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Compilation and Review of The Geology of Bonaparte Gulf Basin, 1962

by

J. M. Drummond

PART I of 2

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TABLE OF CONTENTS

Page

Figures and maps are enclosed in the accompanying volume: Volume II.

SUMMARY

In the Bonaparte Gulf Basin of Northern Australia, hydrocarbon exploration is at an early stage. Considerable surface geological and geophysical work has been carried out, and one bore-hole has been drilled in the search for oil. However, some major stratigraphic problems remain.

Precambrian rocks in the area range from unmetamorphosed sediments to granites. Basic and other intrusive rocks are rare, and most may be Precambrian. Excluding thin Mesozoic or more recent deposits, Phanerozoic sediments have an estimated cumulative thickness of about 25,000', and range from Cambrian to probable Triassic in age, with only the Silurian period unrepresented. As much as 20,000' of sediments can be expected in some areas. Except perhaps for the uppermost few thousand feet, the sediments are predominantly marine. Shales are known to occur throughout the section, although their proportion cannot be gauged at present. Almost 800' of marine shale was encountered in Spirit Hill No.1, which was drilled near the basin edge. A much thicker section can be inferred further within the basin. Devonian reefoid beds are known to occur, and phaneritic limestones, including oolites and encrinites, are found in Carboniferous sediments. Porous secondary dolomites and some porous sandstones are known from the subsurface.

Basin development apparently resulted from non-compressive downwarp of one geotectonic block against another. Minor lateral movement of the blocks possibly took place and a subsidence pattern was maintained most of the time. Several lines of weakness between the blocks, on a north-northeast trend, yielded vertically on different occasions, and may have tended to yield from west to east with the passage of time. Because of these movements, sediment thicknesses of different periods vary within the basin, where the fault trends now conform to basement highs. Most of the basin today is sub-marine.

Deposition may have been widespread in the Lower Palaeozoic, but from Devonian to Permian or Triassic times probably was largely confined to the present day basin limits. Because the overall tectonic pattern was tensional, compressive folds will probably be absent in the area. In spite of this, and in spite of the fact that the only bore-hole drilled to date was unsuccessful in finding hydrocarbons, prospects for the area are considered very attractive. Types of traps which may be present are reefs, erosional cut-offs, and to a lesser extent, fault traps. Anticlines may be absent or poorly developed because of the lack of compressive folding.

INTRODUCTION

The geology of Bonaparte Gulf Basin, in Northern Australia, (Fig.1) was summarised in 1953 by Traves (1955), who concluded (p.104), that petroleum prospects were not attractive. Since then, surface geological work and geophysical investigations have added greatly to the knowledge of the area, and it can now be said that prospects are very attractive.

This report has two main purposes. The first is listing sources of information and presenting abstracted data of geological significance. Bibliographies at the end of the report list data sources under three main headings, which correspond to availability. These refer to published reports, unpublished reports and private company reports. Data from the latter are included in this report with the approval of the permit operators, who are Oil Development N.L., Mines Administration Pty. Ltd., and Westralian Oil Ltd.

The appendices provide a direct reference to several types of data. Appendix 1 discusses the geological maps enclosed in the back pocket. The surface geology is shown on two sheets and the interpretative solid geology on two others. Appendix 2 contains a complete alphabetical list of Phanerozoic rock unit names in the Bonaparte Gulf area. The names are discussed fully in the report. General geological and geophysical activities in the area since 1955 are shown in Appendix 3. Appendix 4 contains descriptions of surface and bore-hole sections from the area, including some type sections. Appendix 5 records core descriptions of Spirit Hill No. 1,* and Appendix 6 lists porosities and densities of cores from the bore-hole.*

The second purpose of this report is evaluation of hydrocarbon possibilities. Spirit Hill No. 1 is the only bore-hole presently drilled at Bonaparte Gulf in the search for hydrocarbons. A number of coal bores, shallow stratigraphic tests, and some shallow water bores have also been drilled. Geophysical data are the main basis for subsurface interpretation, and, owing to a lack of subsurface geological data, cannot be used as fully as might otherwise be the case. The subsurface extent of source, seal and porous horizons remains uncertain. The more reliable data are assessed by discussing rock units, structure, etc., systematically. An attempt is then made to interpret the structural and depositional history of the area and to predict the type of hydrocarbon traps that may be present. In effect, therefore, the report is in two parts, with the first predominantly descriptive and compilative, and the second interpretative.

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* The term "bore" is established in Australia, where it was used for many years to refer to drilling for water. Elsewhere in the world the petroleum industry refers to various types of "hole." The fuller term "bore-hole" is here preferred to either as a general term. Bore-holes are sunk mainly to test for hydrocarbons, coal or water; to obtain stratigraphic data, or to position explosives in seismic work. These objectives may be distinct but drilling results are not. For example stratigraphic data and water can be obtained from all types of bore-hole, and hydrocarbons from all except, perhaps, seismic shot holes. Where necessary, the specific purposes for which bore-holes were drilled will be indicated in this and subsequent reports as follows:

- (i) Only a name and number will be used in most cases for hydrocarbon tests.
- (ii) The name "coal bore" and the abbreviation "C.B." will be used whether or not these found coal, if this was the purpose in drilling the test.
- (iii) Water tests will be distinguished by using the term "bore", and if the bore-hole was successful, "water bore", in the name. The abbreviated form will be B. or WB.
- (iv) Stratigraphic tests will have Stratigraphic Test or ST in the name.
- (v) Seismic Shot Hole or SSH will be used in the name of this type of bore-hole.

TERRAIN AND CLIMATE

Traves (1955) employed the name "Cambridge Gulf Lowlands" (Fig.2) for the land area immediately south and east of Joseph Bonaparte Gulf, and the name "Joseph Bonaparte Gulf Depression" for the general marine area into which the Ord and Victoria Rivers drain. The name "Bonaparte Gulf Basin" which was first used by Reeves (1948, 1951) for the area of Palaeozoic sediments, can be considered to include both physiographic features. The Cambridge Gulf Lowlands corresponds fairly closely with the land part of the sedimentary basin (Figs. 1 and 2). The relationship between the marine part of the basin and the Gulf Depression are interpretative and are discussed later. The area of Phanerozoic sediments on land in the basin is about 6,000 square miles.

Neither topography nor climate is discussed in detail (see Traves, 1955). Near the sea, swampy flats are widespread, especially beside the rivers. In the south, Enga Ridge and Burt Range reach elevations of just over one thousand feet, and represent the highest attained by the Phanerozoic sediments of the basin. A more gradual increase in general elevation occurs to the east of Port Keats. Precambrian rocks around the basin are generally higher, and heights over 1,000' are quite common. There are apparent relationships between physiography and geology, on a detailed as well as on a regional scale. In general, hard resistive conglomerates or sandstones form caps on topographic structures, and limestones or shale form low-lying country. Various topographic maps may be obtained for the area.*

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* The sheets indicated on Figure 2 are available from the Department of National Mapping, Canberra. Medusa Banks and Cambridge Gulf may be obtained in colour, on a scale of 1:250,000. Cape Scott, Port Keats and Auvergne can be had in 4-mile provisional planimetric sheets.

The average wet summer season lasts from November to March, and rainfall ranges from moderate in the south to heavy in the north. No surfaced roads are present in the area, so land travel is limited during summer. During winter, travel is possible on most of the roads shown, although local conditions should be checked before attempting travel, and the use of four-wheel-drive vehicles is advisable. Problems of access for rigs and other heavy equipment require a knowledge of local conditions. In general, equipment of this type can be moved wherever roads already exist, although in some areas loose sand and swampy ground will require temporary surfaces to be laid. Off the roads, which reach to within 20 miles of almost any part of the area accept that north of Port Keats, movement may or may not be possible. Small boats or landing craft can reach many parts of the area from the sea. Wyndham is a deep water port, and Port Keats has facilities for small craft.

EXPLORATION AND TENEMENT HISTORY

The geological history of the area began with a coastal investigation by Commander Stokes, who discovered fossils at Fossil Head on the north shore of Treachery Bay in 1839. The first comprehensive work was performed by the South Australian State Government between 1905 and 1909, when eight coal bores were drilled under the supervision of the South Australian Government Geologist, H.Y.L. Brown, at several places on the coast. None of these was successful in finding coal.

The first serious surface investigations in the southern part of the area were in 1944 by Matheson and Teichert (1948), and the overall petroleum prospects were first evaluated by Reeves (1948, 1951), who was favourably impressed with the basin. The Bureau of Mineral Resources next investigated the general area, in conjunction with a major survey by the Land Research and Regional Survey section of C.S.I.R.O., between 1949 and 1952. The results of the geological work are published (Traves, 1955).

Standard Vacuum Oil, in combination with other interests, first investigated the area through Reeves in 1947, and after field investigations relinquished their concession in 1948, pri[redacted]sin too small. The following year Ampol Exploration Pty. Ltd., took up the tenement which passed to West Australian Petroleum Pty. Limited (Wapet), when California Asiatic Oil Co. and Texaco Overseas Petroleum Co. (Caltex) and Ampol formed this new group in 1952. Wapet in turn relinquished the tenement in 1955, principally because of commitments in other parts of Western Australia. The overall pattern of Tenements 127H, 2 and 3 (Figure 3) was then adopted, and in 1955 Gulf Oil Syndicate was granted Tenement 127H by the West Australian Government, while on 24th June of that year the Northern Territory Administration granted Permit No. 3 to Westralian Oil Ltd., and Permit No. 2 to Associated Australian Oilfields N.L. The latter organisation operates through Mines Administration Pty. Ltd.

Permits No. 2 and No. 3 are still nominally held by the original companies, but various affiliations have occurred. The Papuan Apinaipi Petroleum Co. Ltd., and Associated Freney Oilfields N.L., both joined Associated Australian Oilfields N.L., in Permit No. 2 on 29th October, 1959. Sleigh Exploration N.L., Interstate Oil Ltd., and Associated Continental Petroleum N.L. then joined the first three, to form the informally named "Associated Group." In February, 1960 the northern boundary of Permit No. 2 was extended out to sea. During 1962, this group applied for and obtained the Marine Permit No. 83, the southern end of which is shown on Figure 3. Finally the "Associated Group" entered into an agreement with the Societe Nationale de Petrole d'Aquitaine (SNPA), in which the latter organisation has to make exploration commitments in Permits No. 2 and 83.

In Permit No. 3, Westralian Oil Ltd. remained unaffiliated until May, 1960, as did Gulf Oil Syndicate in Tenement 127H. At that time Oil Development N.L. took over the Gulf interest and became the active company in Permit No. 3.

In 1955 the tenement holders began fairly detailed exploration work, [redacted] (Appendix 3). Much of the geophysical work done for companies during this period, and for a number of years after, was carried out by or under the direction of Mines Administration Pty. Ltd.. J.E. Burbury, of Mines Administration, was responsible for most of the gravity work. During the same period, the Bureau of Mineral Resources performed considerable geophysical work, consisting of a regional aeromagnetic survey, gravity work on both land and sea, and seismic work in the south. Surface geology, to date, has been carried out mainly south of Queens Channel, where exposures are better than to the north. J. Rade and others, under the supervision of E.P. Utting, have been responsible for much of this, and Utting has written a series of private reports evaluating the stratigraphy. The viewpoint adopted in these has of necessity altered as more data accumulated, but all are important. Palaeontologists of the Bureau of Mineral Resources (Jones, 1958; Thomas, 1957, etc) have also made important contributions to the stratigraphy.

The only bore-hole drilled to the end of 1962 in Bonaparte Gulf in the search for oil is Spirit Hill No. 1, begun by Westralian Oil Ltd., in 1959, and deepened from 2458' to total depth of 3003' by Oil Development N.L. The most recent (1962) activities in the area have been detailed geophysical surveys carried out for tenement holders, again in the south, mainly within holdings 127H and No. 2. Activities will continue at a fairly high rate for the next few years, because of commitments on the part of farm-in companies. The Bureau of Mineral Resources intends to operate a geological field party during the 1963-64 field seasons.

PART I - COMPILATION

STRATIGRAPHY

Phanerozoic rocks in Bonaparte Gulf Basin include most of the Palaeozoic, with one major erosional break between the Ordovician and Upper Devonian, (Fig.4). Excluding recent and some Tertiary or Cretaceous deposits, the youngest beds in the basin are probably of Triassic age. Permo-Triassic sediments are largely confined to the area north of Queens Channel, while the older beds outcrop only in the south (Fig.1).

Surface geological interpretation is difficult throughout the basin, because exposures are largely restricted to resistant beds, which typically occur as inliers of greater or smaller size within recent deposits. The easily-weathered shales of the Milligans Beds were first discovered as bit cuttings in stratigraphic tests. Shales were proven in the Burt Range Formation in much the same way, although limited exposures occur. The maximum thickness of shale in either unit is still unknown. Limestones are better exposed in the area as a whole, mainly because they are capped and partially protected by coarse clastics* e.g. Burt Range, Mount Septimus and Spirit Hill. In some cases (Traves, 1955) carbonates are strongly silicified in fault zones and so are made resistant. The most consistently exposed rocks are conglomerates and sandstones. Conglomerates commonly occur in the Border Creek Sandstone and conglomeratic lenses are present in most of the other formations. All of the conglomerates, except perhaps

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* The term "clastics" is used in the sense normally applied in petroleum geology, for only terrigenous rocks. Excluding conglomerates, terrigenous limestones are probably rare. Limestones, some of which may be of clastic but intrabasinal origin, are referred to as calcarenites or more specifically as oolites, encrinites etc., if this is known.

those in the Keep Inlet Beds, have rather similar lithology, and correlation of isolated exposures, where there is no palaeontological control, becomes difficult or impossible. This can be of direct importance to both stratigraphic and structural interpretation. For example, the type Nigli Gap Sandstone, which is unfossiliferous sandstone and conglomerate, can be correlated only with difficulty to other formations. The most probable correlation seems to be with the Cockatoo Sandstone, which is Devonian in age. On this basis the Cockatoo Fault is a normal fault which has undergone only one major movement. If the Nigli Gap Sandstone is assigned to the younger Border Creek Sandstone, as it is by some authorities (Rade, 1957, 1958), the Cockatoo Fault was a normal one which later underwent reverse movement. Either possibility could be true. A number of important relationships of this kind will only be determined when more data become available.

Traves (1955) summarised the surface geology of Bonaparte Gulf and surrounding areas, and revised the formal stratigraphic nomenclature. Since then very little geological work has been performed on the pre-Devonian rocks, and the following discussion contains little data post-dating work done by Traves. The Devonian and younger rocks, on the other hand, have been the subject of fairly intensive field work in some localities, and a large amount of new data have accumulated.

PRECAMBRIAN SEDIMENTS AND IGNEOUS ROCKS

Apart from some local trachytes and possibly some dolerites, all igneous rocks in the area are of Precambrian age. In this basin area, as in others, some of the Precambrian sediments are unmetamorphosed, and could constitute reservoirs for hydrocarbons, or even source rocks, judging by the presence of the alga Collenia (Traves, 1955, p.24). The chances of finding either primary or secondary accumulations of hydrocarbons are small however, by comparison with the Phanerozoic beds, and the Precambrian rocks can be referred to as economic basement.

The only important work performed on Precambrian rocks in the area since Traves (1955) is by Mines Administration Pty. Ltd., in the Port Keats area (Derrington et al, 1957). The geological maps indicate the main Precambrian sedimentary and igneous units which outcrop around the basin. Their thicknesses are unknown. The following subdivision can be made of sediments of Precambrian age and igneous rocks of Precambrian or other ages.

Unmetamorphosed Sediments: For convenience, this category of Precambrian sediments includes some undifferentiated low grade metamorphics of probable Upper Proterozoic age, (Traves, 1955, p.25) forming Pincombe Range and underlying the area directly south. The Precambrian sediments east of the basin are mainly sandstones, shales and dolomites, probably of the Upper Proterozoic Victoria River Group. In the south-west most Precambrian rocks belong to formations which may be correlative with the Victoria River Group.

Metamorphosed Sediments and Granites: The sediments in this category include rocks assigned to the Halls Creek Metamorphics which, in this area, are sandstones, quartzites, slates and schists. The associated granites, granodiorites and gneisses, probably of the Lamboo Complex, have a related distribution.

Basic Rocks: South-west of Ivanhoe Research Station and to the east of Port Keats, basic intrusives are present. Those in the north are principally dolerites, and in the south are gabbro. Most of the intrusions are probably plugs, but some of those in the north may be dykes. Traves (1955, p.27-28), considered the southern intrusions to be of Upper Proterozoic age, but they could be younger. West of Port Keats the intrusions could be of post-Triassic age, judging by their distribution, although Derrington et al (1957) were uncertain of their age.

Rhyolites: The only Phanerozoic igneous rocks proven to occur in the area are two very limited exposures of rhyolites in the Keep River area. These occur near Nigli Gap in the south-east, and in the exposures near Lat. 15°12' and Long. 129°11'. Neither are shown on the geological maps. Traves (1955, p.74), considered these rocks contemporaneous with the sediments associated with them, and described a case of interbedding by a minor flow. Rade (1956) thought that the rhyolites might post-date the sediments. Allen (1956) agreed with Traves. The sediments interbedded with the rhyolite are Devonian or Carboniferous in age.

CAMBRO-ORDOVICIAN

Antrim Plateau Volcanics

Ancient lavas in isolated outcrops in this area were classified by Traves (1955) as Antrim Plateau Volcanics. Elsewhere the Antrim Plateau Volcanics show local strong erosional unconformity * on the Precambrian and underlie the

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* The terms "unconformity" and "disconformity" are structural terms, and for an unconformity to occur there should be visible or deducible lack of structural conformity between the rock units involved. The time factors involved in any unconformity are the duration of the hiatus, and the time-rock interval lost by erosion. The second factor can be difficult to determine, and the hiatus will not normally be determinable. The following definitions will be applied in this and subsequent basin study reports:
(i) An angular unconformity is determined by visible differences of attitude in the beds above and below the contact at a specified outcrop. (ii) An erosional unconformity occurs where infilled erosional channels are visible at a specific outcrop. The beds above and below the contact will have general conformity. (iii) With an angular disconformity or regional unconformity, differences of attitude are not visible above and below the contact in any one exposure, but can be interpreted to occur on a regional basis. (iv) A depositional or hidden disconformity can be major or minor, depending upon the duration of the hiatus, but the beds involved are essentially conformable. In some cases there may be only faunal evidence of a break. (v) A diastem is a local depositional break between conformable beds, determined by lithologies, and for which palaeontological evidence cannot prove a significant time-break.

Middle Cambrian with apparent conformity, so were assigned to the Lower Cambrian by Traves. The only contacts observed within the basin are near Martins Bluff, where the Devonian Cockatoo Sandstone can be inferred to overly the volcanics unconformably, and north of Carlton Homestead, where Cambrian beds rest on the basalt. All of the outcrops of the volcanics in this area occur in the extreme south.

Formations of the Carlton Group

Cambrian rocks have a wide distribution south of Bonaparte Gulf near the Ord River. In the Gulf area itself the Cambrian rocks are confined in outcrop to a strip between Cambridge Gulf and Pincombe Range, and are associated with Ordovician beds. Reeves (1948) discovered and measured a section of these Cambrian strata, and Öpik (1950) identified Ordovician fossils in the Pander Sandstone (now Pander Greensand). Traves (1955) performed the first fairly intensive field work on the Carlton Group, and showed that strike faulting caused section repetition, making interpretation difficult. He set up formational names, based upon local outcrop sections, and on his map indicated areas where two or more formations seemed to predominate. No important work has been performed since and there is insufficient data for detailed stratigraphic interpretation. On the geological maps which accompany this report these sediments are shown as Cambro-Ordovician. Traves' report should be consulted for type areas, section descriptions, etc.

The units defined, or formalised, by Traves are listed below, together with points of interest to petroleum geology:

Hart Spring Sandstone: Reddish fine grained sandstone with some ripple marks, sun cracks and other signs of shallow water deposition. Probably Middle Cambrian. Maximum known thickness 500'.

Skewthorpe Formation: Limestone, grey to green shale and sandstone, and characterised by oolites. Middle Cambrian. Estimated total thickness more than 600'.

Pretlove Sandstone: Reddish well-bedded sandstone. Probably low Upper Cambrian. Thickness at least 400'.

Clark Sandstone: Greenish to reddish glauconitic sandstone and friable red sandstone. Middle to upper part of the Upper Cambrian. 430' exposed at surface.

Pander Greensand: Glauconitic sandstone with local cross bedding and worm tracks. Ordovician. Thickest measured section 401'.

Lateral facies changes may be present within the Carlton Group, or the stratigraphy may be more complicated in other ways than present data suggest. On the basis of formational age assignments, however, the thickness of the group may total more than 2000'. The beds contain an abundant fauna in places and include shales, so could be considered to be possible source beds, if they persist under the basin. The entire group has a shallow water aspect, exemplified by rock colour, sun cracks, glauconite, etc.

DEVONO-CARBONIFEROUS

In Upper Devonian time deposition recommenced in the Bonaparte Gulf Basin, and with only one proven significant break within the Lower Carboniferous, continued to the end of the Lower Carboniferous or later. The boundary between the Devonian and Carboniferous systems appears to lie within the Burt Range Formation, (Fig.4), and further palaeontological work is needed to determine its location. Many Devono-Carboniferous units of formational status now require revision, so all are discussed here systematically.

The time scale used by Australian palaeontologists largely depends upon their special field, and both American and European Carboniferous stage-names have been employed in the Bonaparte Gulf Basin. There is, at present, variation in stage assignments, which in part at least is due to this factor. For the purpose of this report faunal determinations are of greatest importance in relating rock units of otherwise doubtful affinity within the basin.

ACCEPTABLE ROCK UNITS:

Cockatoo Sandstone

Authors : Matheson and Teichert (1948)

History: The name "Cockatoo Series" was applied by Matheson and Teichert (1948) to cross-bedded sandstones with pebble beds which outcrop on the Ivanhoe road 5½ miles north of Cockatoo Springs. These authors reported similar sands in the surrounding area, south-west and west of Burt Range. Traves (1955) introduced the name "Cockatoo Sandstone" and applied it also to areas west of Ninbing, so including the "Onslow Beds" (Noakes et al, 1952), and to two outliers about 20 miles south-west of Ivanhoe Research Station. Subsequent field work by Utting (1960) resulted in some changes in the interpretation of the outcrop pattern between Ninbing and Ivanhoe, mainly in showing extended outcrops. On the interpretative geological maps, beds formerly described in various ways, but generally referred to the "Nigli Gap Sandstone", are also included in the Cockatoo Sandstone, following Utting (1962). The outcrops involved are discussed under "Nigli Gap Sandstone".

Lithology: The Cockatoo is principally a white to yellow, locally reddish, medium to coarse grained quartz sandstone, composed of rounded to well rounded, generally well sorted grains. It is occasionally feldspathic, and has some presumed shallow-water features including ripple marks and cross bedding, and minor slumping. Occasional pebble bands and thin conglomerates occur south-west of Burt Range. Limestone beds occur in the outliers south-west of Ivanhoe, and probably do so elsewhere.

Sections: Because of partial exposures no complete section of the Cockatoo Sandstone has been, nor can be, measured at surface. Allen (1956) gave the fullest description of the formation, measured north and south of the Cockatoo Springs/ Ivanhoe road (Appendix 4, Section No. 1). The more resistive lower part measured 2000' and the poorly exposed upper part 1500' to the highest exposed bed. Total thickness is about 3800' if the 300' covered interval to Eight Mile Creek is included. The base of the overlying Burt Range Formation was formally defined to be still higher than this, and the total thickness of the Cockatoo Sandstone could be about 4200' at this section. The section occurs in the vicinity of Matheson and Teichert's type exposures, so can be regarded as the type section of the formation.

There are two other published descriptions of sections of the Cockatoo Sandstone. One section (Traves, 1955, p.60), is found in the eastern outlier, south-west of Ivanhoe Station, where 2500' feet of sandstone with some limestone are probably Cockatoo equivalent. The other occurs near Kimberley Research Station and was briefly described by Matheson and Teichert (1948).

Upper Contact : The upper contact is not exposed in the type area. North-west of Carlton the contact between the Cockatoo Sandstone and the overlying Burt Range Formation may or may not be exposed. Interbedding appears to occur between the two units and hinders delineation of the contact. Undifferentiated Cockatoo Sandstone/Burt Range Formation is shown at this horizon on the geological maps (after Utting, 1960). Given better exposures, subdivision of the two formations might be equally difficult in the type area (see lower contact of Burt Range Formation). The Cockatoo Sandstone may occur in Spirit Hill No. 1 and may be present at the surface at the south end of the Spirit Hill anticline.

Lower Contact : The Cockatoo Sandstone overlies undifferentiated Precambrian rocks on either side of the Pincombe Range and possibly also in the Mount Cecil Inlier, but the contact is not reported to be exposed. It apparently overlies the Antrim Plateau Volcanics in exposures at Martin Bluff. At the type section the contact is covered. By inference the sandstone rests on Cambro-Ordovician between the Ivanhoe Fault and Cambridge Gulf, and overlaps the older beds in the east.

Thickness : The maximum measured thickness of the Cockatoo Sandstone in the Bonaparte Gulf area is 3500' but it could be 4200' at the type section. The unit could be thick in the western exposures near Elephant Hill, judging by outcrop width. It thins to zero on both sides of Pincombe Range, and is probably absent in the subsurface north of there.

Palaeontology : The plant Leptophloeum australe (McCoy), was first collected near Mount Cecil (Matheson and Teichert, 1948). Traves (1955) later collected this form in the same area, together with five genera of marine pelecypods, and in the area west of Ninbing found several genera of molluscs together with fish remains. The age of the marine faunas could be Middle to Upper Devonian. Stratigraphic relationships with younger beds suggest that Upper Devonian is present, with or without Middle Devonian towards the base of the formation.

Interpreted Depositional Environment : The Cockatoo sandstones are medium to coarse, generally well rounded and well sorted, so are similar to those deposited along and off modern shorelines. The degree of sorting and rounding might be considered to suggest an aeolian origin, but the contained faunas, lack of red colouration and the ripple marks, current bedding etc., do not support this possibility. The pebble bands within the formation also suggest shoreline or off-shore conditions.

Most of the invertebrates recovered to date are heavy marine pelecypods which would be relatively resistive to abrasion, and are comparable to the thick shelled forms which may be found in present day beach sands. The fish remains and plants may indicate temporary brackish or fresh water conditions.

If its depositional environment is correctly interpreted, the Cockatoo Sandstone must originally have been a highly porous sand body. In present surface exposures the sandstone is very porous, and disintegrates to form large sand flats in some areas. In contrast, sandstones of similar type penetrated in Spirit Hill No. 1 have low porosities, due mainly to cementation by calcite or silica. This cementation need not be a local phenomenon. It is therefore suggested that the Cockatoo Sandstone and sandstones of similar type may be infilled by silica or calcite in the subsurface, and that present surface porosity in them may be due to recent leaching. This possibility is important to petroleum geology. Interpretation of gravity data in the Bonaparte Gulf area also requires consideration of this possibility (see Spirit Hill No. 1).

Burt Range Formation

Authors: Matheson and Teichert (1948)

History : Matheson and Teichert used "Burt Range Series" for the exposures of limestone with intercalated shale and sandstone above those of the Cockatoo Sandstone, on the east side of Eight Mile Creek around Burt Range. These beds included an upper sandstone unit, several hundred feet thick, referred to by Traves (1955) as the "Enga Sandstone." Traves also formally introduced the name "Burt Range Limestone" for the remainder, having used it earlier (1949) in an unpublished report. The name "Burt Range Formation" was formally substituted for "Burt Range Limestone", because the formation has been proven to contain major amounts of clastics not found in surface exposures. This step was suggested by Utting (1958), and was taken in the Spirit Hill No. 1 Completion Report.

Matheson and Teichert (1948) also recognised Burt Range equivalents at Buttons Crossing west of the Burt Range area. Reeves (1948) used the name "Burt Range Series" for outcrops in the Ninbing area, where Traves (1955), later made a more detailed analysis of their distribution. Traves also showed the beds in Amphitheatre, the fault block within Burt Range, as Burt Range Formation and Enga Sandstone. This interpretation remains virtually unchanged on the geological maps, although minor ones, based on Utting (1960) are shown for the Ninbing area.

Lithology : The Burt Range Formation seems to differ appreciably in lithology in the Burt Range and Ninbing areas. Exposures between Pincombe Range and Cockatoo Springs consist almost entirely of limestone, except in the top few hundred feet, where sandstones also occur. Only this upper part of the section is reasonably well exposed. The remainder has very poor exposures. Fortunately, two bores drilled in 1960 (Ivanhoe B. No. 2 and B. No. 3) helped to evaluate the overall lithology of the middle part of the formation. These cut a combined footage of over 300' and showed (Utting, 1958a) that the predominant lithologies were fine-grained calcareous sandstone, siltstone and some shale. This suggests that the Burt Range Formation on the west side of Burt Range is predominantly composed of fine clastics with subordinate interbedded carbonates. The clastics evidently coarsen towards the top, for in the uppermost 700' they are fine to medium grained quartz sandstones. The carbonates in the formation are predominantly high energy intrabasinal ones, with encrinites, coquinites, spergenites and oolites, and undifferentiated calcarenites. These limestones are important over a 600' thin bedded interval toward the base of the section.

In the Ninbing area the section is less well known. Carbonates are well exposed in places, but the proportion and nature of interbedded clastics is uncertain. Reeves (1948) reported the main limestone exposures as a ridge running twenty five miles northwards from Ninbing to Knob Range, and estimated the section to be 500' thick. It is conceivable that this unit correlates approximately with the 600' section in the Burt Range area, although the two appear to be of different facies. Whether or not they are correlative, it is probable that carbonates are quantitatively more important in the section near Ninbing.

Reefoid deposits may be significant in the Ninbing area. Reeves (1948) reported the topographic relief of the Ninbing ridge to be due to stromatoporoidal reef masses, underlain by thinner bedded crinoidal limestones. Subsequently Traves (1955) reported biohermal stromatoporoidal accumulations and related biostromal limestones south of Ninbing. Stromatoporoids have also been reported at Buttons Crossing (Matheson and Teichert, 1948) and in the sand flats west and south-west of Point Spring (Reeves, 1948). Although not conclusive, this suggests that stromatoporoids may be confined to the area west of Pincombe Range and absent or rare near Burt Range, where these organisms apparently are not recorded in fossil collections. The Ninbing limestones are reported to be dolomitised in places.

Sections : There are to date no sections fully covering the Burt Range Formation and it does not seem advisable to designate formal type sections at this time. Two separate sections near Burt Range can be considered the main reference section and a supplementary reference section for the upper part. The first (Appendix 4, Section No. 2) lies toward the north end of the outcrops to the west of Burt Range, and was measured and described by Allen (1956). As already noted, exposures consist of limestone, but in the subsurface fine sandstones and siltstones predominate. The supplementary section (Section No. 3) also from Allen, consists of the uppermost 600' of the Burt Range Formation and over 100' of the Enga Sandstone. Traves (1955, p.63) described a less complete section either at or near the same location. Although the supplementary section cannot be correlated to the other, the two can be regarded as typifying the general sequence of the Burt Range Formation, exclusive of the basal few hundred feet.

Section No. 4 was measured by Reeves (1948) where the Burt Range Formation apparently directly overlies Proterozoic strata on Pincombe Range. Reeves was uncertain of the stratigraphic position of the section and referred to it in the text of his report as a non-fluviatile facies of the Cockatoo Sandstone. However, he showed it as Burt Range Formation on his map. Thomas (in Glover et al, 1955) identified fossils from the vicinity as Upper Devonian or Lower Carboniferous. Sands are clearly in the minority in the section, and the basal conglomerate may be locally derived.

Section No. 5 (Glover et al, 1955), was measured in the extreme north end of the Amphitheatre area and is believed to belong to the Burt Range Formation, although the identification is tentative. Rade (1956) measured two sections of 350' and 100' in this vicinity. The thicker section was near that of Glover, and included 100' of silicified sandstone referred by Rade to the Enga Sandstone (see Enga, lower contact).

Upper Contact : The upper contact is exposed in Section No. 3 below Enga Ridge, and was described by Traves (1955, p.63) as a rapid gradation from grey to brown calcareous sandstone of the Burt Range Formation to well bedded white non-calcareous fossiliferous sandstone of the Enga Sandstone. Later workers (Allen, 1956) considered the contact less well defined, because although it is clearly recognisable, Enga-type sandstone beds occur within the upper Burt Range Formation. The Enga Sandstone/Burt Range Formation contact may also occur near Section No. 5, where both Rade (1956) and Glover et al (1955) reported apparent conformity between the rock units involved. The contact may also occur further south within the Amphitheatre area.

At Spirit Hill, sandstones assigned to the Point Spring Sandstone overlie carbonates of the Spirit Hill Limestone with possible unconformity. The Spirit Hill Limestone may be Burt Range equivalent, but on present evidence, is probably younger (see Spirit Hill area). In most of the area the upper contact of the Burt Range Formation is probably unconformable beneath the Milligans Beds. This relationship has not been reported from surface exposures, but is suggested by the inferred field relationships between the two formations.

Lower Contact : Matheson and Teichert (1948) defined the base of the Burt Range Formation in its type area as "the limestone bed which outcrops about a quarter to half a mile east of Eight Mile Creek, and whose northern continuation was found two miles south-east of the eastern end of Martin's Gap." Lack of exposures appears to make this procedure advisable. The base of the main Burt Range Formation reference section (Section No. 2) starts several hundred feet above this basal limestone.

The contact between the Burt Range Formation and Cockatoo Sandstone is nowhere exposed at surface in the type area. It may be present but undetected in the Ninbing area.

Thickness : The main reference section of Burt Range Formation (No. 2) has a maximum measured thickness of a little over 3000' according to Allen (1956), but there is room for error because of difficulties in determining dips accurately in the field. Non-exposures above and below the measured section could account for another thousand feet, so at the type section the maximum thickness may be as much as 4000'.

