schist identified in drillholes consists of fine-grained graphite, quartz, minor disseminated pyrite and pyrrhotite, and quartz-rich bands. The graphite is present along sheared foliation and crenulation cleavage surfaces. The carbonaceous schist contains phlogopite in places, and also tremolitic amphibole, accessory scapolite, epidote, and carbonate minerals, which suggest that the rock was derived from a magnesium carbonate-bearing sediment similar to the pyritic carbonaceous dolomitic shale and siltstone found throughout the central and western parts of the Pine Creek Geosyncline.

Marble, calc-silicate rock, para-amphibolite

Marble is unique to the lower member of the Cahill Formation. The most common variety is a massive crystalline rock ranging in composition from calcitic dolomite to magnesite (Needham, 1976). It crops out 12 km west of Jabiluka as discontinuous ridges, up to 10 m high, or iron-stained, vuggy, cherty, rock formed by near-surface and surface silicification and ferruginisation; fresh, crystalline magnesian dolomite has been intersected less than 10 m below an outcropping ridge of ferruginous silicified dolomite near Nanambu Creek in CAHILL (Needham, 1976). No exposures of fresh carbonate rock are known in EAST ALLIGATOR.

Exposures of silicified ferruginous calc-silicate rocks containing idioblastic tremolite, diopside(?) and forsterite(?), and skarn-like idioblastic tremolite-garnet rocks at 608198, are interpreted by Swingler (1977) as metasomatised calc-silicate hornfels. Swingler suggests that a granitic intrusive may occur nearby under the Magela Plain. Cuttings from a drillhole, and material from exposures 200-700 m further south are described by Swingler as silicified and ferruginised metasediments; rock types are brown goethitic quartz-veined massive rock with possible relict amphibole textures, banded graphitic silicified quartzite with schistose layers, and silicified calcareous(?) rock with traces of phosphate and alunite. A low ridge striking east at 585190 marks the northern limb of a southeast-plunging syncline of silicified and brecciated carbonate. Nearby is float composed of 'skarn' (90% granoblastic andradite-grossularite, 10% quartz) and silicified marble with tremolite(?) and olivine(?); these rock types are also thought by Swingler to indicate contact metamorphism of dolomite, and in some places the float contains cellular and curved laminated structures that may be stromatolitic. These rocks were evidently a sequence of dolomite and dolomitic sediments which in places were carbonaceous and pyritic. Apart from the olivine, identification of which is doubtful, the mineral assemblage described for these rocks is consistent with the staurolite-almandine amphibolite facies of regional metamorphism that pervades this area, and in the author's view, no concealed intrusive granite body need be invoked to explain them.

BMR scout drilling near Obiworbby Brook in the southwest has indicated that a carbonate-dominated sequence forms the lower member of the Cahill Formation west of the Nanambu Complex (Wallace, 1980). Biotite-carbonate rock in drillholes East Alligator 17 and 18 gives way westwards to muscovite-carbonate rock, with interbeds of quartz-muscovite schist.

Pseudomorphs of magnesite and chert after gypsum are evident in some Cahill Formation carbonate rocks exposed on the eastern side of the Nanambu Complex in CAHILL, and are also present in massive and brecciated carbonate rocks at Jabiluka, Ranger 1, and Koongarra (Crick & Muir, 1980); they are not apparent however in the cores of carbonate rock from west of the Nanambu Complex. Evaporites may have been deposited in a sabkha environment east of the Nanambu Complex, and carbonate rocks in a deeper marine environment on the western side.

Thin interbeds of magnetite-calcite-biotite-hornblende-diopside-quartz schist represent an intermediate stage in the transformation of a sediment to a para-amphibolite. Mineralogical layering in para-amphibolite of the Cahill Formation is distinct, and probably reflects compositional layering typical of that found in thinly bedded dolomitic marls. In contrast, ortho-amphibolite of the Zamu Dolerite, which interfingers with the sediments of the Cahill Formation, is homogeneous in composition, widespread in occurrence, thicker (up to 600 m), and generally lacks distinct mineralogical layering.

Other rock types

Rock types other than the carbonaceous and carbonate rocks are similar to the mica schist, feldspathic quartzite, and quartz schist of the upper member. However, accessory amphibole and sphene in feldspathic quartzite are confined to the lower member, and reflect the carbonate affinity.

Upper member (Ꝑc_2)

In adjoining Sheet areas the upper member is seen to gradationally overlie the lower member and is up to 2500 m thick. Its boundary with the overlying Nourlangie Schist is marked by an increase in the proportion of mica schist, and a change in magnetic response (Horsfall & Wilkes, 1975). Pancontinental drillhole DH209 (3 km northwest of Jabiluka, 683191) intersected 102 m of sericitised quartz-mica schist, lepidoblastic mica-quartz-feldspar schist with garnet in places, and garnet-feldspar-mica schist with layered sulphides, graphite, magnetite, and massive chlorite (Swingler, 1977), part or all of which may be the upper member of the Cahill Formation.

The upper member was probably a well-bedded sequence of feldspathic arenite and siltstone, minor conglomerate, and thin bands of shale. The high proportion of Fe- and Al-bearing silicates in the pelitic schists suggests that they were originally iron-rich shale and siltstone.

Cahill Formation at the uranium deposits

The host rocks to the Jabiluka uranium deposits have been described in detail by Rowntree & Mosher (1975), Hegge (1977), Eupene (1978), Ewers & Ferguson (1980), Binns & others (1980), and Riley & others (1980). The orebodies occur in rocks of the lower member of the Cahill Formation, which are given local informal stratigraphic names (e.g. Main mine series, Hangingwall series etc) (Fig. 5). Eupene (1978) summarised and compared the detailed stratigraphy of the Jabiluka deposits and the other uranium deposits of the region.

The dominant host rock types are chlorite and/or graphite-quartz schist, muscovite-quartz schist, feldspar-quartz schist, massive chlorite rock, and chert, which are commonly interbedded with carbonate rock; carbonate rock may form lenses up to 250 m thick at the base of the sequence but rarely contains uranium mineralisation. Rocks of the lower member of the Cahill Formation at Jabiluka form an asymmetric isoclinal synform in which no rocks of the upper member are preserved.

Nourlangie Schist (Ꝑo)

This unit crops out mostly in the footslope of mesas of Kombolgie Formation sandstone in the northeast, and as deeply weathered micaceous rubbly rises in the lowlands. Judging from drill core obtained from CAHILL it is a monotonous quartz-mica schist sequence, commonly containing one or more of the following: garnet, feldspar, amphibole, magnetite, kyanite, and staurolite (Needham & Stuart-Smith, 1976). However, minerals other than quartz and mica are only very rarely apparent in outcrop. The formation also contains minor quartzite and feldspathic quartz schist.

The base of the Nourlangie Schist is not exposed. The similarity between Nourlangie Schist and Cahill Formation upper member indicates little disturbance to the sedimentary cycle during their deposition, and it is possible that the contact is conformable. However, Needham & Stuart-Smith (1976) interpret a discordance between photo trends related to foliation in the two formations in southeast CAHILL as a possible local unconformity. Mica-quartz schist mapped as Nourlangie Schist at Cannon Hill and further east appears to overlie Koolpin Formation(?) rocks (see below) and may be equivalent to the Fisher Creek Siltstone, which overlies the Koolpin Formation in the South Alligator valley area (Walpole & others, 1968).

Koolpin Formation(?)(Ꝑsk)

Siliceous and ferruginous banded rocks form discontinuous strike ridges along the eastern margin of Magela Plain, and are best exposed at the Magela 1 and 2 prospects. They lie in the southwest limb of the Oenpelli Syncline, a large fold east of the Nanambu Complex, and because the rocks lie northeast of the Cahill Formation and closer to the axis of the syncline they may be 2 to 5 km stratigraphically higher than the Cahill Formation. They resemble 'banded ironstone' and contain carbon, as does the Koolpin Formation of the South Alligator valley area 140 km to the south-southwest, where the Koolpin Formation is about 2 km stratigraphically higher than Cahill Formation correlatives (Stuart-Smith & others, 1980). The Magela 1 and 2 exposures contain thinly interlayered mica-quartz schist and quartzite with some thicker layers (0.1 to 0.2 m) of quartzite, magnetite quartzite, and amphibolite, and, near the base, layers of graphitic and porphyroblastic schist (Swingler, 1977). Above this interlayered sequence, schist is subordinate to quartzite and amphibolite. The schist consists of thin layers and lenses 4 to 10 mm wide of medium to coarse mosaic quartz interlayered with biotite-amphibole-feldspar schist ± quartz ± magnetite. Some of the quartzite is black and contains thin layers of magnetite, amphibole (actinolite?), and chloritised biotite(?). The graphitic rocks contain thin parallel layers of microcrystalline quartz with included and intergranular graphite, alternating with laminae and lenses of limonite, probably after feldspar. The porphyroblastic rock is a banded and lenticular quartz-biotite schist. The rare porphyroblasts are about 4 mm across and are altered, but polygonal shapes suggest they were garnet; they are more abundant in graphite-rich layers.

