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# SEDIMENTARY ENVIRONMENT AS A CONTROL OF URANIUM MINERALIZATION IN THE KATHERINE-DARWIN REGION, NORTHERN TERRITORY.

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## ABSTRACT.

A dominant and widespread sedimentary control of deposition of uranium is recognised in the Katherine-Darwin region of the Northern Territory of Australia. The lithological association is described and the environment of sedimentation and its effect on the deposition of uranium are suggested.

Appreciation of this control suggests a means of increasing the rate of discovery of uranium prospects in the Northern Territory and indicates a lithological association which may repay investigation in other areas.

## INTRODUCTION.

Since 1952, geologists who have studied the uranium occurrences in the Rum Jungle area have realized that a particular formation, the "quartz-hematite breccia", occupies a position in the sedimentary sequence very close to the more important uranium occurrences in that area. Various explanations of the origin of the "quartz-hematite breccia" were advanced, but no agreement on this question was ever reached.

It was further realised that the Rum Jungle sequence was probably the lowest stratigraphically in the succession of geosynclinal sediments called by Noakes (1949) the Brocks Creek Group. In 1952, a synthesis by B. P. Walpole (unpublished) of the known regional geology of the Katherine-Darwin region led him to the opinion that a repetition of the Rum Jungle sedimentary environment could be expected in the South Alligator River area. During a brief reconnaissance of this area in 1953, uranium mineralization was discovered in the Coronation Hill/Koolpin Creek area, but no stratigraphical correlation was then established between this area and Rum Jungle. As a consequence of these discoveries, however, companies have taken an increasing interest in the area, and several new and potentially important discoveries have been made.

In 1954, J. Sleis of the North Australia Uranium Corporation recognized the similarity between the "quartzite breccia" in the Sleisbeck area and that at Rum Jungle and as a result discovered the "Sleisbeck" uranium prospect.

In August and September of 1954, geologists of the Bureau of Mineral Resources engaged on regional mapping in the Sleisbeck area recognized that the "quartzite breccia" was actually a silicified limestone breccia. The descriptive name "quartzite breccia" was replaced by "silicified limestone breccia", abbreviated in the field to "S.L.B.".

In October 1954 the authors with Messrs. D. A. White and K. G. Smith, also of the Bureau Mineral Resources, inspected radioactive prospects at Sleisbeck, along the valley of the South Alligator River, and in the Coirwong Creek locality. The silicified limestone breccia was definitely established as a biohermal reef rock. A constant association between uranium mineralization and the biohermal limestone and limestone breccias was recognized, although the mineralization was not confined to these reef-rock types.

Objective demonstration of the fundamental reasons for the presence of metalliferous minerals in orebodies frequently proves almost impossible, especially if the possibility of sedimentary deposition (either detrital or precipitant) is allowed as an alternative to hydrothermal deposition in a "favourable bed". It seems logical to assume that, if mineralization is concentrated in a particular sedimentary environment over a wide area and in a variety of structural and metamorphic-igneous conditions, the sedimentary environment may be the controlling factor in the genesis of the mineralization in its present position. If, in addition, the lithological association indicates an environment which could favour the precipitation of metallic ions from solution, it is not unlikely that the metals were deposited as sedimentary materials with the sedimentary rocks in which they are found. Such metals, of course, may be further concentrated by diagenetic or orogenetic processes without losing their fundamental syngenetic characteristics, although such concentration will also produce characteristics which may be taken to indicate an epigenetic origin.

## REGIONAL GEOLOGY.

In the Katherine-Darwin region, geosynclinal sediments of Lower Proterozoic age are intruded by granite and are unconformably overlain by sedimentary rocks of Upper Proterozoic, Middle Cambrian, and Cretaceous ages.

The main rock units recognized are listed below, although only the Lower Proterozoic rocks are considered.

| | | |
|---|---|---|
| Cretaceous | Mullaman Group | |
| | UNCONFORMITY | |
| Middle Cambrian | Daly River Group | |
| | UNCONFORMITY | |
| Upper | Mt. Callanan "Beds" | |
| Proterozoic | UNCONFORMITY | |
| | "A.B.C. Group" | |
| | UNCONFORMITY | |
| | Granitic intrusion | |
| Lower | Brocks | (Burrell Formation |
| Proterozoic | Creek | (Knights Formation |
| | Group | (Masson "Beds" - Rum |
| | | (Jungle "Beds" |

The Lower Proterozoic sediments, called Brocks Creek Group by Noakes (1949), occupy a belt with a maximum width of 120 miles trending south-east from Darwin to Maranboy, a distance of about 200 miles. Recent work (1954) has resulted in the subdivision of the Brocks Creek Group into the units listed above. The lithology of the two younger formations - Burrell Formation and Knights Formation - and their outcrop position within the geosyncline indicate that they are trough-type sediments. These formations overlie the Masson "Beds" in the east and the Rum Jungle "Beds" in the north west. (Plates 1 and 3). The Masson "Beds" and the Rum Jungle "Beds" include sediments of both shelf and slope facies.