The outcrop pattern, used in conjunction with structural data, suggests that the Burt Range Formation thins towards the south from the type section. Utting (1958a, p.6) considered this to be so and stated : "At the extreme south end of the basin, in the vicinity of the Cockatoo Fault, the thickness is diminished considerably." The Cockatoo Sandstone thins in the opposite direction, and this relationship tends to suggest major diachronism between the two. Whether or not this occurs the Burt Range Formation could have originally continued to thicken north from the type section. Pre-Weaber Group erosion apparently has removed part of the formation to the north, and the overlapping relationship of the Weaber Group prevents evaluation of the thickness of Burt Range Formation which may be preserved. On the north-east side of Pincombe Range it seems probable that less than a thousand feet of the formation remains.

In the Ninbing area pre-Weaber Group erosion may have severely reduced the original thickness of the Burt Range Formation. Utting (1960, p.4) estimated the minimum thickness at 1500' and stated that the full section was not present at surface owing to erosion. If the Cockatoo Sandstone/Burt Range Formation contact is diachronous in this area, then the distribution of Cockatoo Sandstone suggests that the Burt Range Formation would have been depositionally thinnest in the south-west, and thickest toward Pincombe Range. Under the Weaber Group re-entrant south of Ninbing considerable thicknesses of both Burt Range Formation and Cockatoo Sandstone have probably been removed.

Palaeontology : Present palaeontological interpretations suggest that the Burt Range Formation has the Devonian/Carboniferous contact within it. Matheson and Teichert (1948) made the first collections in the area west of Burt Range, mainly from the lower part of the formation, and determined the age as Upper Devonian. They also collected definite Upper Devonian forms from Buttons Crossing. Traves (1955) collected from across the Burt Range Formation in the type area, including a high fossiliferous horizon west of Mount Septimus (his locality 31), and Öpik, in classifying the fauna, remarked on its similarity to the Lower Carboniferous fauna of the Septimus Limestone, but regarded it as Upper Devonian. Utting (1957) next collected from a locality 50' below the top of the Burt Range Formation, and Thomas (1963) considered the fauna to be of probable Carboniferous age. Ivanhoe Bore No. 3 and exposures near No. 2 provided further fossil material from lower in the formation, and Thomas (Spirit Hill No. 1 Report, Appendix) again considered this to be of Lower Carboniferous aspect.

The determination of the Devonian/Carboniferous boundary is of both academic and practical importance in the Bonaparte Gulf area. The Burt Range Formation shows no evidence of an internal depositional hiatus. If diachronism occurs between the Burt Range Formation and Cockatoo Sandstone, detailed palaeontology may eventually show its extent and nature.

Even if diachronism is extensive, the lowermost Burt Range Formation in the type area is probably of Upper Devonian age, and the upper part may be either Devonian and/or Lower Carboniferous. In the Ninbing area, the fact that a lesser thickness of the formation is preserved implies that the beds there are likely to be of Upper Devonian rather than of Carboniferous age.

Interpreted Depositional Environment : At already noted, stromatoporoids (and algae) are reported mainly from the area west of Pincombe Range. Well defined biostromes are similarly restricted in area. This apparent distribution pattern may be due to inadequate data, but it suggests, when considered in conjunction with the known predominance of carbonates around Ninbing, that this area may be one of separate provenance.

The extent and nature of stromatoporoidal reefing around Ninbing has not yet been accurately determined. Reeves (1948) reported massive stromatoporoidal reefs north of Ninbing, and Traves (1955, p.65) reported biohermal dolomitic limestone five miles east of the Ninbing turn-off on the Legune Road. Utting (1960, p.4) considered the identification of reefs to be difficult in the field and stated: "No convincing mound shaped bioherms were found in the recent survey, despite careful search, and the beds are more accurately described as biostromal. The limestone shows regular and consistent bedding over large areas. In view of the presence of reef building fauna, sometimes prolific, and the identification south of Ninbing of a possible reef and back-reef relationship, a reasonable statement is that a reef building environment was present during deposition of the limestones."

"Except for the lack of obvious reef cores, the general nature of the outcrops is very similar to the Fitzroy Basin occurrences, which are proven reef complexes of Upper Devonian age."

Although there are insufficient data to interpret the reefoid beds in the Ninbing area, it is apparent that the general area was one of deposition on a shallow-water marine shelf. The predominance of carbonates in outcrop also suggests that once Cockatoo clastic deposition ceased, clastics became of relatively minor importance. As already noted, the reefoid beds may correlate with the 600' carbonate-rich unit near the base of the Burt Range Formation in its type area, and an upper clastic phase could be absent at surface because of erosion and subsequent overlap by younger beds. As discussed later, when extrapolated to the subsurface, the presence of stromatoporoid-bearing accumulations near Ninbing is one of the most promising features for hydrocarbon possibilities in the Bonaparte Gulf area.

In the Burt Range area carbonates are unlikely to constitute more than a minor part of the section, which is predominantly clastic. The fact that the clastics are finer than those of the underlying Cockatoo Sandstone and overlying Enga Sandstone may suggest quieter and possibly deeper water conditions. The limestones are predominantly high energy types and indicate that, as in the Ninbing area, wave-base-level was attained quite frequently. The fauna of the limestones is reported to be mainly brachipods, crinoids, molluscs, and common gastropods, which also suggests relatively shallow water. The interbedded nature of the limestones and clastics probably indicates periodic variation in the influx of clastics.

<u>Enga Sandstone</u>

Author: Traves (1955)

History : The name "Snowie Sandstone" was first informally applied by Öpik (1950) to beds subsequently named the Enga Sandstone. Traves (1949) separated this unit from the Burt Range "Series" of Matheson and Teichert (1948), but did not name it. The term "Snowie Sandstone" was introduced to the literature by Noakes et al (1952) and was used by Fairbridge (1953), but became unacceptable when the ridge after which the formation was named was designated as Enga Ridge by the West Australian Lands and Surveys Department. Traves (1955) formally introduced the name Enga Sandstone in lieu of "Snowie Sandstone."

The main exposures of the Enga Sandstone are on the type ridge south-west of Burt Range, and some smaller ones may occur in the Amphitheatre area. Enga Sandstone may be present in Spirit Hill No. 1, and may be exposed in limited areas south of Spirit Hill.

Lithology : The Enga Sandstone ranges from fine to medium in grade, but is reportedly predominantly medium grade. The grains are subangular to rounded and often well sorted. Cement is limited and porosity is present in surface exposures. In the lower part of the section, the sandstones, which are slightly felspathic, contain worm tracks. Calcareous material, including crinoids and other shelly fragments, is present near the top.

Sections : Although moderately resistive to weathering, most exposures of the Enga Sandstone lie on dip slopes and in consequence are poorly exposed. The lower 150' of the formation has been described (Section No. 3). In the south of Burt Range, the uppermost 120' has been generally described by Glover et al (1955) as shelly crinoidal calcareous medium grained sandstone consisting of subangular to rounded, well sorted quartz grains. The beds contain calcareous sandstone concretions up to one inch in diameter. The middle portion has not been measured or described.

Upper Contact : According to Glover et al (1955) in the south of Burt Range the Enga Sandstone is transitional with the overlying Septimus Limestone. The actual contact is not exposed.

Lower Contact : The lower contact is essentially gradational on the west side of Burt Range at Section No. 3. Near Section No. 5 in the Amphitheatre area, silicified sandstones rest upon probable Burt Range Formation, and have been referred to the Enga Sandstone both by Glover et al (1955) and Rade (1956). These sandstones, which are not distinguished on the geological maps, contain Leptophloeum. Glover, and later Utting (1962, p.6), both noted that the sandstone was more similar to post-Septimus beds than to Enga, so its equivalence is not yet determined, although Leptophloeum is unlikely to occur in post-Septimus beds (see Spirit Hill area). The sandstones appear to be conformable upon the beds beneath, but the contact has not been reported exposed.

Thickness : Traves (1955) estimated the Enga Sandstone to be approximately 1000' thick on the southern part of the type ridge, but subsequent workers have reduced this estimate. Glover et al (1955) estimated 900', Allen (1956) 500' and Utting (1958) 400'. At the north end of Enga Ridge the formation disappears, probably beneath an angular disconformity. Erosion prior to deposition of the Weaber Group may be largely responsible for the loss of the ridge topography. It is at present uncertain whether the Enga Sandstone thins to the north. Judging by its outcrop pattern this may be the case.

Palaeontology : A Lower Carboniferous age has been accepted for the Enga Sandstone, partly because of its stratigraphic position and partly because Dickins (Traves, 1955, p.66) tentatively identified a species of Cardiopsis in it. He subsequently noted a similar species in the Tournaisian Burindi Beds of New South Wales.

Interpreted Depositional Environment : The shelly material together with grain size, sorting and roundness all suggest shallow water marine deposition.

Septimus Limestone

Author : Noakes et al (1952)

History : The name "Mount Septimus Series" was first used informally by Reeves (1948, Plate V), for Carboniferous limestones discovered by Matheson and Teichert (1948) on central Burt Range. "Mount Septimus Limestone" was used by

Traves (1949) and introduced in print by Noakes et al (1952). Traves (1955) abbreviated the name to "Septimus Limestone" and specified the area of outcrop as "the slopes of Mount Septimus and the western slopes of central Burt Range. Small outcrops of Septimus Limestone were also found near Milligans Lagoon. It has not been found in the Carlton area of Palaeozoic sediments". This definition is still valid except in that the outcrops at Milligans Lagoon overlie Milligans Beds, and should be equated with the lower part of the Point Spring Sandstone, and not with the Septimus Limestone. The outcrops on Burt Range are confined to the south-west, west, and to the north, where they occur within a fault block.

The Septimus Limestone fauna has been more recently identified in limestones at a locality 3·5 miles north-east of Spirit Hill,[*] and less certainly at a locality 1 mile north of Spirit Hill. At Spirit Hill itself the faunas in the limestones have affinities with the Septimus Limestone (Thomas, 1963, and in Spirit Hill No. 1 Completion Report, Appendix). It is possible that outcrops referred to the Sandy Creek Beds, about 13 miles north-east of Spirit Hill, are also Septimus equivalent (see area North-east of Spirit Hill). Septimus Limestone may also be present in Spirit Hill No. 1. It appears to occur in Seismic Shot Hole No. 449 on the traverse across Milligans Lagoon judging by faunal evidence (Jones, 1958, p.8-9).

Lithology : The formation comprises sandy crinoidal limestones and interbedded calcareous sandstones. In places it is thin-bedded; elsewhere it is massive. Brachiopods are common, and corals occur.

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* The locality name "Spirit Hill" is used here in the sense of Allen (Fig.5), and others. Utting (1957, etc.) used the name for the more general topographic high centred about 2 miles further north-west.

Sections : Matheson and Teichert (1948) referred to 350' of very hard crystalline (limestone) rock on central Burt Range, and stated that similar Carboniferous rock probably also occurred at Mount Septimus. Reeves (1948) described two partial sections on the north-east side of Mount Septimus. One was simply described as 100' of fossiliferous limestone. The other gave some details of the upper part of the formation (Section No. 6). Traves (1955, p.67) described what should be regarded as the type section from the western slopes. It is incomplete at the base, and the upper contact is marked by a covered 6' interval. Glover et al (1955) described two further sections (No. 7 and 8). The first, located in the area examined by Matheson and Teichert (1948), is the thickest known. The other, in the fault block at the north end of Burt Range, contains the contact with the overlying Weaber Group, as interpreted by Glover. Rade (1957) described a partial section near that of Reeves.

Upper Contact : The only reported exposure of the upper contact is below Section No. 13, at Mount Septimus, where there is no apparent unconformity. There is however a general colour change from grey weathering below to grey-brown above the contact, and the sandstones of the basal Weaber Group differ in character from those of the Septimus Limestone (see Point Spring Sandstone, basal contact). A similar colour change occurs at the nearby type section, and Traves (1955, p.66) reported an unconformity at this contact at Mount Septimus and central Burt Range, presumably on the basis of bedding habit, lithological change etc., as follows: "At both localities, the Septimus Limestone is unconformably overlain by sediments of the Weaber Group, although the apparent unconformity is very slight."

Lower Contact : The lower contact is nowhere reported exposed, although, as noted in the discussion of the Enga Sandstone, Glover et al (1955) stated that the underlying Enga Sandstone grades to the Septimus Limestone.

Thickness: At its type section the thickness of the Septimus Limestone is 355', plus an unknown covered interval at the base. Glover et al (1955) estimated a total thickness of 450' at Section No. 7 to the south. The formation should be erosionally truncated beneath the Weaber Group towards the north in the type area, but there is no direct field evidence of this.

Palaeontology : The formation is of Lower Carboniferous age. Öpik (Noakes et al, 1952) considered the productid Marginirugus to indicate equivalence with the Warsaw and Keokuk Formations of the Mississippi Valley, and these may be approximately middle Visean. Thomas (1963) suggested a late Tournaisian to earliest Visean age from the brachiopod fauna. ☆

Interpreted Depositional Environment : Current bedding and ripple marks (Traves, 1955 p.67) and the marine faunas suggest shallow water marine conditions.

Milligans Beds

Author: Utting (in Spirit Hill No. 1 Completion Report)

History : This shale unit is almost unexposed in Bonaparte Gulf, and was discovered by seismic shot-hole and stratigraphic drilling during 1956. The latter was performed by contractors for Westralian Oil Ltd. within Permit No. 3, and consisted of Milligans Stratigraphic Tests Nos. 1 - 3 and Spirit Hill

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☆ Thomas (pers. comm) stated: "The faunas are mainly from the upper 200 feet or so. They are recorded also in Thomas (1964, in press), and in Appendix 4 of Spirit Hill No. 1 Completion Report. Certain forms indicate Visean rather than Tournaisian, but I feel that too fine age limits ought not be drawn at this stage. I regard the faunas as definitely somewhat younger than the Tournaisian faunas of the Moogooree Limestone and Laurel Formation. On the other hand they are somewhat older than the Point Spring faunas, which are essentially late Visean in affinities, with certain species which could range into the Namurian."

Stratigraphic Tests Nos. 1 - 3. All of these recovered at least some black or grey shale which Utting (1957) assigned to the Burt Range Formation because only that formation was known to contain shale, and because initial conodont identifications allowed for an age range of Upper Devonian to Carboniferous. During 1956 the Bureau of Mineral Resources carried out seismic work in both the Spirit Hill and Ninbing areas. Shot hole samples from thiswork were analysed palaeontologically and some were shown to consist of shale of Carboniferous age (Jones, 1958). Such shale occurred below cover along part of the Ninbing line, and north of Spirit Hill. At the same time the shale samples from Milligans Stratigraphic Tests No. 1 and 2 were found to be of Carboniferous age. In Spirit Hill S.T. No. 1 the shale was fossiliferous but the fauna was not diagnostic of age. The location of the other holes and the shale lithology suggest a Carboniferous age for the strata penetrated.

In view of these results, Utting (1958) suggested the name Milligans Beds for the Carboniferous shales. He included the sandstones at the top of the Spirit Hill outcrops, interpreting them as the basal part of the formation. This is unacceptable for several reasons (see Point Spring Sandstone and Group Relationships). The name "Milligans Beds" was introduced in print in the Spirit Hill No. 1 Completion Report.

At present details of the stratigraphy of the Milligans Beds are lacking, because of their recessive topographic expression. The interpretation of the near-surface distribution of the beds was attempted on the interpretative geological map by assuming that where covered areas occur around proven occurrences of the shale at surface or in bore-holes, the shale can be assumed to be present near to the surface. The shale is restricted to occurences in bore-holes in the Spirit Hill - Burt Range area. In the Ninbing area, Utting (1960) reported poor exposures of shale from near Ninbing to about two miles south of Knob Peak. The large re-entrant shown on the map south of Ninbing is mainly based on Bureau of Mineral Resources shot-hole data. Unless shallow drilling at key points is carried out, it is unlikely that the detailed near-surface distribution of the formation will be resolved. Lateral facies changes of the shale to sandstone may occur, and are considered later.

Lithology : The Milligans Beds are composed of grey to black, soft, fissile to blocky shale. They are calcareous to non-calcareous, commonly silty, contains fairly common sand grains in places, and occasional fine to coarse grained sandstone and siltstone stringers and beds. Gypsum inclusions reportedly occur locally, as do streaks and thin beds of limestone. Sporadic pebbles of quartz and siltstone are present. Near the surface at Spirit Hill No. 1 the shale is altered to soft pale grey clay.

Sections : Because surface exposures are lacking, the sections are based on bore-hole data. Milligans S.T. No. 1 with 364' (Appendix 4, Section No. 9) and Spirit Hill No. 1 (Fig. 7) with over 700', are complementary reference sections which illustrate the upper and lower contacts respectively. Milligans S.T. No. 2 provides a third section, of more doubtful value (Utting, 1957). On the basis of their lithology, Milligans S.T. No. 3 (Section No. 10) and Spirit Hill Stratigraphic Tests Nos. 1-3 (Utting, 1957) can also be regarded as having penetrated partial sections of the Milligans Beds. All of these are in the Milligans Hills - Spirit Hill area. No sections have been described in detail from near Ninbing.

Upper Contact : The upper contact is not exposed at the surface. It is present in Milligans S.T. No. 1, and possibly in Milligans S.T. No. 3. Both bore-holes indicated interbedding between the Milligans Beds and the overlying Point Spring

Sandstone. In Milligans S.T. No. 1 there is about 82' of interbedded siltstone, shale and calcareous sandstone between hard non-calcareous sandstone and the main shale. Following Utting (1958), the top of the Milligans Beds are placed at 146', and the overlying interbeds are assigned to the Point Spring Sandstone. In Milligans S.T. No. 3 it is less certain that the Milligans Beds were entered, as only 8' of shale occurs at the bottom of the hole, and the overlying transition zone is only 34' thick. If present, the top of the unit lies at 82'.

Basal Contact : In Spirit Hill No. 1, the formation was penetrated at 826', at which depth the contact between black shale and pale carbonates of the underlying formation is abrupt. This contact is probably an unconformity (see Group Relationships).

In the Ninbing area, Utting (1960) reported 700' of Carboniferous basal beds consisting of sandstones, conglomerates and minor shale, and (pers. com.) believes that at least some of the coarser clastics occur at the base of the Milligans Beds. The formation is clearly transgressive on older beds south of Ninbing, and basal clastics are to be expected.

Thickness : The section of Milligans Beds is 364' thick in Milligans S.T. No. 1 and 786' in Spirit Hill No. 1, but neither section contains both contacts. The formation definitely thins south from Milligans S.T. No. 1. It does not occur at all on Mount Septimus unless field relationships have been misinterpreted, as exposures of Point Spring Sandstone directly overly the Septimus Limestone. In view of the conformable relationships between the Point Spring Sandstone and the Milligans Beds in Milligans S.T. No. 1, this can best be interpreted as due to non-deposition of Milligans Beds at Mount Septimus. The relationship suggests that thickening of the shales may occur north from Milligans S.T. No. 1. Some support for this possibility was provided by Jones (1958), who thought that there may be two stratigraphic faunal horizons in the area. Only the older was found in Milligans S.T. No. 1 and only the younger in the seismic shotholes north of Spirit Hill and in Spirit Hill No. 1, but both were present in Milligans S.T. No. 2, between the two areas. This implies that younger beds, and hence a thicker total section, occur towards the north. An unknown amount of section is missing at the top of Spirit Hill No. 1 by recent erosion. On the whole, it seems most unlikely that 786' represent the maximum thickness of the formation in the Bonaparte Gulf area, particularly as Spirit Hill No. 1 is located near the edge of the basin. ☆

In the Ninbing area Utting (1960) estimated 400' as the maximum thickness of Milligans shales, and 700' for basal Milligans clastics.

Palaeontology : Utting, (1958) summarised the earliest palaeontological findings on the Milligans Beds and concluded, largely on the basis of work by Jones and Thomas, that they were Visean to possible Namurian in age. Jones (1958) did not give a more restricted age than Carboniferous on the basis of his microfaunal work, because of the uncertainty of Australian microfossil ranges. He listed several forms which range from Upper Mississippian to Pennsylvanian or Permian in North America, and his comparisons with overseas species are consistent with Chesterian-Pennsylvanian in terms of North American age units, or Upper Visean to Namurian in European stages. Thomas (in Spirit Hill No. 1 Completion Report, Appendix) stated that Zeller of the University of Kansas suggested a Chesterian age for several endothyrid genera. On the whole, it seems probable that the Milligans Beds should be placed high in the Mississippian somewhere in or near the Chesterian (late Visean to early Namurian).

☆ Alliance Bonaparte No. 1, north of Ninbing, by October, 1963 had penetrated over 5,000' of shale, much or all of which could be Milligans Beds.

Interpreted Depositional Environment : The Milligans Beds contain a varied marine fauna, differing from those in underlying formations mainly in the rarity of large benthonic forms. Shale deposition would give a muddy sea bed unsuited to many large forms. At Spirit Hill No. 1, rounded sand grains are sporadically present in the shale, as are larger less rounded pebbles. This suggests proximity to a higher energy environment which, on the basis of the coarser clastics, could be a shoreline or near-shore shelf. The occasional interbedded sands, slumping, fine cross bedding and current bedding all suggest periodic, but short-lived, high energy conditions during deposition of the shale. In the other bores, sand stringers suggest similar conditions. In the Spirit Hill - Milligans Hill area the predominant shale lithology indicates quiet water and possibly lagoonal conditions of deposition, especially as minor secondary gypsum is reported in two of the stratigraphic tests. The rich marine fauna shows however, that normal marine conditions occurred periodically. It is inferred, on the basis of fauna, lithology, thickness, and distribution that deposition took place near the edge of a arine basin, possibly in a bay. Although the Spirit Hill - Milligans Hill area was probably one of relatively shallow inshore waters during Milligans Beds deposition, water depths of several hundred feet could have been attained at times.

Point Spring Sandstone

Author : Noakes et al (1952)

History : Reeves (1948) described two sections along the scarp of the Weaber Range, and the more easterly is now considered to include the type Point Spring Sandstone. Öpik (1950, p.7) discussed the general lithology of some beds a few miles west along strike from this section, near Point Spring, and referred to them as Point Spring Sandstone. The name was published by Noakes et al (1952). Present usage is in the sense of Öpik, and the unit was formally defined in the Spirit Hill No.1.

Completion Report.

Traves (1955, p.78) reproduced Reeves two sections and referred them to Point Spring Sandstone, so including conglomerates at the top of the type section. Traves did not analyse the relatively complex stratigraphy of related beds in the Spirit Hill/Weaber Range area in detail, but tentatively designated his expanded Point Spring Sandstone as the uppermost of three formations comprising the Weaber Group, (i.e. Nigli Gap Sandstone, Spirit Hill Limestone and Point Spring Sandstone). Glover et al (1955) agreed tentatively with this grouping, and suggested that the sandstones on top of Spirit Hill looked like those of the Point Spring Sandstone. They did not apply the group nomenclature in the Spirit Hill - Burt Range area, as it proved difficult to assign outcrops to the various formations, and concluded (1955, p.24) that facies variation might be present. Allen (1956) performed detailed work at Spirit Hill, subdividing the exposures there into lithological units. Of these units "d" and "d_1", now appear to be equivalent to the Point Spring Sandstone. Rade (1957) worked in the Spirit Hill - Burt Range area, and introduced the name "Keep River Sandstone" for the post-Septimus sandstone beds on the sides of Mount Septimus and for the sandstones on the west side of Amphitheatre. He used the term "basal sandstone" in the Spirit Hill area and did not equate it with the "Keep River Sandstone." Utting (1957) did so, and using the Rade's terminology, equated the "Keep River Sandstone" to the sandstones below the conglomerates in the type area of the Point Spring Sandstone, thus in effect renaming the type formation. This meant however, that the Mount Septimus, Spirit Hill and Point Spring areas had been related. At the same time Utting restricted Traves' (1955) usage of the name "Point Spring Sandstone" to the conglomerates above the "Keep River Sandstone" at the Point Spring Sandstone type section. The use of the name "Point Spring" for the unit above the original Point Spring Sandstone of Öpik was unacceptable. Utting (1957) also clarified the lithological definition of the "Keep River Sandstone" as a clastic unit with negligible conglomerate in it, overlain by conglomerate beds of the "Point Spring Sandstone."

In 1958 Utting realised that the name "Keep River Sandstone" was unacceptable, both because of synonymy and homonymy (i.e. Keep Inlet Beds, see later), and reapplied the name "Point Spring Sandstone." He also recognised the lower exposures at Milligans Hills as being equivalent not to the Spirit Hill Limestone but to the Point Spring Sandstone, partly on the basis of palaeontological work by Thomas (1963). By interpretation he excluded the uppermost Spirit Hill beds, earlier included in the Point Spring Sandstone, as "basal Milligans Beds." Utting also (1958, p.10) raised the question as to whether the original "Keep River Sandstone" of the Septimus exposures should be referred to the Point Spring Sandstone or "basal Milligans Beds." In the same report, the "Point Spring" conglomeratic beds were renamed Border Creek Sandstone.

The use of the name "basal Milligans Beds" is here considered unjustifiable on the basis that the beds are sandstones, of Point Spring type, and not shale. The beds occur beneath Border Creek conglomerate at Mount Septimus, and in the Spirit Hill area a similar relationship can be interpreted to occur. Stratigraphically and lithologically, therefore, the beds should be identified with the Point Spring Sandstone, and are so placed here, on the assumption that field identifications are correct.

Although there is room for doubt, the overall distribution of Point Spring Sandstone between the type area and the Spirit Hill - Burt Range area can be considered as tentatively established. North-east of Spirit Hill, this is not the case. Rade (1957) performed reconnaissance field work there and described several sections as "Keep River" or Point Spring Sandstone (see Area North-east of Spirit Hill).

In the Ninbing area the distribution of Point Spring Sandstone is not well known. The section described by Reeves (in Traves, 1955, p.78) appears to be Point Spring Sandstone. The Border Creek Sandstone and Point Spring Sandstone are not subdivided on the enclosed geological maps. The distribution of the two together should be fairly representative, and the Point Spring Sandstone should occur beneath the Border Creek Sandstone in most of the exposures.

Lithology : The Point Spring Sandstone lithology is difficult to summarise. The formation can be divided into one or two units, depending on locality. In the type area, at Milligans Hills and possibly at Ninbing, a lower calcareous/arenaceous and an upper arenaceous unit are present. At Mount Septimus, in Burt Range and at Spirit Hill the formation is predominantly arenaceous, and is composed of distinctive brown weathering, locally feldspathic, sandstone. At Mount Septimus, Rade (1957) divided this sandstone in turn into a dark brown lower part and a pale brown upper part.

In the type area the upper unit is a flaggy to massive brown-weathering sandstone, with current bedding, clay pellets and a variety of worm tracks. It contains abundant plant remains.* The lower unit consists of buff to brown sandstone with a thin bed of limestone, and contains marine fossils. At Milligans Hills the upper unit of the section is reddish-weathering sandstone and carbonates. A sandstone at the top of the section contains large silicified concretions. The

* Thomas (pers. comm.) stated that plant remains also occur in the lower unit at the section at Point Spring, and elsewhere.

lower unit is mainly a gritty carbonate consisting of grey-green oolites which grade upward to reddish weathering ones.

The formation as a whole is arenaceous, even where limestone is important. The sandstones, where described in detail, are generally composed of rounded to sub-rounded, well sorted, fine to coarse grains. Sporadic pebbles and thin conglomeratic streaks are also present. The most characteristic feature of the formation is that appreciable beds of conglomerate are absent.

Sections : Reeves' (1948) easterly section, published by Traves (1955, p.78), should be regarded as the type section and was so designated by Utting (in Spirit Hill No. 1 Report). The locality was originally reported as 4 miles north-west of the State Boundary, and meant to refer to a point 4 miles north-west of the intersection between the Carlton-Legune track and the State Boundary. The point is in fact, nearer to 3½ miles from the intersection. Rade (1958) described a section 5 miles east-northeast of Point Spring. This is at or very near to the type section, and as Rade's descriptions are more detailed, this section, (No. 11), can be considered to supplement the type section. In the latter, the top of the Point Spring Sandstone should be placed at the base of the second highest bed, a 10' boulder conglomerate. Rade measured the section from the base of this bed. The most distinctive bed is 5' of limestone, at the base of Rade's section and 125' from the base of Reeves', which includes lower strata. This limestone may be a good marker horizon, as a limestone has been reported 1 mile east of Point Spring (Glover et al, 1955, p.30) and by Rade (Section No. 12) one half mile east of Point Spring, at roughly the same stratigraphic horizon. A possible equivalent 5' limestone was also recorded from Ninbing by Reeves (in Traves, 1955 p.78).

The base of the formation is not exposed at the type section, but is present in Milligans S.T. No. 1 (Section No. 9), which can be regarded as a reference section. Utting (1958, p.11) combined surface data with the bore-hole data and compiled an interpretative section showing a thickness of 251' for the entire formation at Milligans Hills. Judging by other data this is anomalously thin, e.g. at Mount Septimus the formation is more than 300' thick, and should be, if anything, thinner than at Milligans Hills. The following interpretative section, constructed from Glover et al (1955) and Utting (1957, 1958), may be more representative:

Border Creek Sandstone; boulder and pebble conglomerate,

25' Quartz sandstone, grey to light grey, weathered red brown, medium grained, well sorted. Contains ferruginous concretions locally.

175' Oolitic limestone, grey-green, weathered grey-brown except top 40' where weathered red-brown. Contains grit lenses. Fossiliferous except top 40'.

30' Sandstone, fine grained, with some worm tracks.

25' No exposures - top 25' of Milligans S.T. No. 1

39' Mainly sandstone, white to brown, fine grained, and some limestone.

82' Passage beds to Milligans Beds.

Total: 376

Other described sections of Point Spring Sandstone include the one (No. 12) measured by Rade (1958) near Öpik's locality one half mile east of Point Spring, and three from Mount Septimus. Two of these, of which one (No. 6) is given in Appendix 4, were described by Reeves (1948) and the third (No.13) by Glover et al (1955). The only detailed sections from the Spirit Hills area are by Allen (1956). No. 14 is an 80' section of Point Spring Sandstone from the south end of the hill (Fig.5) and is unusual in that a 6' conglomerate occurs near the top. The section could be regarded either as representing the whole or only the basal part of the formation, depending upon interpretation (see Group Relationships). The other (No. 15) is poorly exposed and incomplete. Allen (1956, p.7-8) also provided a generalised section from 2,000 yards north-west of Spirit Hill. Both Allen and Rade (1957) give still more generalised interpretations of the succession around Spirit Hill, discussed under "Spirit Hill Area." The only section described from the Ninbing area by Reeves (in Traves, 1955) cannot be precisely located. It comprises 355' of sandstones containing a limestone bed.

Upper Contact : The contact between the Point Spring and Border Creek Sandstones can be defined as the base of the lowest well developed conglomerate bed where both formations are exposed.* As both are clastic units and as the Point Spring Sandstone contains sporadic pebbles and thin conglomerates, the delimitation of the two formations will be somewhat arbitrary, and may become still more so as the stratigraphy becomes better known. This basis has however been the one applied in practice in the past. A "well developed conglomerate" can be defined as any layer or lens more than 2' thick, composed of cobbles or coarser clastics. Reeves (1948) described a 5' cobble conglomerate at Mount Septimus near the middle of what is here accepted as Point Spring Sandstone. His work was based on a rapid reconnaissance, and the identification was probably an error, as later workers (Glover et al, 1956; Rade, 1957), did not report the bed.

In all available descriptions there is no note of a disconformity or other hiatus ø between the Point Spring Sandstone

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* This is essentially the view of Utting (in Spirit Hill No. 1 Completion Report).

ø Utting (pers. comm.) made the following comment on this point. "In a V-shaped recession at the north end of Spirit Hill a very small outcrop of conglomerate lies on probable Point Spring Sandstone. The dip in the conglomerate seems at variance with that of the sandstone, but this could be illusory. There must be local irregularities at the base of a conglomerate, and when these are seen in isolated occurrence they can be misleading."

and Border Creek Sandstone, in spite of the high energy conditions implied by the presence of conglomerate. Utting (1958) at one time equated the Nigli Gap Sandstone with the Border Creek Sandstone and concluded that the latter should be unconformable on the Point Spring Sandstone. He later (1962) suggested that the Nigli Gap Sandstone was equivalent to the Cockatoo Sandstone (see Nigli Gap Sandstone).

As defined, the upper contact occurs at the type section and elsewhere in the Weaber Range, at Mount Septimus and Burt Range, north and west of Spirit Hill, at Milligans Hills, and presumably at a number of places near Ninbing.

Basal Contact : In the type area the base is covered, but the formation almost certainly rests on Milligans Beds. At Milligans S.T. No. 1 the formation is transitionally interbedded with the Milligans Beds, (Section No. 9) and this relationship could apply wherever the older formation occurs. For example, the shaly sandstones recorded by Reeves at the type section may be significant. Where Milligans Beds are absent the Point Spring Sandstone lies upon various formations. At Mount Septimus and on the south side of the Burt Range it overlies Septimus Limestone with a marked colour change but no apparent disconformity (see Septimus upper contact). The Point Spring Sandstone is probably present in Amphitheatre (Rade, 1957) where the base is unexposed but the sandstone could rest upon Burt Range Formation. In the Spirit Hill area, Allen (1956) mapped what is here referred to as Point Spring Sandstone (units "d" and "d_1") without reporting a disconformity. His data can be re-evaluated now that the area is better known, to suggest that the Point Spring Sandstone may be separated from older beds by an erosional unconformity.

In the Ninbing area the base of the formation is undescribed, but interpretation of available data suggests that the relationships there will be similar to those further east.

The Milligans Beds should underlie the Point Spring Sandstone in most of the area, but at least in one locality Point Spring Sandstone may rest directly on Cambro-Ordovician strata, i.e. in the Onslow Hills.