Zamu Dolerite (Ꝑdz)

Foliated, dark green to black, fine to medium-grained amphibolite forms sill-like bodies commonly 1–10 m thick in the Nanambu Complex, Cahill Formation, and Nourlangie Schist, and dyke-like bodies up to 2 m wide in the Nanambu Complex. Two sills of amphibolite, 290 m and 15 m thick, underlie the Jabiluka 1 orebody (Ferguson & Needham, 1978) where they are interlayered with chloritic sericite schist. Where more than 10 m thick the amphibolite is medium-grained towards the centre, and in places relict igneous textures are preserved. Hornblende comprises between 50 and 85 percent, and is always strongly pleochroic in shades of green. In the medium-grained varieties amphibole forms mainly poikiloblastic amoeboid grains up to 3 mm across and euhedral prisms usually less than 0.2 mm long; the prisms are mostly included in the amoeboid grains together with minute grains of quartz and plagioclase, as well as accessory sphene, apatite, opaques, and carbonate in the marginal parts. Plagioclase and quartz together form up to 45 percent of the amphibolite, and minor interstitial K-feldspar may be present. Plagioclase (labradorite-bytownite) forms fine to medium-grained laths, and quartz forms tablets up to 0.5 mm long. Chlorite alteration is common, and biotite, usually an accessory, may be a major phase in areas of intense chloritisation, for example near the uranium orebodies. Biotite is always partly altered to chlorite, and is usually interspersed with amphibole; the biotite generally parallels the foliation, but in some cases may be at high angles to it. Chlorite may form veins less than 4 mm wide, with opaques and muscovite ± epidote ± prehnite. Ilmenite, chalcopyrite, and pyrite are additional common accessories (Ferguson & Needham, 1978).

The amphibolite grades southwards, in CAHILL and JIM JIM, through metadolerite to unmetamorphosed tholeiitic dolerite sills folded concordantly with the enclosing very low-grade metasediments (Stuart-Smith & others, 1980). Page (1981) reports a 1940-m.y. Rb/Sr total-rock age for Zamu Dolerite from this area.

Myra Falls Metamorphics (Ꝑxm)

East of the East Alligator River, the Early Proterozoic metasediments grade into metamorphically differentiated schist and gneiss of the Myra Falls Metamorphics, formed by metamorphism and progressive migmatisation of the metasediments at about 1800 m.y. The unit contains two 'zones', the Transitional Zone and Lit-par-lit Gneiss Zone (Needham & others, 1975). The Myra Falls Metamorphics partly surround the granitoid and migmatitic Nimbuwah Complex (east of EAST ALLIGATOR, Needham & Stuart-Smith, 1980) which appears to have developed as a migmatite diapir or nappe, with a complementary syncline on its west flank in the area between the East Alligator estuary and Oenpelli (i.e. the Oenpelli Syncline).

The Myra Falls Metamorphics occupy this syncline. Quartzites in the Myra Falls Metamorphics in OENPELLI may correlate with the Munmarlary Quartzite.

Transitional zone (Pxm$_2$)

The boundary between the Myra Falls Metamorphics and the Early Proterozoic metasediments is defined by the first appearance of metamorphic feldspar as layers of pegmatoid leucosome (Needham & others, 1975). In the transitional zone leucosome is only sporadically developed as layers or lenses up to 1 cm thick, parallel to foliation in the schist and gneiss. The rocks become more gneissic to the east, towards the lit-par-lit gneiss zone.

Lit-par-lit gneiss zone (Pxm$_1$)

This zone is characterised by the regular development of leucocratic layers that represent the start of metamorphic differentiation to form migmigmatite (Needham & others, 1975). The leucosome consists almost entirely of quartz and feldspar, and the melanosome biotite with some feldspar and quartz, and minor garnet and opaque minerals. Finely foliated biotite gneiss represents metamorphic differentiation on a microscopic scale, and lit-par-lit gneiss differentiation on a macroscopic scale. The incipient development of quartz-feldspar augen in feldspathic schist and banded biotite gneiss reflects a more advanced stage of metamorphic differentiation.

Essential minerals in the gneisses are quartz, potash feldspar (generally microcline), plagioclase, and biotite. Plagioclase and potash feldspar are commonly equally abundant in the gneiss, although either may predominate in the other rock types. Plagioclase ranges in composition between albite and andesine, and is relatively resistant to alteration, generally being only partly replaced by sericite; the potash feldspar is mostly sericitised, and may be completely replaced. Mafic minerals are mainly biotite, but hornblende is present in places. Muscovite, where present, is intimately interlocked with biotite, and rarely exceeds biotite in abundance. Pink garnet porphyroblasts, colourless in thin section, are a common minor accessory; other accessory minerals are apatite, sphene, iron oxides, and zircon.

The gneisses are commonly metasomatised adjacent to the Oenpelli Dolerite: the feldspars are completely altered to chlorite and sericite, and biotite is replaced by chlorite; relict gneissic textures however are retained.

The schists of the lit-par-lit gneiss zone are mineralogically similar to the gneisses, apart from the predominance of biotite (and, in places, muscovite) over quartz and feldspar. Porphyroblastic garnet is the most common accessory mineral.

Granuloblastic amphibolites are common in the lit-par-lit gneiss zone and are mostly strongly retrogressively metamorphosed to radiating fibrous aggregates of actinolite, tremolite, and chlorite; some however retain relict ophitic textures and are composed of actinolitic hornblende and plagioclase, acccessory subhedral sphene, magnetite, granular quartz, fine apatite prisms, and minor garnet porphyroblasts and orthopyroxene (En_{90}); the texture and composition suggest they are ortho-amphibolites derived by metamorphism from Zamu Dolerite.

CORRELATION OF EARLY PROTEROZOIC UNITS

Correlations between Early Proterozoic units of EAST ALLIGATOR and areas to the west have been advanced by Needham & others (1980) and Ferguson (1980). However, the change in metamorphic grade over an area of particularly poor exposure on the South Alligator River floodplain immediately west of the Sheet area, coincident with sedimentary facies changes at some stratigraphic levels, makes correlation of units in the Alligator Rivers Uranium Field with units to the west difficult; therefore some of the lines of argument are circumstantial.

Needham & others believe that the EAST ALLIGATOR sequence is continuous with, and a higher-grade metamorphic equivalent of, the lower part of the complete Early Proterozoic sequence exposed further west. Ferguson suggests that the higher-grade rocks of the Alligator Rivers Uranium Field are older and unconformably underlie the less metamorphosed rocks to the west. In this case, the greenschist-facies metamorphic event would have occurred at 1800 m.y., and the higher-grade event earlier, perhaps at about 2000 m.y. A 10–30 km wide gradation between greenschist and amphibolite facies metamorphic rocks across the South Alligator River (Stuart-Smith, 1977; Wallace, 1980), the ability to trace some stratigraphic units across this zone further south in the MUNDOGIE-KAPALGA areas (Needham & others, 1980), and the occurrence of 1940 m.y.-old intrusives (Zamu Dolerite) in both 'old' and 'young' sequences, support the correlation of Needham & others, which is summarised in Table 3. Page & others (1980) find that isochrons from Nanambu Complex rocks in CAHILL which correspond to an 1875-2020 m.y. age range reflect metasomatism and partial or complete isotopic mixing during the 1800 m.y. regional metamorphism, and require an interpretation involving primary derivation from a late-Archaean protolith, rather than a medium to high-grade metamorphic event as proposed by Ferguson.