The sediments of the Brocks Creek Group are strongly folded in the central part of the geosyncline, but in general show little regional metamorphism. The zone of strongest deformation appears to be in the Pine Creek/Union area. North and east of this area the fold structures broaden out to domes and basins with contorted and fractured zones marking axes of regional pitch-change between adjoining domes. To the east, the fold structures flatten out, and between the Mary and South Alligator Rivers the beds commonly dip at angles as low as $15^{o}$ to $30^{o}$. The zone of change from a belt of severe orogenic folding to one of minor folding is marked by strong block faulting (the South Alligator fault zone); it coincides with a thinning out of the Knights and Burrells Formations and with the main area of outcrop of the Masson "Beds".

The source area of the sediments of the Brocks Creek Group and the basement on which they were deposited have not yet been positively identified, although a garnetiferous granite (Nanambu Granite) which crops out east of the South Alligator River (Plate 1) may be part of this older terrain. The western edge of the outcropping rocks of the Brocks Creek Group has not been investigated in any detail.

Granite intrudes the Lower Proterozoic sediments. In the south, the Cullen Granite forms the main intrusive mass. The long axis of this granite strikes north, and the body as a whole is discordant. Granitic intrusions to the north occupy the cores of domal structures and are more concordant.

## URANIUM DEPOSITS.

Most uranium occurrences found to date in the Katherine-Darwin region are located in rocks belonging to the Brocks Creek Group. Some minor occurrences are known in younger rocks: the "A.B.C. Prospect" consists of a small body of secondary uranium minerals in volcanics of the A.B.C. Group, and several small uranium occurrences which have been found in shears within the Cullen Granite.

The deposits in the Brocks Creek Group are mainly confined to the basal members of the succession and are concentrated in the Rum Jungle and South Alligator River areas. The distribution is indicated on Plate 2. Nearly all these deposits are closely associated with silicified limestone (reef) breccias or in sediments of off-reef facies - siltstones and carbonaceous shales with intercalated thin limestone lenses. In some places the original bioherm is still evident as a discontinuous line of hills; in others only the reef breccia is present. In general, however, the line of reefs can be traced, as in the South Alligator area, over a considerable distance, even though the reefs themselves were probably stratigraphically discontinuous.

A brief account of the geology of some of the uranium occurrences associated with the silicified limestone breccias or the off-reef silts is given below.

## GEOLOGY OF URANIUM PROSPECTS.

### Sleisbeck.

At Sleisbeck, secondary uranium minerals are present in the rock on either side of the nearly vertical junction between soft dark quartz siltstone and hard reddish silicified limestone breccia.

The outcropping breccia forms a discontinuous line of hills. The discontinuity of outcrops probably reflects the stratigraphical discontinuity of the breccia.

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Uranium mineralization has been proved on the south side of the vertical silicified limestone breccia, and has also been indicated on the northern side. Radiometric anomalies appear to be related, in part at least, to the areas where the cover of rubble from the hill of breccia is very thin or absent. The secondary uranium mineralization is mainly within the siltstone, but is also within the silicified limestone breccia near its boundary with the siltstone. The contact between the two rock types is sheared.

### Koolpin Creek.

Silicified limestone breccia, very similar in lithology to that at Sleisbeck, forms a high ridge to the east of the South Alligator River. Uranium mineralization has been found near the edge of outcrop of the breccia. The adjoining rock is not exposed.

Nearby, uranium mineralization is found in siltstones and in laminated siltstones with thin chert bands.

### Coirwong Creek.

Radioactivity has been found in a ridge of silicified limestone breccia with a sharp synclinal structure. North of this ridge is another ridge where the silicified limestone is little brecciated. This is interpreted as having been a bioherm and as representing the rock type from which the limestone breccia was formed. To the north of this bioherm is another ridge of thin-bedded and slumped silicified limestone and chert, which may be the back-reef facies of the bioherm.

The reef limestone member of varying facies is known to crop out in a typical discontinuous manner for at least 60 miles northwest from Coronation Hill (see sketch map).