Thickness : The Point Spring Sandstone is more than 300' thick at its type section. On Mount Septimus its thickness has been reported as 355' (Reeves, 1948), 325' (Glover et al, 1955), and 303' and 306' at two localities on either side (Rade, 1957). As noted, the section may be about 375' thick at Milligans Hills. On the north-west side of Spirit Hill the thickness is about 600', as interpreted from Allen (1956), and just south of the hill may be only 80' thick. One mile or so west of Spirit Hill Rade (1957) estimated the total thickness as 460', but this need not be the full section, as the base is not exposed. In the Ninbing area the Point Spring Sandstone is at least 355' thick. The known thickness of the formation therefore, ranges from 300' to about 600', and may not greatly exceed this range.

Palaeontology : Öpik (1950, and in Traves, 1955) analysed a limited faunal collection and thought that the Point Spring Sandstone and other formations assigned by Traves to the Weaber Group were of Permian age. Thomas (in Traves, 1955, Appendix D) thought the fauna to be Carboniferous. Subsequently more complete faunal collections were made, and Thomas (1963, and Spirit Hill No. 1 Completion Report, Appendix) concluded that brachiopods from the Weaber scarp and Milligans Hills indicated a Visean to possibly Namurian age. This is much the same as that of the Milligans Beds.

Interpreted Depositional Environment : Marine forms and limestones apparently occur only where Point Spring Sandstone overlies the Milligans Beds. Where the latter formation is known to be absent the Point Spring is a red weathering sandstone, showing ripple marks (Allen, 1956) and containing weathered feldspar (Glover et al, 1955, p.27). This suggests shallow water, and the sporadic pebbles and conglomerate stringers suggest relatively near-shore conditions. The marine facies pass up to beds with a probable shallow water origin, e.g. the red beds at Milligans Hills and the cross bedded sandstones at Point Spring.

These points suggest that where the Point Spring Sandstone succeeded the Milligans Beds the water was still deep enough to allow marine or marine shelf (oolite) deposition, and that where Milligans Beds are absent, Point Spring deposition took place directly onto older strata on higher ground, in a still shallower water environment. With further deposition, these shallow water clastics may have spread over the entire Burt Range-Weaber Range area. Similar conditions may have occurred around Ninbing.

Border Creek Sandstone

Author: Utting (in Spirit Hill No. 1 Completion Report).

History : The name "Border Creek Sandstone" was first applied by Utting (1958) to conglomeratic clastics in the western part of the Spirit Hill area, after he recognised that the name "Point Spring Sandstone" applied to these beds in 1957, was invalid.* Utting, (1957, 1958) thought that at least part of the "Nigli Gap Sandstone," in the area south-east of the Cockatoo Fault, should be included with the Border Creek Sandstone but on the basis of the results of Spirit Hill No. 1, later (1962) changed this opinion. He also identified the Border Creek Sandstone in the Milligans Hills, at Mount Septimus

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* "This stemmed from Traves' (1955, pp.78, 79) re-definition of Öpik's (1950) Point Spring Sandstone to include the sediments above it in the Weaber Range. In 1957 I did not realise Öpik's claim to priority, and retained the greater part of the section (i.e. that now known as Border Creek Sandstone) in Point Spring Sandstone as used by Traves, therefore having, at that time, to give another name (Keep River Sandstone) to Öpik's section".

Utting (pers. comm).

and in the Weaber Range. Rade (1956-58) worked in all these areas and using the names "Policeman's Waterhole Conglomerate" for the basal Border Creek conglomerate and "Nigli Gap Sandstone" for the remainder, arrived at essentially similar conclusions to those of Utting (1958), although Rade did not correlate to the reference area west of Spirit Hill. At the reference area Rade retained Allen's (1956) local terminology of "Upper Beehive Sandstone" etc., (see Spirit Hill area). Border Creek Sandstone can be accepted as occurring at the Weaber Range, and in the Mount Septimus-Burt Range area. Utting's (1957) correlation of the formation to west of Spirit Hill is also accepted here. Correlation of the Border Creek Sandstone with "Nigli Gap Sandstone" is possible but not probable (see Nigli Gap Sandstone). The formation was formally defined in the Spirit Hill No. 1 Completion Report, the section in the Weaber Range being designated as the type section.

Lithology : The Border Creek Sandstone is sandstone with interbedded conglomerates, and is quite resistant to erosion. The conglomerate forms prominent turrets on Weaber Range. Sandstone beds cap Burt Range and Mount Septimus, and west of Spirit Hill form prominent beehive shapes by weathering along joints.

The conglomerates are mainly composed of rounded to sub-rounded fragments of quartzitic rocks ranging from pebble to boulder grade. Cryptogenetic angular blocks of mudstone, some over 6' long, occur in the area west of Spirit Hill (Allen, 1956, p.12).

The sandstones of the formation tend to be silty and thin bedded and are mainly brown-weathering, medium to coarse-grained, often feldspathic and occasionally micaceous. Ripple marks occur in places.

Sections : The type section of the formation has not yet been fully measured. The basal part overlying the type Point Spring Sandstone was described (in Traves, 1955, and in Spirit Hill No. 1 Completion Report). A useful reference section was described by Allen (1956, and Section No. 16), from about three miles west-southwest of Spirit Hill. The formation includes Allen's members "h" to "e" plus the 20' conglomerate at the top of "d". The type locality and formal terminology were nominated by Utting (in Spirit Hill No. 1 Completion Report).

Section No. 13 (from Glover et al, 1955) at Mount Septimus contains beds of lower Border Creek Sandstone. The formation is also present on Burt Range and at Milligans Hills. Sections over 1,000' thick have been reported in the type area. No sections have been specifically described near Ninbing, where the unit is relatively poorly exposed.

Upper Contact : The formation is the youngest exposed in the Ninbing - Spirit Hill area. It may be directly overlain by Keep Inlet Beds, or other unexposed units could intervene.

Lower Contact : As discussed in the section dealing with Point Spring Sandstone, the base of the Border Creek Sandstone is arbitrarily defined as the base of the first prominent bed of conglomerate where both units are present. By this definition the contact will almost certainly occur at different stratigraphic horizons at different localities, as the basal conglomerate can be shown to pinch out locally. For example, on Mount Septimus (Rade, 1957) the conglomerate thins from 52' in the south to 15' in the north, and according to Utting (1958a) is absent at the north end of the Burt Range. For this reason at Milligans Hills the basal conglomerate, which according to Rade (1956) is 12' thick and according to Glover et al (1955 and Section No. 17) is 25' to 40' thick, is unlikely to be the same horizon as that at Mount Septimus. Interpretative aspects of the interformational relationships are discussed under the heading "Group Relationships."

Thickness : West of Spirit Hill only 350' of relic strata can be measured. At Mount Septimus the maximum uneroded thickness is 125' and at Milligans Hills is 94' according to

Rade (1957). At the latter locality Glover et al (1955) reported 135' to 140' (Section No. 17) and at Mount Septimus, Reeves (1948) reported 300' of section. The latter is probably an overestimate, as Glover et al (1955 and Section 13) measured only 90'.

A relatively thick section of the Border Creek Sandstone occurs east of Point Spring. Glover et al (1955) measured 2,000' of Point Spring and Border Creek strata in reconnaissance one mile east of the Spring. If the Point Spring Sandstone is 500' there, the Border Creek Sandstone will be a minimum of 1,500'. From aerial photographs of the type section a few miles east, Utting (1958) estimated a similar thickness, and in 1960 reported 1,000' to 1,300' as the maximum thickness exposed in the Ninbing area. On this basis the Border Creek Sandstone must be well over 1,000' thick and may reach several thousand feet in a complete section.

Palaeontology : No diagnostic fossils have been found in the formation. On the basis of its stratigraphic position it is most likely to be Carboniferous but could contain Permian beds.

Interpreted Depositional Environment : There appears to have been continuous deposition from Point Spring Sandstone to Border Creek Sandstone. The sandstones are coarser than those in the Point Spring Sandstone, and the presence of conglomerates suggests short-lived but very high energy conditions. The common occurrence of feldspars or materials derived from feldspar indicates an igneous provenance. The formation may have originated on near-shore flats in a subsiding basin (see Group Relationships).

ROCK UNITS OF DOUBTFUL VALIDITY OR ASSIGNMENT

Nigli Gap Sandstone

Author: Traves (1955)

History : Traves (1955, p.72) gave this name to "the sandstone that crops out in Nigli Gap, which is situated less than a mile south of the south-eastern end of Policeman's Waterhole on the Keep River", and described it as predominantly sandstone with common rafted pebbles and conglomerate members. The thickest section of conglomerate, near the base of the formation, and situated one mile or so north-east of Cockatoo Springs, attains a thickness of 1,000' of unsorted conglomerate. The main outcrops of the formation occur east of the Cockatoo Fault, in the eastern parts of Burt Range, where the unit is faulted against Burt Range Formation. Traves tentatively equated some limited exposures between Spirit Hill and Ochre Mine with the Nigli Gap Sandstone, and the post-Septimus beds on the north-east side of Burt Range were also considered to be its possible equivalent. Traves noted that the formation rested unconformably on various Precambrian horizons eight miles north-east of Cockatoo Springs. The only fossil found was Equisetales at a locality in Nigli Gap. The poorly bedded and unsorted nature of the conglomerates was considered by Traves to suggest a glacial origin; this was also implied by the term "rafted" pebbles. The formation was tentatively placed at the base of the Weaber Group.

Glover et al (1955) followed Traves' usage, but were unsure of the relationship between the Nigli Gap Sandstone and other members of the Weaber Group, and did not identify the post-Septimus sandstone on Burt Range as Nigli Gap Sandstone. Rade (1959) identified the Nigli Gap Sandstone in this area however, using a slightly different nomenclature, and argued that older Palaeozoic sediments could also underlie the formation in the type area. Utting (1957, 1958), correlated the type Nigli Gap Sandstone with the Border Creek Sandstone (i.e. Point Spring in 1957) but in 1962 reintroduced the name at the type area, suggesting that the formation might be equated with the Cockatoo Sandstone. Utting's final correlation was based upon a number of points which can be expressed and expanded as follows:

(a) In its type area the Nigli Gap Sandstone rests transgressively with angular unconformity upon granites, metamorphosed and unmetamorphosed sediments of Precambrian age, and upon Antrim Plateau Volcanics. Equisetales sp., identified from Nigli Gap, ranges from the Devonian to the present, so the Nigli Gap Sandstone is of Devonian age or younger. Correlation with the Keep River Beds or younger beds is improbable on the basis of comparative distribution. Traves (1955) believed that the Nigli Gap Sandstone might be partly of glacial origin, and if so it could be related to the Keep River Beds, which have glacigene characteristics. However, in the Nigli Gap Sandstone the evidence of glacial activity is cryptic. The "rafted" pebbles, conglomerates and current bedding could signify littoral or near-shore conditions of deposition rather than ice action. The coarser clastics consist of fragments of quartzites and igneous rocks, presumably of local provenance, with no indication of exotic types brought from distant areas by ice, such as are found in the Keep Inlet Beds. These points suggest that the Nigli Gap Sandstone may be related to transgressive deposits of Devono-Carboniferous age and hence to either Border Creek Sandstone or Cockatoo Sandstone.

(b) The thickness distribution of the Cockatoo Sandstone in Burt Range area indicates a south-easterly source. As a near-shore shallow water sandstone, the Cockatoo Sandstone could pass to landward conglomerates. This facies change could occur near Cockatoo Springs, and although the abundant conglomerate in the Nigli Gap Sandstone suggests relationship with the Border Creek Sandstone, correlation with the Cockatoo Sandstone is equally possible.

(c) If, as suggested later, the Border Creek Sandstone is a diachronously recessive deposit, any initial transgressive on-shore conglomerate would tend to be stripped off again as soon as the recessive cycle became established. This is less likely to have occurred if the Nigli Gap Sandstone is Cockatoo equivalent, as the Cockatoo Sandstone probably represents the beginning of a transgressive cycle.

(d) The main throw of the Cockatoo Fault is down to the west, as proven by the preservation of several thousand feet of Palaeozoic sediments on that side. This structural relationship is consistent with Nigli Gap Sandstone being correlative with the Cockatoo Sandstone. If Nigli Gap Sandstone is Border Creek equivalent it will be younger than Septimus Limestone, and major downthrow on the west along the Cockatoo Fault before Nigli Gap Sandstone deposition would have to be succeeded after Nigli Gap deposition by a reversed movement on the fault to the east.

On the basis of the above points the Nigli Gap Sandstone is tentatively equated with the Cockatoo Sandstone, as Utting suggested, subject to field confirmation or revision, and is so shown on the interpretative map. The formal status of the unit cannot be changed on the basis of present data, but the formational name should be used with reservation, until the precise relationship between the Nigli Gap Sandstone and other sediments is established. It may be advisable to retain the name "Nigli Gap" for the main conglomerate in the type Nigli Gap Sandstone, as this is a distinctive unit.

The Nigli Gap Sandstone in its type area is shown as such on the surface geological map. Sandstones in the Spirit Hill area are discussed below. Exposures assigned by Traves (1955) to the Nigli Gap Sandstone at (his) locality 18 and Ochre Mine are still referred to the Nigli Gap Sandstone (see Area North-east of Spirit Hill). Rade (1956, 1959) described a number of sections of Nigli Gap Sandstone in some detail.

Spirit Hill Area

The Spirit Hill area is of considerable importance to the interpretation of the stratigraphy in Spirit Hill No. 1., and was discussed in the Spirit Hill No. 1 Completion Report. Figure 5, after Allen (1956), shows outcrops in the Spirit Hill area.

The Spirit Hill Limestone was defined (Traves, 1955, p.76) as the 350' section of sandy limestone and calcareous sandstone which crops out at Spirit Hill, (Section No. 14). Other exposures were recognised north-east of Spirit Hill and at Sandy Creek. The formation was considered to be the middle one of three formations comprising the Weaber Group. The most recent palaeontological work (Thomas, in Spirit Hill No. 1 Completion Report) suggests that the limestone is equivalent to the Septimus Limestone and unrelated to the Weaber Group. Glover et al (1955) referred the sandstones above the type limestone to the Point Spring Sandstone, which was the uppermost formation of Traves' Weaber Group.

Allen (1956) analysed the local stratigraphy in detail and interpreted the sequence as follows:

Sandstone	600'	member "d"	Not equated by Allen.
Quartz Sandstone	90'	member "d_I"	
Dark grey dolomitic limestone and calcareous sandstone	100'	member "c"	Spirit Hill Limestone
Grey dolomitic limestone and sandstone	370'+	member "b"	
Quartz sandstone	30'+	member "a"	Nigli Gap Sandstone

Rade (1957) confirmed Allen's findings and noted that the Spirit Hill Limestone had characteristics partly resembling the Burt Range limestone, but did not equate the units away from the type area. Utting (1957) showed the section at Spirit Hill as Point Spring ("Keep River") Sandstone, Spirit Hill Limestone and Nigli Gap Sandstone, and in 1958 as Milligans Beds sandstone, Septimus Limestone and Enga Sandstone. The two lower assignments were partly based on the fact that Septimus-type faunas had been found in limestones about 3.5 miles north-east of Spirit Hill. As already discussed, the name "Point Spring Sandstone" is preferable for the upper unit. Utting (1962) subsequently discovered Leptophloeum in member "a", so tentatively correlated this unit with the Cockatoo Sandstone, and the Spirit Hill Limestone with the Burt Range Formation. Satisfactory interpretation of the stratigraphy in the Spirit Hill area cannot be made with present data. The following points may be established, however:

(a) Apart from the Spirit Hill area, Leptophloeum is known from five localities. It occurs in the type Cockatoo Sandstone, at a depth of 2161' in Spirit Hill No. 1, at a locality in the Amphitheatre area near Section No. 5, and at two localities on the Burt Range Formation. One of these is at the top of the limestone sequence at Buttons Crossing on the Ord River (Matheson and Teichert, 1948); the other is near the base of the formation about two miles south-east of Martins Gap (Rade, verb. comm.). The identity of the sandstones which contain Leptophloeum in the Amphitheatre locality is uncertain. The entire section in the area might be Burt Range Formation, but it is more probable that the sandstones are part of a younger formation. On the basis of lithology the Amphitheatre sandstone is closer to Point Spring Sandstone than to the Enga Sandstone, according to both Glover et al (1955) and Utting (1962). The range of Leptophloeum is not certain. Thomas (Spirit Hill No. 1 Completion Report, Appendix) suggested that the plant may be as typical of the lower part of the Lower Carboniferous as of the Upper Devonian. If so, it could occur in many of the Devono-Carboniferous deposits of the area, but is unlikely to range as high as Point Spring

Sandstone. The Amphitheatre sandstones with Leptophloeum are therefore unlikely to be Point Spring Sandstone but may be Enga Sandstone. On the basis of other occurrences, the Leptophloeum locality at Spirit Hill cannot be considered diagnostic of the Cockatoo Sandstone.

(b) There is some evidence at Spirit Hill of an unconformity between Point Spring Sandstone and the Spirit Hill Limestone.

i) Utting (1958, p.9) reported: "At one place on Spirit Hill there is a suggestion of unconformity at the base", (of the overlying sandstone), "but this feature may be due to slumping over an irregular top of the Spirit Hill Limestone".

(ii) Significance might be attached to field observations by Allen (1956) who apparently assumed that conformable relationships occurred in the area. His units "d" and "d_1" suggest unconformity upon "c" and "b" in Figure 5. Allen was uncertain of the relationship between units "d_1" and "c", stating that on the south-east side of Spirit Hill "b" is overlain by some 90' of "d_1" and that "if the base of this sandstone is traced laterally around the eastern side of the hill here, it is found that the arenite gives way abruptly to sandy limestone, and calcareous sandstone of member 'c'. The point where the 'limestone' ceases is readily seen, for this member crops out well.

The two members appear, at first glance, to be separated by a fault, but the topmost bed of the underlying 'lower limestone' 'b', seems to be continuous under both 'limestone' 'c' and sandstone 'd'." -----"An alternative explanation is one of lateral gradation from 'limestone' to sandstone. This is not likely, as the 'limestone' ends abruptly, without interfingering with sandstone."

A third possible explanation is that an unconformity exists between "d_1" and "c" and the latter forms an erosional scarp under the younger sandstone.

(c) Thomas (Spirit Hill No. 1 Completion Report) discussed the poorly preserved faunas of the Spirit Hill Limestone and concluded that the evidence indicated age equivalence to the Septimus Limestone. More positive correlation was possible from a locality 1·5 miles north-northeast of Spirit Hill, and less certainly from a locality 1·5 miles north of Spirit Hill. On this basis all three localities may be correlative with the Septimus Limestone. On the other hand, this may be a simplification.

(d) If the lithologic units at Spirit Hill are identifiable with those further west, the sandstone under the Spirit Hill Limestone should be Enga Sandstone, rather than Cockatoo, assuming that the Spirit Hill Limestone is equivalent to the Septimus Limestone.

(e) Utting (1962) argued that field observations suggest a thinning of the Burt Range Formation - Enga Sandstone succession to the south of Burt Range in the Amphitheatre area. This would reduce the lithologic interval between the Cockatoo Sandstone and the Septimus Limestone. If the thinning was sufficiently pronounced, the sandstones under the Spirit Hill Limestone could be equivalent to the Cockatoo Sandstone.*

If the type Spirit Hill Limestone is equivalent to the Septimus Limestone then it will be invalid as a formal rock unit.

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* There is also a possibility that facies changes are involved. "Since the results of Spirit Hill No. 1 became available I have felt inclined to accept the possibility that the eastern or south-eastern side of the Burt Range Basin is a sandy expression of the whole sequence of Cockatoo Sandstone to Septimus Limestone. Spirit Hill Limestone could reasonably be related to the Septimus Limestone, because a calcareous environment was present for both. Further basinwards and to the north of Spirit Hill, i.e. in Spirit Hill No. 1, the sequence 826 - 1215 feet has many similarities with Spirit Hill Limestone, with which it should be correlated on present evidence, <u>but below this</u>, from 1215 to 2013 feet at least, is a mixed sand-carbonate-silt section that could be the equivalent of much of the lower Burt Range Formation and possibly of some of the Cockatoo". (Utting, pers. comm).

Further work will be required to determine the relationship of the Spirit Hill Limestone to other stratigraphic units. Allen's informal units "b" and "c", and also "d_1" and "d" of the Point Spring are unlikely to be of more than local application, as indicated in his report.

Area West of Spirit Hill

Allen (1956) used informal sub-units "c" to "h" for the reference section of the Border Creek Sandstone, and introduced the names "Upper and Lower Beehive Sandstone" (Section No. 16). Rade (1957) arrived at the same general section but subdivided it slightly differently, emphasising the conglomerate horizons, as follows:

Rade (1957)		Allen (1956)
170' Upper Beehive Sandstone	-----	Upper Beehive Sandstone, member "g"
70' Upper Conglomerate	-----	Member "f"
80' Lower Beehive Sandstone	-----	Lower Beehive Sandstone, member "e"
50' Lower Conglomerate	-----	Conglomerate at top of member "d"

Rade's terminology is more compact, apparently agrees with the topographic expression of the rocks, and also seems more acceptable because conglomerates, which are important in the Border Creek Sandstone, are emphasised. The Lower Conglomerate etc., can be accepted as informal units of member status. It remains to be seen whether they are more than local in extent.

Area North-East of Spirit Hill

Isolated exposures of sandstone, conglomeratic sandstone and limestone occur at various localities north-east of Spirit Hill in the Keep River Plains, and few of them can be assigned to formations further west with any degree of certainty. They are here referred to as the Septimus Limestone, Nigli Gap Sandstone, Point Spring Sandstone, Border Creek Sandstone and Cockatoo Sandstone on the basis of lithology, distribution and fossil evidence. In some cases the basis for allocating beds to known stratigraphic units is quite uncertain, and further field work is needed to clarify the stratigraphy. No attempt is made to interpret the solid geology in this area. The more important exposures are as follows:

"Sandy Creek Limestone":

These exposures, comprising up to 100' of flaggy sandstone overlying 100' of sandy limestone and limestone, occur immediately north-east of the intersection between "Sandy Creek" and the Legune-Point Spring track, some 22 miles from Legune. The beds were first described by Reeves (1948), and Öpik (1950) introduced the name "Sandy Creek Limestone." Traves (1955, p.76) equated the beds to the Spirit Hill Limestone, so invalidating the name. Unles Traves' equation proves invalid, the name "Sandy Creek Limestone" is redundant.

Teichert (in Reeves, 1948) thought the exposures were of Carboniferous age and Öpik (1950) thought them Permian. Glover et al (1955) subsequently collected fossils identified by Thomas as Carboniferous and finally, (Thomas 1963) as probable Tournaisian to Visean, which suggests age equivalence to the Septimus Limestone.✫

Rade (1957) equated the upper sandstones with the Point Spring ("Keep River") Sandstone on the basis of lithology. In view of this, the sandstones might be tentatively equated with Point Spring Sandstone, and the underlying limestone with the Septimus Limestone.

✫ Thomas (pers. comm.) stated: "These faunas are described in Thomas (1963, 1964) and are recorded in an Appendix in the Spirit Hill No. 1 Completion Report. Preservation is rather poor but quite a few specimens are available, some collected by myself. I was at first impressed by the resemblance of one form to _Choristites_ but have since referred it to _Ectochoristites_? sp. and consider that an Early Lower Carboniferous age is the most likely. Thus, the sparse faunas available suggest that the Sandy Creek and Spirit Hill Limestone may be correlatable. It is of interest that Teichert suggested a Carboniferous age from the very sparse collections made by Reeves at Sandy Creek."

Flapper Hill Sandstone:

140' of brown-weathering silicified sandstone at Flapper Hills, north-west of Legune, were first reported by Traves (1949) and named by Öpik (1950). They were described more fully by Glover et al (1955). Traves (1955) retained the name, "Flapper Hill Sandstone", but was uncertain of the stratigraphic relationship of the unit. Öpik (1950) considered the exposures to be slightly older than those of Sandy Creek. Thomas (1963), was also of this opinion, but thought that the fauna was much older than Permian, and dated it tentatively as Dinantian. On the basis of lithology, and age relative to the "Sandy Creek Limestone", the beds are here tentatively classified as Cockatoo Sandstone. Their status is by no means resolved.

Ochre Mine Exposures:

West of Alligator Springs, beds reported by Traves (1955) were identified by him as Nigli Gap Sandstone. The beds comprise 100' of conglomerate and pebbly sandstone overlain by 240' of medium to coarse grained pebbly sandstone containing mud pellets. The conglomerate materials are made up of Precambrian quartzite and sandstone.

Buffalo Hills Exposures:

Glover et al (1955) described two isolated knolls formed by 80' of felspathic quartz sandstone at Buffalo Hills. The beds may be Point Spring Sandstone or Cockatoo Sandstone.

Trachyte Locality:

Exposures 3½ miles south-southwest of the "Sandy Creek Limestone" locality consist of sandstones with occasional pebbles. The beds were referred to Nigli Gap Sandstone by both Traves (1955, p.74) and Rade (1958, p.8). The locality is unusual in that it contains trachytes, probably as interbeds with the sediments. Rade (1956, p.2) considered the trachyte to be intrusive.

Keep River Sandstone and Policeman's Waterhole Conglomerate.

The name "Keep River Sandstone" was first used by Rade (1956, p.5) in an unpublished report, for the sandstones, here referred to as Point Spring Sandstone, which lie above the Septimus Limestone in the Mount Septimus and western Burt Range area. At the same time Rade introduced the name "Policeman's Waterhole Conglomerate," which at Mount Septimus is the basal Border Creek conglomerate, and equated it with the main conglomerate of Traves' Nigli Gap Sandstone, east of Cockatoo Fault. The Keep River Sandstone was designated by Rade as Unit 1, and the Policeman's Waterhole Conglomerate as Unit II, in a group of four informal units. All were considered to equate with Traves' Nigli Gap Sandstone, which name Rade restricted to the uppermost Units III and IV.

The rock correlations upon which Rade's breakdown of Units I -IV is based differ from those of other workers in the area. The name "Keep River Sandstone" is of doubtful acceptability because of the prior existence (1955) of the Keep Inlet Beds. Also, Rade (1957) applied the name "Keep River Sandstone" to the type section of the Point Spring Sandstone, and the latter name has both priority and formal status. The name "Policeman's Waterhole Conglomerate" possibly could be used for the conglomerate in the area east of Cockatoo fault, but whether or not it could be applied west of the fault depends upon stratigraphic relationships yet to be established.

PERMO-TRIASSIC

Keep Inlet Beds

History: Isolated outcrops of clastics have been described from the Keep Inlet area by Glover et al (1955), and on the basis of their distinctive lithology were referred to by these authors as "Keep Inlet Beds". The exposures are poor, and it will require drilling before the detailed stratigraphic relationships between these beds and others in Bonaparte Gulf area is understood. The less formal designation "Beds" should be retained until then. The Keep Inlet Beds have not previously been described in print.

Lithology: In contrast to the Border Creek Sandstone, the Keep Inlet Beds weather pale grey. The main exposures are of light grey, felspathic, calcareous quartz sandstone, with clay pebbles, other pebbles, and boulders. Large boulders up to six feet in length appear to have weathered from the sandstones. These boulders are composed of schist, slate, quartzite, gneiss, granite and Middle Cambrian glauconitic limestone, so are more varied than material in any of the older conglomerates in the area. Striae were tentatively identified on one boulder.

Sections: Outcrops are apparently too poor to enable a type section to be designated. The reference area is north-east of Cleanskin Bore.

Upper and Lower Contacts: The upper and lower contacts are unknown. The interpretative geological map shows the unit resting on Border Creek Sandstone, but other non-outcropping formations may intervene. The unit may be correlative with part of the Port Keats Group to the north.

Thickness: The thickness of the unit is unknown.

Palaeontology: A probable Strophalosia sp. from a clay pellet indicates a Permo-Carboniferous and possible Lower Permian age[*] according to Hill (Glover et al, 1956, p.34). On the basis of its possible stratigraphic position below the Permian of the Port Keats area, the unit could be of Sakmarian age.

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[*] Thomas (pers. comm.) stated: "Strophalosia was identified by Professor Dorothy Hill as a 'juvenile form'. This genus in the Australian context indicates a Permian age. The glacial evidences suggest a correlation with the partly glacigene Grant Formation and Lyons Group. The latter is essentially Sakmarian on marine faunas."

Depositional Environment: The coarser clastics are considered to be of glacial origin by Glover et al (1955) on the basis of composition, the presence of possible striae, and the large size of some boulders. The presence of _Strophalosia_ may indicate marine conditions.

Port Keats Area

History: North of Queens Channel in the Port Keats area exposures are generally poor. Most of the strata in this area have been assigned to the Port Keats Group, discussed later. With some qualification this group is an acceptable unit. The same cannot be claimed for units of lesser rank, for although at least five formations appear to be present, none has been designated.

H.Y.L. Brown, as Government Geologist for South Australia, examined strata exposed along the coast in 1895, and during 1906-1909, supervised eight tests drilled for coal between Port Keats and Cliff Head. Oil Company geologists subsequently measured a number of surface sections in the inland area. None of these exposes more than part of the section penetrated in the bore-holes, which form a useful guide to the stratigraphy. Samples from the coal bores unfortunately are no longer available, so original descriptions have to be used. Brown (1907, p.25 etc.) made it clear that core recoveries were often poor, and lithologic descriptions were recorded by the drilling foreman. Consequently although the bore-holes fulfilled their purpose of determining coal possibilities, they do not always provide reliable lithological data, and emphasis cannot be placed on details of the logs. It is, however, possible to delineate major lithologic units. Figure 6 is an interpretative cross section based upon the coal bores, showing informal formational units designated I-V. There are seven described coal bores (Brown, 1907-1909), and one (Cape Ford C.B. No. 1) in which no samples were obtained above the total depth of 360' at which the bore was abandoned due to sand inflow. Cape Ford C.B. No. 2 was then located 13' to the south. Total depths for the other coal bores are shown on Figure 6 and locations are given on the geological maps.

General Lithology: In surface sections the Permian beds are predominantly sandstone but include siltstone and shale. The sandstone is generally micaceous and kaolinitic, fine to coarse grained, cross bedded, and displays ripple marks and some concretions. Local pebble and grit bands, in which the pebbles are mainly quartzite, are present. The shales are micaceous and of a yellow to brown colour.

The distribution of Formation I, the uppermost unit, appears to be limited to the coast. Surface exposures in the south have been described by Thomas (1957) as "thin-bedded grey and yellow to reddish mottled cross-bedded siltstone." Burbury (1959) reported Cape Dombey beds as reddish quartz sandstone. The coal bore correlations suggest that the thickest section is present at Cape Scott peninsula, and that the overall lithology comprises sandstones, siltstones and shale, the finer clastics being predominant. Some carbonaceous layers occur, and limestones are absent except in the Port Keats area (C.B. No. 3). Formation I is distinguished from the underlying formations in the bore-holes by the general fine grade of its clastics, and a lack of pebble bands.

The other formations in the subsurface are subdivided mainly on the basis of coal distribution. Coal is easily recognised, so should be a reasonably reliable lithological guide. Formation II is predominantly sandstone with shale towards the base. Formation III is typified by coaly streaks and is also mainly composed of sandstone with some shale. Formation IV was not penetrated, but consists of sandstone in the upper part, and appears to grade down to shale about 100' below the top. Thin beds of limestone are present in all the formations in the

Port Keats area. Formation V, present only in the north, is composed of pale coloured sandstones and coarser beds. It appears to be stratigraphically equivalent to all or part of Formations I to IV.

Sections: It should be possible to designate some surface sections as type or supplementary type sections once the geology is better known. The best sections found are between Kurriyippi Hills and Table Hill, south-east of Port Keats. Six surface sections were described by Evans (in Reeves, 1948). These were located during a reconnaisance survey, before 4-mile maps were available, and only the section at Mount Goodwin (Section No. 18) and a 400' section at Table Hill (in Traves, 1955, p.80) can now be located. Derrington et al (1957) measured a Mount Goodwin section, probably at Reeves' locality, a Table Hill section, and five other sections between Port Keats and Table Hill. Two of these sections, at Kurriyippi Hills, are reproduced here (Nos. 19 and 20). Derrington et al also measured a further section near Moyle River, as did Burbury (1959 and Section No. 21).

Interpretative Formational Relationships: It is possible to relate surface and subsurface data to some extent on a tentative interpretative basis. In surface exposures Thomas (1957) identified four Permian fossil assemblages of which the upper two (C" and "D") and the lower ("A") were marine faunas, and the second lowest ("B") was of plant remains. Thomas tentatively correlated faunas "C" and "D" to the interval 555'-715' in Port Keats C.B. No. 3, and accepted the suggestion by Brunnschweiler (1953) that the beds above 555' may be Triassic in age. Flora "B" was equated with the <u>Glossopteris</u> shale recorded at 724'-730' (in C.B. No. 2) so in effect the three upper assemblages were correlated to the upper half of Formation III of Figure 6. It is only in C.B. No. 2 that plants are recorded in this part of the section, so the occurrence is, in fact, anomalous. On the other hand in the deeper holes Formation III is defined by coal streaks.

By inference this formation should contain plants. For this reason it is suggested that the "B" flora may be the surface expression of Formation III, that faunas "C" and "D" may correlate with Formation II, and fauna "A" with Formation IV.

Subsurface and surface data can be further related in a tentative manner. Sections at Moyle River consist either of clean pale-weathering sandstones (No. 21) or argillaceous sandstones comparable to the section in the Cliff Head Coal Bore. The Table Hill and southern Kurriyippi Hills (No. 23) sections, which are unfossiliferous, are also composed of white-weathering sandstones, suggesting that Formation V may be present at these localities. On the basis of its possible distribution at surface and in the bore-holes, Formation V is interpreted as replacing the others progressively from south to north.

Upper Contact of Formations I to V: This is an unconformity. The overlying deposits are either Tertiary laterites, formed on the Permian, or are lateritised beds of probable Cretaceous age (see ?Mesozoic).

Basal Contact of Formations I to V: Formation V in the Cliff Head Coal Bore rests on granite. The contact may be found at the surface in the area north of Moyle River, but is not recorded. Possible relationships between the Keep Inlet Beds and Formations I-V are discussed under "Group Relationships."