TABLE 3. CORRELATION OF EARLY PROTEROZOIC METASEDIMENTS IN THE PINE CREEK GEOSYNCLINE (* indicates present in EAST ALLIGATOR)

West of the South Alligator River		*Alligator Rivers Uranium Field*
Burrell Creek Formation (siltstone, greywacke)	Fisher Creek Siltstone (siltstone, phyllite, shale, minor arkose)	
Mount Bonnie Formation (chert-banded ferruginous siltstone, tuff, greywacke, minor shale, carbonate)	Kapalga Formation (chert-banded ferruginous siltstone, greywacke, shale)	
Gerowie Tuff (tuff, tuffaceous siltstone, argillite, shale, rare chert nodules, banded iron formation)		*Nourlangie Schist
Koolpin Formation (chert-banded ferruginous siltstone, carbonaceous shale, carbonate, banded iron formation)		*Koolpin Formation
Wildman Siltstone (siltstone, carbonaceous shale, minor quartzite)		
Coomalie Dolomite (carbonate)		
Crater Formation (conglomerate, sandstone, minor shale)	Mundogie Sandstone (sandstone, siltstone, phyllite, conglomerate)	*Cahill Formation (upper member)
Celia Dolomite (carbonate)		*Cahill Formation (lower member)
Beestons Formation (feldspathic sandstone, arkose)	Masson Formation (carbonaceous shale, calcarenite, carbonate, sandstone)	*Kakadu Group

CARPENTARIAN

Oenpelli Dolerite (Ᵽdo)

Porphyritic and ophitic olivine dolerite forms scattered low exposures in the northeast. The mineralogy of these rocks has been described by Needham & others (1975) and Stuart-Smith & Ferguson (1978); Page & others (1980) report an age of 1690 m.y., and Stuart-Smith & Ferguson suggest a depth of intrusion of 1-2 km. In EAST ALLIGATOR igneous laminations and parallel joint planes mostly dip at less than 5°, and are thought to mirror the gross attitude of the dolerite body, indicating that the scattered exposures are part of a large undulating dolerite sheet that is believed to be continuous at depth with a series of large lopoliths exposed mostly in OENPELLI and HOWSHIP; results of an airborne magnetic survey indicate the presence of a continuous dolerite body in the northeast (Needham & others, 1973b). Country rocks in between the dolerite exposures are commonly chloritised and sericitised, providing further evidence of shallow dolerite. The contact of the dolerite is sharp, and a 50-m wide aureole of albite-epidote hornfels is evident in places. Mafic minerals are chloritised, and feldspar is altered to sericite ± chlorite ± epidote. Biotite gneiss is altered to quartz-sericite-chlorite rock.

In places the upper margin of the dolerite is serpentinised, which suggests thrusting may have accompanied intrusion in places. The serpentinite, which is strongly slickensided, weathers readily to yellow-green clay and is exposed in erosion gullies to 2 m depth. Magnesite nodules, talc schist, and pyroxenite occur near chloritic slickensided serpentinite (too small to show at 1:100 000 scale) 16 km northwest of Ngara airstrip (646578).

The source of a 4 km-wide zone of high magnetic intensity trending north from Poalmiddy Waterhole (518284) has been interpreted as Cahill Formation by Needham & others (1973b), but company drilling (Horizon Exploration NL, 1974) in this zone intersected olivine dolerite; this, together with the presence of two small mapped occurrences of Oenpelli Dolerite a few kilometres northwest of Poalmiddy Waterhole, suggests the presence of an extensive dolerite body. The magnetic results suggest it is an east-dipping dyke.

Katherine River Group

Kombolgie Formation (Ᵽhk$_1$)

The Kombolgie Formation overlies all older rocks with marked regional unconformity. It is the only unit of the Carpentarian Katherine River Group present in EAST ALLIGATOR. The contact with older rocks is commonly concealed by scree, or by sand of the Lowland plains. The bulk of the formation is made up of quartz sandstone that forms the Arnhem Land plateau and is best exposed in the plateau's bounding cliffs. The elevation of the sandstone plateau generally decreases northwards, and northeast of the East Alligator River estuary the sandstone is in places covered by low-lying Mesozoic sediments.

The sandstone is composed mainly of medium to coarse (0.25–1.0 mm), moderately well sorted, subrounded to subangular quartz grains in a matrix which ranges 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.

Other rock types are medium-grained ferruginous siltstone, and conglomerate in beds ranging from 20 cm to over 30 cm thick with well-rounded quartz cobbles up to 20 cm across. A separate sub-unit of ferruginous sandstone (Phk_{1f}) is up to 40 m thick and confined to the mesa immediately east of Jabiluka; it is unconformable and may be a large scour fill. Volcanic members present in the formation to the south and east are not present in EAST ALLIGATOR. Basal conglomerates generally consist of subangular quartz and quartzite pebbles which are often feldspathic (up to 80%), blade-shaped clasts of schist, rodded quartzite, and sandy shale (up to 20%), and highly angular pieces of vein quartz (up to 2%). Distribution of the conglomerates is sporadic, and was doubtless controlled by relief of the pre-Kombolgie surface.

The sandstone throughout the formation is commonly cross-bedded and ripple-marked. The cross-bedding varies from medium (sets 5 cm to 2 m thick) to large-scale (2–8 m) and is mainly of the 'alpha' type described by Allen (1963) as indicating a shallow freshwater origin. Ojakangas (1979) described planar, trough, and herringbone cross-beds and suggested a braided alluvial plain model of deposition. Measurements of directional sedimentary structures generally fall within the south-eastern and southern quadrants, suggesting prevailing deposition from the north to northwest.

The Lowlands are in part an exhumed pre-Kombolgie Formation land surface, their terrain being similar to that of the unconformity surface exposed 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 (Needham & Smart, 1972). Local drape structures over partly exhumed dolerite bodies are obviously depositional in origin, whereas the low dips in the main scarp probably resulted from an overall tilt to the south-east. Basinal depositional dips near Mount Borradaile have been modified by tectonism, producing dips of up to 20° (e.g. 10 km south-south-west of Mount Borradaile), with associated faulting. Minor irregularities are represented by small pebble-filled channels at the base of the Kombolgie Formation.

Volcanics higher in the Kombolgie Formation sequence to the southeast yield an age of 1648 ± 29 m.y. (Page & others, 1980).

Dyke-like bodies of massive chloritic rock in Kombolgie Formation sandstone above the Jabiluka 1 and 2 uranium deposits may be altered Mudginberri Phonolite, which intrudes Nanambu Complex rocks further south in CAHILL and has yielded an age of 1316 ± 50 m.y. (Page & others, 1980).

CRETACEOUS

Thin strata of the Cretaceous Bathurst Island Formation form low tablelands and mesas in the northeast, and underlie Cainozoic sand plains throughout much of the Sheet area. Exposures of ferruginised or leached sandstone and siltstone up to 10 m thick in the southern half of the Sheet area are grouped as Kl, undivided Cretaceous sediments. The thickest known Cretaceous sequence in EAST ALLIGATOR is 72.5 m in BMR East Alligator No. 7 drillhole (Needham, 1976), and Figure 3 is an interpretation of the Cretaceous stratigraphy encountered in BMR drillholes across the western half of the Sheet area. Information on the Bathurst Island Formation in EAST ALLIGATOR has been obtained mainly from the shallow drilling program, and the thickness information has been incorporated in the cross-section on the map (note: on cross-section ABCDE, BMR Field Island 1 has been wrongly labelled East Alligator 1). The Bathurst Island Formation consists of two interfingering members, the Marligur and Darwin Members (Hughes, 1978). The psammitic Marligur Member (Kla) forms tongues up to 20 m thick that thin to the west; the sandstones exposed north of the East Alligator River are poorly sorted, but similar rocks in drillhole intercepts south of the river range to well-sorted and rounded (Needham, 1970). The pelitic Darwin Member (Kld) has an aggregate thickness of 20 to 40 m in the northeast and appears to be confined to the area west of the East Alligator River. The Marligur Member contains frequent gastropods, crinoid ossicles, worm borings, and a heteromorphic ammonite, *Bacculites*(?) sp. (Hughes, 1978). Spores in cuttings from drillhole BMR Cobourg Peninsula 4 (in the Marligur Member north of EAST ALLIGATOR) are of late(?) Neocomian to Aptian age (Burger, *in* Hughes, 1978). The Darwin Member contains a molluscan fauna including belemnites (described by Skwarko, 1966), and brachiopods, echinoids, bryozoans, corals, and arenaceous foraminifera. Burger (*in* Hughes, 1978) gives a palynological age