### Rum Jungle.

Silicified limestone breccia, very similar in lithology to that at Sleisbeck and along the South Alligator River, crops out around the Rum Jungle and Waterhouse granites.

Whites uranium orebody occurs between a synclinal remnant of silicified limestone breccia (the "quartz-hematite-breccia" of Sullivan and Matheson, 1952) and a lower anticlinal limestone bed, in carbonaceous shale and siltstone.

Dysons orebody occurs in altered lenticular calcareous rocks and siltstones adjacent to outcropping silicified limestone breccia. The structure is synclinal and could be explained as a compactional syncline resulting directly from the formation of the now altered limestone breccia.

## THE SILICIFIED LIMESTONE BRECCIA.

The silicified limestone breccia (for which the field contraction "S.L.B." is now in common usage) or "quartz-hematite breccia" or "quartzite breccia" as it has been called previously, looks like an arenaceous rock but consists predominantly of fine-grained (0.1 mm) saccharoidal quartz with disseminated very-fine-grained hematite in a large part of the rock; some patches, strings, and small lenses of hematite, patches of detrital quartz sand of grain-size 0.5 to 2 mm., a few rounded pebbles of quartz and quartzite of about $\frac{3}{4}$" dia.

Although almost the whole of the rock is composed of uniformly fine-grained saccharoidal quartz the rock appears to consist of angular white tetrahedral and platy fragments up to 9 inches across of an apparently granular reddish rock; and a matrix, constituting 20 to 80% of the rock, of the same material. The "grains" of this reddish rock are $\frac{1}{4}$ to $\frac{1}{2}$ mm. in diameter. The whole rock is cut in random and irregular fashion by white veins $\frac{1}{8}$" to 1" thick consisting also of white fine-grained saccharoidal quartz but showing relict comb-structure.

In some places bedding is obvious but irregular, in others the rock is massive.

Rock dominantly of this type was seen at Sleisbeck, Koolpin Creek, Coirwong and Rum Jungle.

### Origin.

Bioherms, from which limestone breccia is formed by the abrasive action of waves, can grow only in clear, well-aerated shallow water. They commonly establish themselves at the edge of the continental shelf (as barrier reefs) and around islands (as tolls).

Although the breccia consists predominantly of fine-grained saccharoidal quartz, the relict texture, which is most obvious on weathered surfaces but still recognizable on broken surfaces, indicates that it had a detrital origin. The appearance of weathered surfaces is strikingly similar to that of the limestone breccias of the Devonian of the Fitzroy Basin, Western Australia, where they are found in obvious association with limestone bioherms. The white tetrahedral fragments were originally fragments of previously formed biohermal limestone from the reef, the white platy fragments are from layers of calcite precipitated on or within the reef as surface crusts or veins, and the granular rock is calcarenite produced by abrasion of the limestone.

The detrital quartz sand and pebbles were terrigenous material washed into the reef environment. The white irregular veins are typical of the veins of calcite that fill solution or slumping tension cracks in a reef breccia. A small amount of hematite is characteristic of reef limestone breccias.

In the South Alligator and Rum Jungle areas the reef material is completely silicified, although bedded limestone which crops out in the vicinity is not. This selective silicification is considered by Öpik (personal communication) to be due to the relatively higher porosity of the reef material, compared to the bedded limestone, which allowed the calcite within the reefs to be replaced. The conditions necessary for such replacement to take place are simple and require only an inherently porous calcareous rock such as a biohermal limestone and an abundant supply of silica. The presence of chert bands in the off reef facies and the wide distribution of cherts in the Knights Formation indicate that silica was in fact plentiful.

Significance.

At present (November, 1954) twelve prospects are known in the South Alligator/Sleisbeck area, all of which are closely associated with the reef limestones or the immediate off-reef facies. Most of these are recent discoveries, and there is every reason to believe that more discoveries will be made in this area in the future. Several deposits are known in a similar environment in the Rum Jungle area. In addition to these, two separate thorium occurrences in the Ella Creek area are close to a silicified limestone breccia.

The coincidence of uranium (and thorium) occurrences with reef facies in the Katherine-Darwin area is thus obvious.

This association between mineralization and the sedimentary environment favoured by bioherms is present in the Mt. Marumba region of the Northern Territory, where lead-zinc deposits occur in the same facies as Collenia bioherms.