Contacts between Formations I-V: As far as the limited data suggest, Formations I - IV are mutually conformable. The contact between II and III is probably exposed at Kurriyippi Hills (Section No. 19) and that between III and IV is present but probably covered between Fossil Head and Fossil Summit. Formation V, as a lateral equivalent, has rather arbitrarily defined relationships to the others, e.g. in Anson Bay C.B. No. 1.

Thicknesses: Figure 6 suggests that the cumulative thickness of the Permo-Triassic in the Port Keats area probably exceeds

2500' near Cape Ford. The thickest formational sections are: Formation I in Cape Ford C B. No. 2, 785'; Formation II in Port Keats C.B. No. 4, 325'; Formation III in Anson Bay C.B. No. 1, 587'; Formation IV in Port Keats C.B. No. 4, 191'; and Formation V in Anson Bay C.B. No. 1, 1231'. None of the surface sections represents more than a few hundred feet of any one formation.

Palaeontology: Etheridge (1907) made the first palaeontological analyses of the area using collections from Fossil Head and from the Port Keats bore-holes. He classified the beds below 555' in C.B. No. 3 as Permo-Carboniferous and thought that the younger beds, on the basis of their appearance, might be Mesozoic or Tertiary. Etheridge also noted the ostracod Estheria in C.B. No. 3 at 220'. Crockford (1943) confirmed the presence of Permian bryozoa between 550'-580' in C.B. No. 3. Teichert (1947) suggested an Upper Permian age for Etheridge's fauna from the upper part of the bore and for a fauna collected near Port Keats by Evans (Reeves, 1948, p.9). Brunnschweiler (1953) considered the Estheria to be the Isaura of the Blina Shale of the Fitzroy Basin, and thought that the upper part of the bore-holes might consist of Triassic rocks. Thomas (1957) accepted this interpretation, and suggested that the beds above 555' (Formation I) should be Triassic. The faunal contact need not be identical with the formational one but, subject to confirmation, Formation I could be considered to be mainly of Triassic age. As already noted, Thomas (1957) made the first systematic analysis of fossils collected from surface exposures and showed that there were three faunal assemblages and one floral assemblage present. He correlated faunas "C" and "D" with the Middle and Upper Productus Limestones and with the Hardman Member of the Liveringa Group in the Fitzroy Basin, of later Upper Permian age. The "B" flora is not particularly diagnostic of age. The "A" fauna is closely allied to that in the Lower Liveringa Formation, which Thomas considered to be of late Artinskian to early

Kungurian age. If the lithologic relationships suggested here are correct, then Formation II could be Tartarian/Kazanian, III could be middle to upper Kungurian, and IV could be late Artinskian to early Kungurian. Older beds in the basin could represent the remainder of the Permian succession, and could be represented further south by the Keep Inlet Beds. This possibility is speculative at present.

Interpreted Depositional Environment: The Permo-Triassic formations of the Port Keats area, unlike the Keep Inlet Beds, are not reported to contain any glacial deposits. The conglomerates are composed predominantly of quartzite pebbles. The lithologic uniformity of these, where reported, implies a single source.

Formations I-V are all principally shallow water deposits, judging by the widespread occurrence of pebble bands, ripple marks and current bedding. In the north and west, Formation V has pale sandstones and high proportion of coarse clastics. These characteristics suggest that it may have been deposited in relatively shallow water, in high energy near-shore areas. The interbedding of sands and finer clastics in the other formations suggests that they were laid down in slightly deeper water, further out in the basin, where subsidence kept a more even pace with deposition. In outcrop the shales are described as micaceous and silty but not fossiliferous, so they need not be of marine origin. In the subsurface around Port Keats the presence of coal streaks in the shales suggests that the shales there may be mainly of non-marine origin. The marine fossils in both outcrop and in the bore-holes show , however, that marine conditions occurred during deposition of Formations I-IV, at least for limited periods of time.

? MESOZOIC

Thin lateritised deposits, of possible Mesozoic age, form caps on mesas between Queens Channel and the north of the area.

Noakes (1949) defined the Mullaman Group as comprising an unnamed lower freshwater unit, of Lower Cretaceous or possibly Jurassic age, and the marine Darwin Formation, of Lower Cretaceous age. He traced these beds through the Katherine-Darwin area and tentatively identified the Mullaman Group at Mount Greenwood in the north of the Bonaparte Gulf area, suggesting that at Mount Greenwood only the Darwin Formation might be represented. Further south comparable lateritic beds form caps on mesas and also may represent the Mullaman Group. Evans (Reeves, 1948), interpreted the uppermost part of all his mesa sections (and the bore sections) as being of Mesozoic age. Derrington et al (1957, p.33) stated that only laterites of Tertiary origin could be identified on the mesas in the Port Keats area, but that the Mullaman Group could be present. There is no palaeontological evidence that Mesozoic beds occur in the Port Keats area.

In this area, as in others, sediments exposed during the Tertiary have been thoroughly lateritised, and the interpretation of the altered beds can be difficult. On the whole, Evan's field identification of an unconformity and basal conglomerate suggests that some of the lateritised beds in the Port Keats area were deposited during the Mesozoic, so the name "Mullaman Group" is used tentatively for them. It is also quite possible that the laterite caps in the Port Keats area were formed on Permian deposits.

Lithology: Evans referred laterites, the underlying shales and sandstones and a supposed basal conglomerate to the Mesozoic. The shales and sandstones often show ferrugination or other lateritisation effects. Noakes (1949) made a similar assignment to the 70-80' of sandstone and shale capped by 16' of porcellanite at Mount Greenwood.

Sections: The sections exposed at Mount Goodwin and Table Hill have been described by both Evans (Section No. 18 and in Traves, 1955, p.80) and Derrington et al (1957). The thicknesses logged in both cases were similar, but interpretations differed. Two sections from the Kurriyippi Hills (Nos. 19 and 20) are the only others reproduced in Appendix 4 of this report in which Mesozoics could occur.

Upper contact: This is everywhere a modern erosion surface.

Lower contact: Evans (in Reeves, 1948) reported an angular unconformity between possible Mesozoic beds and Permian strata at the north end of the Sugarloaf Range. Dips reportedly are 3-4° in the younger beds, and in the Permian are as high as 30°.

Thickness: The Table Hill section of 62 - 64' is the thickest described in the south, but thicker sections may occur. Section No. 20 for example, has some lithological features to suggest that the upper 88' could be Mesozoic, although neither Evans (judging by a section that he described in the vicinity) nor Derrington et al (1957) so interpreted it. Total thickness is unlikely to exceed the 89'-96' recorded at Mount Greenwood by Noakes (1949).

TERTIARY AND YOUNGER DEPOSITS

Apart from lateritisation north of Queens Channel, there appears to be no record in the area of the Tertiary epoch. The laterites and Quaternary deposits are discussed by Traves (1955).

SPIRIT HILL NO. 1

The only hydrocarbon test drilled in Bonaparte Gulf area is Spirit Hill No. 1. This bore-hole was completed as a water well in November 1960, after being abandoned at a total depth of 3003'. Electrical logs were not run in the bore-hole, which was cored except for a few feet of the section. The published Well Completion Report gives details of drilling, testing, and the stratigraphy. The bore-hole provided useful information, but interpretation of strata older than the Milligans Beds proved to be difficult. Figure 7 summarises the stratigraphy and shows three alternative interpretations of the well section. All are equally acceptable by present data. Six inch samples at 50' intervals were obtained by the Bureau of Mineral Resources and these are described in Appendix 5.

Faulting is well defined by a pyritised breccia at 2465'-69'. Above this interval, except for some which have slump characteristics, beds show consistently low dips, averaging 10° or less. Drilled thickness above the fault should, in consequence, be close to the true thickness. Below the fault, the dips commonly range between 10° and 20°. The drilled thickness will slightly exceed the true thickness in this part of the bore-hole. Judging by the tectonic framework of the area the fault is a normal one, which will mean loss of stratigraphic section in the hole, by faulting out, and not section repetition.

Cores show that the Milligans Beds are good seal rock. Slight oil-staining occurred in a silty streak in a Bureau of Mineral Resources sample from 550'. This oil is assumed to be due to gradual bleeding from very low permeability in the siltstone. It enhances the source possibilities of the formation. Pebbles and rounded sand grains in the shale suggest proximity to a near-shore depositional environment.

Few of the carbonate samples below the Milligans Beds are free of clastic materials, and so are typical of Devono-Carboniferous rocks in the area. Samples at 851', 900' and 950' appear to represent a gradation from crystalline dolomite to unaltered limestone, and are underlain by 300' of limestones with a low or negligible dolomite content. The dolomite is secondary, and the lithological succession, judging by core samples, shows some similarity with the Lower Mississippian in the subsurface of the Alberta Plains in Canada. There, leaching at an unconformity is believed to have promoted dolomitisation and porosity development, and the lithological correspondence suggests that the same conditions may have occurred before the

Milligans Beds were laid down in the vicinity of Spirit Hill No. 1. Porosity is shown to be present in the dolomite zone by water production of about 50 barrels per day. Porous secondary dolomite is also present below 1250', possibly having developed as the result of fluid migration via porosity associated with joints or minor faults. There is also the possibility that an undiscovered depositional hiatus may be present. Organic carbonates, mainly encrinites, are present to 2300'. Below this depth the carbonates are aphanites, with rare organic material, and could be of primary or secondary origin. Another major lithologic change may occur between 2750' and 2800', where paler greys and greenish colours become common, and the silt content increases.

Thyer et al (1959) reported Phanerozoic sandstones from exposures in Bonaparte Gulf as having dry densities ranging from about 2·0 gms./cc. to about 2·2 gms/cc., but suggested that sandstones in the subsurface might be more dense. This seems to be borne out in Spirit Hill No. 1, where the sandstones, in contrast to those at the surface, have average wet densities of about 2·6 gms./cc. This difference appears to be due principally to the fact that the sandstones in the bore-hole are well cemented, by silica, or more commonly by calcite. This applies to all but the finer grade sandstones, which tend to remain porous and free of cement. Perhaps significantly, sandstones of this type also have relatively low permeabilities (see Petroleum Geology). Carbonates in Spirit Hill No. 1 have generally similar densities to the sandstones there. The least dense materials are shales of the Milligans Beds. Appendices 5 and 6 can be compared for details of relationships between lithology, density and porosity.

The palaeontological data from Spirit Hill No. 1 are disappointing considering that the entire section was cored. A microfossil assemblage at 99' includes endothyrids, ostracods and spores, similar to that from nearby shot-hole samples of Milligans Beds (Thomas and Jones, Spirit Hill No. 1 Completion Report, Appendix). A ?Linoproductus at 991' indicates a Carboniferous age for the bed, and a Spirifer at 1070' has affinities with the fauna in the Septimus Limestone, while Leptophloeum australe found at 2161' suggests a Lower Carboniferous or Upper Devonian age (Thomas, Spirit Hill No. 1 Completion Report, Appendix). From the occurrence of a cosmoid fish scale at 2564' the beds 95' below the fault are almost certainly of Upper Devonian or younger age. Traces of plants at 2920' (Balme, Spirit Hill No. 1 Completion Report, Appendix) indicate a post-Proterozoic age for the lowest part of the hole. Balme interpreted spores found as low as 2412' as of possible Carboniferous age, but made it clear that the determination was tentative.

GROUP RELATIONSHIPS

No rock units of group status have been proposed for the Bonaparte Gulf area since Traves (1955) suggested the following:

Mullaman Group
Port Keats Group
Weaber Group
Carlton Group

Carlton Group

The Carlton Group was defined by Traves (1955) to include four Cambrian formations and one Ordovician formation. Previously Reeves (1948, Plate V) had referred in an unpublished report to the Carlton "Series," and Noakes et al (1952) had published the name "Carlton Formation." Even if changes are made in the definition of the formations, it seems possible that the group will remain a satisfactory one, on the basis of the common lithological characteristics of the formations included in it, and on the fact that the base and top are both well defined. The group rests on Antrim Plateau Volcanics or Precambrian rocks and the hiatus at the top is coincident with a regional unconformity.

"C-D" Group

Traves (1955) suggested that there was an unconformity beneath the Weaber Group. Data have accumulated to support this view. Evidence for the unconformity can be summarised as follows:

i) In the Carlton area the Weaber Group apparently lies directly on rocks ranging from Burt Range Formation to the Carlton Group.

ii) In the Burt Range-Pincombe Range area, Septimus Limestone, Enga Sandstone and much of the Burt Range Formation seem to be locally removed beneath the Weaber Group.

iii) The dolomitised carbonates below the Milligans Beds in Spirit Hill No. 1 may indicate an important hiatus.

If the existence of the unconformity is accepted, the rock units beneath it, and above the Carlton Group, seem to form a natural unit, referred to in this report as the "C-D" Group. Formal definition of the group is left to the future, but it will include the following formations:

Septimus Limestone
Enga Sandstone
Burt Range Formation
Cockatoo Sandstone

The validity of the group is supported by the following points:

i) It is composed of formations which have common lithological characteristics. All are relatively shallow water marine sediments and although carbonates are locally important, clastics predominate.

ii) The strata represent a common cycle of deposition, commencing with the Cockatoo transgression and only ending some time after the Septimus was deposited. No erosional breaks have been detected within the group.

iii) The group is overlain and underlain by unconformities. At the base, the time-rock break is proven by the absence of at least Silurian and Lower and Middle Devonian strata in the Carlton area, and a greater stratigraphic interval near Burt Range. At the top, strata above the lower Burt Range Formation are missing locally by erosion. At Mount Septimus, where there is probably the least amount of erosion, known Tournaisian or possibly Lower Visean beds of the Septimus Limestone are overlain by Upper Visean or Namurian beds of the Point Spring Sandstone.

<u>Weaber Group</u>

The name "Weaber Group" was first used in print by Noakes et al (1952) for beds here referred to as the Point Spring Sandstone. The group was then fully defined by Traves (1955) as composed of a basal Nigli Gap Sandstone, Spirit Hill Limestone and an uppermost Point Spring Sandstone, with the Flapper Hill Sandstone as a related formation of unassigned position. Of these, Traves' Point Spring Sandstone was the original "Weaber Range Series" of Reeves (1948). This group requires major revision. Formal redefinition of the group is left to the future, but the following points are apparent.

The type section of the Nigli Gap Sandstone can probably be correlated with the Cockatoo Sandstone, or possibly the Border Creek Sandstone. In either case it is not a basal formation of the Weaber Group. The Spirit Hill Limestone can probably be equated with the Septimus Limestone. It is unlikely to be younger than the Septimus Limestone. If the Spirit Hill Limestone is older than the Septimus Limestone it is still related to the "C-D" Group. The Flapper Hills Sandstone is still of doubtful assignment, but is probably also part of the "C-D" Group. Provided that the Point Spring Sandstone is revised to exclude the Border Creek Sandstone it forms the only remaining formation of Traves' Weaber Group.

In 1955 there was no suggestion of the occurrence of the Milligans Beds. Now that the unit is known, it would be logical to revise the Weaber Group to include the Milligans Beds, Point Spring Sandstone and Border Creek Sandstone, in ascending order.

The details of the relationships between the formations of the Weaber Group are still not known, but can be inferred from field data. Regardless of actual water depth, the formations represent a shallowing sequence from the fine marine clastics of the Milligans Beds, which are low energy deposits, to the periodic coarse conglomerates of the Border Creek Sandstone, which are high energy deposits. This implies that the overall sequence of deposition would be recessive, and with the passage of time, clastic materials of increasingly coarse grade would tend to be transported progressively farther into the depositional basin. The overall relationships are believed to approximate those shown in Figure 8, in which formational contacts are diachronous. The only sandstones referable to the Milligans Beds will be overlain by shale or will occur within the shale of that formation. Utting's (1958) assignment of the sandstones on top of Spirit Hill and above the type Septimus Limestone to the "basal Milligans Beds" was partly based upon the fact that he (pers. comm.) found shale interbeds in the sandstones north-east of Spirit Hill. On the basis of the interbeds, the Spirit Hill area sandstones may be laterally equivalent to the Milligans Beds at Spirit Hill No. 1, as Utting suggested, but these sandstones should be assigned to Point Springs Sandstone. This is necessary both on lithological grounds, and because not far west of Spirit Hill apparently equivalent sandstones are overlain by Border Creek Sandstone.

Field data which support the relationships tentatively suggested in Figure 8 are:

i) the Milligans Beds thicken north, or basinwards, in the Milligans Lagoon - Spirit Hill area, and palaeontological data suggest that the upper beds are younger to the north (see Milligans Beds).

ii) The basal Border Creek conglomerate thins north and disappears at the north end of Burt Range. At Spirit Hill, Allen's (1956) member "d_1", which occurs only on the south-east side of the hill, is topped by a quartzite pebble and sandstone conglomerate which appears to be absent to the north-west. This conglomerate could be interpreted either as a basal Border Creek conglomerate or as the equivalent of a coarser basal conglomerate farther east. Both the Burt Range and Spirit Hill occurrences indicate basinward fingering out of basal Border Creek conglomerates.

iii) The shale interbeds found by Utting to the north-east of Spirit Hill apparently occur in the equivalent of sandstones which overlie the Spirit Hill Limestone. The shales are thin and are locally developed. This seems to support the intragroup relationships suggested here. By analogy, the shale interbeds are inferred to correspond to a diachronic finger of the Milligans Beds in Fig. 8.

Palaeontological data suggest a generally younger age for the Weaber Group, than for the "C-D" Group. Permian beds could be present in the Border Creek Sandstone to the north of Weaber Ridge, but unless this is proven, a Carboniferous age could be accepted for the group. Only Lower Carboniferous fossils have been found in it.

Port Keats Group

This group was defined by Noakes (1949) before the Australian Code of Stratigraphic Nomenclature became operative.

Under the Code, formations have to be adequately defined before groups can be set up. Formations I-V indicate that acceptable formations exist in the Port Keats Group and the group name can be retained in anticipation of the formal definition of formations. On the joint basis of their probable age and their surface distribution the Keep Inlet Beds could be related to the Permo-Triassic formations further north and are here tentatively included in the Port Keats Group, on the premiss that this is the case.

Mullaman Group

The Mullaman Group (Noakes, 1949) may or may not be represented by a thin lateritised sequence in the Port Keats area. Only the upper part of the group, or Darwin Formation, may be present (see Mesozoic).

MARINE GEOLOGY

Most of the Palaeozoic sediments of Bonaparte Gulf Basin probably lie beneath the sea, and their nature and extent are unknown. Figure 9, compiled from bathymetric charts AUS 87, 88, 94 and 97, 1047 and 2759a, shows slightly generalised 30 and 60 fathom isobaths. Submarine features cannot be directly interpreted in geological terms in this area. The reasons are as follow:

i) Present sea level is high, and several Pleistocene erosional surfaces and related topographic features could be represented on the sea bed.

ii) Reef growth is known to be locally abundant and both small and large rises on the sea bed could be due to it.

Fairbridge (1953b) related underwater topography to regional geotectonic patterns, and suggested that the well-defined 60 fathom depression between Sahul Bank and Joseph Bonaparte Gulf corresponds to the central part of the basin. A number of points, discussed later, favour this interpretation.

Both structural and depositional pointers suggest however, that the limits of the basin are less extensive than Fairbridge implied. Delimiting or related features used by him are the Cambridge Gulf Fault, the Londonderry Rise, the Van Diemen Rise, and submarine canyons west of Bathurst Island. The latter are of doubtful geological significance as they are probably due to Pleistocene erosion. There appears to be no evidence for the Cambridge Gulf Fault, which is postulated to parallel the land west of Cambridge Gulf, and to be downthrown to the north. The Londonderry Rise, in the south, runs from Cape Londonderry to the north-west The Van Diemen Rise extends from the north end of Bathurst Island to the south of Troubadour Shoals and then swings west-southwest to the Sahul Bank. Of the two rises, the Londonderry Rise is best defined, but neither is unequivocally present.

STRUCTURE

Bonaparte Gulf Basin is well defined structurally. Although much structural information has been obtained in the area since the work carried out by Traves (1955), most of it consists of local detail. As Traves pointed out, the sedimentary basin is bounded on the east by the Precambrian Sturt Block. In the south-west it is bordered by the Kimberley Block. Traves regarded the Phanerozoic sediments as having been deposited in discordant troughs off one end of the Kimberley Block, but it is argued later in this report that they are related to subsidence of the north-east end of the block, combined with subsidence in the mobile zone between the two blocks.

Gravity anomalies can be interpreted as indicating several large scale structural features in the subsurface, but only three major structural units are clearly defined at the surface. One of these is represented by the Cave and Pincombe Ranges and will be termed the Pincombe High. The high has played an obviously important role in deposition, having affected the distribution of both the Carlton Group and the Cockatoo Sandstone. After Traves (1955, p.9), the Palaeozoic sedimentary areas on either side of the Pincombe High are referred to as the Burt Range Sub-basin* and the Carlton Basin, which constitute the other two structural units. The subsurface extent of these is a matter of interpretation.

Smaller scale structures in the area include numerous faults and some relatively gentle folds. It is significant that the only steep dips recorded in Phanerozoic sediments in the area seem to occur near faults or suspected faults. This can also be said of known folds; for example the Burt Range Syncline, Spirit Hill Anticline and Amphitheatre Anticline are all near or within the Cockatoo Fault trend.

The most apparent fault trends in the area run north-northeast. The main faults are the Cockatoo Fault in the south, and the Moyle River Fault to the north of the headwaters of Moyle River. Granite is upthrown against Precambrian sediments by the Moyle River Fault. Faults with a north-northeast trend are most common between the west side of Pincombe High and the Cockatoo Fault. In most of them, the downthrown side is on the west. A second trend, west of Pincombe High, is essentially one of strike faults. In most of these faults it is not known which side is downthrown.

Earlier workers argued in favour of tectonic periods of varying intensity to explain the observation that in this area faulting is progressively less common in the younger beds. Reeves (1948, p.20) postulated a Caledonian orogeny to account for the apparent absence of Ordovician and Silurian strata. Traves (1955, p.92) suggested four important periods of diastrophism. The structure of the area, and the increase in faulting in older beds, however, can be explained mainly by gentle, more or less continuous, epeirogenic movements related

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* Sub-basin in the sense that it is a subsidiary basin within the general basin area but has some depositional and/or structural individuality. The Carlton Basin is considered to be more directly related to the main basin, as discussed later.

to basin subsidence. There was only one period of relatively extreme diastrophism, and it can be argued that this also was related to subsidence (see Tectonics).

GEOLOGICAL SURVEYS

Figure 10 indicates the detail in which geological surveys were performed to December, 1962 in Bonaparte Gulf Basin. Individual surveys are not shown on the figure, but are listed in Appendix 3 for the period after 1954. Before then the only important field work in the area was that of Öpik (1950), Matheson and Teichert (1948), Reeves (1948, 1951) and Traves (1949, 1955).

WELL RECOVERIES AND HYDROCARBON INDICATIONS

Asphaltite is known to occur at surface in the Bonaparte Gulf area and surrounding areas, but the deposits are small and of doubtful significance (Traves, 1955, p.102). Reeves (1951, p.2481) suggested that the material might be of Precambrian origin, and a residue of hydrocarbons distilled from shale by the Antrim Plateau Volcanics. This explanation seems to fit known occurrences. The only significant hydrocarbon shows to date are those recorded from Spirit Hill No. 1. Rade noted slight oil-staining in cores from 490', 1,818' and 2,269'. Light oil bled over a period of time from a core retained by the Bureau of Mineral Resources. The core came from 550' in the Milligans Beds. Extraction methods also indicated traces of hydrocarbons in the Milligans Beds in Spirit Hill No. 1.

Artesian water was found in Spirit Hill No. 1. The presence of such water, and of local springs, suggests that artesian water may be characteristic of the basin.

PART II - INTERPRETATION

Many of the reports on the Bonaparte Gulf area, particularly those by Reeves, Utting and Traves, contain interpretations which have been accepted in this report. Some of the interpretation expressed in this report is not in agreement, either directly or indirectly, with earlier views. In such cases the viewpoint taken here is explained.

Owing to a lack of control, it is impractical to attempt more than an outline interpretation of the subsurface stratigraphy. The amount of interpretation, in any particular case, can be assessed from the data presented. A single borehole could radically alter the interpretations of possible sedimentary facies or thicknesses in the subsurface. These interpretations should be considered tentative in all cases.

GEOLOGICAL MAPS

The methods used in constructing the geological maps are outlined in Appendix 1. Several major points of interest emerge from the interpretative maps.

1) The sedimentary basin is clearly outlined by Phanerozoic sediment distribution.
2) A relatively large area of Antrim Plateau Volcanics may be present beneath recent sediments in the south-west corner of the sedimentary basin.
3) The "C-D" Group in the Burt Range area lies in a well defined sub-basin.
4) In the west, and to a lesser extent in the south, the Weaber Group appears to transgress older sediments.
5) The present distribution of the Port Keats Group appears to lie east as well as north of older Phanerozoic deposits.

BASIN SHAPE AND EXTENT

Reef growth and the possible occurrence of old erosional surfaces limit direct geological interpretation in Bonaparte Gulf (see Marine Geology), but it is possible to apply the principle of uniformitarianism with some effect. At present, the area of Phanerozoic sediments on land coincides quite closely with a general physiographic low (Figs. 1 and 2), surrounded by relatively gentle Precambrian highs. If similar conditions occurred when sea-level was much lower, present day marine lows may correspond to sedimentary areas. On this basis the 60 fathom low off Bonaparte Gulf could be a sedimentary area (Figure 11). A reasonably consistent line can be drawn along the western edge of the low to connect with the known edge of sediments on land. It is suggested that this line corresponds to the western edge of the sedimentary basin.

The eastern side of the basin is not as easily defined from isobathic relationships. This may be because both a main basin and a basin shelf are present, the extent of the shelf being controlled by north-northeast trending structure. Known structures on this trend include the Cockatoo and Moyle River Faults, the Pincombe High and a well defined positive gravity anomaly in Queens Channel. This anomaly is here accepted as a probable separate structure on structural continuation with the Pincombe High. Points supporting the identity and nature of the shelf are discussed more fully later. The isobathic map shows only that a general line of shallowing, possibly corresponding to the eastern edge of the main basin, can be outlined. No indication exists of the extent of the shelf itself. Both the main basin and shelf trend towards the Timor Trough, which can be regarded either as an ancestral sea or as a geotectonic vacuity supplanting the original ancestral sea as a result of continental drift.

Figure 12 combines the bathymetric interpretations and interpretations of Bouger gravity maps made by the writer, to show probable major structural features of the south end of Bonaparte Gulf Basin. The north end of the basin is not considered, owing to lack of data. The Carlton Basin is the part of the main basin on land. On the shelf, the Burt Range Sub-basin is the only one well defined. The Keep Inlet and Port Keats Sub-basins both seem to have loosely defined structural limits. If, as is probable, they were in fairly continuous depositional connection with the main basin, it may be impossible to define them precisely.

TECTONICS

Faults

The fault patterns in the Bonaparte Gulf area appear to provide a foundation for tectonic interpretation. All known faults have been plotted on Figure 13, showing the downthrown side where this is known or can be deduced. As noted earlier, there are two consistent fault trends. One, in the east and south, runs north-northeast. The other trend is shown by strike-faulting in the Carlton area, within the main basin.

The north-northeast trend is formed by strike faults in the north, and cross strike faults in the south. The faults are predominantly downthrown to the west. This applies also to the Ivanhoe Graben, if the faults are considered collectively rather than individually. The westerly of the two faults in the graben is interpreted as downthrown to the east at its north end, but it may be downthrown to the west at the south end. It therefore may be a scissors-type fault. Alternately, both faults could be tear faults, downthrown to the west, with decreasing throws to the north. If so, the structure will not be a graben in the strictest sense.

There is a suggestion of transcurrency in both of the main faults on the east side of the shelf. The sinuosity of the Cockatoo Fault and the pattern of its off-shoots both suggest lateral movement, with the east side displaced to the north. Derrington et al (1957) mapped the Moyle River Fault as transcurrent, with similar displacement directions.

There is no evidence of significant downthrow to the east on any of the north-northeast trending faults. This may be due to inadequate data. The only north-northeast trending fault near Cambridge Gulf with a known direction of throw occurs between Mount Connection and the Onslow Hills. It is downthrown to the west, suggesting that this direction of throw is maintained on the west side of the basin. The overall pattern of the north-northeast trend seems to be one of progressively greater step faulting from west to east, suggesting an assymmetric origin for the basin.

The Carlton area strike faults have an undetermined direction of throw, but it could be argued that they may be mainly normal faults with basinwards downthrow, if it is assumed that they are related to basin subsidence.

The geological maps indicate that faulting affects all sediments older than those assigned to the Mullaman Group, which overlie both Permian and Precambrian horizons, and appear to be tectonically undisturbed. If this interpretation is correct, it shows that tectonic activity intense enough to cause faulting persisted at least to the end of the Permo-Triassic period of deposition.

Fault distribution shows that faulting is more abundant in older beds. In one case at least it seems probable from field evidence that faulting in older sediments preceded deposition of younger beds. Utting (1962) showed outcrops of Weaber Group strata which overlapped the Cockatoo Fault. On the interpretative geological map, the north branch of the Cockatoo Fault which passes west of Spirit Hill affects the Weaber Group as well as older beds, but to a much lesser extent. Figure 5 shows the same fault, which can be seen to cut the Point Spring Sandstone in the south but to be doubtfully present in the north. Perhaps significantly, this fault trends towards Spirit Hill No. 1 (Figure 13) where it may be the one which cuts the section at 2,469'. Figure 5 also shows several minor, probably sympathetic, faults cutting the Spirit Hill Limestone but not younger beds. Although not conclusive, these points all suggest that major movements occurred on the Cockatoo Fault before Weaber Group deposition began.

Other Structures

Some important palaeotopographic structures occur in the Bonaparte Gulf area. One type effected deposition at several periods. This includes the Pincombe High, which had its structural origin in the Precambrian, and as a high continued to influence deposition during the Cambro-Ordovician, Devonian, and possibly other periods, presumably by continuing fault adjustment. The Weaber Group re-entrant near Ninbing also is probably a palaeotopographic feature, but unlike the Pincombe High, the re-entrant need not be related to pre-existing tectonic structure. It may be related to a fortuitously located erosional channel formed during the erosional period which preceded deposition of the Weaber Group.

Folds appear to be both rare and poorly developed within Bonaparte Gulf Basin. The most important folds discovered to date are the Burt Range Syncline, the so-called Spirit Hill anticline, and a syncline in Permian beds south of Port Keats. Lesser folds have been reported near Nigli Gap and within the Burt Range Formation. It is suggested here that all these folds are due to structural readjustment during faulting, especially by drag.

The Burt Range Syncline is the largest fold structure in the area. Judging by its surface expression, it is gently folded. The west limb is well defined, but the entire limb could be related to tilting of strata by downthrow on the Cockatoo Fault. The throw of the fault is several thousand feet locally, and if relative movement decreased to the west away from the fault, east-southeast dips of about 5 - 10° would result. Most dips recorded are of this order. The synclinal closure in the south-west could be the result of drag, if as suggested, the fault is transcurrent, the east side being displaced to the north.

The Spirit Hill structure is a poorly defined fold (Figure 5). Structural variation at this locality could be due to the location of the structure between the Cockatoo Fault and a branch fault.

On the basis of these two structures, and the absence of well developed folds, it is argued that all Phanerozoic fold structures in the area may be related to faulting. If this is so, the presence of such folds does not imply that compressive forces have ever occurred in the area. On the contrary, the apparent absence of well defined compressional folds and of other structures such as reverse faults suggests that compressive tectonic forces may never have been important. Because of this negative evidence, and because all structure apparently can be explained by non-compressive movements, the view is taken here that compressive forces may have been absent or may have been of minor importance in Bonaparte Gulf area during Phanerozoic times.

Tectonic Interpretation

It can be shown that the area of deposition during Phanerozoic times in the Bonaparte Gulf Basin tended to lie within what is here termed the main basin and shelf, both of which were involved in basin subsidence, in spite of their structural differences. The main basin is relatively homogeneous in a structural sense, and appears to be free of major faulting on a north-northeast trend. The shelf, on the other hand, is cut by the Moyle River, Cockatoo and Ivanhoe faults, and includes north-northeast or north trending structures like the Pincombe High - Queens Channel High Trend, and the Port Keats Sub-basin.

A well defined north-north-east trending granite belt occurs south of Bonaparte Gulf. Traves (1955, Fig.33) referred these granites to the Halls Creek Mobile Zone, which he showed as continuing up the east side of Bonaparte Gulf where granite is exposed at surface. It is now suggested that the western side of the Mobile Zone coincides with the western limit of the shelf. On this basis the shelf is part of the Mobile Zone, distinguished only by its Phanerozoic sediments.

Granites often show well defined jointing which may have originated by cooling contraction. Although the suggestion may be novel, cooling contraction could also cause important subsidence where the near-surface area of the granite mass is small and its volume large. For example, these conditions may have applied at the Glencoe cauldron subsidence in Scotland, where sediments have been lowered thousands of feet in a narrow cauldron. The mechanism may have been important in the development of the Bonaparte Gulf Basin as an area of Phanerozoic sedimentation.

Contraction should occur after a relatively hot igneous body is emplaced, by any means, and begins to cool. If emplacement occurs near the surface preferential yield will tend to occur there if the overlying rocks are structurally weak. If the igneous emplacement is widespread near the surface, contraction effects may be widespread, but would be inobvious. Where the near-surface area of the igneous body and of yield is limited, however, small contractions could cause quite large amounts of subsidence. If the body is several miles deep and has the shape of a cone, for example, volume contraction of the order of one per cent could cause a thousand or more feet of subsidence at the surface. Given a large enough igneous body with a small enough near-surface area of yield, subsidence of the order of many thousands of feet could be achieved, in theory at least. In Bonaparte Gulf area, the Halls Creek Mobile Zone is laterally restricted in extent, and may be of considerable depth and volume, so could have been such an area of yield.