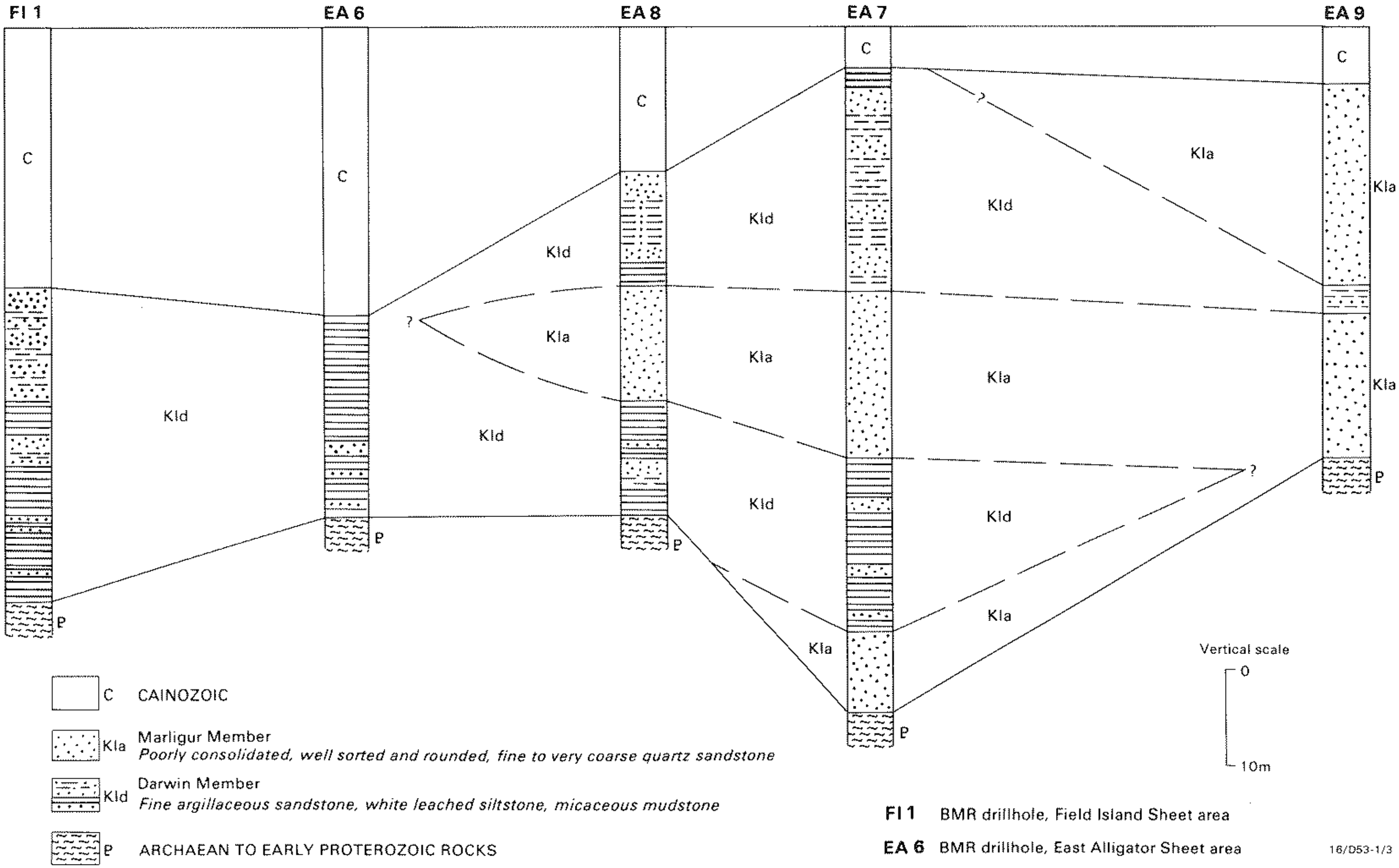

Fig. 3 Interfingering of the Marligur and Darwin Members of the Bathurst Island Formation (Early Cretaceous)

range also of late(?) Neocomian to Aptian for the Darwin Member on Melville Island and Cobourg Peninsula.

The Bathurst Island Formation was deposited under shallow epicontinental seas. The finer-grained Darwin Member was deposited during a marine transgression over the Bathurst Terrace, and the coarser Marligur Member sediments were deposited near the shore. The shoreline in places probably coincided with the present position of the Arnhem Land escarpment, which thus may have formed sea cliffs.

CAINOZOIC

Cainozoic alluvial fan sediments form a veneer in the Lowlands and Floodplains, and talus slopes and colluvial and residual sand occur adjacent to, and upon, the Arnhem Land Plateau. The deposits have been divided into the following units: laterite (Czl), late Tertiary sands (Czs, Cza), and Quaternary continental deposits (Qa, Qs, Qas, Qf) and marine sediments (Qcr, Qcp, Qca, Qcm).

Laterite (Czl)

Generally, the profiles seen in EAST ALLIGATOR are either detrital or are truncated remnants of the standard laterite profile described by Whitehouse (1940). Lateritisation processes have been active in the area mainly between the Early Tertiary and Early Pleistocene (Williams, 1969); those preserved in the Sheet area are dominantly mid Tertiary where developed on Early Proterozoic bedrock, and late Tertiary where developed on broadly coeval sands of the Koolpinyah Surface. Of the laterite types described by Williams, the following have been recognised:

Detrital laterite is formed mainly from reworked material cemented in a ferruginous matrix. It generally forms blocks up to 1 m, and continuous pavements on low hills or breakaways over the Nanambu Complex.

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 forms blocks or pavements, and is commonly exposed on or within late Tertiary sands at the margins of the Floodplains where the Koolpinyah surface is being actively eroded at its edge, and as the uppermost part of the standard laterite profile above Early Proterozoic rocks.

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 heads of creeks, and is usually surrounded by a breakaway of pisolitic or detrital laterite.

Concretionary laterite is pedogenic in origin and, unlike the laterites already described, is actively forming. It occurs as ferruginous mottles in poorly drained alluvial soils, or as ironstone nodules formed in situ in the soil profile, and has been noted in the flood plains of Magela Creek.

Late Tertiary sands (Czs) (Cza)

Coarse unconsolidated quartz sands (Czs), up to 75 m thick in places (Needham, 1976) and with a hematitic clayey matrix, form the remnants of the Tertiary sand plain named the Koolpinyah Surface by Story & others (1969). This surface persists throughout most of the northwest of EAST ALLIGATOR, and for the most part the Lowlands coincide with a dissected Koolpinyah Surface. Where the sands have been almost completely removed, structures within the underlying weathered rocks are apparent on aerial photographs.

According to Story & others, the sands are probably fan deposits derived from Mesozoic sands, silt, and claystone, Kombolgie Formation sandstone, and Early Proterozoic metamorphics. Continuous erosion of Carpentarian and Mesozoic sediments on the Arnhem Land Plateau since the early Tertiary supplied detritus for accumulation of the sands on the Lowlands, and formed residual sand deposits on the plateau. Laterite formation on the plateau is restricted to the talus slopes adjacent to the volcanic members of the Kombolgie Formation.

Rubble of laterite, vein quartz, quartzite, and dolerite is widely scattered over the Lowlands, and is included in Czs. The quartz and quartzite rubble borders strike ridges of Early Proterozoic rocks or overlies shallow subcrop of these rocks. Dolerite rubble also occurs next to outcrops of vein quartz, quartzite, and the more massive varieties of gneiss, on which 'grinding hollows' are seen. Aboriginals commonly ground pieces of dolerite against the quartz or gneiss to make tools, and it is assumed that most of the dolerite rubble has been transported by Man.

At the margins of the Floodplains, erosion and redeposition of the sands have produced a narrow but distinct photogeological unit (Cza) characterised by a relatively steep slope of 5°; washing of the sands has resulted in the development of a sand and silt veneer on this slope. The clay and silt deposits found in isolated depressions developed on the Koolpinyah Surface are also included in the Cza unit, because they are a direct product of erosion of unconsolidated sands and not part of the open drainage system. In some places the depressions are aligned, which has led Williams (1969) to suggest they may be 'spillways eroded into the lateritised lowlands'. Generally, however, they are unconnected and unaligned and may be 'swallow holes' developed by solution and collapse of the mottled and/or pallid zones of the underlying clayey sands; their formation has probably been continuous since the early Tertiary.

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) occur in the courses and flood plains of active rivers and creeks. The large bodies of unconsolidated quartz sand (Qa) 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 Tertiary sands, and are mostly deposited during floods. The sediments of abandoned river courses (Qas) consist mostly of silt and mud, and were deposited in shallow depressions in the Floodplains, into which the present drainage system is incised. Black humic soils and clays (Qf) may be developed in poorly drained depressions within the drainage systems.