The writers consider that a similar sedimentary environment is present in the Mt. Isa metalliferous province in Queensland; R. Stanton, Sydney University (Personal communication) has noted a close association between pyrrhotite and copper mineralization and biohermal limestones in the Burraga district of N.S.W.; E. A. Rudd (personal communication) has informed the writers that similar conditions prevail in the Bonne Terre deposits in the Tri-State District of the U.S.A.; Garlick (1953, p.13) has stated:

> "In the Katanga the mineralization is intimately associated with organic activity. The "Roche Siliceuse Cellulaire" is an algal reef of the Collema type and occurs between the cupriferous laminated siliceous shales below and the dolomitic shales above."

The biohermal limestones and reef breccias mark a sedimentary environment, commonly at the edge of the continental shelf, where the physical character of the sea water, its salinity, temperature, pH, aeration, turbidity, etc. may vary rapidly over short distances. This zone of chemical and physical change may be made even narrower by the establishment of a reef, as the ocean water then meets the water containing land-derived material only over the reef itself and at channels through the reef.

Thus the bioherm may be regarded as an indicator of a marine zone or environment of sedimentation where the physical and chemical character of sea water changes rapidly. Such a zone may be euxinic and reducing processes therefore operative. The solubility of many materials will be decreased by the change in conditions and they will be precipitated; and if such materials flow continuously into the zone (such as, for instance, land derived material, either in suspension or in solution, passing seawards) the precipitate may accumulate selectively within the zone even if the initial concentration in solution or suspension is extremely low.

Garlick (1953) has indicated this sort of marine precipitation as the likely cause of the zoning of the sulphides of the Northern Rhodesian Copperbelt.

Bioherms and the rocks associated with them are easily recognized indicators of this environment, but other criteria may also be used. These include:-

(a) Marked change in thickness of formations, especially if restricted to a linear zone

(b) Change in lithology from shelf type (quartz sandstone, calcarenite, coquinite, quartz greywacke) to slope type (cyclic laminated siltstone-shale, calcilutite, quartz greywacke) or trough type (greywacke, chert, bedded dense limestone, shale), in some places emphasized by a linear belt of sandstone, conglomerate or reef-limestone.

(c) Linear belt of anticlinal folding and thrust faulting severe compared with the folding (or lack of it) on either side; or the zone of change from a belt of severe (orogenic) folding to one of minor folding and block faulting in rocks of the same general age.

(d) Geophysical indication of marked change of total thickness of sediments, along a linear zone. This may by sufficiently abrupt to simulate a large fault but will commonly indicate throw in the opposite direction from that indicated by surface faults in the same zone.

(e) In fossiliferous rocks, the zone of change from neritic organisms to infra-neritic or deep-sea organisms.

Dr. Breyer of Sydney University (personal communication) considers that micro-organisms possibly act as the precipitating agents of metals in such an environment. Evidence that marine life existed in Lower Proterozoic times is furnished by the bioherms themselves and by the remnants of algal fossils within the reefs.

The upwelling of nutrient oceanic water at the edge of the shelf is well-established as the cause of abundant growth of micro-organisms. This may well be the dominant cause of the precipitation of syngenetic minerals in the area of change from shelf to off-shelf facies. With a biological control, metals such as uranium, lead, iron, copper, nickel, zinc, vanadium, and cobalt, each of which can act as a heavy poison to the micro-organisms, may be precipitated. The micro-organisms could possibly act both as a precipitant and as a "protective colloid" to the metallic substances. Each individual micro-organism could attract only a limited number of metallic ions, depending on its electrostatic charge, and the tendency would therefore be for minerals deposited in this way to have, initially, very fine grain-size.

The problem of the means of transport of the metallic ions and of the means of transformation of these ions to the mineral state are unsolved. Both living cells and proteins must be considered as well as the secondary chemical processes which take place when cells die. The problem is not simply one of the normal reduction potential for each particular metal, as once the metal is absorbed onto protein or living cell, the reduction potential is changed.

From field evidence, it would appear that much of the uranium in the Katherine-Darwin region was precipitated in the ionic form - possibly as the hexavalent uranyl ion which remained mobile until diagenetic or orogenetic processes caused it to move and concentrate in structural traps. Within the region, particular beds such as carbonaceous shales, siltstones, and greywacke siltstones are noticeably more radioactive than the surrounding rocks. No mineral which could cause the radioactivity has yet been identified. The authors consider that the radioactivity is produced by uranium or thorium attached to carbon derived from organic matter or to clay minerals.