After the emplacement of the Precambrian granite masses of the Halls Creek Mobile Zone, at least some subsidence may have been caused by contraction. Contraction in turn would give a density increase, and this might tend to cause still further subsidence by gravitational sag, particularly if accompanied by sedimentary loading. It is suggested that subsequent to the granitic intrusions, the joint effects of contraction and sag, both of which could be effective over long periods of geological time, may have been the main causes of the prolonged subsidence which occurred in what is now the Bonaparte Gulf Basin of Phanerozoic sediments.

In Bonaparte Gulf Basin, the main basin may be underlain by granite at depth, and contraction could have caused it to be tilted or flexed as a single structural unit against the Mobile Zone, which became the shelf. Movements on the shelf could have differed from those in the main basin because the granites are at or near the surface there, and pre-existing planes of weakness could more easily form lines of yield. The majority of faults in the Precambrian rocks trend in a north-northeast direction, and it is inferred that this trend was related to the development of the Mobile Zone, which has a similar trend. On this basis, contractional subsidence of the shelf could be expected partly to occur by faulting along north-northeast trending faults such as the Cockatoo, Moyle River and other faults. The tendency for transcurrency to develop on the larger faults could be due to several causes, but might also be explained by contraction, because a widespread area of granite occurs north-east of Bonaparte Gulf in the Darwin area. Contraction of this mass may have tended to cause relative movements to the north on the east side of the Moyle River and Cockatoo faults.

Regardless of its causes, in Bonaparte Gulf Basin subsidence appears to have taken place fairly continuously, with only two known important depositional breaks during the Phanerozoic period of deposition. As already noted, there is no evidence of significant compressive forces having effected the Phanerozoic rocks, and all local tectonic movements could have been part of the pattern of basin subsidence. After the initial period of deposition, in Palaeozoic time before the Upper Devonian, there was a period of erosion. The tectonic significance of events up until the Devonian transgression is unclear but Cambro-Ordovician deposits were preserved only in the main basin. After the period of "C-D" Group deposition, which represents the first recorded period of subsidence of the main basin and shelf, there was a phase of relatively intense stress release which resulted inmajor fault movements within the shelf area. A thick section of the Devono-Carboniferous "C-D" Group was down-faulted on the Cockatoo Fault in the south at Burt Range by these movements. This phase of tectonism is probably related to a short but important period of erosion. Present evidence suggests that the hiatus may have occurred during the middle Visean. Sedimentation was resumed for the period of Weaber Group deposition, the rate of sediment accumulation gradually meeting that of subsidence. During and after the period of Port Keats Group deposition, in Permo-Triassic time, sedimentation appears to have kept pace with a relatively low rate of subsidence. During or at the end of this gerontic phase a final period of stress release caused minor fault movements, and tectonism ceased within the basin. Events thereafter were the result of eustatic changes in sea level, if formational age relationships have been correctly interpreted.

PALEOGEOGRAPHY

Carlton Group

Residual Middle Cambrian deposits occur south of Bonaparte Gulf near the Ord River and in other areas. The stratigraphy of the Cambro-Ordovician Carlton Group in Bonaparte Gulf area is only known in outline, but the occurrence of Cambrian deposits south of the Gulf area implies that Cambrian seas were widespread. This suggests that eustatic changes of sea level may have been involved in Cambrian deposition and that the Bonaparte Gulf Basin need not have been downwarped during the Cambrian. The shallow water clastics of the Carlton Group are not the type normally deposited a great distance from shore, but this is not sufficient to determine the palaeogeography. Present surface expression of the beds may be significant, in that it suggests that the main basin was a subsiding unit before the Devonian transgression. Preservation of Antrim Plateau Volcanics along the west side of the basin implies that subsidence may have occurred there before Cambro-Ordovician time, but is less acceptable as evidence. The possibility certainly exists however, that the main basin was downwarped during Cambro-Ordovician time, whether or not eustatic changes of sea level, or general changes due to other causes, also occurred.

The present extent of Cambro-Ordovician deposits in Bonaparte Gulf Basin must remain a matter of speculation. In Figure 14 it is assumed that sediments are restricted to the main basin, primarily because of lack of evidence that they exist in the sub-basins. The fact that Cambro-Ordovician beds are regionally extensive, where preserved, also suggests that the deposits may extend a considerable distance within the basin, although their northern limits cannot be approximated.

"C-D" Group

Both the main basin and shelf became well defined areas of subsidence during the Upper Devonian. Deposition at this and later periods was more or less confined to the present general basinal area, and the deposits were laid down in what is inferred to have been a relatively restricted gulf.

Of the formations of the "C-D" Group, the Burt Range Formation and the Cockatoo Sandstone are the most important stratigraphically. The relationship between these is difficult to interpret on the basis of present data, but is of great importance to the interpretation of the palaeogeography. The Cockatoo Sandstone could be either a clastic infill of local hollows on a transgressed surface, or it could be a near-shore facies which passed laterally to the Burt Range Formation further off-shore. It is impracticable at present to say whether either or even both relationships occur between the two formations. Cockatoo lithologies suggest high energy near-shore conditions which would apply in both cases. The formation is absent on the north and north-east end of Pincombe High, which must have been a local topographic high. If this high was covered during Cockatoo deposition, the deposits on it must have been the finer clastics of the Burt Range Formation and the two formations must have at least local diachronic relationships with each other. Diachronism will be absent only if the high remained above water during Cockatoo deposition, and if the change to deposition of the Burt Range Formation elsewhere took place at the same time as the submergence of the high. This seems rather unlikely, but at present the only point strongly in favour of a diachronic relationship is the fact that in the Burt Range area the Burt Range Formation apparently thins from north to south under the Enga Sandstone while the Cockatoo Sandstone thickens in the same direction. If the Enga Sandstone is of uniform age these relationships indicate diachronism between the Burt Range Limestone and Cockatoo Sandstone. The problem may be resolved with better palaeontological control.

Cockatoo Sandstone:

Figure 15 shows the possible former extent and the interpreted distribution of the Cockatoo Sandstone. Both this figure and those which follow represent only an interpretative summary of known data, and are partly conjectural.

The former palaeogeographic extent of the Cockatoo Sandstone was approximated in the following way: Inliers south of Ivanhoe show that it occurred there. Still farther south

Traves (1955) identified a Ragged Range Conglomerate as Cambrian, from its conformable relationship with underlying beds of that age. This conglomerate is suitably located to be an on-shore Cockatoo deposit, and its age should be confirmed.* The conglomerates of the Nigli Gap Sandstone here are considered as on-shore Cockatoo deposits, and depositional limits are drawn immediately east of them. This inferred limit is continued to the north a few miles east of the Port Keats Sub-basin, on the assumption that the thicker deposits there are of "C-D" Group age and that conditions of deposition were similar to those further south. In the west, the geological maps suggest Cockatoo thickening, and depositional limits are suggested to have existed not far west of where the western edge of the main basin is inferred to occur.

Cockatoo distribution within the basin is difficult to interpret because of the alternative possibilities for the relationship between the Cockatoo Sandstone and the Burt Range Formation. East of the Pincombe Range-Queens Channel high trend the distribution of the sandstone can be shown to be limited between the high trend and a speculative erosional edge, and diachronism between the Cockatoo Sandstone and Burt Range Formation may or may not occur. West of the high trend, basal transgressive clastics of the "C-D" Group will almost certainly occur, but from the inference that this is the main basin it is considered possible that in the east these clastics will be very thin, and that the Cockatoo will not be distinguishable as a rock unit, but will be represented by Burt Range deposits. Thinning out of the Cockatoo Sandstone from west to east in exposures in the Carlton Basin is the only fact which supports this interpretation.

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* Devonian fossils were found in this conglomerate during the 1963 season by a Bureau of Mineral Resources Field Party. Details of the occurrence will be discussed in future reports.

Towards the north-west and north-east the Cockatoo Sandstone is shown as being unconformably overlain by younger deposits, on the basis of the possibility that the Weaber Group lies upon the sandstone in these areas.

Burt Range Formation:

In Figure 16 the palaeogeographic extent of the Burt Range Formation is shown to be the same as that of the Cockatoo Sandstone. If the two formations are diachronously related, this will be essentially the case. If they are not, the Burt Range probably would be originally of wider extent both because it lies directly on Precambrian rocks on Pincombe Range and because it consists of finer grade clastic deposits which may have been deposited further from the clastic source, thereby implying more distant shorelines. In the Burt Range area the formation is conformably overlain by the Enga Sandstone. On the figure, conformable relationships are postulated to occur in the central parts of the main basin and in the Keep River and Port Keats Sub-basins.

Some possible lithologic variations of the Burt Range Formation, or its chronostratigraphic equivalents, are indicated on Figure 17. The formational name will have limited applicability if the interpretation is even approximately correct, because considerable facies changes are inferred to occur. Towards the basin centre, for example, equivalents of the Burt Range Formation might be shale.

The clastic facies on the map are delineated as follows:

(i) The sand/silt boundary in the south-west follows the line of the unit referred to on the geological maps as "undifferentiated Burt Range/Cockatoo Formations."

(ii) In the Burt Range Sub-basin the contact is speculative and is drawn on the basis of assumed diachronism between the Burt Range Formation and the Cockatoo Sandstone.

(iii) Areas of shale or silt deposition are drawn to correspond roughly to gravity lows in the south and north-east.

Three areas of possible reef facies are shown on the figure, but there may be more. Possibilities of reef development occuring are discussed under the heading "Petroleum Geology."

Enga Sandstone and Septimus Limestone:

The Enga Sandstone and Septimus Limestone are known only in the Burt Range Sub-basin, and is impossible to reconstruct their former depositional limits. Figure 18 suggests the possible present distribution of these beds, or their time-rock equivalents, in the subsurface. The figure is constructed on the basis that, as the youngest units in the "C-D" Group, the formations are preserved only in the axes of the sub-basins and main basin. In the latter area, continuity of sedimentation is assumed between the "C-D" and Weaber Groups.

If the figure has significance, Enga Sandstone and Septimus Limestone might be identifiable in the Port Keats Sub-basin. In the central area of the Bonaparte Basin the formations are more likely to be represented by shale. If this occurs, and the remainder of the "C-D" Group is also in shale facies in the main basin, then the entire "C-D" Group there may be represented by a shale unit. Figure 18 suggests that this shale unit could also include the Milligans Beds in the basin centre.

Weaber Group

The Weaber Group deposits lie on Cambro-Ordovician beds in the south-west, and in the Burt Range Sub-basin they are probably deposited on various horizons of the "C-D" Group. Figure 19, which is based on the assumption that the Weaber Group formations are diachronously related, shows the possible initial palaeogeographic limits for the facies of the group. This is postulated to be the greatest area ever covered by Weaber Group deposits in Bonaparte Gulf. Shortly after this phase, recessive deposition may have resulted in lessening of the area of deposition and in erosion of the initial deposits at the basin edge over a belt several miles wide. Figure 19 also indicates an area of possible crinoid biostrome development on the Queens Channel High.

"C-D" Group palaeogeographies can be interpreted to suggest that Phanerozoic areas of sedimentation corresponded approximately to present areas of Phanerozoic sediments, but the evidence is not decisive. The Milligans Beds, on the other hand, provide fairly definite evidence on this point, in spite of the fact that these beds can only be identified in limited areas in the south. The Milligans Beds clearly onlap from the north, and the basinward direction must have been to the north. The northerly thickening of the shale in the Burt Range Sub-basin supports this view. A corollary is that relatively widespread deposits should have occurred northwards because marine seas, unlike lakes, must be part of a major depositional area. If this implication and the structural interpretations of the area are combined, it is reasonable to predict the original occurrence of the Weaber Group in the subsurface north of known occurrences, as shown on Figure 19. Assuming that recessive deposition during Weaber Group time removed only basin-edge conglomerates and that there was no major period of erosion to the north between Weaber Group time and Port Keats Group time, this will also be the essential present subsurface extent of the Weaber Group.

Port Keats Group

There are insufficient data to reconstruct the palaeogeography of the Port Keats Group. If the simplest interpretation is accepted, the group belongs to a single period of subsidence, an initial marine transgression being followed by gradual off-lap deposition similar to that which occurred with the Weaber Group, but involving either less intensive relative subsidence or clastic material being derived from a relatively denuded source. In either case the clastics would be of finer grade.

Present depositional limits suggest that the central area of deposition for the Port Keats Group was east and north of the Carlton Basin (see Fig. 21). If this inference is correct, the Mobile Zone had become the main area of subsidence by Permian time. This would be explained if there was consecutive yielding from west to east by the north trending faults in the Mobile Zone during the Phanerozoic. If, at the same time, the main areas of deposition were tending to move north, the basin centre would migrate to the north-east. Points which favour this possibility include the apparent restriction of the Carlton Group to the main basin, and the relatively great thickness of the "C-D" Group in the Burt Range Sub-basin. The thick Cretaceous sequence at Bathhurst Island, still farther north-east (Figure 10), also favours the possibility of basin migration to the north-east, as these deposits could represent the next centre of deposition.

Whether or not basin migration occurred, major subsidence ceased in this area some time after deposition of the Port Keats Group. Following a period of peneplanation, the basin assumed its present geological form. During the Cretaceous there was a possible marine transgression, and during the Tertiary, a period of lateritisation. Reconstruction of the palaeogeography for these times is impossible with present data. All of the changes are believed to have taken place as a result of relatively minor, possibly eustatic, change of sea level, as there is no known evidence of tectonic activity.

SEDIMENTARY THICKNESSES

Formation thicknesses measured at the surface and found in the subsurface tests drilled to date have already been described. For the most part the thickness of sediments in the subsurface is unknown, and will only be discovered by drilling. The following summaries incorporate known data, including geophysical data, and outline possibilities for subsurface sediment thicknesses.

Carlton Group

In this area Cambrian deposits may occur only within the main basin. Unless there is loss of section at the base of the Carlton Group, the possible existence of the main basin in pre-Devonian times suggests that the group may thicken in the subsurface, where the post-Ordovician hiatus can be inferred to have been of shorter duration, and the amount of sediments removed by erosion to have been less. As far as is known, approximately 2,000-3,000' of Cambro-Ordovician sediments occur at the surface. On the assumption that added Ordovician or even Silurian strata may be preserved in the subsurface, it is conceivable that up to five thousand feet of pre-Devonian Phanerozoic sediments may be present within the main basin.

"C-D" and Weaber Groups

The "C-D" Group attains a reported cumulative thickness of approximately 9,000' in the Burt Range Sub-basin, the maximum thickness of the section at any one locality being approximately 7,000'. The total thickness may approximate about four thousand feet in the Carlton Basin, where erosion preceeding Weaber Group deposition was more pronounced. It would not be surprising if the group reached 8,000 or more towards the basin centre, where erosion can be assumed to be minimal or absent.

The Weaber Group has a known cumulative thickness of under 4,000', but if its depositional environment is correctly interpreted (Fig. 8), it should attain a greater thickness. The Milligans Beds or their time-equivalents alone could attain a thickness of several thousand feet towards the basin centre. The Border Creek Sandstone could be up to 2,000' thick in the Weaber Range, and even allowing for considerable repetition of section at the surface by strike faulting, could have more than twice this thickness further north. Only the Point Spring Sandstone can be expected to remain thin. If these extrapolations are valid the Weaber Group could be more than 10,000' thick in the basin centre.

These possibilities suggest that the Devono-Carboniferous rocks could reach as much as 20,000' towards the basin centre, but it would be surprising if they actually do so. Erosion of either the "C-D" Group or Weaber Group could have occured to seriously reduce original total thicknesses. Another possiblity is that a general change to a shale facies in the "C-D" Group could result in a thinner section, either because the rate of shale deposition was low, or because of later compaction of the shale.

Figure 20 attempts to strike a balance between these possibilities, and incorporates such data as is available from geophysical surveys, surface thicknesses, and structural interpretation, to show possible Devono-Carboniferous rock thicknesses in the basin.

Port Keats Group

It is, as yet, impossible to prognosticate the thicknesses of the Port Keats Group. Figure 21 shows the interpreted approximate surface or submarine distribution of Formation I, and that of lower formations. Cumulative thickness of beds in the Port Keats area in places exceeds 2,500'. On a pro rata basis less than 4,000' of sediments could account for the entire Permian in the Port Keats area, assuming that rates of sedimentation did not vary greatly throughout the section and that the age determinations made to date are correct. Whether or not the group will greatly exceed this thickness probably depends upon the Keep Inlet Beds. If the Keep Inlet Beds are very thick, then the thickness of the Port Keats Group may attain a maximum south-southwest of Port Keats.

PETROLEUM GEOLOGY

The petroleum possibilities for this area are considered in the following brief discussion of source beds, cap rock, and as they are related, types of porosity and types of traps.

Possible Source Beds

Marine sediments deposited under reducing conditions conventionally are usually accepted as the most probable source rocks for hydrocarbons. Arguments have also been put forward for a terrestrial origin for hydrocarbons, essentially by artesian transportation into basins of organic materials formed on land, (Weaver, 1962). Whether either or both modes of origin occurs may not be of crucial importance in this instance, as both may have been adapted to past conditions in the Bonaparte Gulf Basin.

On the basis of a terrestrial source, the Bonaparte Gulf Basin could have excellent potential, as it appears to have existed as a periodic area of basin downwarp at least since the Upper Devonian, and there were opportunities for artesian conditions to exist at various times. Plants are preserved in almost all the sediments post-dating the Carlton Group, and indicate that terrestrial plant life was present around the basin edges. Accumulation of hydrocarbons could be proceeding at present if the terrestrial theory of origin is correct.

Conventional source beds are also well represented in the area. Oil traces, of probable indigenous origin, occur in the Milligans Beds at Spirit Hill No. 1, and the formation contains shale with many of the reputed characteristics of a source rock, i.e. it is black fissile shale with a locally abundant marine microfauna. Marine shales also probably occur in the Carlton Group and in the Burt Range Formation, and may be present in the Port Keats Group. If the stratigraphic interpretation presented in this report is correct, the Milligans Beds thicken towards the basin centre while the "C-D" Group tends to change facies to shale, and it is therefore predicted that source shale will be abundant in the area. Organic limestones are known in the Burt Range Formation and are postulated to occur in the subsurface. Although such rocks are typical of high energy environments and are not source beds, the organic material associated with them in surrounding low energy clastics may have been a source of hydrocarbons.

The apparent lack of surface seeps in Bonaparte Gulf area is no reason for assuming a lack of either source beds or hydrocarbons. Only a small number of surface seeps are recorded in southern Alberta in Canada, in spite of the fact that a number of fields there, in the Cordillera, occur in zones tectonically disrupted by thrust faults. Bonaparte Gulf underwent much more gentle stress only until late Mesozoic times, and because the strata are relatively undisturbed the lack of surface seeps is understandable.

Possible Seal Beds

Evaporites have not been proven to be stratigraphically significant in Bonaparte Gulf area, where the only recorded occurrences are of secondary anhydrite in the Milligans Beds. The most important potential cap rock in the area, therefore, is shale. This will be coextensive with possible source shale, but will also include any non-marine shale which occurs. The Port Keats Group should contain some shale of this type.

Porosity Types and Traps

Porosity in sediments can be referred to the three classes of planar, vuggy and intergranular porosity (Drummond, 1963). The relationships between and within the classes are complex, but can be simplified as follows:

(a) Planar porosity is principally; tectonic fracture porosity due to stress release in folding; and fissure porosity due to solution along partings.

(b) Vuggy porosity, whether secondary or primary, is only effective if another type is present, and can be ignored for present purposes.

(c) Intergranular porosity, which can be primary, as in some sands, or secondary, as in some dolomites, is the most important porosity class.

Types of traps are also complex in detail, but can be outlined as follows:-

(i) Structural traps mainly occur in folds or against faults, and so have a tectonic origin. Traps formed by draping of sediments over a buried feature can be included here, although this is an over-simplification.

(ii) Stratigraphic traps can be classified as; stratigraphic pinchouts; erosional cut-offs; and reefs or reefoid accumulations. The only structural factors in this type are related to erosional and depositional processes, and to regional structure.

Porosity types likely to occur in this area are considered in this report under the headings of the various types of traps.

i) Structural traps:

Folds: Compressive folds are believed to be absent in the area. The only tectonic folds which occur are interpreted as having developed sympathetically with fault movements, principally by drag. This type of fold tends to have a low amplitude, so is less likely to form trap than compressive folds, which may be very tight. It is considered unlikely that folds will be important to hydrocarbon reserves in this area.

Draping by compaction of sediments over highs could provide structural closures, especially if facies changes within the basin are pronounced. Drape structures are likely to complement other types of traps, particularly pinchouts and reefs. Present data do not allow independent evaluation, but features like the Queens Channel High have an obvious potential for traps involving drape.

Faults: Traps which depend upon normal faults alone for closure are quite rare. On the basis of local conditions in the Bonaparte Gulf Basin however, there is a possibility that this type of trap may be present by itself or in conjunction with stratigraphic traps.

Towards the north, the north-northeast fault trend involves strike faulting. In the Carlton Basin, in the south, strike faulting is again important. Strike faulting has greater potential for trap formation than cross strike faulting, because any closure due to local structure will be most effective in forming trap if it occurs in conjunction with strike faulting. For this reason strike faulting is considered to have the greatest potential, although block or other faulting could also form fault trap in this area. The Pincombe High - Queens Channel High trend is of obvious interest for possible fault traps.

The lack of well developed folds implies that tectonic fracture porosity may be absent in the area. Fissure porosity is the only planar type which is likely to prove important. As a solution porosity, it should be best developed in carbonates, and can be regarded as complementary to any secondary intergranular porosity present in them. Good examples of open fissures occur in cores from Spirit Hill No. 1, and the artesian water presently produced from the bore-hole comes from a zone with both fissure and secondary intergranular porosity. By itself fissure porosity does not constitute an exploration target, and any structural traps present in the area will probably owe their porosity to intergranular porosity. The distribution of intergranular porosity is at present a matter for speculation, and is considered below.

ii) Stratigraphic Traps: Intergranular porosity is the most important type found in stratigraphic traps. At present little is known about the intergranular porosities of sediments in the Bonaparte Gulf Basin. The following points are probably pertinent.

(a) Porosity in sandstone outcrops may not be significant, as with few exceptions the sandstones in the subsurface at Spirit Hill No. 1 are cemented, and present surface porosity may be due to leaching.

The fact that most sandstones are cemented by calcite or silica in Spirit Hill No. 1 implies that sandstones in the subsurface may be generally tight. The cemented sandstones in the bore-hole are medium to coarse grained orthoquartzites which would be highly permeable if uncemented. It is suggested that, except where artesian flow is presently occurring, many sandstones of this type in the subsurface of Bonaparte Gulf Basin may be found to be similarly cemented. Further drilling should clarify this point. It is also significant that minor porous sandstones of finer grade are present in Spirit Hill No. 1. These imply that porous sandstone traps could occur in the area. The porosity in this case could be primary or secondary, but the lower permeability of the sandstones favours the possibility that the porosity may be primary.

(b) Intergranular porosity has not been reported from the Ninbing area reefoid beds. The factors governing porosity development in stromatoporoid reefs involve detailed study. In Western Canada for example, there are porous unaltered limestone reefs, completely cemented limestone reefs, and all gradations from both of these to completely dolomitised porous reefs. These Devonian reefs are still only partly understood despite the great deal of work that has been performed upon them. Porosity at the surface in the Bonaparte Gulf reefoid beds could be due to recent leaching, relic primary porosity, dolomitisation, or a combination of all three.

(c) In Western Canada, the Middle East, and probably elsewhere, secondary porous dolomites tend to occur beneath unconformities, and appear to be due to leaching of phaneritic limestones such as encrinites, oolites, etc., during the hiatus. Cores from Spirit Hill No. 1 show that porosity related to dolomitisation is present below the Milligans Beds. If this secondary porosity is related to the unconformity below the Milligans Beds, similar porosity could develop wherever these beds occur above phaneritic carbonates.

(d) Dolomites are reported at surface in the area, and their distribution is known to vary. Some at least are secondary. Glover et al (1955) stated that, in many cases, dolomitisation appeared to be commonest near faults. Faults can form highly permeable channels for fluid migration, and further work may show that permeability due to faults is related to dolomitisation in the area. There is mild support for this from a porous secondary dolomite at 1250' (Appendix 5) in Spirit Hill No. 1. The dolomite retains most of the textural features of the original granular limestone, and in the absence of a known hiatus, could have developed by solution transfer along faults or joints. The Bonaparte Gulf area was subject to tensional forces of varying intensity for long periods of time, during which permeability could have occurred in such partings.

There are other possible ways in which porosity may have developed in the area, but in the absence of data, they remain hypothetical. The possibilities for development of stratigraphic traps are outlined below:

Pinchouts: In any basin primary porosity will be best developed within the clastic zone along the basin edge. These zones generally pinch out down depositional dip in a basinward direction without forming trap. Assuming that they are not cemented, the clastics in this area have some possibilities for hydrocarbon entrapment where they onlap internal basin structures such as the Queens Channel High and/or where depositional dips have been reversed by draping or tectonic action.

Pinchouts are rare in carbonates unless other factors like secondary leaching are involved. Carbonates such as encrinites, oolites and reefoid types could form pinchout traps over subsurface highs in Bonaparte Gulf area.

Unless they are related to local structures, pinchout traps are difficult to locate, other than by systematic drilling.

Present data does not suggest that there was great scope for the development of this type of trap in this area, but they may exist.

Erosional Cut-offs: The unconformity beneath the Weaber Group raises possibilities that both primary and secondary intergranular porosity traps related to erosional cut-off may be present in Bonaparte Gulf Basin. The unconformity below the "C-D" Group and any other unconformities as yet unrecorded may offer similar possibilities.

The type of sedimentary basin development which is ideal for the formation of cut-off traps involves continuous subsidence in the more central parts of the basin, and periodic intervals of erosion nearer to the basin edges. During any erosional period, earlier deposited strata are progressively truncated from the more central parts of the basin towards the edges. Subsequent transgression will cause overlap of the outcrop of the strata. Wherever such outcrops form topographic highs composed of rocks having either original or secondary intergranular porosity and the transgressive beds provide a seal, trap will form. In Bonaparte Gulf Basin conditions were suitable for cut-off trap development after the Weaber Group transgression and may have been so on other occasions. It is concluded that erosional cut-offs could form important hydrocarbon reservoirs in the basin.

Reefs: Stromatoporoidal reefs could occur in the Devonian rocks of Bonaparte Gulf area, if surface indications of reefoid beds have been correctly reported. Such reefs can form highly productive stratigraphic traps. At the present stage of exploration, only broad suggestions can be made on possible reef development in Bonaparte Gulf Basin. Whether or not such reefs might be porous cannot be surmised. Examples in other countries such as Canada suggest that porosity development varies greatly in stromatoporoidal reefs. Adjacent reef knolls may be respectively non-permeable and highly permeable. The only point of note with regard to possible reef porosity in the Bonaparte Gulf Basin is that unconformities, faults and joints all could have promoted the development of secondary porosity, and that primary reefoid porosity could also occur.

If the Burt Range Formation passes to shale towards the basin centre there are ample prospects of both seal and source shales being present in this formation. Even if this change does not occur, the Milligans Beds, the Port Keats Group, and known shale horizons within the Burt Range Formation could all provide seals to Devonian reefs, depending upon locality.

Stromatoporoids have been reported from Devonian surface exposures in the Bonaparte Gulf Basin, showing that these organisms did exist in local Devonian seas. The Devonian stromatoporoid reefs of the Fitzroy Basin are geographically near enough to the Bonaparte Gulf area to suggest that marine conditions at the two localities may have been sufficiently similar to allow abundant reef growth in Bonaparte Gulf Basin, if other conditions were satisfied. The world-wide nature of Devonian reefing also supports this possibility. Unlike some organisms, stromatoporoids can thrive in environments in which heavy clastic deposition is proceeding. On this basis, and on the evidence that stromatoporoids occur, any area in the Bonaparte Gulf Basin could have become one of reef growth during the period of Devonian sedimentation, if the water was at asuitable depth for organic growth. Thick stromatoporoidal reef development would require continuous or periodic relative subsidence of the growth area. The stratigraphy of Bonaparte Gulf area is not well enough known to allow the interpretation of depth relationships within the Devonian strata. However, the Burt Range Formation was deposited in a subsiding basin in the area of Burt Range, and the sequence elsewhere in the area was probably similar. Under these circumstances reef growth might be expected on some of the features which formed submarine highs or offshore shelves within the Bonaparte Gulf Basin during Devonian time.

The Queens Channel High and the subsurface extension of the Pincombe High are obvious areas for possible development of Devonian reefs as stratigraphic traps, both because of the structure and because the features occur in areas where seal and source beds are likely to be present. Other structures within the basin would have equal possibilities. Excluding the Burt Range area, where reefoid beds appear to be absent, the perimeter of the basin and shelf has possibilities for fringing reef development in the subsurface, and such possible reefs have a potential for hydrocarbon entrapment. (See cross sections on the Interpretative Geological Map).

The fact that only limited, doubtfully reefoid, rocks of Devonian age occur at the surface in the Bonaparte Gulf area could be interpreted as unfavourable for the probable occurrence of reefs in the subsurface. On the other hand, the lack of apparent surface reefs could be regarded optimistically. In the Fitzroy Basin, fringing reefs are well exposed, but are valueless as traps, because they are breached. If comparable reefs developed in Bonaparte Gulf Basin then they have either been removed by later erosion or are present in the subsurface. The probable near-shore nature of many of the coarser Devonian clastic rocks in the south and the common occurrence of finer clastics in the Burt Range Formation both tend to suggest that if fringing reefs developed, they might have done so nearer to the basin centre than the rocks presently exposed. This favors their preservation in the subsurface.

Crinoid biostromes are as typical of the Mississippian as stromatoporoidal accumulations are of the Devonian. These are not reefs, but can form important reservoirs, particularly where aqueous migration and leaching have been active. If the beds have not been leached they are almost always infilled by calcite. Crinoidal limestones are known to occur in the upper part of the Burt Range Formation. The Milligans Beds, and possibly the Point Spring Sandstone also could contain locally thick encrinites. Submarine highs within the basin could have been areas of crinoid growth during Mississippian times, and could be considered as possible areas for the entrapment of hydrocarbons. On the basis of present data, the encrinites of the Burt Range Formation provide the best possibilities, as they could form reservoirs in cut-off traps beneath the Milligans Beds.

From the foregoing discussion, it can be considered that the two best reservoir possibilities in the Bonaparte Gulf area are stromatoporoidal reefs and cut-off traps. The next best possibility is fault traps. Pinchout traps and fold structures are likely to prove less important. Comparison of the stratigraphic succession with that of oil-producing areas elsewhere suggests that the overall possibilities are very good. In Western Canada, for example, the greater part of hydrocarbon reserves occur in Devonian reefs and Mississippian cut-off traps, in rocks with comparable lithological characteristics to those of Bonaparte Gulf.

CONCLUSIONS

The purpose of this report is to summarise available data and to evaluate the hydrocarbon possibilities of Bonaparte Gulf Basin. It is obvious that considerable work will have to be performed before the stratigraphy of the area can be evaluated with any precision, and before the hydrocarbon possibilities can be properly assessed. Gaps in the knowledge of the area are apparent in this report.

At least two steps will be taken in future to gather more data. Several exploratory bore-holes are in prospect, the first to be drilled during 1963. Field work will also be performed in the area by the Geological Branch of the Bureau of Mineral Resources, during the 1963 and subsequent dry seasons. A field party, under the leadership of J.J. Veevers, will carry out detailed stratigraphic and palaeontologic work at this time. Under these circumstances, fairly rapid evaluation of both the stratigraphy and of the hydrocarbon potential of the area should be possible.

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This report is based upon the work of many geologists, geophysicists and others. Data from their reports are acknowledged, wherever possible, in the body of the report.

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BIBLIOGRAPHY

The following bibliography lists sources of data under the headings: (i) published reports and articles (ii) unpublished reports and (iii) private Company reports. [redacted]

(i) All the published reports and articles include significant reference to the area. Some may not be readily available. In such cases the report or article, with very few exceptions, can be examined at the Bureau of Mineral Resources, Canberra.

(ii) This category of reports mainly deals with the area directly, and includes Bureau of Mineral Resources Records and two types of Company reports. Of these Company reports, the majority are Completion Reports on subsidized geophysical or drilling operations, and eventually will be published. Completion Reports are retained by the Bureau of Mineral Resources, and can be examined freely after an initial period of six months following completion of the operation. Other Company geological reports listed are no longer confidential due either to tenement lapse or to their having been specifically released for general use by the Company concerned. All reports in this category can be examined at the Bureau of Mineral Resources in Canberra.

(iii) Private Company reports are on either unsubsidized geophysical operations or on surface geological surveys, which are ineligible for subsidy. All of these are the property of the Companies concerned. Most of these reports are held in Canberra, but can be inspected only by letter of authorisation from the Company.

Almost all the references in the bibliography have been used in this report; those which have not are indicated by an asterisk.

Published Reports and Articles

* BROWN, H.Y.L., 1895 - Report on Northern Territory explorations. _S.Aust. parl. Pap._ 82, 4-5

BROWN, H.Y.L., 1907 - Record of Northern Territory boring operations _in Suppl. to parl. Pap._ 55, 1906.

BROWN, H.Y.L., 1907 - in Gov. Res. Rep. for 1907.

BROWN, H.Y.L., 1908 - in Gov. Res. Rep. for 1908.

BROWN, H.Y.L., 1909 - in Gov. Res. Rep. for 1909.

BRUNNSCHWEILER, RO., 1953 - Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia. Geol. Soc. Aust. 1, 35-44

BUREAU OF MINERAL RESOURCES 1960 - Summary of oil-search activities in Australia and New Guinea to June, 1959 Rep. 41A.

CROCKFORD, JOAN, 1943 - Bryozoa from the Port Keats bore, Northern Territory. Proc. Linn. Soc. N.S.W., 68, 145-148.

DRUMMOND, J.M., 1963 - Carbonates and grade size. Bull. Can. Petrol. Geol. 11, 33-53.

EDWARDS, A.B., and CLARKE, E. de C., 1940 - Some Cambrian basalts from the East Kimberley, Western Aust. J. Roy. Soc. W.Aust.,26, 77-94.