Quaternary coastal deposits

During the wet season (November to April) the coastal and estuarine Floodplains are completely inundated by brackish water; in the dry season brackish conditions extend as far inland as the Border Store in the East Alligator River system.

Coastal alluvial deposits (Qca) are comparatively well drained silt and clay with sparse vegetation, such as sedge or samphire; these deposits stand above the poorly drained black soil plains and mud flats (Qcp) that are developed adjacent to, and within, the estuarine channels. Salt pans occupy some mud flats; they generally lack vegetation except in areas bordered by Czs where perennial springs give rise to permanently waterlogged pans which support paperbark and waterweed growth (e.g. Didygeegee Swamp).

The coastal beach ridges and cheniers (Qcr) are generally parallel to and within 2 km of the present coastline, or are adjacent and parallel to the edge of the late Tertiary sand plains. By analogy with dated sand ridges at Point Stuart 65 km west of the Sheet area (Clarke & others, 1979), the innermost ones mark the coastal position at about 7000 years B.P., a time consistent with a change in invertebrate fauna on the coastal plains of EAST ALLIGATOR from marine to freshwater (Kamminga & Allen, 1973). Thus significant coastal emergence is indicated in the middle Holocene, but subsequent coastal changes are the result of coastal accretion at a rate of 20–30 cm/year with little or no sea-level change (Clarke & others, 1969). The ridges are commonly composed of shelly sands, and support a woodland of non-eucalpyts or semi-deciduous trees. There are no present-day sandy beaches in EAST ALLIGATOR.

Mud of the intertidal zone (Qcm) supports dense mangrove growth in many places, and overlies landward beach-ridge or clay-plains deposits.

METAMORPHISM, METASOMATISM

The western margin of EAST ALLIGATOR approximately marks the eastern side of a 10–30 km-wide zone of metamorphic gradation from the mainly amphibolite-facies terrain of the Alligator Rivers Uranium Field to the mainly lower-greenschist-facies terrain over the rest of the Pine Creek Geosyncline (Needham & others, 1980). Wallace (1980) records the position of the biotite isograd between BMR drillholes East Alligator 16 and 17 in the Munmarlary Traverse in the southwest of the Sheet area. The metamorphic facies boundary roughly concides with a major gravity lineament trending south near the South Alligator River estuary (Fig. 2; Ferguson & Needham, 1978).

Except for the 2–6 km wide area of greenschist-facies rocks along the western edge of the Sheet, scattered fresh exposures and drillcore indicate that the Early Proterozoic rocks of EAST ALLIGATOR are metamorphosed to the staurolite-almandine subfacies of the amphibolite facies (Smart & others, 1976). This is consistent with the much more extensive petrological studies of Needham & Stuart-Smith (1967) of Cahill Formation rocks from CAHILL.

The metamorphism occurred in what was probably a protracted orogenic event, possibly 70 million years long, which culminated about 1800 m.y. ago (Page & others, 1980).

Almandine is found in most rock types in the Cahill Formation, but is more abundant in mica schist. Kyanite is found only with staurolite, indicating that conditions of the kyanite-almandine subfacies have not been attained (Winkler, 1967). The rarity of staurolite and abundance of potassium feldspar in Cahill Formation schist contrast with the mineralogy of the Nourlangie Schist, and indicate a relative abundance of alkalis in the parent sediments of the Cahill Formation.

Retrograde metamorphism has resulted in chloritisation of ferromagnesian minerals and sericitisation of feldspars. Garnet, biotite, and amphibole commonly show complete or partial alteration to chlorite; chloritised haloes surrounding small quartz veins are common in the Early Proterozoic metasediments.

The Early Proterozoic rocks have also undergone iron and magnesium metasomatism. This alteration is most pervasive in the lower member of the Cahill Formation, where all rock types are enriched in Mg and carbonaceous and calcareous rocks are depleted in Na (Table 2), and where chlorite has replaced feldspar in feldspathic quartzite to give rise to quartz-chlorite schist. Chloritisation is particularly intense in some sheared and brecciated schists of the lower member near the contact with the Nanambu Complex, suggesting that chloritisation followed cataclastic deformation. The association of chlorite with the sheared contact between the Nanambu Complex and the Cahill Formation, and also with the unconformity between the Cahill Formation and the Nourlangie Schist, suggests that stratigraphic and structural breaks have provided channelways for Fe and Mg-rich fluids. Chloritisation is extensive in the uranium orebodies, to the extent that massive chlorite rocks are common. A zone of intense chlorite alteration up to about 200 m wide surrounds the ore zones, grading out into largely unaltered rocks. Page & others (1980) determined an age of about 1610 m.y. for chlorite alteration at Jabiluka and in the other uranium orebodies of the Alligator Rivers region. Eupene & others (1975) report the presence of chloritised downfaulted blocks of Kombolgie Formation sandstone at the Ranger 1 uranium deposit in CAHILL.

Hematitisation is widespread, and is associated with chlorite alteration, particularly in areas of uranium mineralisation. Hematite is a common vein-filling mineral, replaces ferromagnesian minerals, and forms pseudomorphs after magnetite.

STRUCTURE

Owing to poor exposure, structural concepts are based almost entirely on small-scale structures evident in drill core, aerial photo trends, and the regional distribution of units. The style and orientation of folds and faults in the Precambrian rocks have been governed largely by basement configuration (the Archaean rocks of the Nanambu Complex) and by the development of a large migmatite complex (the Nimbuwah Complex) to the northeast.

Microstructures reveal at least four phases of deformation (two of which were isoclinal) in the Early Proterozoic metasediments, probably all related to the 1870–1800-m.y. period of deformation and metamorphism (Needham & Stuart-Smith, 1976; 1980).

Mineralogical and textural banding form the oldest preserved foliation (S_0), and are probably original bedding. S_1 foliation was produced by the parallel growth of phyllosilicates at a shallow angle (less than 10°) to S_0. These two foliations are rarely apparent in the mica schist, but are dominant features of the quartzofeldspathic schist.

Intense isoclinal folding transposed S_0 and S_1, and with recrystallisation of the phyllosilicates produced the dominant schistosity (foliation S_2). Relict isoclinal fold noses are preserved in the more competent quartz-rich bands. Almandine and magnetite porphyroblasts show deformed, rotational, and crosscutting textures indicating their development before, during, and after this phase of deformation.

Foliation S_3 — parallel to the axial planes of tight, angular, and rarely isoclinal folds — was produced by recrystallisation of phyllosilicates and development of crenulation cleavage, which rarely transposed older foliations.

Large unstrained mica and idiomorphic kyanite and staurolite porphyroblasts cut across the S_3 foliation, and indicate a probable temperature increase associated with greater hydrostatic pressure after the development of the foliation. Poorly developed kinks, forming a later set (S_4) are unrelated to major recrystallisation or folding, and are deflected by these minerals.

Local unconformity between the Cahill Formation and Nourlangie Schist evident in CAHILL suggests that minor folding took place at times during Early Proterozoic sedimentation, but the main deformation took place after the close of sedimentation, when diapiric growth of the Nimbuwah Complex in the northeast of the Alligator Rivers region caused marginal overfolding and intense isoclinal folding of the sedimentary pile, accompanied by amphibolite-facies regional metamorphism. In EAST ALLIGATOR, isoclinal fold axes are arranged concentrically around the granitic Archaean core of the Nanambu Complex. A strong foliation (S_2) developed parallel to the axial planes of these folds, and gave rise to the dominant regional schistosity. Complex small-scale cross-folding with axial plane crenulation cleavage (S_3) developed in the less competent rock types, and may have been related to further (relatively minor) movements of the migmatite and Archaean granite masses, and to higher temperatures attendant on the intrusion of anatectic granites outside the Sheet area as the grade of metamorphism reached its peak after the formation of S_2. Biotite that grew during the development of S_3 has yielded a K-Ar isotopic age of about 1800 m.y. and dates the climax of late Early Proterozoic tectonism in the Alligator Rivers region.