The probability of a syngenetic origin of mineralization in the shelf-edge environment of the Pine Creek Geosyncline is supported by the occurrence of current bedded hematite in the Coirwong area, by the wide distribution of bedded and disseminated pyrite, and by the occurrence of fine-grained lead minerals, probably disseminated, in the Coirwong and Rum Jungle areas.

The sulphur-selenium ratio in pyrite at Rum Jungle is regarded by Edwards (1954) as indicating its epigenetic origin; on the other hand, Frankovich and Firman (1954) believed that the distribution of the pyrite indicates a syngenetic origin. The writers consider that both ideas may be correct because the pyrite examined by Edwards is probably from a different locality from that in the sedimentary beds described by Frankovich and Firman.

The extremely fine grain-size of the uranium and lead minerals in the Rum Jungle and South Alligator areas may perhaps be more easily explained if these minerals were of sedimentary biological deposition. The copper mineralization at Rum Jungle, which is generally regarded as belonging to a different metallogenetic generation, may well be epigenetic.

The significance of the evidence indicated by Erickson, Myers and Horr (1954) that "metals such as vanadium, nickel, copper, cobalt, molybdenum, lead, chromium, manganese, arsenic and uranium are consistently present - at some places in exceptionally high concentrations -" in the ash of crude oils is apparent when the sedimentary environment of the South Alligator area is compared with the shelf-edge environment of many important oilfields. The biohermal reef which is sometimes present in this environment may, because of its permeability, become a reservoir for oil or a favourable bed for metals both of which migrate from the source beds in the immediate vicinity.

The biohermal limestones, as well as marking and concentrating a particular set of physical and chemical conditions, are important in the structural sense. A pre-existing line of weakness is formed by the contrasting rigidity of the bioherm and the off-reef sediments. Later stresses would tend to find relief in such a zone; and in fact, from a brief study of the uranium occurrences in the Sleisbeck area, irregularities on the margins of the reef-rock and the ends of the discontinuous reef masses appear to be important loci for uranium mineralization. In the depositional irregularities of a reef, low-density muds and slimes are concentrated in hollows and behind prominences by wave and current action. Metallic elements deposited with these muds and slimes can therefore also be concentrated by original sedimentary processes.

Furthermore, the weight of the reef may produce a synclinal structure, by compaction, within the sediments on top of which the reef grows. Such a structure provides a pre-existing zone of weakness which might assist in directing and concentrating tectonic stress on that zone. The structure at Dysons orebody at Rum Jungle may have been produced in this way.

It is not proposed to deal with the granitic bodies of the Katherine-Darwin region in detail. Within the region, orebodies such as the tin lodes at Maranboy and the quartz-gold and quartz-cassiterite veins at Pine Creek and Burrundie are undoubtedly of hydrothermal origin.

Wherever structures can be seen to control uranium occurrences in the South Alligator area, they are younger than the granite. Furthermore, uranium occurrences at Edith River, which are within the Cullen Granite, are localised by a system of fractures younger than the granite itself. The writers consider that in some uranium occurrences, the metal has migrated from or within its source rock - either igneous or sedimentary rock - and has been concentrated in a favourable structural environment. Hubbert (1953) has shown how, when stress is applied to a medium, a zone of high potential energy is set up. In a rock medium the stress finds relief in zones of low potential energy such as fold crests and fractures. Fluids tend to move from the zones of high potential energy to those of low potential energy. The writers consider that this sort of potential energy gradient may cause movement of metallic ions from or within their original host rock to structural traps where they occur as orebodies.

The granites of the Katherine-Darwin region play no part in the origin of most of the uranium deposits; in the Edith River occurrences, the granite itself may be considered in the same way as a sediment containing, as an original constituent, uraniferous material which has later been concentrated by orogenic rather than introduced by epigenetic processes.

## CONCLUSIONS.

In the Katherine-Darwin region there is an empirical association between uranium mineralization and silicified limestone breccia, which should be important in directing prospecting and thus increasing the rate of discovery of uranium.

This empirical association is believed to be a reflection of a fundamental relationship between the sedimentary environment, indicated by the limestone breccia, and syngenetic uranium mineralization. Indications of syngenesis include:-

(a) The association of the mineralization with sedimentary rock types which indicate a particular sedimentary environment;

(b) the suitability of such an environment for the precipitation of metallic ions from solution;

(c) the extensive area over which mineralization is associated almost exclusively with a facies marked by the distinctive silicified limestone breccia;

(d) the absence of any obvious granitic source for hypogene uranium in the South Alligator area.

Precipitation of uranium and other metallic ions is postulated as likely in this environment where the physical properties of the sea water are most likely to change rapidly over a narrow linear zone, and where there is likely to be a concentration of plankton which are probably important in precipitating metallic ions.