☆ ETHERIDGE, R., 1897 - Official contributions to the palaeontology of South Aust. in S. Aust. parl. Pap. 127,13-16

ETHERIDGE, R., 1907 - in Supp. to parl. Pap. 55, 1906

FAIRBRIDGE, R.W., 1953a- Australian Stratigraphy. Un. W. Aust. Text Books Bd.

FAIRBRIDGE, R.W., 1953b- The Sahul Shelf, Northern Aust. Its structure and geological relationships. J. Roy. Soc. W. Aust. 37, 1-33.

GLENISTER, B.F., 1960 - Carboniferous conodonts and ammonoids from Northwestern Australia. Quatrieme Congr. Strat. Geol. Carb. Heerlen, 1958, 1, 213-217

HEILAND, C.D., 1946 - Geophysical Exploration. Prentice-Hall, New York.

JONES, P.J., 1961 - Ostracod assemblages near the Upper Devonian - Lower Carboniferous boundary in the Fitzroy and Bonaparte Gulf Basins in Geology of the Canning Basin, Bur. Min. Resour. Aust. Bull. 60, Appendix 3, 277-281.

JONES, P.J., 1962 - The Ostracod Genus Cryptophyllus in the Upper Devonian and Carboniferous of Western Aust. Bur. Min. Resour. Aust. Bull. 62, Part 3.

McWHAE, J.R.H., et al., 1958 - The Stratigraphy of Western Aust. Geol. Soc. Aust., Cambridge University Press.

MATHESON, R.S., and TEICHERT, C., 1948 - Geological reconnaissance in the eastern portion of the Kimberley Division, Western Australia. Ann. Rep. Dep. Min. W. Aust., 1945, 73-87.

NOAKES, L.C., 1949 - A geological reconnaissance of the Katherine-Darwin region, Northern Territory. Bur. Min. Resour. Aust. Bull. 16.

NOAKES, L.C., OPIK, A.A. and CRESPIN, J., 1952 - Bonaparte Gulf Basin, North Western Australia. 19th. Cong. Int. Symp. Gond. Ser. 91-106.

REEVES, F., 1951 - Australian oil possibilities. Bull. Amer. Ass. Petrol. Geol. 35, 2479-2525.

SPIRIT HILL NO. 1 COMPLETION REPORT - See Westralian.

THOMAS, G.A., 1957 - Oldhaminid brachiopods in the Permian of Northern Australia. J. Pal. Soc. India, D.N. Wadia Jub. No., 2, 174-182.

THOMAS, G.A., 1963 - The Carboniferous stratigraphy of the Bonaparte Gulf Basin. Quatrieme Congr. Strat. Geol. Carb. Heerlen, 1958, in press.

THOMAS, G.A., 1964 - Carboniferous and early Permian brachiopods from Western and Northern Australia. Bur. Min. Resour. Aust. Bull. 56, in press.

TRAVES, D.M., 1955 - The Geology of the Ord-Victoria region, Northern Australia. Bur. Min. Resour. Aust. Bull.27.

WEAVER, P., 1962 - Have we overemphasised one source environment for petroleum? Bull. Amer. Ass. Petrol. Geol. 46, 2099-2100.

WESTRALIAN OIL LTD., AND OIL DEVELOPMENT N.L., 1963 - Spirit Hill No. 1. Bur. Min. Resour. Aust. Petrol. Search Subs. Acts Publ. 24.

Unpublished Reports

BURBURY, J.E., and TRAVES, D.M., 1962 - Report on a marine reflection seismograph survey in the Port Keats O.P. 2, Northern Territory. Mines Administration Pty. Ltd, NT/2/103.

HARRIS, J.L., 1962 - Seismic survey report, Keep River area, O.P. 2, Northern Territory. Rep. by Geophysical Service Int. to Mines Administration Pty Ltd

JONES, P.J., 1958 - Preliminary report on micropalaeontology of samples from the Bonaparte Gulf Basin. Bur. Min. Resour. Aust. Rec. 1958/26.

NEUMANN, F.J.G., 1959 - Gravity effect of the Burt Range Limestone and basin structure in the Burt Range Sub-basin. Bur. Min. Resour. Aust. Rec. 1959/6.

ÖPIK, A.A., 1950 - Notes on Palaeozoic stratigraphy, Cambridge Gulf Area. Bur. Min. Resour. Aust. Rec. 1950/31.

REEVES, F., 1948 - Report on geology and oil possibilities in the Bonaparte Gulf Basin. Rep. to Standard Vacuum Oil Co.

ROBERTSON, C.S., 1957 - Preliminary report on a seismic survey in the Bonaparte Gulf Area, June - October, 1956. Bur. Min. Resour. Aust. Rec. 1957/46.

SCHNEEBERGER, W.F., 1960 - Report on a gravity survey in Permit 127H, Western Australia. Rep. by Mines Administration Pty Ltd via Ball Associates for Gulf Oil Syndicate

STARKEY, L.J., 1959a- Report on a gravity survey in Permit 127H, Western Australia. Rep. by Mines Administration Pty Ltd for Gulf Oil Syndicate.

STARKEY, L.J., and ABEL, K.W., 1961 - Carlton gravity survey, P.E. 127H, Western Australia. Rep. to Oil Development N.L.

TINLINE, R.J., and FIFE, J.S., 1962 - Final report, Carlton seismic survey, Rep. by General Geophysical Company (Bahamas) Ltd. to Oil Development N.L.

THYER, R.F., STOTT, P.M., and NEUMANN, F.J.G., 1959 - Report on a gravity survey in the Bonaparte Gulf Basin, 1956-1958. Bur. Min. Resour. Aust. Rec. 1959/20.

TRAVES, D.M., 1949 - Preliminary report, Ord-Victoria region. Bur. Min. Resour. Aust. Rec. 1949/22.

UTTING, E.P., 1959 - Bonaparte Gulf Basin of Northern Australia. Preliminary statement on Permit 127H. Rep. to Gulf Oil Syndicate.

UTTING, E.P., 1960 - Surface exploration and oil prospects of Permit 127H, Western Australia. Rep. to Gulf Oil Syndicate.

WARNER, D.F., 1961 - Seismic report for the Port Keats Area, Oil Permit No. 2, Northern Territory. Rep. by Austral Geo Prospectors Pty Ltd for Mines Administration Pty. Ltd.

WILLIAMS, L.W., and WATERLANDER, S., 1959 Preliminary report of an underwater gravity survey, Darwin-Wyndham, 1958. Bur. Min. Resour. Aust. Rec. 1959/156

Private Company Reports

ALLEN, R.J., 1956 - Report of the Keep River party, 1956. Rep. by Mines Administration Pty Ltd for Westralian Oil, NT/KR/25.

BURBURY, J.E., 1957 - Gravity survey, Burt Range Basin, Northern Territory. <u>Rep. by Mines Administration Pty Ltd for Westralian Oil</u>, NT/3/36

BURBURY, J.E., 1958 - Regional gravity survey, Bonaparte Gulf Basin, North-Western Australia, 1957. <u>Rep. by Mines Administration Pty Ltd for Associated Australian Oilfields</u>, NT/2/46.

BURBURY, J.E., 1959 - Gravity and geological investigations north of Moyle River - Port Keats area, Northern Territory. <u>Rep. by Mines Administration Pty. Ltd. for Associated Australian Oilfields</u>, NT/2/72.

DERRINGTON, S.S., WARREN, A., and BURBURY, J.E., 1957 - Preliminary geological and geophysical report. Port Keats area, Northern Territory, (1956) <u>Rep. by Mines Administration Pty Ltd for Associated Australian Oilfields</u>, NT/BG/27.

GLOVER, J.J., RICHARDSON, L.A., and McGILVRAY, J.P., 1955 - Geological and geophysical report on the Keep River area, Bonaparte Gulf Basin. <u>Rep. by Mines Administration Pty Ltd for Associated Australian Oilfields</u>, NT/BG/20.

RADE, J., 1956 - Report on the southern portion of Westralian Oil Limited's Permit Area, Bonaparte Gulf Basin. <u>Rep. to Westralian Oil Ltd</u>.

RADE, J., 1957 - Reports on plane-tabled areas in Bonaparte Permit 3, N.T., 1956. Rep. to Westralian Oil Ltd.

RADE, J., 1958 - Report on sampling of conodonts and geological reconnaissance in the Bonaparte Gulf area during 1957. Rep. to Westralian Oil Ltd.

RADE, J., 1959 - Report on Bonaparte Gulf Permit 3, 1958. Rep. to Westralian Oil Ltd.

SCHNEEBERGER, W.F., 1959 - New views on the oil possibilities of Permit 127H, Bonaparte Gulf Basin Western Australia. Rep. to Gulf Oil Syndicate.

☆ SPRIGG, R., 1960 - Report on seismic survey, Spirit Hill Area. Rep. by Geoseismic Surveys Ltd for Westralian Oil Ltd.

STACH, L.W., 1958 - Petroleum prospects of Bonaparte Gulf Basin, Northwest Australia. Rep. for Westralian Oil Ltd.

STARKEY, L.J., 1959b- Preliminary notes on aeromagnetic survey - Permit 2. Rep. by Mines Administration Pty Ltd for Associated Australian Oilfields N.L.

UTTING, E.P., 1957 - Report on exploration and geology within Permit 3, Northern Territory, during 1956. Rep. to Westralian Oil Ltd.

UTTING, E.P., 1958a- Progress geological report, Permit No. 3, Bonaparte Gulf Basin (1957). Rep. to Westralian Oil Ltd.

UTTING, E.P., 1958b- Discussion of results of fossil research and stratigraphy, Bonaparte Gulf. Rep. to Westralian Oil Ltd.

★ UTTING, E.P., 1961 - Permit to Explore No. 127H, West Australia; Geological map with associated maps and notes. Rep. to Oil Development N.L. (May 11th, 1961)

UTTING, E.P., 1962a- Interpretation of Geoseismic survey, 1960. Rep. to Oil Development N.L., (28th January, 1962)

UTTING, E.P., 1962b- Considerations effecting future exploration in Bonaparte Gulf area. Rep. to Oil Development N.L. (March 20th, 1962).

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APPENDIX 1

CONSTRUCTION OF GEOLOGICAL MAPS

The Bonaparte Gulf area is covered by 1/250,000 or 4-mile sheets, available from the Department of National Mapping, Canberra (Fig.2). The Geophysical Branch, Bureau of Mineral Resources, prepared planimetric maps of the area on a standard scale of 1/250,000. These maps were compiled at Petroleum Exploration Branch into two sheets which cover Bonaparte Gulf Basin, and this base was used for the geological maps in the back pocket of this report.

Surface Geology Maps

The surface geology maps limit interpretation as much as possible. Controversial exposures are indicated and are discussed in the body of the report. Map reliability can be judged approximately from Figure 8, which indicates the detail in which geological surveys have been performed. Where photogeology is the main basis for identifying and classifying exposures, as in the extreme north, some errors will occur. In the other areas, the exposures shown have been identified on the ground. In less thoroughly examined areas, fresh exposures will probably be found with time, and may or may not alter present concepts of the geology.

The Port Keats Group is undifferentiated, because the subdivision of it is highly interpretative. The Point Spring Sandstone is relatively thin and cannot be distinguished everywhere from the overlying Border Creek Sandstone. Because of this, the two formations are shown together. In the south-west, beds which cannot as yet be assigned to either the Burt Range Formation or Cockatoo Sandstone are distinguished as a separate unit. The Carlton Group is shown as a single unit, because it has not been subdivided at the surface other than locally. Beds of Precambrian age are shown as major lithological units; more specific breakdowns in terms of age or lithology cannot as yet be made.

In the Precambrian beds structural data are limited to fault trends. These trends appear to be related to the evolution of the Phanerozoic basin. Dips and strikes or other features are not shown for Precambrian rocks, partly because folding is relatively complex and has no apparent bearing upon the subsequent basin development, and partly because only limited data are available. The faults shown in the Cambrian and younger beds can all be considered identified on the ground, and their expression in all cases is reasonably well established. The amount of dip data vary in different areas; where data are abundant, dips representative of the vicinity are shown.

Interpretative Geology Maps

The degree of interpretation in any area of the interpretative geology maps can be assessed from the data on the surface geological map. On the northern sheet the formational subdivision was determined from coal bore data (Fig. 6) and from the inferred relationship between this data and surface exposures (see Port Keats Permo-Triassic Formations). Many of the contacts on both sheets of the interpretative maps are very approximate. On the southern sheet no attempt is made to interpret the area north-east of Spirit Hill, where the exposures in many cases are difficult to assign to established formations.

APPENDIX 2

ALPHABETICAL LIST OF STRATIGRAPHIC NAMES

Cambrian and younger rock-unit names which have been used in the Bonaparte Gulf area are listed below in alphabetical order.

APPENDIX 3

SUMMARY OF GEOLOGICAL AND GEOPHYSICAL ACTIVITIES

In Bonaparte Gulf area, exploration for hydrocarbons became active during 1955. Before then the only work evaluating hydrocarbon possibilities was by Reeves (1948, 1951) and Traves (1955). The following summary lists activities and refers to reports which resulted from these activities.

1955 Private companies carried out geological and gravity surveys in the lower Keep River plains (Glover et al, 1955) and geological work further south in the Keep River area (Rade, 1956).

1956 Geological work was performed in the Keep River area both by Rade (1957) and Allen (1956). Utting (1957) summarised this work together with the results of shallow stratigraphic drilling. Derrington et al (1957) investigated the geology and carried out a gravity survey in the area south and south-east of Port Keats.

The Bureau of Mineral Resources became active during this year, and performed the first seismic survey in Bonaparte Gulf Basin, in the Carlton-Keep River area (Robertson, 1957) as well as gravity work in the same area (Thyer et al, 1959). The Bureau also carried out an extensive aeromagnetic survey over the area of Phanerozoic sediments and a large part of the Gulf.* Aeromagnetic intensity maps resulting from this survey are available.

1957 Rade (1958) continued geological work in the Keep River area and Utting (1958a) summarised the findings. A local gravity survey was performed in the Burt Range area by Burbury (1957) who also surveyed a considerable part of the coastline (Burbury, 1958), and compiled gravity results to that time. Gravity work was also performed by the Bureau of Mineral Resources between Daly River Crossing and Moyle River area.

* Erratum: The aeromagnetic survey was performed in 1958.

1958 Bureau activity continued with a marine gravity survey (Williams and Waterlander, 1959). Rade (1959) concluded his investigations of the Keep River area.

1959 The geophysical surveys performed were again gravity work, by private companies. One survey was carried out along the Moyle River (Burbury, 1959) and a second in the Carlton Basin (Starkey, 1959a; Schneeberger, 1960). Some geological work was also performed in the latter area (Utting, 1959, 1960). During the year Spirit Hill No. 1 was spudded and suspended.

1960 Tenement holders began seismic work this year, with a survey in the area south-east of Port Keats (Warner, 1961) and in the Spirit Hill area (Sprigg, 1960). Spirit Hill No. 1 was deepened and completed as a water bore (Westralian Oil Ltd., and Oil Development N.L., 1963).

1961 No geological work was carried out this year. Geophysical surveys consisted of a marine seismic survey (Burbury and Traves, 1962) and detailed gravity work in the Carlton area (Starkey and Abel, 1961).

1962 In this year two further seismic surveys were performed. One took place on the lower Keep River plains (Harris, 1962) and the other between the Keep River area and the Ninbing area (Tinline and Fife, 1962).

APPENDIX 4

SECTION DESCRIPTIONS

The section descriptions given below are from private Company reports, and are verbatim except in a few cases where additional data, by the original author, could be introduced. The sections are numbered in correspondence to their order in the report. It is impractical to reproduce all sections which have been described, and those given here are limited to those which have not already been made available in a publication and are considered to merit publication. In a number of cases it is necessary to suggest contacts not given by the original authors, or to revise the names given to formations. In order to differentiate between such interpretations and original data the former are shown in parenthesis.

List of Sections

Section No. 1. Cockatoo Sandstone Type Section.

Location: Either side of Wyndham - Nicholson Road near Burt Range.

Author: Allen, 1956.

Remarks: Measured in three parts, the contacts between these parts being traced along strike. Measurements by Brunton level and aircraft altimeter. Top and base of section covered but still within the Cockatoo Sandstone.

10'+	Friable, medium grained quartz sandstone, with siliceous skin; few thin bands of small pebbles.
160'	No outcrop.
60'	Sandstone.
30'	No outcrop.
230'	Fawn, fine to medium grained quartz sandstone, very friable, fairly well sorted, well bedded, cross bedded.
10'	White, very friable, medium grained quartz sandstone with a little white felspar, grain size larger than that of 20' sandstone exposed below, roundness 0·7, fairly well sorted, strongly cross bedded.
90'	No outcrop.
20' or more	Fawn, very friable, medium grained quartz sandstone with a little white felspar, some fawn clay between grains, roundness 0·5, fairly well sorted, cross bedded, slight beehive weathering.
550'	No outcrop; sandy soil of Cockatoo Sands.
1,160'	
	base upper part/top middle part.
60'	Friable, medium grained quartz sandstone with a few grains of white clay mineral, few pebbles and pebble beds, cross bedded, slight beehive weathering.
10' or more	White, medium grained quartz sandstone with very little felspar, very friable and somewhat rounded.

175'	Arenaceous beds, some cross bedded; light grey, friable, medium grained quartz sandstone with felspar, and white argillaceous cement; felspathic quartz grit; fawn, medium grained felspathic quartz sandstone with very little felspar, friable, well sorted.
10' or more	Brown, friable, medium grained felspathic quartz sandstone, with a few pebbles of quartzite.
500'	Pebbly sandstone to pebble conglomerate, both with cobbles; towards top of member phenoclasts are fewer and there are beds of sandstone without them; roundness of phenoclasts 0·3 - 0·5, shape tends to be tabular, especially where source rock thin bedded, composition quartzite, fine grained sandstone and granite; sandstone and matrix of felspathic quartz composition, poorly sorted, cross bedded.
35'	Fawn, medium grained quartz sandstone with a little felspar, siliceous skin in parts but slightly friable within, thin bedded.
70'	No outcrop.
20' or more	Medium grained quartz sandstone, mottled red-brown and fawn, also dark brown and fawn; overlain by fine to medium grained quartz sandstone, some bands ferruginous, finely bedded.
100'	No outcrop.
20' or more	Fine grained quartz sandstone, finely mottled red-brown and fawn also dark brown and fawn, thin bedded, poor outcrop.
25'	No outcrop.
35'	Medium grained felspathic quartz sandstone.
25'	Pebble conglomerate, with cobbles and boulders, average size of phenoclast 2", roundness 0·5, composition quartzite, quartz sandstone and felspathic quartz sandstone; matrix felspathic quartz sandstone.
1,085'	

base middle part/top basal part.

20'	Red-brown, medium to coarse grained highly felspathic quartz sandstone, silicified.
20'	Medium grained quartz sandstone with very little white clay minerals, grains subangular.
20'	No outcrop.
10'	Quartz sandstone with white clay cement, on weathered surfaces are numerous subspherical bodies of harder sandstone, average diameter $\frac{3}{8}$".
20'	No outcrop.
10'	Fawn, medium grained quartz sandstone, with some grains of white clay mineral, poorly sorted, slightly friable; pebbles of quartzite, vein quartz, felspathic sandstone and indurated shale; hard bands about 2' thick of pink-fawn fine grained felspathic quartz sandstone.
230'	No outcrop.
20' or more	White, friable, fine to medium grained quartz sandstone with white to fawn grains of clay mineral; pebble bands.
140'	No outcrop.
20' or more	Grey to fawn, friable, fine to medium grained pebbly quartz sandstone with much fawn clay between grains, cross bedded.
170'	No outcrop.
20' or more	Fine to medium grained felspathic quartz sandstone; a few inches of pebble conglomerate at base containing subangular tabulate pebbles of fine bedded quartzite.
20'	Grey, medium to fine grained quartz sandstone with up to 30% of white clay mineral after felspar and some lithic fragments, well bedded.
40'	Friable, medium grained quartz sandstone with about 10% of white and fawn clay mineral, well bedded.
20'	Friable, fine grained quartz sandstone.
15'	Pebble conglomerate with some cobbles and small boulders, phenoclasts of quartzite and siliceous quartz sandstone, some with white clay.

250'	Fawn, friable, medium grained quartz sandstone, fairly well sorted, with a little fawn clay mineral, few small pebbles, siliceous skin in places, some cross bedding.
35'	No outcrop.
8'	Pebble conglomerate, similar to those below.
35'	Light red-brown, fine to medium grained siliceous quartz sandstone.
5'	Conglomerate.
2'	Siliceous sandstone.
10'	Pebble conglomerate with cobbles, index of roundness 0·5, average size 2", matric quartz sandstone with white argillaceous cement.
24'	Brown, fine to medium grained siliceous quartz sandstone with white to fawn grains up to 3/16" diameter, some of clay minerals after felspar, others lithic, thin bedded first 3', then massive.
1,164'	

Remainder of section covered, but Antrim Plateau Volcanics outcrop a short distance below. Total measured section 3,409'.

Section No. 2   Burt Range Formation Reference Section.

Location: Due west of Mount Septimus.

Author: Allen, 1956.

Remarks: Thicknesses calculated assuming dip of 10°. Horizontal distances measured by vehicle odometer. Top and base of section not exposed but still within Burt Range Formation. Less than 10% of section is exposed, and thicknesses are approximate.

5'	Secondary limestone.
179'	No outcrop.
5'	Secondary limestone.
182'	No outcrop.
2'+	Light grey coquinite, containing fine quartz sand.
83'	No outcrop.
2'+	Light grey calcarenite, containing fine grains of quartz, and some organic fragments.
59'	No outcrop.
2'+	Light grey coquinite, containing mostly crinoid fragments, with a small quantity of shell fragments.
45'	No outcrop.
2'+	Light grey coquinite, containing shell and crinoid fragments, and a well-preserved small rhynchonellid, also some medium grains of quartz.
85'	No outcrop.
2'+	"Floaters" of light grey coquinite, containing brachiopods and crinoid stems; grey-brown on fresh surface.
58'	No outcrop.
2'+	Light grey limestone containing streaks of quartz sand, and numerous small rhynchonellids.
5'	Grey, medium grained calcarenite containing quartz grains.
30'	No outcrop.

10'+	Grey limestone, and medium grained calcarenite, both with brachiopods and shell fragments; the limestone contains bands up to 1" thick of quartz sandstone, the grains of which are medium, sub-angular.
84'	No outcrop.
3'+	Light grey, medium grained calcarenite, with shell fragments; white on fresh surface.
307'	No outcrop; sandy soil.
2'+	Light grey, medium to coarse grained calcarenite, with shell fragments; light grey-brown on fresh surface.
38'	No outcrop.
2'+	Light grey shell coquinite, light grey on fresh surface.
178'	No outcrop.
2'+	Fawn-grey calcarenite, fawn-grey on fresh surface; numerous organic fragments and irregular brown streaks of fine to coarse grained quartz sandstone.
88'	No outcrop.
2'+	Fawn-grey, fine grained calcarenite with shell fragments; fawn-grey on fresh surface.
171'	No outcrop; sandy soil.
10'	Light grey, fine to medium grained calcarenite, with shell fragments; light grey on fresh surface.
97'	No outcrop.
2'	Light grey, fine to medium grained calcarenite, light grey on fresh surface.
80'	No outcrop.
2'	Light grey, medium to coarse grained calcarenite with shell fragments; grey on fresh surface.
85'	No outcrop.
2'+	Grey, medium to coarse grained calcarenite with organic fragments; grey-brown on fresh surface.
42'	No outcrop.

2'+	Light grey, coarse grained calcarenite, grey-brown on fresh surface.
44'	No outcrop.
2'+	Light grey, medium to coarse grained calcarenite, with shell fragments.
87'	No outcrop.
2'+	Light grey, medium grained calcarenite.
88'	No outcrop.
2'+	Light fawn-grey, medium grained calcarenite with shell fragments and gastropods.
90'	No outcrop.
5'+	Secondary limestone.
168'	No outcrop; sandy soil with some secondary limestone.
80'	Secondary limestone.
66'	No outcrop.
2'	Grey, fine to medium grained calcarenite, grey on fresh surface.
76'	No outcrop.
2'+	Grey, fine to medium grained calcarenite with shell fragments; grey on fresh surface.
35'	No outcrop.
2'+	Light grey, fine grained calcarenite with shell fragments.
30'	No outcrop.
2'+	Grey, medium grained calcarenite.
2'+	Medium grained calcareous quartz sandstone with a little felspar.
65'	No outcrop.
2'+	Brown, medium grained calcareous quartz sandstone, with very little felspar; grains sub-angular, fairly well-sorted.
8'	No outcrop.
2'+	Medium grained calcarenite with shell fragments.

75'	No outcrop; fine sandy soil.
2'+	Grey, medium grained calcarenite, grey on fresh surface; shell fragments.
70'	No outcrop; sandy soil, with a 4' band of secondary limestone 10'-14' from base and "floaters" of light grey limestone with quartz sand and shell fragments.
2'+	Grey calcarenite with fossil gragments.
29'	No outcrop.
50'	Much secondary limestone, and "floaters" of (1) medium grained calcareous quartz sandstone; (2) grey medium grained calcarenite with fossil fragments; (3) grey calcarenite with some medium grains of quartz, some of which have a coating of calcareous matter i.e. are oolitic; (4) grey shell and crinoid coquinite; (5) brown medium grained calcareous quartz sandstone, fawn on fresh surface; in stratigraphic order (1)-(5) upwards.
3,045'	Total measured section.

Section No. 3 Burt Range Formation/Enga Sandstone.

Location: South-west side of Enga Ridge.

Author: Allen, 1956.

Remarks: Thicknesses measured by Brunton level.

5'+	"Hard band" of fine grained quartz sandstone with thin skin of silica. Friable fine grained quartz sandstone; weathered surface shows numerous sub-conical holes up to 1" diameter and 1" deep.
4'	No outcrop.
2'+	Friable, white to fawn, fine grained quartz sandstone; slightly purplish in parts; little felspar.
19'	No outcrop.
1'+	Friable, white to fawn, fine grained quartz sandstone.
5'	No outcrop.
1'+	Very friable, fine grained quartz sandstone with a little felspar.
6'	No outcrop.
3'	Poorly resistant, pinkish-white, fine grained quartz sandstone.
5'	White to fawn, fine grained quartz sandstone, finer at base than at top; a little felspar at top; well-bedded, beds at top less than 4" thick.
16'	No outcrop.
1'+	Slightly friable, fine grained quartz sandstone; faintly purplish-white in colour; appears slightly siliceous.
14'	No outcrop.
1'+	Friable, fawn-brown, medium grained quartz sandstone capped by friable, brown, medium grained quartz sandstone containing ferruginous matter between grains.
5'	No outcrop.
1'+	Very friable, fawn, fine to medium grained quartz sandstone, with some sub-conical holes; slightly siliceous at top.

14'	Very friable, fawn-white, fine to medium grained quartz sandstone containing a little felspar; grains fairly well-sorted, sub-angular; numerous sub-conical holes up to 1" diameter and 1" deep on weathered surface.
½"	Purple, fine grained, ferruginous quartz sandstone.
5'	No outcrop.
1'+	Fawn, fine grained quartz sandstone, white on fresh surface.
7'	No outcrop.
1'+	Friable, white-fawn, fine to medium grained quartz sandstone.
3'	No outcrop.
1'+	Friable, white-fawn, fine to medium grained quartz sandstone with white argillaceous matter between grains.
4'	No outcrop.
1'+	Slightly friable, fawn-brown, fine to medium grained quartz sandstone.
1'	No outcrop.
1'+	Brown, medium grained, ferruginous quartz sandstone.
4'	No outcrop.
6'	Fawn, fine to medium grained quartz sandstone, not well-sorted; beds 3" thick.
2'	White to fawn, fine grained quartz sandstone, fairly well-sorted; non-friable.
12'	No outcrop.
4'	Quartz sandstone, fairly well-bedded (2-3")
	Base Enga Sandstone/top Burt Range Formation.
2'	Resistant, fawn-brown, fine to medium grained calcareous quartz sandstone; grains sub-angular.
1½'	Poorly resistant, brown, fine grained, calcareous quartz sandstone.
1½'	Brown, fine grained, calcareous quartz sandstone; quartz grains sub-angular; calcareous cement is very fine grained.

3'	Poorly resistant, fawn, fine grained quartz sandstone containing fossil shells.
18'	No outcrop.
1½'	Brown-grey, fine to coarse grained, calcareous sandstone, brown on fresh surface; quartz grains sub-angular to sub-rounded; calcareous cement is very fine grained.
1½'	Friable, fawn, fine grained quartz sandstone, slightly calcareous.
2'	Fawn-brown to brown-grey, fine grained, calcareous quartz sandstone showing Fontainebleu effect near top of bed; well-bedded.
2'	No outcrop.
1'+	Poorly resistant, fawn, fine grained quartz sandstone, slightly calcareous.
11'	No outcrop.
1'+	Poorly resistant, fawn-brown, fine grained quartz sandstone, fawn on fresh surface.
2'	Brown, fine grained, calcareous quartz sandstone.
15'	No outcrop.
1'	Poorly resistant, fawn-brown, very fine grained limestone, fawn-brown on fresh surface, with about 30% quartz grains, fine to medium, poorly sorted; crinoid fragments.
1'	No outcrop.
3'	Brown, fine grained, calcareous sandstone, with about 52% quartz sand by weight; sand grains are about 0.1mm. in diameter, sub-angular, except for a few angular and a few sub-rounded grains; fairly well-sorted; few larger grains.
9'	No outcrop.
1'+	Slightly friable, white, fine grained quartz sandstone, well-bedded (½")
10'	No outcrop.
1'+	Friable, fawn, quartz sandstone, with a little felspar; fairly well-sorted.

11'	No outcrop.
1'+	Friable, fawn, fine to medium grained quartz sandstone, with a little white and fawn felspar; sorting fair.
11'	No outcrop.
1'+	Fawn, fine to medium grained quartz sandstone with a little felspar; slightly friable.
6'	No outcrop.
1'+	Friable, fawn, medium grained quartz sandstone, with a little felspar; grains sub-angular, fairly well-sorted, contains shell fragments.
13'	No outcrop.
1'+	Brown, fine grained quartz sandstone, with a little yellowish felspar; fawn on fresh surface; fairly well-sorted; slightly friable.
7'	No outcrop.
7'	Friable, fawn-brown, fine grained quartz sandstone, with a little white and fawn felspar, and a little white mica; fair well-sorted, well-bedded (1").
27'	No outcrop.
1'+	Brown limestone, fawn on fresh surface, containing about 40% by weight of fine quartz sand, and some brown clay or fine silt; Fontainebleu effect.
15'	No outcrop.
1'+	Grey-brown, fine grained, calcareous quartz sandstone, pink-fawn on fresh surface.
4'	Grey limestone, fawn on fresh surface; contains quartz sand.
3'	No outcrop.
12'	Poorly resistant, friable, yellow-fawn, fine grained calcareous sandstone, containing rhynchonellids.
2'	No outcrop.
1'+	Fawn-grey, fine grained, calcareous sandstone.
10'	No outcrop.
2'	Light grey, fine grained, calcareous quartz sandstone, fawn on fresh surface; contains fossil shells.

15' No outcrop.

1'+ Grey-brown, fine grained, calcareous quartz sandstone, with a little brown clay or fine silt; fawn-brown on fresh surface; calcareous matter mainly calcite with some dolomite; quartz grains sub-angular, poorly sorted.

2' Light grey, fine grained, calcareous sandstone, fawn on ffesh surface.

3' No outcrop.

1'+ Fawn-brown, medium grained limestone with quartz sand; fawn on fresh surface.

4' No outcrop.

1'+ Light grey limestone, fine grained, fawn-grey on fresh surface, containing quartz sand.

1'+ Fine grained, calcareous sandstone.

13' No outcrop.

1'+ Fawn, calcareous sandstone, brown-fawn on fresh surface.

1' Fawn limestone, brown-fawn on fresh surface, containing 30% by weight of very fine grained quartz sand and a little clay.

2' No outcrop.

1'+ Poorly resistant, light grey, fine grained limestone, fawn-grey on fresh surface; fossiliferous.

6' No outcrop.

3' Fine grained, calcareous quartz sandstone containing fossil brachiopods.

5' No outcrop.

6' Light fawn-grey sandstone, fawn on fresh surface; fine to medium grained; mainly friable and non-calcareous; except near top, where it is calcareous.

5' No outcrop.

1'+ Poorly resistant, fine grained, calcareous quartz sandstone, showing Fontainebleu effect.

2' No outcrop.

6' Light-grey, calcareous quartz sandstone, fawn on fresh surface; quartz sub-angular to sub-rounded, medium to coarse grained, poorly sorted, few fossil fragments.

4' No outcrop.

4' Slightly friable, fawn, fine grained quartz sandstone, fairly well-sorted.

7' No outcrop.

1'+ Friable, brown, medium grained quartz sandstone, with brown ?ferruginous clay between grains.

3' No outcrop.

1'+ Friable, fawn-brown quartz sandstone.

1' No outcrop.

2' Light grey-fawn, fine to medium grained limestone with about 40% medium grained quartz sand, sub-angular to sub-rounded, not well-sorted.

9' No outcrop.

8' Friable, fawn-brown, medium grained quartz sandstone, with a little white and fawn felspar; fairly well-sorted, poorly bedded; top of bed is resistant and forms prominent broad ledge.

10' No outcrop.

9' Friable, white, medium grained quartz sandstone, with a little white felspar; fawn-brown on fresh surface; grains sub-angular to sub-rounded, fairly well-sorted; poorly bedded.

9' No outcrop.

1' Light grey, medium to coarse grained, calcareous quartz sandstone, fawn-grey on fresh surface; quartz grains sub-angular to sub-rounded, not well-sorted; fossil shell fragments.

2'+ Friable, brown, medium grained quartz sandstone, with some coarse grains; fossil shell fragments, ? rhynchonellids.