Faulting in the Early Proterozoic rocks probably mostly postdates S_2. Faults in EAST

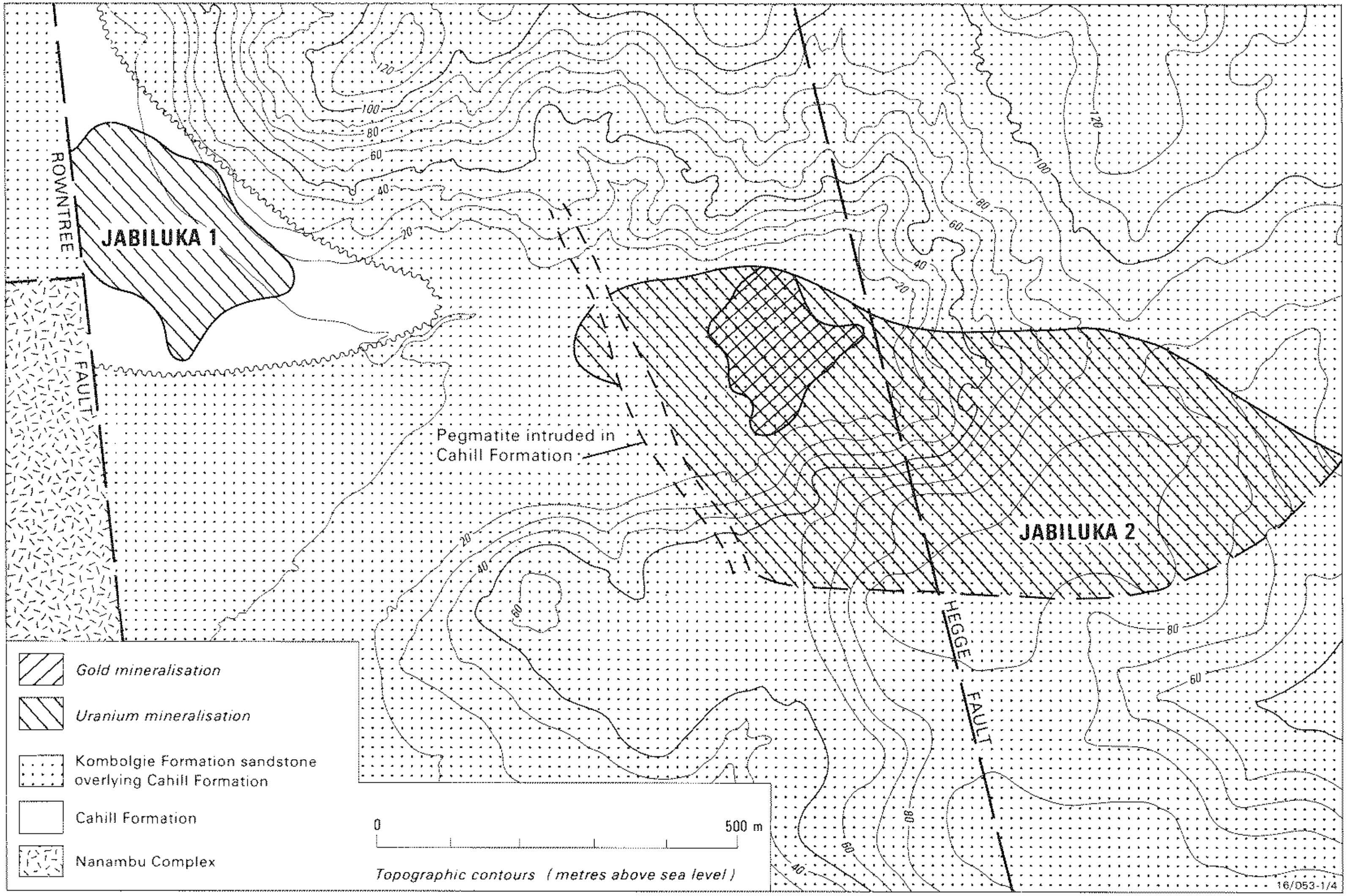

Fig. 4 Solid geology of Jabiluka 1 and 2 uranium-gold deposits (adapted from revised, unpublished data, by courtesy of Pancontinental Mining Ltd).

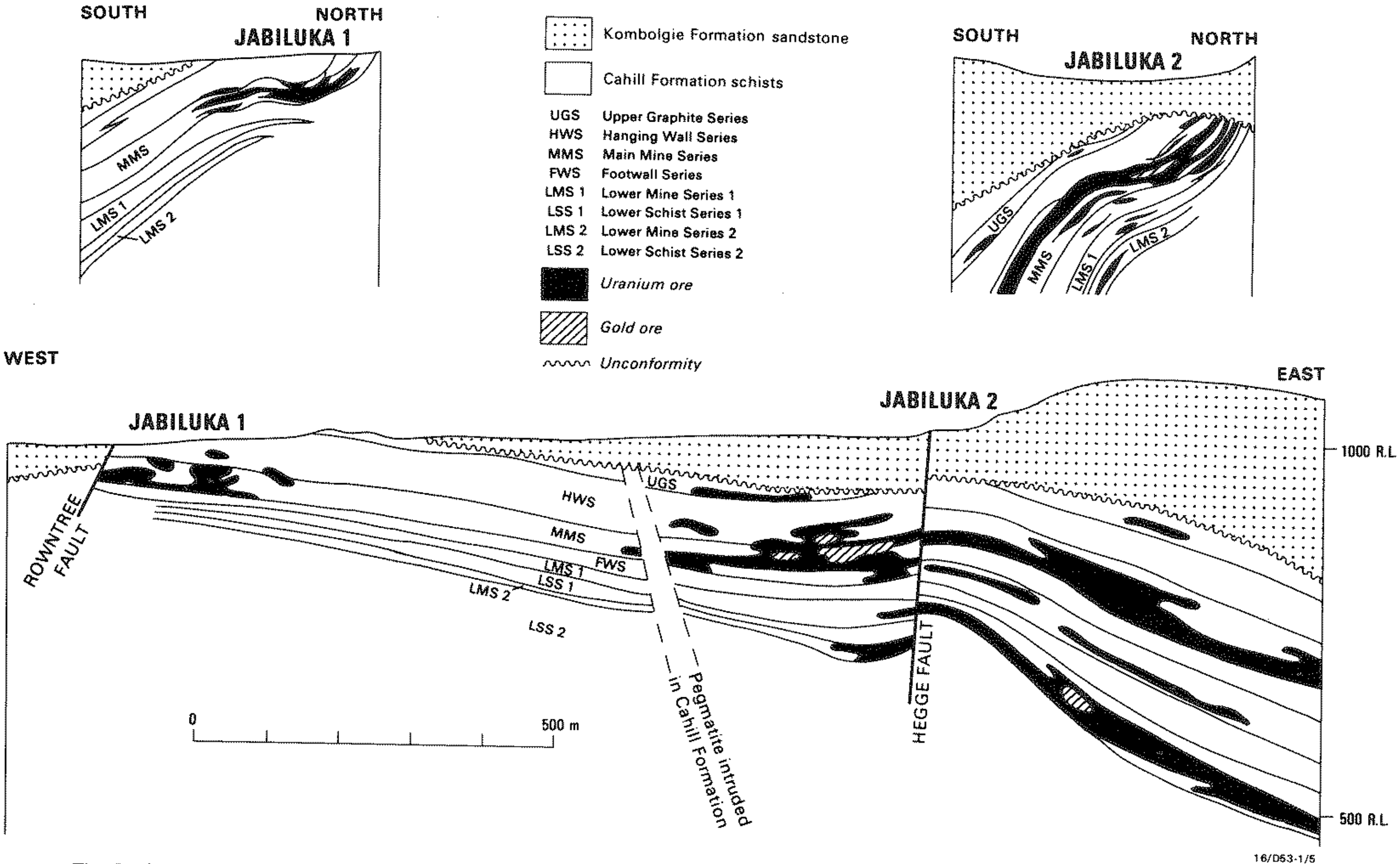

Fig. 5 Generalised long-section and cross-sections of Jabiluka 1 and 2 uranium-gold deposits (adapted from revised, unpublished data, by courtesy of Pancontinental Mining Ltd).

ALLIGATOR are generally poorly exposed and some are indicated only by photo-lineaments. The major fault trends are northwest and about north. The Nanambu Complex is partly fault-bounded by the north-trending faults.

Some faults show displacements of up to 20 m for the latest movements affecting the overlying Carpentarian strata, but do not affect Mesozoic rocks. The rectilinear joint pattern in the Kombolgie Formation probably developed during slight tilting or downwarping to the southeast, of the McArthur Basin succession.

The Kombolgie Formation is in places fault-bounded, although the actual fault contacts are rarely exposed.