In such a zone, concentration of metallic ions from solutions containing low concentrations of those ions may occur.

This relationship should be significant in other geosynclines.

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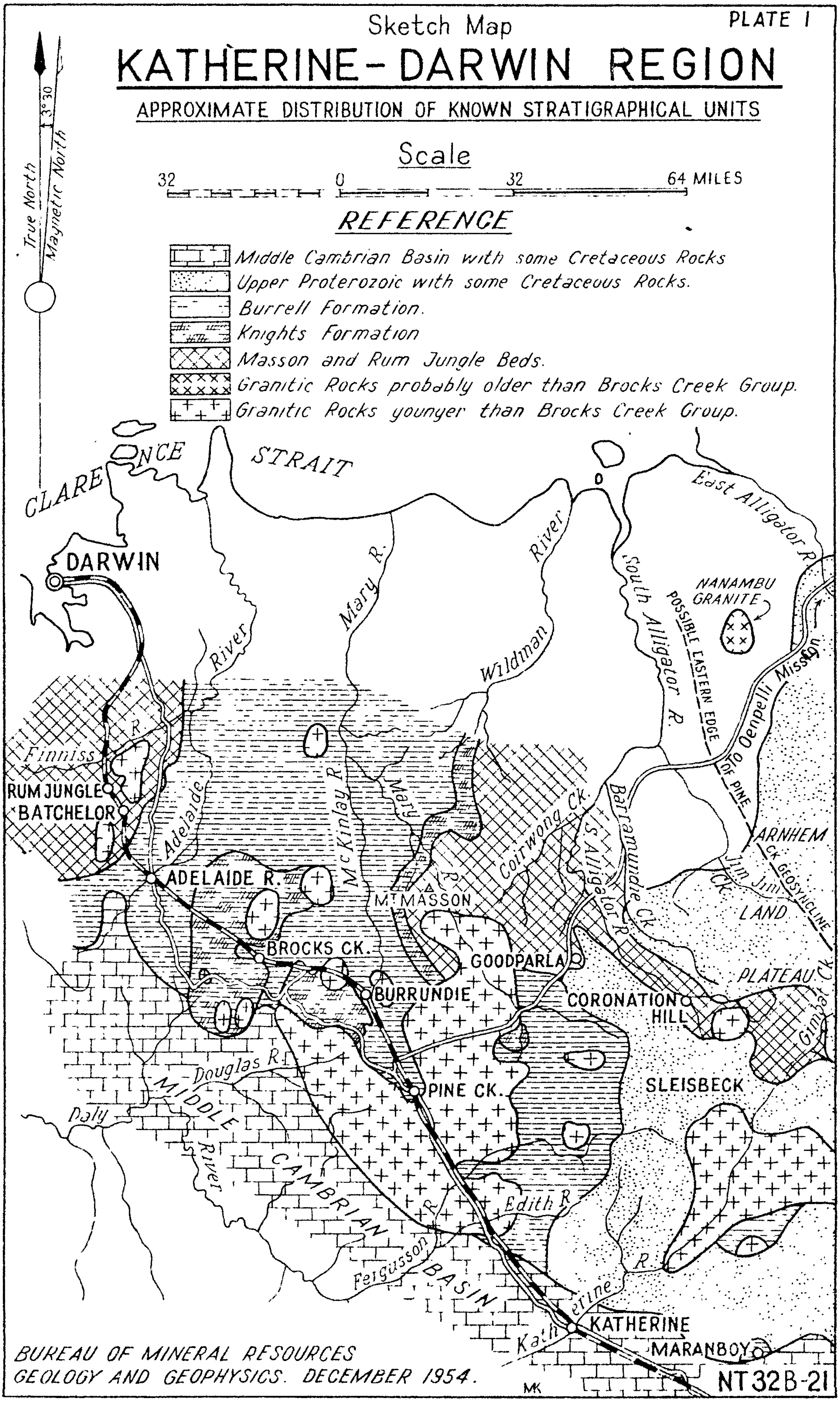
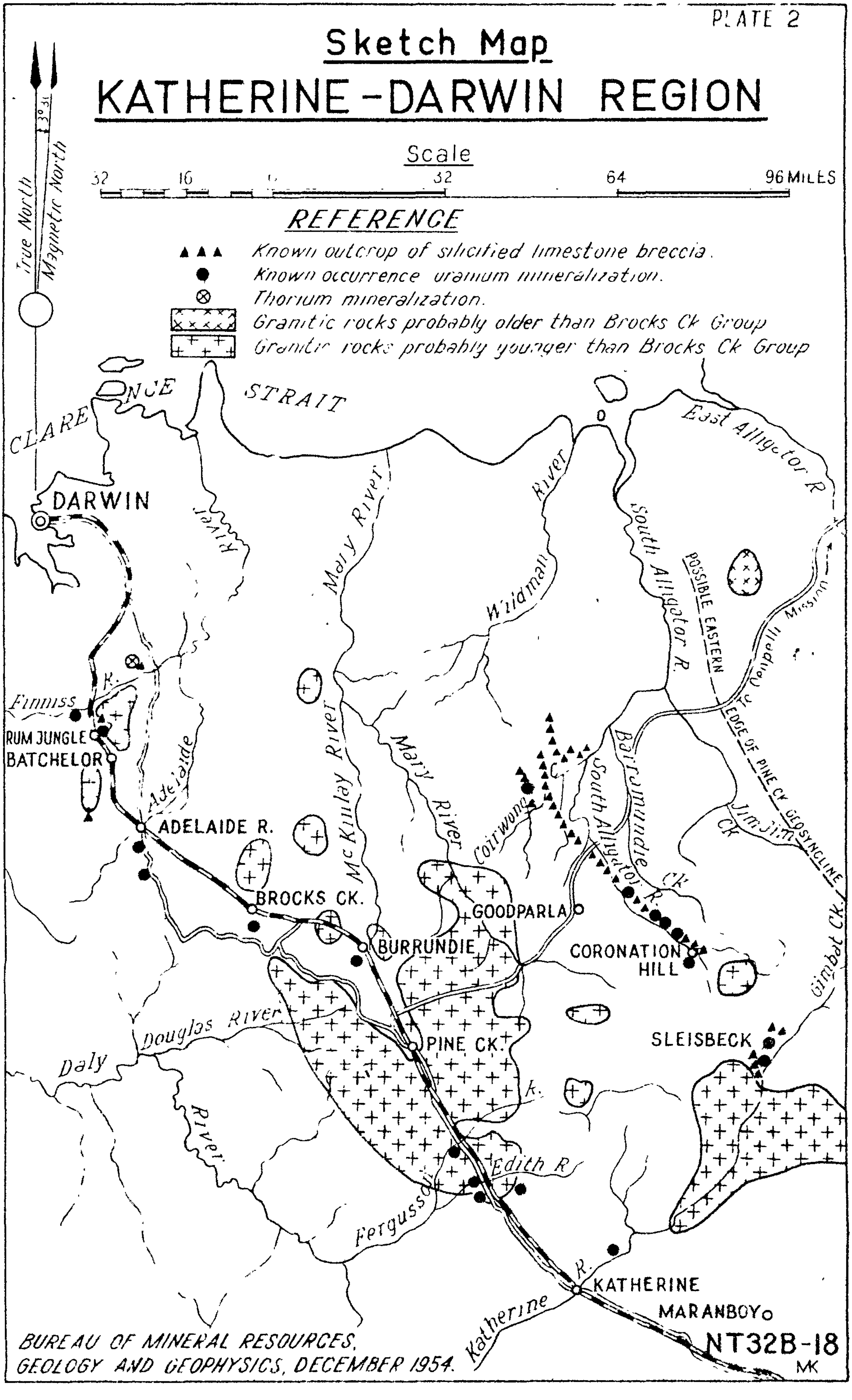