13'	No outcrop.
5'	Friable, brown, medium grained quartz sandstone with a little white and fawn ? felspar; not well-sorted; few coarse grains, more numerous at top of bed; grains sub-angular to sub-rounded; a little brown ferruginous clay between grains; rock is poorly bedded and fairly resistant.
8'	No outcrop.
1'+	Friable, grey, medium grained quartz sandstone, fawn on fresh surface.
2'	No outcrop.
5'	Light grey-fawn, medium to coarse grained, calcareous quartz sandstone, fawn on fresh surface; poorly sorted: "buckwheat" quartz up to 3/16"; grains sub-angular; fossil rhynchonellids.
8'	No outcrop.
1'+	Light grey, fine grained, calcareous quartz sandstone, fawn on fresh surface; fossil rhynchonellids.
12'	No outcrop.
3'	Fawn-grey, calcareous quartz sandstone, fawn on fresh surface.
4'	No outcrop.
1'+	Fawn-grey, medium grained quartz sandstone, fawn on fresh surface
5'	No outcrop.
1'+	Grey, fine grained, calcareous quartz sandstone, fawn on fresh surface.
26'	No outcrop.
1'+	Light grey, fine grained quartz sandstone, fawn on fresh surface.
9'	No outcrop.
3'	Fawn-grey, fine to medium grained, calcareous quartz sandstone, fawn on fresh surface; not well-sorted.
26'	No outcrop.

1'+	Fawn-grey, fine grained, calcareous quartz sandstone, fawn on fresh surface.
11'	No outcrop.
4'	Friable, fawn-grey, fine grained quartz sandstone, fawn on fresh surface.
11'	No outcrop.
1'+	Fine grained, calcareous quartz sandstone.
9'	No outcrop.
1'+	Friable, fine grained quartz sandstone; poorly resistant; non-calcareous; contains large fossil gastropod.
2'	No outcrop.
18'	Fairly resistant, rather friable, grey-fawn, fine grained quartz sandstone, fawn to grey-fawn on fresh surface; non-calcareous below, but very calcareous (? sandy limestone) at top; on weathered surface 3' from top are round nodules of calcareous sandstone, the average $\frac{3}{4}$" in diameter.
3'	No outcrop.
1'+	Poorly resistant, grey-fawn, medium grained, calcareous quartz sandstone, light grey on fresh surface.
22'	No outcrop.
1'+	Poorly resistant, grey-fawn, medium grained calcareous quartz sandstone.
5'	No outcrop.
1'+	Grey-fawn, medium grained, calcareous quartz sandstone, fawn on fresh surface; fossil crinoid fragments.
3'	No outcrop.
1'+	Fine grained, calcareous quartz sandstone, with large fossil gastropods.
6'	No outcrop.
1'+	Grey, medium grained, calcareous quartz sandstone, fawn on fresh surface.
6'	No outcrop.

1'+	Fawn to light grey limestone, pink on fresh surface, with numerous fine grains of quartz.
5'	No outcrop.
1'+	Fawn-grey, medium crystalline limestone; shell fragments, many preserved as coarsely crystalline carbonate.
783'	Total measured section.

1'+	Fawn to light grey limestone, pink on fresh surface, with numerous fine grains of quartz.
5'	No outcrop.
1'+	Fawn-grey, medium crystalline limestone; shell fragments, many preserved as coarsely crystalline carbonate.
783'	Total measured section.

Section No. 5. Probable Burt Range Formation.

Location: In fault block in central part of Burt Range.

Author: Glover et al, 1955.

Remarks: The assignment of this section to the Burt Range Formation cannot be considered proven. The authors thought assignment probable, and stated that the strata "are thought to represent the upper part of the Devonian sequence."

50'	Fine grained, yellow-brown, calcareous, quartz sandstone partly obscured by rubble from adjacent Weaber rocks.
40'	Sandy, dolomitic limestone, minor sandstone.
20'	Fine grained, yellow-brown sandstone.
5'	Grey, massive, dolomitic limestone with a few vughs.
25'	Yellow-grey, fine grained, thin-bedded sandstone which weathers yellow-grey.
5'	Resistant, grey-brown, dolomitic limestone which weathers grey.
6'	Alternating thin-bedded, calcareous sandstone and sandy limestone.
13'	Massive, grey, hard, sandy, probably dolomitic limestone which weathers grey.
25'	Interbedded sandstone and dolomitic limestone.
6'	Massive, hard, grey-brown, sandy, dolomitic limestone.
20'	Soft, nodular, grey and yellow-brown, fine grained, calcareous sandstone weathering grey and brown.
3'	Brown, hard, sandy, dolomitic limestone which weathers grey and fluted.
75'	Yellow-grey to brown, fine to medium grained, locally nodular sandstone which weathers yellow-grey and thin-bedded.
10'	Moderately strongly indurated, yellow-grey, fine to medium grained sandstone which weathers yellow-grey and massive.

17'	Yellow-brown, moderately indurated, fine to medium grained sandstone which weathers yellow-grey, grey and brown, and thin-bedded.
5'	Resistant, massive, pink, sandy, dolomitic limestone which weathers grey and thin-bedded.
10'	Yellow-grey, fine to medium grained sandstone which is cemented by clay minerals and weathers yellow-grey to grey and thin-bedded. Thin lenses of calcareous sandstone and sandy limestone.
45'	Rubble
380'	Total measured section.

Section No. 6 Point Spring Sandstone/Septimus Limestone

Location: North-east end of Mount Septimus.

Author: Reeves, 1948.

Remarks: Reeves recognised the upper 150' as "Permian" (now Lower Carboniferous) and referred to the remainder as Carboniferous.

150'	Gritty, dark brown sandstone with a few pebbles. (base Point Spring Sandstone/ top Septimus Limestone).
100'	Hard, dense, fossiliferous limestone interbedded with calcareous shale and an occasional thin sandstone.
20'	Grey, limestone grit with fossil fragments and angular grains of quartz about the size and shape of buckwheat grains.
180'	Grey, thin-bedded, dense crinoidal limestone; fossiliferous.

Section No. 7 Septimus Limestone

Location: South-west Burt Range.

Author: Glover et al, 1955

Remarks: Measured by abney level.

90'	Thin-bedded, resistant, light grey, sandy limestone which weathers grey and contains lenticular beds 1-2 inches thick of resistant, calcareous sandstone - fragmentary fossil remains - rubble from overlying Weaber Group.
10'	Massively weathering, sandy limestone.
55'	Thin-bedded, resistant, light grey, sandy limestone which weathers grey and contains lenticular beds 1-2 inches thick of resistant calcareous sandstone - fragmentary fossil remains.
38'	Easily weathered, soft, lumpy fragments (probably calcareous siltstone) and lesser, resistant, thin-bedded limestone.
5'	Resistant, slightly sandy, highly fossiliferous limestone containing abundant rhynchonellids (coquinite).
22'	Soft, sandy, coquinoidal limestone which weathers grey and lumpy.
129'	Resistant, well-bedded, light grey-brown, sandy, shelly, crinoidal and coralline limestone. Quartz grains are rounded, medium to coarse grained and constitute 10-40% of the rock. Beds range from 3 to 12 inches thick. About 20% of the section is composed of easily weathered sandy calcareous siltstone which weathers lumpy.
25'	Easily weathered, light grey, calcareous, shelly, crinoidal, medium to coarse grained sandstone which weathers grey and lumpy. Intercalated, thin (4 to 6 inches thick), resistant bands of shelly, crinoidal coralline, sandy limestone.
16'	Limestone rubble.
390'	Total measured section.

Section No. 8 Point Spring Sandstone/Septimus Limestone.

Location: North-east Burt Range.

Author: Glover et al, 1955.

Remarks: The authors assigned the upper 90' to the Weaber Group, and subsequent work suggests it is Point Spring Sandstone of this group (see Point Spring Sandstone).

Thickness unmeasured, approximately 90'. Light grey, medium to coarse grained, moderately friable, quartz sandstone which contains about 10% white clay mineral (after felspar) and weathers grey, grey-brown and red-brown. Quartz grains are subangular to sub-rounded. This sandstone is assigned to the base of the Weaber Group, and here rests without obvious unconformity, on Septimus Limestone.

220' Grey to pink, sandy, shelly, crinoidal limestone which weathers bedded, blocky and grey. The rock is well indurated and forms ledges, and constituent beds normally range from 1/2 inch to 2 feet thick. The formation becomes increasingly gritty toward the top.

90' Rubble, probably obscuring Septimus Limestone.

400' Total measured section.

Section No. 9.	Milligans Stratigraphic Test No. 1: (surface material/Point Spring Sandstone/ Milligans Beds).
Location:	South of Milligans Lagoon.
Author:	Rade, in Utting, 1957
Remarks:	None

10'	Grey clay followed by red clay.
15'	Variegated clays with quartz and geothite.
25'	Fine grained sandstone, dense, white, but in part ferruginous.
3'	Fine grained, sandy limestone, hard and only small recovery made.
11'	Whitish grey, slightly ferruginous, fine grained sandstone, medium hard, non-calcareous.
25'	Grey, medium hard, calcareous siltstone with crystals of pyrite and gypsum. Intercalated with thin layers of grey, slightly calcareous shale with crystals of pyrite.
6'	Light grey, very fine grained, calcareous quartz sandstone.
2'	Grey, silty shale, slightly calcareous with crystals of pyrite.
13'	Grey, slightly calcareous shale with crystals of pyrite and gypsum.
1'	Grey, slightly calcareous shale with crystals of pyrite.
2'	Medium hard, light grey, calcareous, fine grained quartz sandstone.
9'	Hard, whitish, partly ferruginous, fine to medium grained, non-calcareous sandstone, contains mostly quartz (may have fallen from surface).
18'	Greyish, white, fine grained calcareous sandstone.

3'	Dark grey, non-calcareous, silty shale.
3'	Whitish grey, fine grained, calcareous sandstone. Base Point Spring Sandstone/top Milligans Beds at 146'
27'	Grey shale, slightly calcareous with pyrite and gypsum.
18'	Grey shale, non-calcareous with gypsum.
12'	Grey, slightly calcareous shale.
6'	Grey, non-calcareous shale.
6'	Grey, non-calcareous, silty shale.
12'	Grey, non-calcareous shale with crystals of pyrite and gypsum.
42'	Grey, calcareous shale with crystals of pyrite and gypsum, crinoidea, bryozoa and shell fragments.
54'	Grey, calcareous shale.
9'	Grey, calcareous shale with crinoidea.
9'	Grey, slightly calcareous shale with concretions.
12'	Grey, calcareous shale.
28'	Grey, slightly calcareous shale.
130'	Grey, calcareous shale.
510'	Total section.

Section No. 10. Milligans Stratigraphic Test No. 3.
(Point Spring Sandstone/?Milligans Beds).

Location: North of Milligans Lagoon.

Author: Rade, in Utting, 1957.

Remarks: Insufficient shale was penetrated to ensure that Milligans Beds are present.

42'	White, non-calcareous, fine grained quartz sandstone.
6'	Light brownish, fine grained sandstone.
15'	Grey shale, slightly calcareous.
9'	Grey, non-calcareous, fine grained siltstone intercalated with grey shale.
3'	Grey, non-calcareous siltstone.
7'	Grey, calcareous, fine grained siltstone.
8'	Grey, silty shale, slightly calcareous.
90'	Total section.

Section No. 11. Point Spring Sandstone Reference Section.

Location: Five miles east-northeast of Point Spring, at or very near to the type section (Traves, 1955, p.78).

Author: Rade, 1958.

Remarks: These descriptions can be considered to supplement the less detailed ones given for the type section in Traves (1955, p.78).

25'	Brownish grey, flaggy, fine to medium grained sandstone, average thickness of flags 1-5". The flags are intercalated with a few thicker layers of sandstone which averages 9" in thickness. Sandstone is partly ferruginous.
6'	Dark brown, ferruginous, flaggy, fine to medium grained sandstone. Average thickness of flags 3-6".
6'	Brownish grey, fine to medium grained, massively layered sandstone.
4'	Brownish grey, fine to medium grained, partly layered sandstone.
4'	Brownish grey, fine to medium grained, massive sandstone.
10'6"	Brownish grey, fine to medium grained, layered sandstone. Layers are 6" to 1' 8" thick.
12'	Concealed.
4'	Brownish grey, fine to medium grained, layered sandstone. Average layer 5" thick.
3'	Whitish grey, fine grained, flaggy sandstone. Flags are ½-1½" thick.
3'	Brownish grey, fine grained, layered sandstone. Layers are 1½-7" thick.
10'	Concealed.
6'	Grey, fine to medium grained, layered sandstone. Layers are 1½" to 1'6" thick.

30'	Concealed.
4'2"	Brownish grey, fine to medium grained, flaggy sandstone.
4'4"	Brownish grey, fine to medium grained, massive sandstone.
5'	Brownish grey, fine to medium grained, flaggy sandstone.
2'	Brownish grey, fine to medium grained, layered sandstone.
6'	Brownish grey, fine grained, flaggy sandstone. Flags are $\frac{3}{4}$-7" thick, average 2".
95'	Talus, no exposure.
5' approx.	Grey, fossiliferous limestone with gritty bands.
35'	Talus, no exposure.
279'	Total measured thickness.

Section No. 12. Point Spring Sandstone.

Location: $\frac{1}{2}$ mile east of Point Spring.

Author: Rade, 1958

Remarks: This locality is not far from Point Spring, where Opik first used the name "Point Spring Sandstone."

15'	Brown, medium to coarse grained, massive sandstone with few pebbles.
50'	Brown, medium grained, flaggy sandstone. Average thickness of flags 1-4". Sandstone contains worm tracks and imprints of fossil wood.
14'	Whitish grey, medium grained, flaggy sandstone intercalated with nodular shaley sandstone.
2'6"	Whitish grey, medium grained, flaggy sandstone. Average thickness of flags $1\frac{1}{4}$-6".
2'2"	Brownish grey, nodular, shaley sandstone.
1'	Grey, medium grained, flaggy sandstone. Average thickness of flags 3-6".
10'	Concealed.
7'approx.	Grey, gritty limestone, fossiliferous.
88'	Talus, no exposures.
190'	Total measured section.

Section No. 13. Border Creek Sandstone/Point Spring Sandstone.

Location: Mount Septimus.

Author: Glover et al, 1955.

Remarks: Measured by aneroid.

65'(approx.) Massively bedded, poorly to moderately strongly indurated, quartz sandstone with minor muscovite, white clay minerals (probably after felspar) and rare black grains. Quartz grains are moderately well rounded, and the rock is commonly indurated locally by silicification. It weathers light grey and red-brown.

10' Medium to coarse grained sandstone of similar lithology to the sandstone above, containing conglomerate lenses of pebbles and boulders. Isolated pebbles and boulders are also present in beds of otherwise well sorted sandstone, and appear to have been rafted, probably by ice. They are mostly rounded, range in maximum diameter from 1/2 inch to 4 inches and are mainly quartzite. A few flat shale pebbles are present.

15' Pebble and boulder conglomerate with sandstone matrix. Most pebbles range between 1 inch and 3 inches in diameter and some boulders are 12 inches in diameter. Nearly all are quartzite.

(base Border Creek Sandstone/top Point Spring Sandstone).

325' Medium to coarse grained, locally gritty, quartz sandstone which contains white grains of clay mineral (probably after felspar), muscovite and rarer pale green biotite. The rock normally weathers red-brown and rests without apparent angular unconformity, on Septimus Limestone.

415' Total measured section.

Section No. 14. ?Border Creek Sandstone/Point Spring Sandstone/Spirit Hill Limestone.

Location: South-east end of Spirit Hill.

Author: Allen, 1956.

Remarks: See Spirit Hill area.

2'+	Friable, medium grained quartz sandstone, with up to 10% white clay minerals after felspar; hard siliceous skin.
6'+	Quartzite pebble conglomerate; cobbles ranging up to 4"; average pebble size ¾"; poorly-sorted; index of roundness about 0.5; matrix quartz sandstone, ferruginous in part. (? base Border Creek Sandstone/?top Point Spring Sandstone).
34'	No outcrop.
14'	Very friable, medium to coarse grained quartz sandstone with brown clay between grains; fairly well-bedded; eroded appearance; partly silicified near top.
12'	No outcrop.
2'	Friable, medium to coarse grained quartz sandstone; very few grains of white clay mineral; fairly well-sorted.
18'	Red-brown, fine grained, siliceous, felspathic quartz sandstone, fawn on fresh surface; well-bedded at base, more massive and fawn coloured near top.
9'	No outcrop. (approx. base Point Spring Sandstone/top Spirit Hill Limestone).
6'	Grey, fine grained, dolomitic limestone, fawn on fresh surface.
11'	Poor outcrop; several 1' bands of fawn to light grey, fine grained, dolomitic limestone with quartz sand; fawn on fresh surface; quartz medium to fine grained.

6'	Poorly resistant, light grey, fine grained, dolomitic limestone, fawn on fresh surface.
2'6"	Light grey, fine grained, dolomitic limestone with quartz sand, fawn on fresh surface; quartz medium grained.
11'	No outcrop.
36'	Resistant, light grey to grey, fine grained, dolomitic limestone, fawn to pink on fresh surface; about 50% calcite at 18', about 30% calcite at 36'; poorly bedded at 18', fairly well-bedded at 27', massive at 36'; several bands of crinoid fragments.
6'	No outcrop.
2'6"	Grey, fine grained, dolomitic limestone with quartz sand; fawn on fresh surface; well bedded (1/16").
14'	No outcrop.
27'	Resistant, dark and light grey, fine grained, dolomitic limestone; (about 60% calcite at 27'); fawny-grey to pink on fresh surface; few fine grains of quartz sand near base; fossil fragments, including crinoids and <u>Syringopora</u> at 27'.
14'	No outcrop.
18'	Resistant, grey, fine grained, dolomitic limestone with quartz sand; fawn on fresh surface; at top is 50% calcite; massive near base, finer-bedded near top.
5'	Poorly resistant, fine grained, calcareous quartz sandstone, in which caves have formed.
33'	No outcrop.
16"	Resistant, fine grained, fawn-grey, dolomitic limestone, grey on fresh surface; fossil fragments.
8"	Poorly resistant, fine grained, dolomitic limestone.
4'	No outcrop.
4'	Resistant, grey, fine grained, dolomitic limestone; not well-bedded.
4'	No outcrop.

3'	Resistant, grey-fawn, fine grained limestone, grey on fresh surface, with small cavities.
8'	No outcrop.
1'	Resistant, grey, fine grained limestone, with nearly 50% quartz sand, fawn on fresh surface.
1'	No outcrop.
2'	Resistant, grey, dolomitic limestone with quartz sand, to calcareous quartz sandstone; fawn on fresh surface; sand fine to coarse; finely cross-bedded.
18'	Poor outcrop; near top is fine grained limestone with quartz sand.
3'	Resistant, fawn-grey limestone with quartz sand, fawn on fresh surface; fine to medium grained.
8'	No outcrop.
2'	Grey, fine grained limestone, fawn on fresh surface, with numerous fine to coarse grains of quartz.
7'	Poorly resistant, fine limestone with a little quartz sand.
1'	Resistant, grey, dolomitic limestone, fawn on fresh surface; medium to coarse grained; some quartz grains ranging up to 3/16".
6'	No outcrop.
13'	Resistant, light grey to fawn, fine grained, dolomitic limestone, light grey and fawn on fresh surface; approximately 30% calcite; poorly bedded at base, fairly well-bedded (½"-1") at 6'.
5'	No outcrop.
5'	Grey-fawn, fine grained limestone, light grey and fawn on fresh surface; a little fine quartz sand.
4'	No outcrop.
18'	Resistant, poorly bedded, fine to medium grained, dolomitic limestone (about 40% calcite at 6'), with up to 40% quartz, medium to coarse grained.

6' Poorly resistant, sandy limestone.

31' Resistant, dark grey, fine grained, dolomitic limestone, fawn on fresh surface; poorly bedded; contains quartz grains, fine near base, becoming medium to coarse towards top; at 16' are grains of white quartz and quartzite ranging up to ¼"; cross bedding occurs at 22'.

(base Spirit Hill Limestone/?top Enga Sandstone).

12' Poorly resistant, fawn, calcareous quartz sandstone, medium to coarse grained below; fine grained above, weathered to form caves.

458' Total measured section.

Section No. 15 ?Border Creek Sandstone/Point Spring Sandstone

Location: South-west of Spirit Hill.

Author: Allen, 1956.

Remarks: None.

2'	Boulders of quartzite capping small knoll; range up to 2' in length; matrix of conglomerate appears to be ferruginous coarse grained quartz sandstone.
40'	No outcroup.
4'	Scree of small fragments of ferruginous fine grained sandstone and ferruginous siltstone or shale.
2'?	Coarse grained, quartz sandstone with ferruginous cement.
24'	No outcrop.
2'	Scree of quartzite cobbles and pebbles.
6'	No outcrop (?base Border Creek Sandstone/?top Point Spring Sandstone).
12'?	Friable, fine grained quartz sandstone with grains of white to fawn clay mineral; hard siliceous band ½" thick; ripple marked; weathers in tabular blocky fragments.
72'	No outcrop.
20'?	Consolidated, fine grained quartz sandstone; chocolate-coloured; finely bedded; weathers in blocky fragments.
14'	No outcrop.
4'?	Consolidated, fine grained quartz sandstone which weathers in blocky fragments.
15'	Poorly bedded, friable, medium to coarse grained quartz sandstone with grains of white clay mineral; phenoclasts of quartzite mostly about ⅛" in diameter, but ranging up to ½".
57'	No outcrop.

27' Poorly bedded, fawn coloured, quartz sandstone with some white and fawn clay mineral; siliceous skin on surface of outcrop; grain size fine near base, becoming medium to coarse, and poorly sorted, near top.

155' No outcrop.

2'? Very friable, medium grained quartz sandstone with white clay mineral and small chocolate coloured granular inclusions, about 1 mm. in diameter. Also small blocky fragments of fine grained quartz sandstone with brown ferruginous particles.

457' Total measured section.

Section No. 16. Border Creek Sandstone Reference Section.

Location: West of Spirit Hill and north of Milligans Lagoon.

Author: Allen, 1956

Remarks: None.

3'+ Ferruginous sandstone.

170' Medium grained, friable, quartz sandstone, with a little decomposed felspar; in part cement is white, argillaceous; "beehive" weathering structure; pebble beds basal 23"; phenoclasts range up to 6" long, are of average size 2", have index of roundness 0·5-0·7, and consist of quartz sandstone, quartz and quartz pebble conglomerate. "Upper beehive sandstone."

5' Medium to coarse grained quartz sandstone with black crystalline ferruginous cement.

2' Pebble conglomerate, average pebble size 2", index of roundness, 0·5-0·7; pebbles of siliceous quartz sandstone, quartzite, quartz sandstone; matrix of ferruginous quartz sandstone.

3" Convolute band of ferruginous sandstone.

10' Medium grained quartz sandstone with numerous white grains, some of decomposing felspar; others of indeterminate rock; cement black, ferruginous.

12' No outcrop.

6" Pebble conglomerate, average pebble size 2", index of roundness 0·5; pebbles of brown and white quartz sandstone, matrix ferruginous medium grained quartz sandstone.

4' No outcrop.

6" Medium grained quartz sandstone with a little decomposing felspar.

3'	White siltstone or very fine sandstone alternating with red-brown, ferruginous, very fine sandstone.
8'	No outcrop.
6"	Ferruginous, fine grained quartz sandstone with oscillation ripple marks.
9'	Friable, medium grained quartz sandstone with a little decomposing felspar and white mica; several thin bands of siltstone.
3'	Fine grained, felspathic quartz sandstone with red ferruginous cement; 2" bands of soft white argillaceous fine grained sandstone or siltstone.
1'	No outcrop.
1'	Brown, fine grained quartz sandstone, with white grains of decomposing felspar; red and brown ferruginous cement; worm tracks on some bedding surfaces.
18'	No outcrop.
1-2"	Convolute band of ferruginous sandstone.
80'	Cross-bedded, light brown, medium grained, friable quartz sandstone with decomposed felspar; pebble band, about 10' above base, also "floating" pebbles; "beehive" weathering near top. "Lower beehive sandstone".
20'	Pebble conglomerate with cobbles ranging up to 9" long; average pebble size 2"; index of roundness 0·5-0·7; phenoclasts of quartzite, vein quartz, siliceous quartz sandstone, felspathic quartz sandstone; matrix of quartz sandstone with a little felspar; lenses of sandstone up to 30' long and 1" thick. (probable base of Border Creek Sandstone).
349'	Total measured section.

Section No. 17. Border Creek Sandstone/Point Spring Sandstone.

Location: Milligans Hills.

Author: Glover et al, 1955.

Remarks: Measured in two sections above and below conglomerate. Measurements by abney level. The authors reported 175' of limestone below the lowest sandstone (see composite section described under heading of "Point Spring Sandstone").

10' Quartz sandstone with conglomerate lenses of quartzite pebbles mostly ranging in diameter from ·5 inches to 1 inch. The rock weathers light brown to red-brown.

100' Friable to moderately well indurated, medium grained, grey, quartz sandstone which weathers grey, brown and red-brown. Grains of white clay mineral (probably after felspar) constitute 5% of the rock. Minor muscovite and a few rafted pebbles are present.

at least 25' possibly 40' Boulder and pebble conglomerate and sandstone. Boulders are mostly subrounded quartzite, generally with diameter of 2-3 inches, but ranging up to 18 inches. (base Border Creek Sandstone/top Point Spring Sandstone).

25' Grey to light grey, medium grained, well sorted, quartz sandstone containing 10-15% white clay mineral grains, probably after felspar. The rock is moderately well consolidated and weathers red-brown owing to the presence of iron oxide. Ferruginous sandstone concretions, commonly cylindrical and up to 2 feet long and 8 inches in diameter, are found in outcrops on the southernmost hills.

160-175' Total measured section.

Section No. 18: Lateritised ?Mullaman Group/Port Keats Group.

Location: Mount Goodwin, near Port Keats.

Author: Evans, in Reeves, 1948.

Remarks: A similar section was measured by Derrington et al (1957). Correspondence between the two is fairly close. The main differences are interpretative, as Derrington et al suggested that Cretaceous deposits may be absent, and that the lateritic part of the section was formed on Permian Beds.

1'	Surface rubble.
8'	Laterite, mainly ferruginous but occasionally siliceous.
17'	Red-brown ferruginous sand and clay; angular fragments of sandstone; whole mass well cemented.
2'	Conglomerate and grit; matrix white to red sandy clay; quartzite and quartz pebbles.
	Base Mullaman Group (or Tertiary laterites)/top Port Keats Group, (?Formation II).
15'	Medium to coarse sandstone with irregular ¼" shale bands in places, and occasional small pebble and grit bands.
30'	Laminated shales, red and white but stained brown in places.
58'	Covered.
20'	Laminated shales.
20'	Covered.
171'	Total measured section.

Section No. 19: ? Tertiary laterites (?Mullaman Group)/Port Keats Group.

Location: Kurriyippi Hills.

Author: Derrington et al, 1957.

Remarks: The upper part of this section is interpreted as possible Mullaman Group in this report (see Mesozoic).

5' Loose scree of lateritic detritus.

21' Laterite. Basal five feet show fragments of the kaolinitic sandstone.

19' Obscured by soil and rock detritus.

Base Tertiary laterites (or Mullaman Group)/top Port Keats Group (?Formations II and III).

40' Red and red-brown, fine to medium grained, kaolinitic quartzose sandstone. A few nodular concretions. A few thin hard siliceous siltstone bands appear near the top.

9' Coarse grained quartzose sandstone, limonitised. Silicified giving "case-hardening". Current bedded. Grades locally into a pebble conglomerate.

52' Red and brown, friable, micaceous, medium grained quartzose sandstones. Interbedded with a few thin, brown, siliceous, siltstone bands. Quartz grains milky and sub-angular.

11' Massive, coarse grained quartzose sandstone. Exterior case-hardened, interior pink and friable. Grades locally into pebble conglomerate. Pebbles of well rounded milky quartz.

77' Massive, in parts current bedded, friable, medium grained, pink to brown, slightly micaceous, kaolinitic quartzose sandstone. Unfossiliferous. Quartz grains rectangular to subrounded and mainly milky. Mica is muscorite.

(?base Formation II/? top Formation III).

15' Thinly and in parts current bedded, red, white and brown, fine grained, friable, micaceous sandstone. A few thin siliceous nodular concretionary bands. Fragments of Glossopteris.

13' Massive, light to medium brown, fine to medium grained quartzose sandstone. A few thin (4") brown siliceous siltstone bands. Glossopteris common.

4' White and brown, slightly silicified sandstone. Thinly bedded. Overlies decomposed brown shale.

34' Scree slope - outcrop obscured by rock detritus and soil.

300' Total measured section.

Section No. 20: ? Tertiary laterites (?Mullaman Group)/Port Keats Group.

Location: East Mesa, Kurriyippi Hills.

Author: Derrington et al, 1957

Remarks: As for Section No. 19.

33'	Laterite.
	Base ?Tertiary laterites (or Mullaman Group)/top Port Keats Group (?Formation V).
49'6"	Interbedded shales and sandstones, mauve to creamy white.
5'6"	Coarse grained sandstone and grit. Heavily limonitised.
27'6"	Medium to coarse grained, fawn to white, quartzose sandstone. Strongly cross bedded. Containing some clay pellets. A few thin beds of grit.
22'	Interbedded shales and fine grained sandstones, fawn to creamy white in colour.
66'	Medium to coarse grained quartzose sandstone. Creamy white on broken surface, grey on weathered surface. Coarse bedded, contains a few red grains.
11'	Thinly bedded, white and fawn shales.
88'	Fawn to creamy white, quartzose sandstone, slightly coarser grained, with a higher proportion of felspar.
38'6"	Fawn to mauve, speckled white, quartzose sandstone. Minor felspar decompsing to white kaolinitic material. Contains irregular bands of white sandstone and quartzite.
341'	Total measured section.

Section No. 21: Port Keats Group.

Location: Approximately seven miles from the coast near Moyle River.

Author: Burbury, 1959.

Remarks: Formation V may be represented.

40'	Cream to white, medium to fine, kaolinitic quartz sandstone weathering brown to red and forming cap rock on mesa. Small caves have been eroded around base of this section. Sandstone is case-hardened irregularly.
35'	Fawn to white, medium to fine grained, kaolinitic quartz sandstone; moderate amount of white mica and numerous white mud pellets up to ¾". Very friable.
33'	Medium grained, ferruginous, quartz sandstone with minor amounts of felspar and white mica. Cross bedded.
14'	Obscured by rubble.
28'	Medium grained, cream to white, felspathic quartz sandstone with minor amounts of white mica. Weathers fawn to brown; cross bedded. Some small mud pellets.
150'	Total measured section.

APPENDIX 5

SPIRIT HILL NO.1 - CORE SAMPLES

Core samples from Spirit Hill No. 1 were described* at B.M.R. Core Store, Fyshwick. The descriptions are based upon megascopic examination, and grade sizes, dip values, porosity, percentages etc., are visual estimates, unless shown in parenthesis.

49'6" - 50'0"	Shale, slightly calcareous, lateritised, yellow-browns, soft, plastic in water.
99'0" - 99'6"	Shale, slightly calcareous, dark grey, fissile, softish.
145'6" - 146'0"	Shale, non-calcareous, slightly bentonitic, slightly silty, dark grey, rather blocky. Organic fragments, possibly plants.
176'0" - 176'6"	Sandstone, quartz, slightly calcareous, grey-white, medium to coarse grain with 1% larger inclusions, well sorted, well rounded, appears silicified. Inclusions are very coarse to pebble grade composed of quartz, black shert, and of irregular siltstone fragments, slightly calcareous, darkish grey. 5% porosity.
207'0" - 207'6"	Shale, as 145'6", finely cross bedded, with occasional coarse to granule grade grains of quartz, white, sub-angular.
227'6" - 228'0"	Sandstone, quartz, slightly salt and pepper, very slightly calcareous, grey-white, fine to medium grain with some larger grains, well sorted and rounded, appears slightly silicified.
258'0" - 258'6"	Shale, non-calcareous, dark grey, rather blocky with some partings. Dip less than 5°, with some current bedding.

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* by J.M. Drummond.

299'0" - 299'6"	Interbedded siltstone and shale, dark greys, some reddish. Pseudo-augen structure, probably due to slumping.
349'6" - 350'0"	Shale, non-calcareous, slightly silty, dark grey, rather blocky. Dip low but current bedded. Traces organic detritus.
400'0" - 400'6"	Shale, non-calcareous, dark grey, rather blocky, laminated, with apparent dips of 20°-30°.
448'6" - 449'0"	Shale, as 400'0", but not laminated. Sandy streaks, fine to coarse grain.
489'10"- 490'4"	Sandstone, calcareous, silty, pale brown-grey, fine grain, tight, (1% porosity), with organic inclusions, possibly plants.
490'4" - 490'9"	Sandstone, as 489'10", with inclusions shale, dark grey.
502'0" - 502'6"	Shale and siltstone, greys, interbedded with minor sandstone, slightly calcareous, pale grey, very fine grain. Dips average 35°. High angle fault with ½" throw.
550'0" - 550'6"	Shale, non-calcareous, dark greys, blocky, with irregular siltstone laminae. <u>Slight light oil-staining</u> in one siltstone streak, washed off.
600'0" - 600'6"	Shale, non-calcareous, rather silty, dark greys, blocky, with irregular bedding and dips ranging from very low to 20°.
652'6" - 653'0"	Shale, silty in streaks, dark greys, laminated to blocky. Dips a uniform 5°.
690'0" - 690'6"	Sandstone, quartz, pale grey, fine to medium grain, well sorted, sub-rounded, porosity 10% (18%).
699'6" - 700'0"	Shale, sandy and silty, non-calcareous, dark grey. Sand grains very fine to occasional medium grade. Two irregular shale and one very fine sandstone inclusions.