ECONOMIC GEOLOGY

Uranium ore deposits

The Jabiluka 1 and 2 uranium deposits lie on the southern edge of the Sheet. Published reserves figures are listed in Table 4. The deposits are described by Hegge (1977) and Hegge & others (1980), and Eupene (1978) has made stratigraphic comparisons between them and other uranium deposits of the Alligator Rivers Uranium Field. The deposits are elongated west-northwest in the lower member of the Cahill Formation, which strikes east under the Kombolgie Formation. The Jabiluka 1 deposit is exposed adjacent to the Arnhem Land Escarpment, but the higher-grade and much larger Jabiluka 2 deposit (further east, and separated by 300 m of unmineralised schist and carbonate) is concealed by up to 220 m of Kombolgie Formation sandstone (Figs. 4 and 5).

The primary uranium ore is uraninite, mostly pitchblende, found as both disseminated and massive (colloidal and vein-type) forms. The deposits are generally conformable with the host lithologies and are tabular to basin-shaped, each composed of a number of brecciated mineralised lenses in muscovite-quartz-chlorite schist and massive chlorite rock, with carbonate rock and graphitic schist. Carbonate rock forms lenses up to 20 m thick between the two deposits, but in the orebodies themselves it is present only in places as thinner bands, and is commonly replaced by chert. In places above-average uranium grades are associated with carbonaceous horizons. Brecciated material is commonly cemented by chlorite-quartz-sulphide-carbonate rock. Sulphides — mainly pyrite with lesser chalcopyrite and galena — are commonly present throughout the orebodies. Chloritisation is most apparent in sheared zones, where hematitisation is also frequently associated with uranium mineralisation. The more siliceous zones are commonly sericitised. The host rocks and ore zones are intruded by Nanambu Complex pegmatite, and Zamu Complex amphibolite forms two concordant bodies in the host rocks below Jabiluka 1. The Jabiluka 2 deposit contains gold, mainly in breccia zones and in graphite-chlorite schist in the upper section of the mine sequence. The gold orebody is elongated northwest. Gold distribution appears unrelated to uranium distribution (Fig. 4).

The host rocks of the Jabiluka 1 and 2 deposits form basement highs against which basal beds of Kombolgie Formation sandstone and conglomerate thin or pinch out (L. Curtis, pers. comm.). The sandstone is chloritised and hematitised above the orebodies, and alteration is most intense in the crest area of the basement high.

Three modes of formation — syngenetic, epigenetic, and supergene — have been proposed by various workers for the Alligator Rivers uranium deposits, and have been reviewed in general terms by Dodson & others (1974), and more specifically by Taylor & Rowntree (1980). Proximity of the deposits to the regional unconformity at the base of the Carpentarian, both vertically and also laterally in relation to its outcrop, suggests at first glance the possibility of supergene concentration, but the apparent relevance of the unconformity to mineralisation has diminished as mapping and exploration have progressed (Dodson & others, 1974; Ryan & others, 1976). It is now generally accepted that thinner superficial cover over Early Proterozoic rocks near the escarpment at the edge of the Carpentarian units has facilitated more successful airborne and ground exploration in these areas, compared with areas

TABLE 4. DEMONSTRATED IN-SITU RESOURCES OF URANIUM AND GOLD AT JABILUKA 1 AND 2 (Pancontinental Mining Ltd, 1979)

	Ore (Mt)		*Grade*		*Contained metal (t)*	
	U_3O_8	*Au*	U_3O_8 (%)	*Au (g/t)*	U_3O_8 (%)	*Au (g/t)*
Jabiluka 1	1.3		0.25		3 400	
Jabiluka 2	52	1.1	0.39	10.7	204 000	11.8

where Cainozoic cover is thicker or the Kombolgie Formation is present (the Jabiluka 2 deposit was discovered by 'blind' drilling through the Kombolgie Formation along the strike of the host rocks of Jabiluka 1).

Throughout the Pine Creek Geosyncline uranium is almost invariably found in carbonaceous and calcareous host rocks. In the Alligator Rivers Uranium Field all major and most minor uranium mineralisation is stratabound in the Cahill Formation, and is generally near the base of the formation where background uranium values are slightly higher (Table 2) and carbonaceous and calcareous strata are common. This association demonstrates that carbon and/or calcareous rocks may have played a role in the location of uranium, and is an important clue to ore genesis.

Carbon may have fixed uranium in reducing conditions either during diagenesis or after lithification from surface and connate water and circulating groundwater. Uranium may have been concentrated peripherally to, or within open fractures in, the carbonate rocks by adsorption onto clays (Ferguson & others, 1980) or by dewatering; Crick & Muir (1980) suggest that brines released during dewatering of the evaporites, later replaced by carbonate, were important ore-forming fluids. The size and grade of the uranium deposits suggest that the ore-forming process took place over a long period, as is also suggested by the range of uranium isotopic dates from 1700 to 900 m.y. (Hills & Richards, 1976).

Each major deposit is in host rocks which are extensively altered by iron and magnesium metasomatism and containing areas or zones of brecciation with one or a number of faults or shears. Page & others (1980) suggest the alteration took place about 1610 m.y. ago, i.e. after deposition of the Kombolgie Formation; this is consistent with the chloritisation of downfaulted blocks of Kombolgie Formation sandstone in the Ranger 1 deposit in CAHILL reported by Eupene & others (1975). Carbonate solution and collapse have been suggested as a brecciation mechanism (Eupene & others, 1975); however, Crick & Muir (1980) suggest that the breccias were formed on the flanks of evaporite diapirs and that brines formed during dewatering of the evaporites caused the magnesium metasomatism common to each deposit.

The details of ore genesis thus are far from resolved, but regional observations suggest stratabound control of mineralisation, and the uranium/carbon or uranium/carbonate association strongly suggests that the orebodies were formed partly syngenetically. Epigenetic processes appear necessary to produce such high-grade deposits. Giblin (1980) showed that repeated cycling of Eh values makes possible a high degree of uranium enrichment by adsorption of soluble uranium species onto clay. Stratigraphic and structural breaks may have provided pathways for mineralising and metasomatising fluids, thus explaining the association of both chloritisation and uranium mineralisation with unconformities and faults. Such migration, however, has not resulted in any significant movement of uranium away from the lower part of the Cahill Formation.

Uranium prospects

Uranium prospects in EAST ALLIGATOR are mainly in the lower member of the Cahill Formation and in the Nanambu Complex, with a few in the Koolpin(?) Formation. Most were detected as airborne radiometric anomalies, and follow-up exploration has ranged from ground radiometrics and some auger drilling to extensive costeaning and grid rotary and angled diamond drilling. The most significant prospect is the Arrarra prospect (670491). Details of exploration and geology of the prospects are given in relevant company and Australian Atomic Energy Commission (Exploration Division) reports held by the Northern Territory Department of Mines & Energy, Darwin.

Arrarra prospect

Secondary uranium mineralisation occurs in chloritised quartz-sericite schist faulted against Oenpelli Dolerite, about 35 km north of Jabiluka (Hegge & others, 1980). Mineralisation appears to be concentrated at the base of a palaeoweathering horizon below the Kombolgie Formation, which overlies the host rocks and the Oenpelli Dolerite at the prospect. The fault also downthrows the Kombolgie Formation against the Oenpelli Dolerite, and this and other nearby faults coincide in places with radiometric anomalies and appear to truncate the mineralised zones. Host rock types are similar to those of the Cahill Formation, although extensive carbonaceous schist in the area may indicate that these rocks are part of the Koolpin Formation.

Gold

The only known economic occurrence is in the Jabiluka 2 deposit, where reserves are 529 000 tonnes at 15.3 g/t. The gold deposit lies in the western part of the uranium orebody, and is about 100 by 150 m in plan; economic intersections average 2 m thick and range up to 12 m. The gold occurs primarily in breccia zones in graphite-chlorite schist of the lower member of the Cahill Formation (Hegge, 1977).

Minor gold occurs in association with arsenopyrite in magnetite schist at the Ranger 43 prospect 20.5 km north-northeast of Munmarlary homestead (G.S. Eupene, pers. comm.).