A

Reduce AC (10 6½") to AB (5")

B

C




Reduce AC (10 2") to AB (8")

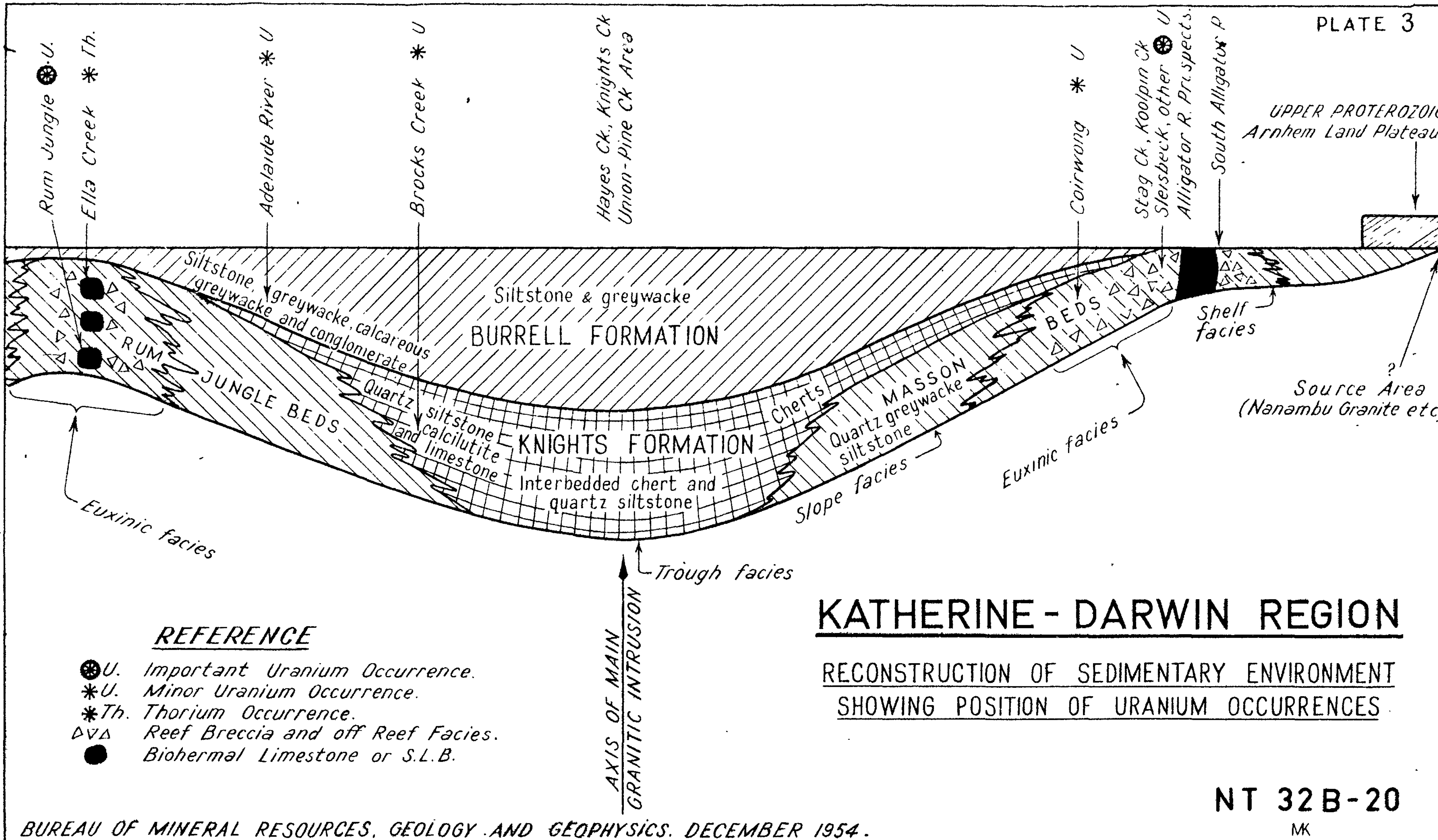


PLATE 3
Rum Jungle ⊛ U.
Ella Creek ✳ Th.
Adelaide River ✳ U
Brocks Creek ✳ U
Hayes Ck., Knights Ck
Union-Pine Ck Area
Coirwong ✳ U
Stag Ck, Koolpin Ck
Sleisbeck, other ⊛ U
Alligator R. Prospects.
South Alligator P
UPPER PROTEROZOIC
Arnhem Land Plateau
Siltstone & greywacke
BURRELL FORMATION
Siltstone, greywacke, calcareous greywacke and conglomerate
RUM
JUNGLE BEDS
Quartz siltstone calcilutite and limestone
KNIGHTS FORMATION
Interbedded chert and quartz siltstone
Cherts
MASSON
BEDS
Quartz greywacke siltstone
Shelf facies
Source Area (Nanambu Granite etc)
Euxinic facies
Slope facies
Euxinic facies
Trough facies
AXIS OF MAIN GRANITIC INTRUSION
REFERENCE
⊛U. Important Uranium Occurrence.
✳U. Minor Uranium Occurrence.
✳Th. Thorium Occurrence.
ΔVΔ Reef Breccia and off Reef Facies.
● Biohermal Limestone or S.L.B.
KATHERINE - DARWIN REGION
RECONSTRUCTION OF SEDIMENTARY ENVIRONMENT
SHOWING POSITION OF URANIUM OCCURRENCES
NT 32B-20
MK
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS. DECEMBER 1954.