TABLE 5. SUMMARY OF GEOLOGICAL HISTORY

Age	*Deposition*	*Igneous events*	*Tectonic events, setting*	*Metamorphism*	*Remarks*
RECENT	Aggradation of valleys and swales		Coastal emergence ~ 7 m; dissection of Koolpinyah Surface		Oxidation of shallow uranium ore zones probably triggered by fluctuating water table
PLEISTOCENE	Aggradation of major valleys; dissection of Koolpinyah Surface; minor deep weathering		Dissection of Koolpinyah Surface		
MIOCENE-PLIOCENE	Deep weathering and lateritisation, followed by deposition of unconsolidated sand in coalescing fans and further deep weathering and lateritisation to form Koolpinyah surface				Modification of Cretaceous sea cliffs by subaerial erosion to produce Arnhem Land escarpment
CRETACEOUS-MIDDLE MIOCENE	Exhumation of Early Proterozoic hills; prolonged deep weathering and lateritisation of lowland areas; local mechanical weathering and redeposition of sand from Kombolgie Formation		Retreat of seas to beyond present coastline		
CRETACEOUS	Sand and silt (Bathurst Island Formation)		Epeirogenic or eustatic rise in seal-level		Paralic to epicontinental sedimentation during transgression (bounded by sea cliffs?)
			REGIONAL UNCONFORMITY		Extended erosional period; peneplanation of Carpentarian rocks
ADELAIDEAN					Intrusion of phonolite dykes at 1320 m.y., and dolerite at 1200–1370 m.y. east and south of Sheet area
CARPENTARIAN			Uplift; extensive faulting and jointing of Kombolgie Formation & reactivation of some basement faults; displacements of up to 100 m	Low-grade metamorphism and metasomatism of Jabiluka uranium deposit and surrounding rocks at 1610 m.y.	
	Quartz sand; minor gravel and silt (Kombolgie Formation)				Braided alluvial fan system with northwesterly provenance; interbedded volcanics to southeast dated at 1648 m.y.
			REGIONAL UNCONFORMITY		Major erosional period; removal of 1–2 km of Early Proterozoic rocks to exhume Oenpelli Dolerite
1688 m.y.		Intrusion of differentiated olivine dolerite of Oenpelli Dolerite			During extended post-orogenic period of peneplanation from approx. 1800 to 1650 m.y.; intruded at approx. 1–2 km depth

EARLY PROTEROZOIC	1800–1870 m.y.				Complex deformation involving at least 4 fold episodes (2 isoclinal); late, near-vertical, mainly northerly faulting	Regional metamorphism up to staurolite-almandine subfacies; formation of Myra Falls Metamorphics by metamorphic differentiation of Early Proterozoic sediments; accretion of parts of Kakadu Group with Archaean granitoid mass to form Nanambu Complex	Degree of metamorphism & deformation extrapolated from south of Sheet area; pre-orogenic (1870 m.y.) granite intrusion east of Sheet area; post-orogenic (1800 m.y.) granite intrusion west, south, & east of Sheet area
	1940 m.y.			Intrusion of quartz dolerite sills and minor dykes of Zamu Dolerite	Possible period of non-deposition		
		2200(?)–1940 m.y. Deposition	Silt: mud: pyritic, carbonaceous, siliceous silt (Koolpin Formation)				Restriction to Cannon Hill area could suggest probably non-deposition elsewhere in Sheet area
					UNCONFORMITY		Postulated by extrapolation from southwest of Sheet area
			Labile sand, minor silt and mud (Nourlangie Schist)		Probable mild folding at close of deposition		Probable correlative of Wildman Siltstone west of Sheet area; may also contain some metamorphosed Koolpin Formation and Fisher Creek Siltstone
					POSSIBLE LOCAL UNCONFORMITY		Inferred by truncated photo-trends east of Koongarra (CAHILL)
			Muddy sand and silt, calcareous and carbonaceous near base (Cahill Formation)		Stable shelf adjoining moderately mature hinterland; intertidal to supratidal (lower member); open marine (upper member)		Probable syngenetic concentration of uranium in black shales in intertidal to supratidal environment
			Sand, commonly feldspathic (Kakadu Group)		Youthful hinterland		Proximal sediments thinning away from provenance
					UNCONFORMITY		
	2200?–2500 m.y.				Erosion of granite basement; removal of Archaean cover rocks		No known preserved Archaean cover rocks
					UPLIFT		
ARCHAEAN 2500 m.y.				Crystallisation of granite basement			

Construction materials

Surface and near-surface accumulations of pisolitic laterite in the Lowlands are commonly exploited for dirt road construction.

Water

Bores supply potable water for stock in the southwest of the Sheet area, in the Munmarlary Quartzite and Nanambu Complex (Christian & Aldrich, 1977). Bores in and near the Floodplains yield water too salty for stock. The drainage systems are recharged each wet season and the larger billabongs have been regularly used to supply stock and human requirements all the year round.

GEOLOGICAL HISTORY

Most deposition (Table 5), and virtually all of the tectonism, metamorphism, and igneous intrusion took place in the Early Proterozoic.

Overall, Early Proterozoic deposition represents a single sedimentary cycle punctuated by mild tectonic events. Juvenile arkose and feldspathic sandstone (now leucogneiss and quartzite) of the Kakadu Group were laid down on Archaean granite basement and were succeeded by the Cahill Formation, predominantly sandstone and siltstone. Black shale and limestone at the base of the Cahill Formation probably were deposited in shallow-marine to supratidal conditions, as suggested by pseudomorphs of magnesite and chert after gypsum with anhydrite inclusions preserved in the present-day metamorphic equivalents of the limestone. The monotonous pelitic assemblage of the Nourlangie Schist indicates little change in the offshore conditions of sedimentation. The most significant interruption to Early Proterozoic sedimentation took place before Koolpin Formation deposition, inferred from unconformable relationships outside the Sheet area: the maturity and homogeneity of the fine-grained rocks of the Koolpin Formation suggest peneplanation preceded Koolpin sedimentation. Restriction of this formation in EAST ALLIGATOR to the Cannon Hill area may, however, indicate that subsequent deposition was not continuous in the Alligator Rivers region.

Sills of Zamu Dolerite were emplaced at 1940 m.y., at or near the close of Early Proterozoic deposition. Intrusion of granite in OENPELLI and GOOMADEER further east at 1870 m.y. is envisaged as the initiation or perhaps the triggering mechanism of the polyphase folding and associated metamorphism which terminated Early Proterozoic deposition (Page & others, 1980). Post-orogenic granites emplaced 1800 m.y. ago outside the Sheet area post-date this regional tectonic event. Faulting was later and probably mainly post-granite emplacement, although some accompanied granite emplacement. Most of the quartzofeldspathic sediments of the Kakadu Group and some of the Archaean granite were transformed to leucocratic and mesocratic gneiss to form a mantled gneiss dome (Nanambu Complex). East of the East Alligator River, metamorphic differentiation advanced to a stage at which it is now impossible to correlate the metamorphic rocks with their sedimentary precursors (Myra Falls Metamorphics).

An erosional period of about 150 m.y. followed the close of orogenesis; during this period two large bodies of Oenpelli Dolerite — an undulating sheet and a probable inclined dyke — were intruded at 1690 m.y., mainly at a depth of 1–2 km. Between the time of dolerite intrusion and onset of Carpentarian deposition at about 1650 m.y., erosion removed this 1–2 km of metamorphics to exhume parts of the lopoliths.

The braided alluvial fan sandstone of the Kombolgie Formation was deposited from a northerly to northwesterly provenance in mid-Carpentarian time. Interbedded volcanic and sandstone units not present in EAST ALLIGATOR may have once been laid down in the area but, if so, have since been removed by erosion. The main faulting of the Kombolgie Formation possibly preceded retrogressive metamorphism and metasomatism of the Jabiluka orebody and surrounding rocks at 1610 m.y., as inferred by chloritised downfaulted blocks of Kombolgie Formation sandstone in the Ranger 1 orebody in CAHILL.

A very long stable-to-erosional period followed for about 1400 m.y., during which minor phonolite and dolerite were emplaced outside the Sheet area about 1370, 1320, and 1200 m.y. ago. Carpentarian rocks were peneplaned and Cretaceous seas eroded much of these to expose Early Proterozoic rocks, exhume the pre-Kombolgie land surface, and form sea cliffs in Kombolgie Formation sandstone, at the same time depositing paralic to epicontinental sediments. None of the generally unconsolidated Cainozoic sediments are recognisably marine, but the dominance of marine fauna in floodplain archaeological sites is consistent with incursion during Pleistocene to middle Holocene high-stands. Sea level has been constant for the last 7000 years. The dominant forces that have moulded today's landscape were chemical weathering to produce laterities, sheet washing of sands derived from the Kombolgie Formation, and 'cut and fill' modification by repeated erosional and aggradational cycles.

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