749'6" - 750'0"	Shale, non-calcareous, dark grey, rather blocky with some laminae. Dips irregular, approximately 40°. Some slickensides.
800'0" - 800'6"	Shale, similar to 749'6", with dips averaging 20°. Common slickensiding.
851'0" - 851'7"	Dolomite, slightly calcareous, very silty, pale grey, cryptograde matrix with 15% crinoid ossicles, coarse to granule grade. Slight leached vuggy porosity, ?2% (3%).
900'0" - 900'6"	Calc-dolomites, varied, part argillaceous, greys, shelly in places. Streak dolomitised calcarenite, medium to coarse grade, finely recrystallised, with ?7% porosity.
950'0" - 950'6"	Limestone, rather dolomitic, appears silty, encrinitic, pale grey, averaging 15% coarse to granule grade ossicles in finely recrystallised matrix. ?3% (2%) porosity. Brecciated with calcite veins.
1000'5" - 1001'0"	Calcarenite, slightly dolomitic, slightly sandy, argillaceous in streaks, greys, 60% fine to granule grade and remainder probably aphanitic but recrystallised. Some large fossils. (2% porosity).
1004'0"	Limestone, probably slightly dolomitic, varied, greys, with argillaceous streaks containing large brachiopods.
1007'8"	Limestone, grey, possibly slightly argillaceous, 20% medium to granule grade, remainder aphanitic, with occasional sand grains, medium grade, and some large brachiopods. Tight (0% porosity).
1008'0"	Limestone, as 1007'8", but 40% medium to granule grade.
1010'0"	Limestone, as 1008'0".

1011'6"	Limestone, sandy, part argillaceous in places, mainly uniform, grey, aphanitic. 40% sand grains, medium grade. Some macrofossils.
1013'0"	Limestone, slightly dolomitic, slightly sandy, fairly uniform with argillaceous streaks, grays, 25% medium to granule grade in micrograde matrix. Tight (1% porosity).
1016'6"	Limestone, similar to 1013'0" but less uniform, very argillaceous in streaks, 40% medium to granule grade. Large ossicles and brachiopods.
1017'6"	Limestone, similar to 1013'0" but 40% medium to granule grade, with well defined argillaceous aphanite 1" thick. Granular material probably crinoidal. Common brachiopods. Well defined dips of approximately 15°.
1024'0"	Limestone, slightly dolomitic, rather sandy, partly argillaceous, greys, rather varied with average 20% medium to granule grade. Larger fossils in more argillaceous parts. Sand grains medium grade.
1026'0"	Limestone, sandy, possibly slightly dolomitic, silty in streaks, pale greys, aphanitic. Sand medium grade, well sorted and rounded.
1028'6"	Limestone, sandy, rather argillaceous, darkish grey, probably aphanitic with sand, 40%, fine to medium grade, moderately sorted and rounded. Some large ossicles. Dips approximately 10°.
1034'0"	Limestone, rather argillaceous and silty, grey, 50% fine to granule grade, with occasional sand grains. Some megafossils.
1036'6"	Limestone, as 1034'0", with common megafossils. Low but indistinct dips.
1037'9"	Limestone, as 1034'0", with some shale breaks, dark grey, low angled.

1038'0"	Limestone, with some thin argillaceous streaks, brownish-grey, 50% fine to granule grade with common megafossils, especially ossicles.
1051'6"	Limestone, probably silty, with sandy streaks, grey, 50% fine to coarse grade. Tight (0% porosity).
1067'0"	Limestone, grey, 70% fine to medium grade, with occasional sand grains, medium grade. Some megafossils.
1067'9"	Limestone, probably silty, grey, 80% fine to granule grade, with occasional sand grains. Tight (4% porosity). Dips approximately 7°.
1081'6"	Limestone, grey, 80% fine to granule grade with occasional sand grains, medium grade. Tight (2% porosity).
1099'0"	Limestone, slightly sandy, probably silty, grey, 30% phaneritic, probably slightly silicified. Slightly argillaceous parting. Megafossils.
1150'0" - 1150'6"	Sandstone, slightly calcareous, appears silty (40%), grey, medium grade, well sorted and rounded. Tight (4% porosity).
1152'0" - 1152'6"	Sandstone, 30% dolomitic and silty matrix, grey, medium to coarse grade, grains less sorted than 1150'0". May be silicified. Low to zero dip in ½" thick argillaceous lamina.
1200' - 1200'7"	Limestone, silty and very finely sandy, some irregular argillaceous streaks, grey. Regular dips, under 5°. Tight (6% porosity).
1250'0" - 1250'7"	Dolomite, very slightly calcareous, pale grey, mainly medium to coarse grade, with good porosity, approximately 15% (16%).
1296'0"	Limestone, probably slightly dolomitic, pelletoid, grey, 85% fine to medium grade and matrix aphanitic, slightly argillaceous. Megafossils. Tight (6% porosity).

1300'0" - 1300'6"	Sandstone, silty, slightly calcareous, pale grey, uniform, very fine to fine grade, appears tight (14% porosity). Dip approximately 5°.
1321'6"	Limestone, mainly pelletoid, grey, mainly fine grade with some argillaceous streaks. Some megafossils. Tight (4% porosity).
1350'0" - 1350'6"	Sandstone, quartz, silty, non-calcareous, pale grey, very fine grade, with thin argillaceous laminae. Appears tight (9% porosity). Dip less than 5°.
1400'0" - 1400'6"	Limestone, probably slightly dolomitic, argillaceous and darker in streaks, part pelletoid, palish greys, fine to granule grade, tight. Dips low.
1450'0" - 1450'7"	Sandstone, quartz, silty, very fine grade, porosity about 5% by visual estimate (16%).
1500'0" - 1500'7"	Siltstone, probably slightly dolomitic, grey, tight (3% porosity), indistinct low dips approximating 5°.
1550'0" - 1550'6"	Siltstone, argillaceous, grey, blocky, tight (2% porosity), with indistinct low dips.
1599'6" - 1600'0"	Sandstone, quartz, silty, palish grey, very fine grade, uniform, tight, (5% porosity).
1650'0" - 1650'6"	Dolomite, slightly calcareous, grey, with dark dense argillaceous streak, mainly medium to coarsely crystalline, with relic ossicles. Intergranular porosity up to 20% (15%) and some fissure porosity. Dip 2-3°.
1700'0" - 1700'6"	Sandstone, quartz, silty, negligibly calcareous, pale grey, very fine grade, appears tight. Mottled low angle dip partings.
1750'0" - 1750'6"	Dolomite, slightly calcareous, part silty and rather argillaceous, grey, mainly medium to coarse grade with some aphanite, formerly shelly, tight (3% porosity). Dip approximately 15°, appears slumped.

1800'0" - 1800'6"	Dolomites, interbedded rather argillaceous, silty, darkish grey, very fine grade, tight, and brown-grey, medium to coarse grade, part granule grade, with relic ossicles and shell fragments and 5-10% (4%) porosity. Indistinct irregular dips.
1818'0" - 1819'0"	Dolomite, slightly calcareous, pale grey, mainly medium to coarse grade, some fine grade, formerly shelly, with sand grains, medium to coarse grade, rounded. Porosity averages 15%. Thin shale streak with 10°dip. Relic ossicle?
1850'0" - 1850'6"	Siltstone, rather calcareous, slightly sandy, probably dolomitic, rather argillaceous, grey, with fine irregular laminae, tight. Sand grains very fine grade. Occasional ossicles.
1891'0"	Limestone, argillaceous, silty, darkish grey, aphanitic, massive, tight.
1900'0" - 1900'6"	Limestone, as 1891'0", with rare sand grains, tight (4% porosity).
1950'0" - 1950'6"	Limestone, as 1891'0" but less argillaceous and very finely sandy. Dips approximately 5°.
2000'0" - 2000'6"	Limestone, rather silty, very finely sandy, slightly pelletoid in places, pale grey, aphanitic, tight. Streaky dip, approximately 10°.
2050'0" - 2050'6"	Sandstone, quartz, very slightly calcareous, silty, pale grey, with very thin partings and some irregular inclusions grey-green shale, very fine grade, tight (1% porosity). Clearest dip 10°.
2060'0" - 2060'6"	Shale with siltstone interbeds, greys. Dips 5-10°.
2150'0" - 2150'6"	Sandstone, quartz, very slightly calcareous, pale grey, very fine to medium grade, some large grains, well rounded but poorly sorted, appears tight (8% porosity). Indistinct dips approximately 10°.

2200'0" - 2200'6"	Sandstone, slightly argillaceous, grey, very fine to medium grade, occasional coarse grade, poorly sorted, moderately rounded, tight (2% porosity). Some sulphide residue.
2250'0" - 2250'6"	Sandstone, quartz, non-calcareous, pale grey, mainly uniform, fine grained, well sorted, probably silicified, appears tight (4% porosity).
2268'3" - 2269'0"	Dolomite, sandy, possibly slightly argillaceous, grey, fine grade tending medium grade, moderate vuggy porosity but matrix appears tight. Sand 20%, fine to medium grade. No relic textures.
2269'6" - 2270'0"	Dolomite, probably silty, slightly sandy, argillaceous in streaks, grey, fine to medium grade, tight. Slight vuggy porosity. Some vein calcite.
2300'0" - 2300'6"	Sandstone, quartz, rather dolomitic, probably slightly argillaceous, greys, very fine to coarse grade, poorly sorted, moderately rounded, tight (5% porosity). Dolomitised ossicles. One irregular shale inclusion. Indistinct dip of approximately 10°.
2350'1" - 2350'7"	Sandstone, quartz, pale grey, coarse grade, well sorted and moderately rounded, appears tight (10% porosity), with some irregular inclusions derived material, subrounded, mainly shale.
2400'0" - 2400'6"	Sandstone, argillaceous, silty, very slightly calcareous, pale grey, very fine grade, tight (2% porosity). Irregular dips, approximately 20°.
2450'0" - 2450'6"	Dolomite, silty, argillaceous, slightly calcareous in places, very finely sandy, grey, tight, with irregular stringers sandstone, medium grade, well sorted and rounded, in matrix of dolomite.

2499'0" - 2499'6"	Dolomitic sandstone, pale grey, with quartz grains, very fine to occasional granule grade, rounded, poorly sorted, in aphanitic dolomite matrix. Some dark chert and shale grains.
2550'0" - 2550'6"	Sandstone, quartz, slightly calcareous, probably dolomitic, glauconitic, pale grey, uniformly coarse grade, well sorted and rounded, tight.
2600'0" - 2600'7"	Sandstone, quartz, glauconitic, pale grey, fine to mainly coarse grade, appears silicified, appears tight.
2649'0" - 2649'6"	Sandstone, quartz, slightly glauconitic, pale grey, coarse to very coarse grade, well rounded, moderately sorted, silicified. Occasional inclusions shaly material, granule grade, rounded. Dip 15°.
2699'6" - 2699'9"	Sandstone, as above but without inclusions. Indistinct bedding with dips of approximately 20°.
2749'6" - 2750'0"	Sandstone, quartz, slightly calcareous, pale grey, mainly coarse grade, moderately sorted, well rounded, probably silicified, appears tight, with inclusion greenish shale ½" in diameter, and some smaller ones.
2800'0" - 2800'6"	Sandy siltstone, dolomitic, rather argillaceous, palish grey with green tinge. Sand grains 50%, very fine grade. Dips variable, but near 20°.
2849'6" - 2850'0"	Siltstone, sandy, argillaceous in streaks, probably dolomitic, greenish-grey, with 20% sand, very fine grade. Dips 5-8°, may be slumped.
2899'5" - 2900'0"	Sandstone, silty, pale greenish-gray, uniform except for slight mottling and some greenish shale streaks, fine grained. Dips indistinct, approximately 10°.

2948'6" - 2949'0"	Sandstone, silty, very slightly calcareous, pale grey, very fine grade, well sorted with occasional medium grade rounded grains.
2971'6" - 2972'0"	Sandstone, slightly calcareous, silty, pale grey, bimodal with 10% coarse and 90% very fine to fine grade, coarse grade rounded. Some small coarse grade shaly inclusions in streaks. Dip approximately 25°.
2999'6" - 3000'0"	Sandy siltstone, rather dolomitic, argillaceous, greenish-grey with reddish streaks. Sand 50%, very fine grade. Dip approximately 10°, possibly slumped.

APPENDIX 6

SPIRIT HILL NO.1 - POROSITY AND DENSITY DETERMINATIONS *

DEPTH	POROSITY % by vol.	GRAIN DENSITY gms/cc.	DRY BULK DENSITY gms/cc.	BULK DENSITY 100% Saturated with water gms/cc.
145'6" - 146'0"	13	2.54	2.21	2.34
258'0" - 258'6"	9	2.58	2.33	2.42
349'6" - 350'0"	9	2.52	2.29	2.38
489'10"- 490'4"	1	2.71	2.68	2.69
690'0" - 690'6"	18	2.75	2.26	2.44
851'0" - 851'7"	3	2.81	2.72	2.75
950'0" - 950'6"	2	2.83	2.77	2.79
1000'5" - 1001'0"	2	2.73	2.68	2.70
1007'8"	0	2.74	2.74	2.74
1013'0"	1	2.72	2.69	2.70
1025'0"	1	2.72	2.69	2.70
1051'6"	0	2.74	2.74	2.74
1067'9"	4	2.73	2.62	2.66
1081'6"	2	2.83	2.78	2.80
1100'0" - 1100'6"	4	2.72	2.61	2.65
1150'0" - 1150'6"	4	2.84	2.73	2.77
1200'0" - 1200'7"	6	2.68	2.52	2.58
1250'0" - 1250'7"	16	2.75	2.31	2.47
1296'0"	6	2.79	2.62	2.68
1300'0" - 1300'6"	14	2.80	2.41	2.55
1321'6"	4	2.80	2.69	2.73
1350'0" - 1350'6"	9	2.81	2.56	2.65
1450'0" - 1450'7"	16	2.76	2.32	2.48
1500'0" - 1500'7"	3	2.77	2.68	2.71
1550'0" - 1550'6"	2	2.77	2.71	2.73
1599'6" - 1600'0"	5	2.80	2.66	2.71
1650'0" - 1650'6"	15	2.88	2.45	2.59

* by Petroleum Technology Section, B.M.R., Canberra.

1750'0" - 1750'6"	3	2.87	2.78	2.81
1800'0" - 1800'6"	4	2.83	2.71	2.75
1900'0" - 1900'6"	4	2.69	2.59	2.63
2050'0" - 2050'6"	1	2.72	2.69	2.70
2100'0" - 2100'6"	2	2.73	2.67	2.69
2150'0" - 2150'6"	8	2.70	2.49	2.57
2200'0" - 2200'6"	2	2.79	2.74	2.76
2250'0" - 2250'6"	4	2.76	2.65	2.69
2300'0" - 2300'6"	5	2.80	2.66	2.71
2350'1" - 2350'7"	10	2.70	2.43	2.53
2400'0" - 2400'6"	2	2.80	2.75	2.77

COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS.

RECORDS:

Record No. 1963/133

Vol. II of II

Compilation and Review

of

The Geology of Bonaparte Gulf Basin, 1962

by

J. M. Drummond

PART 2 of 2

Record No. 1963/133

Vol.II of II

Compilation and Review

of

The Geology of Bonaparte Gulf Basin, 1962

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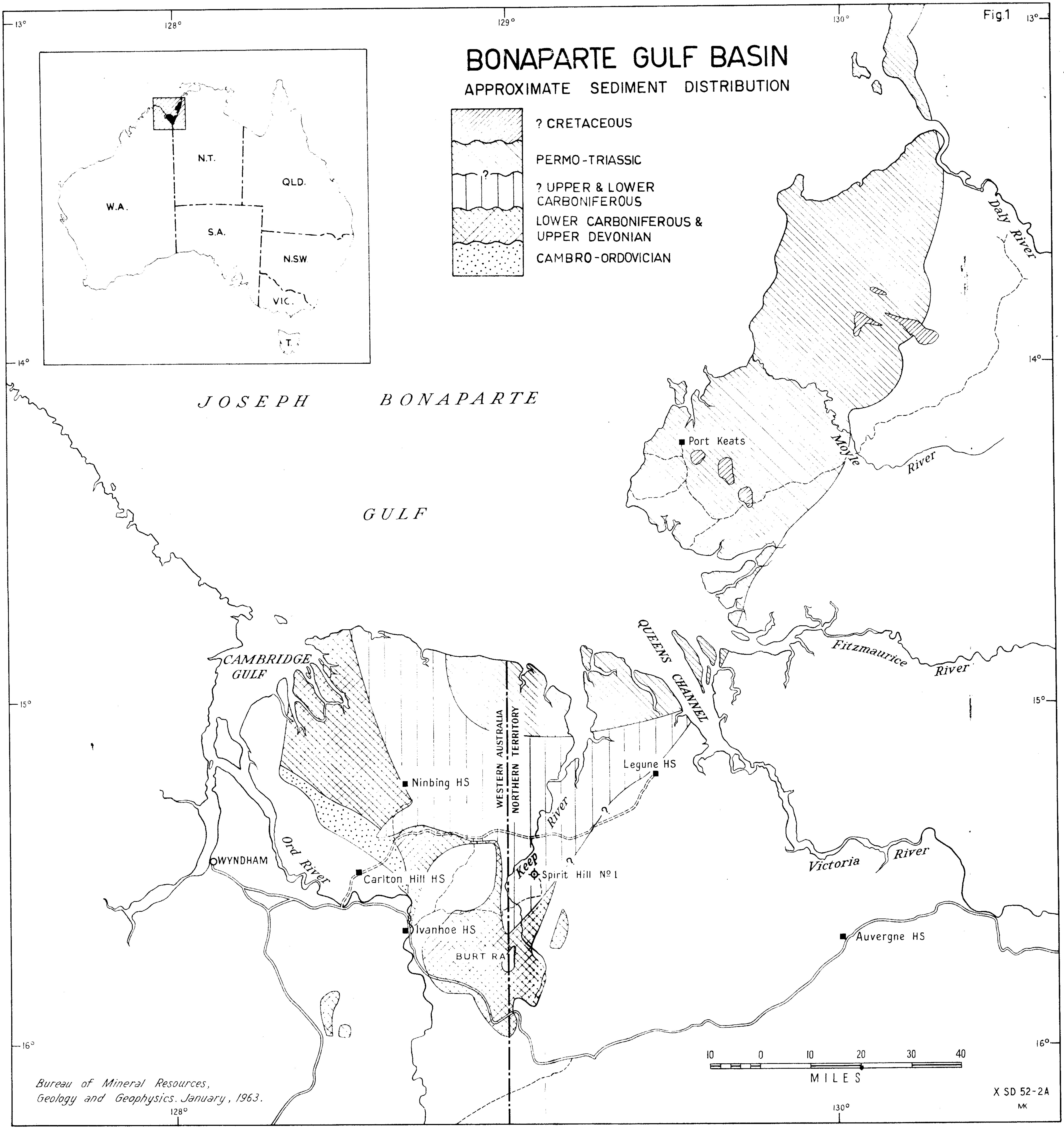
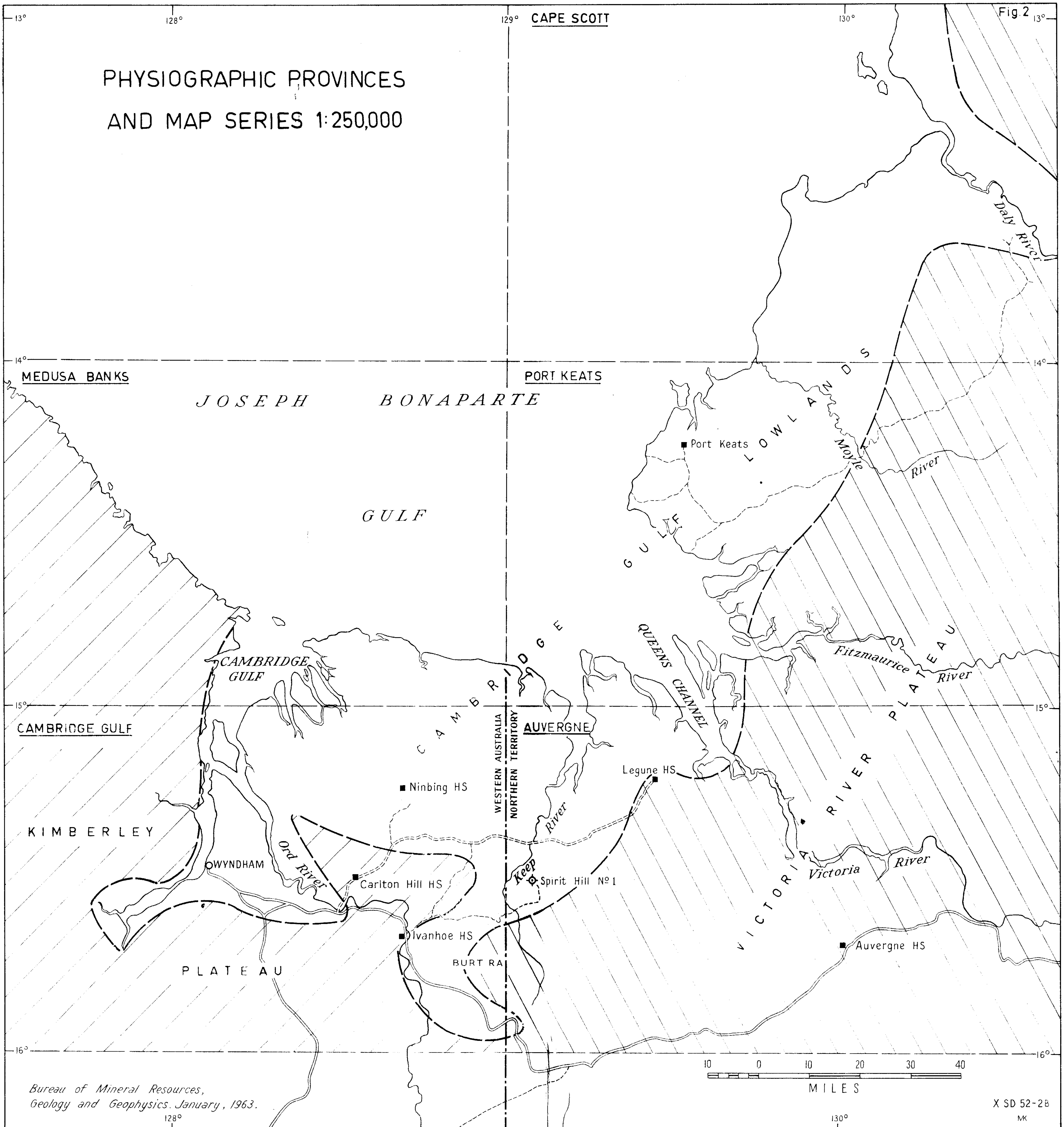
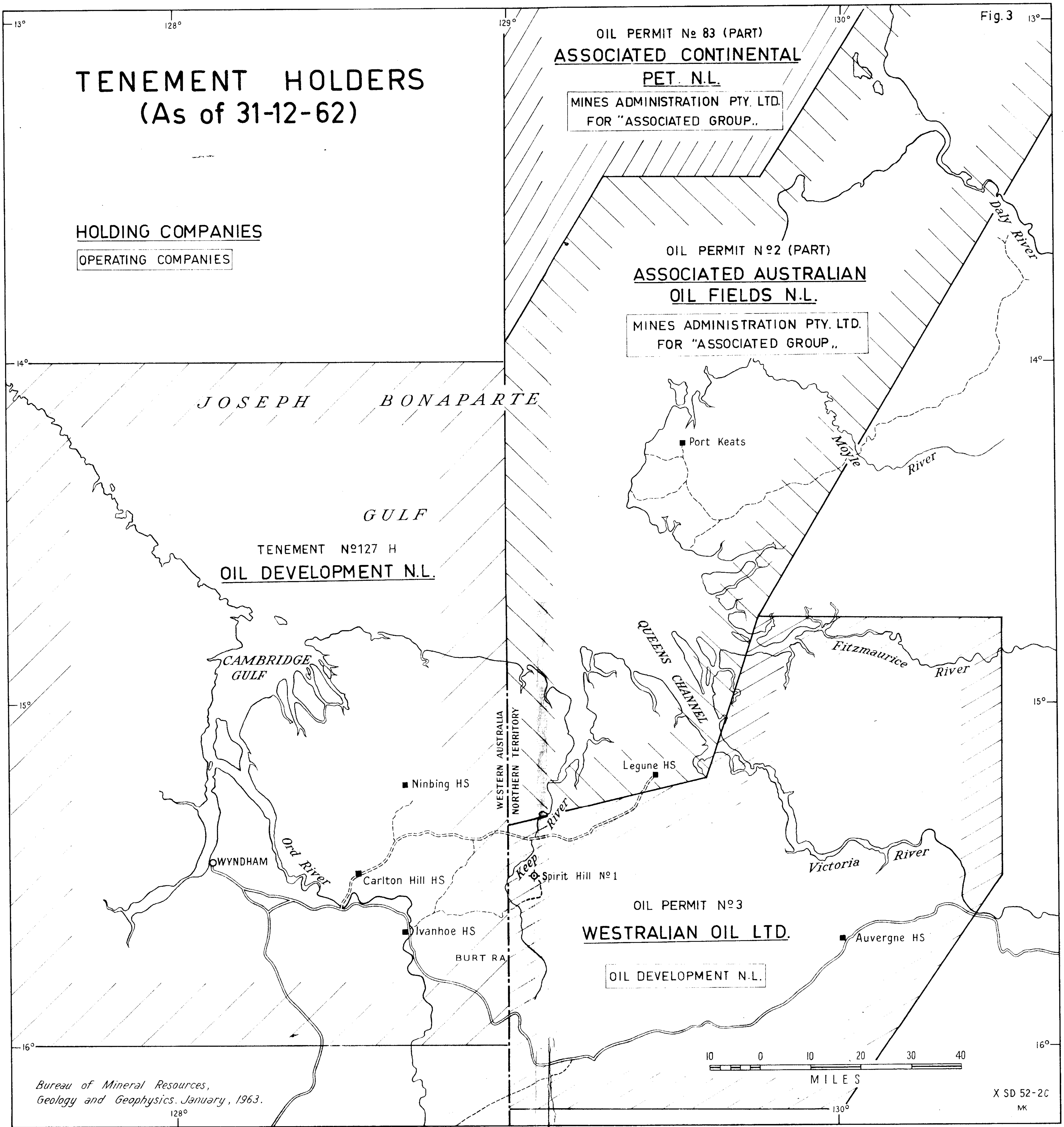
ILLUSTRATIONS



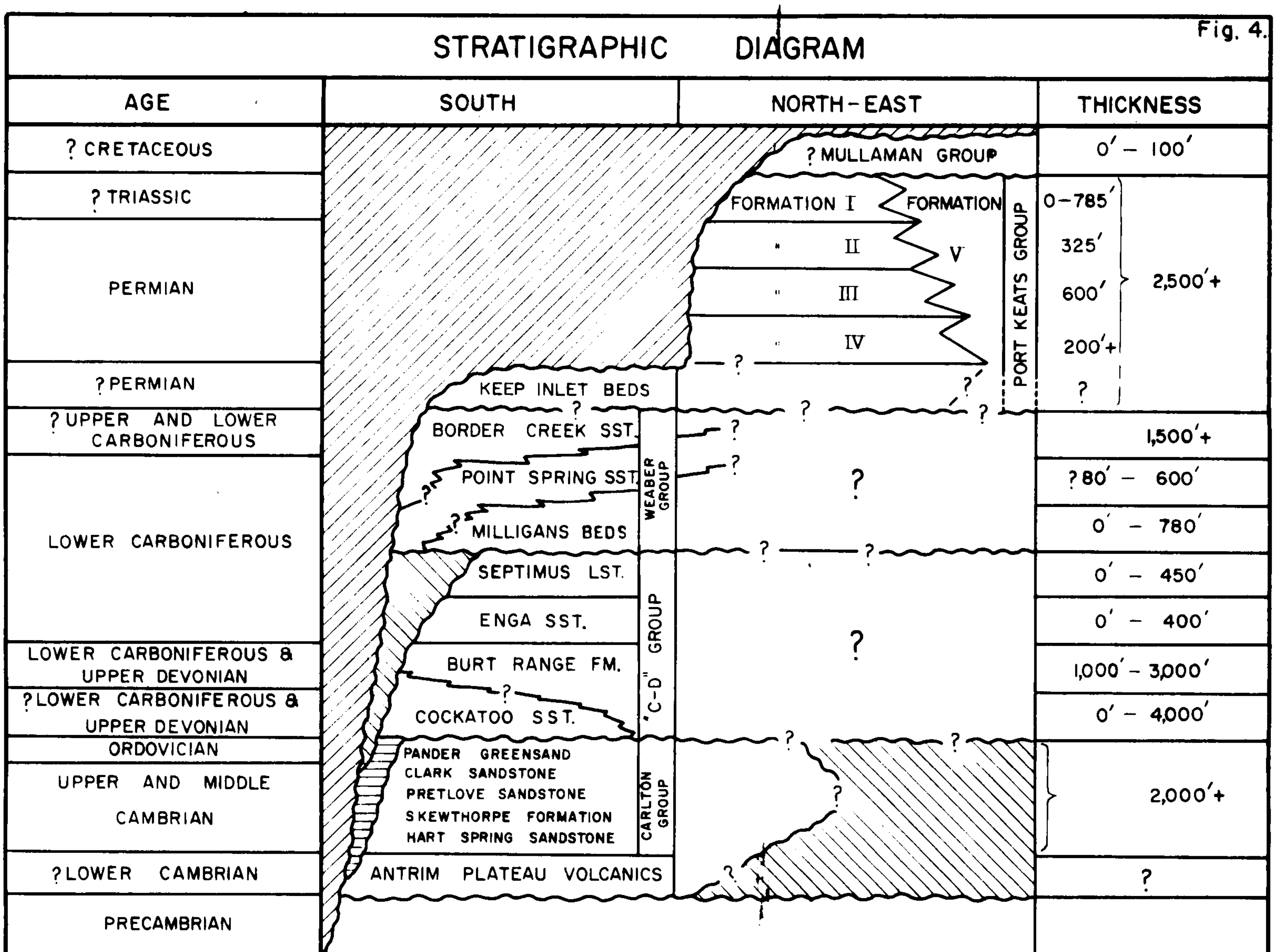
To accompany Record Nº 1963/133



To accompany Record No 1963/133



To accompany Record № 1963/133



STRATIGRAPHIC DIAGRAM

Fig. 4.

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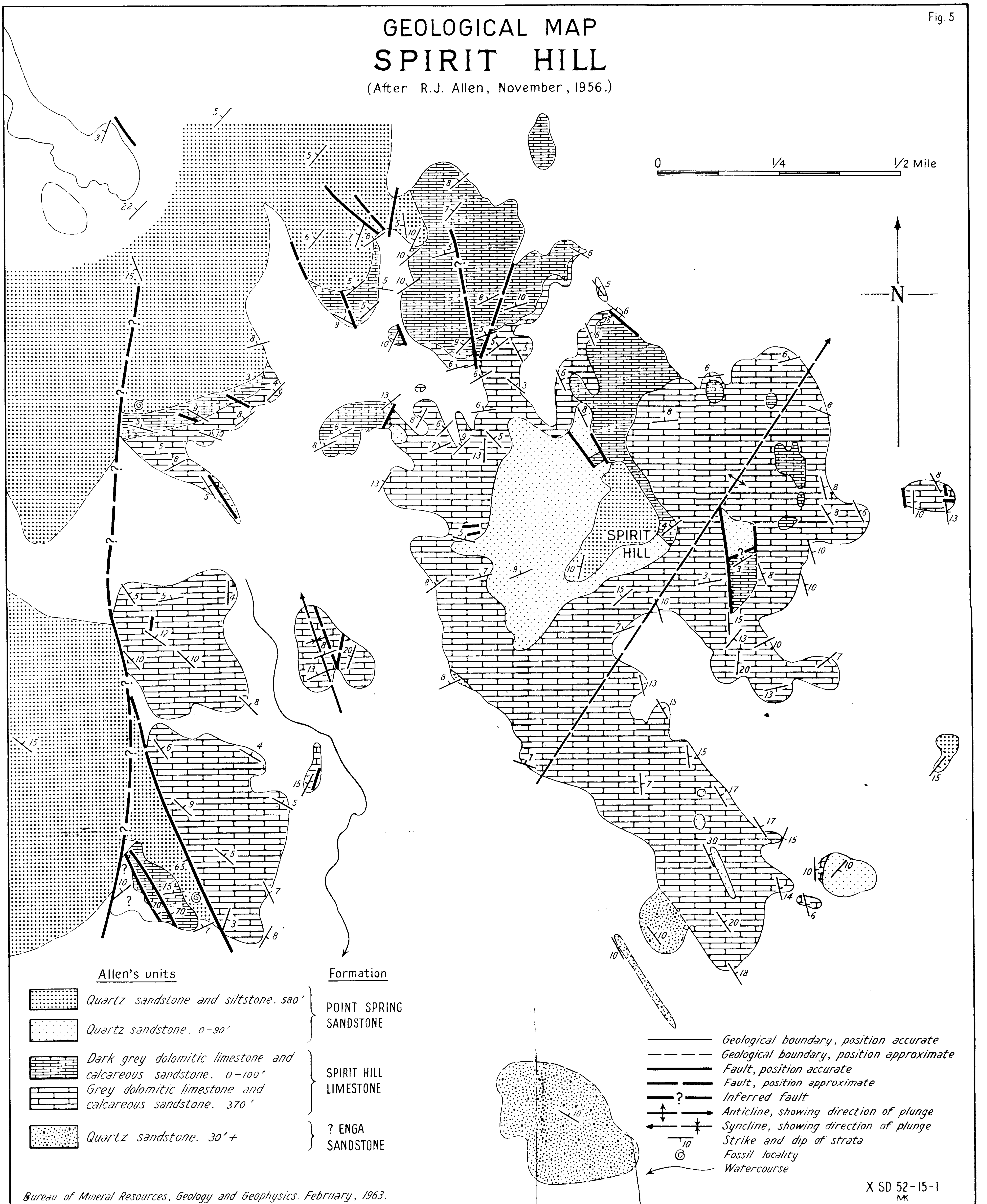
X AUS-2-2

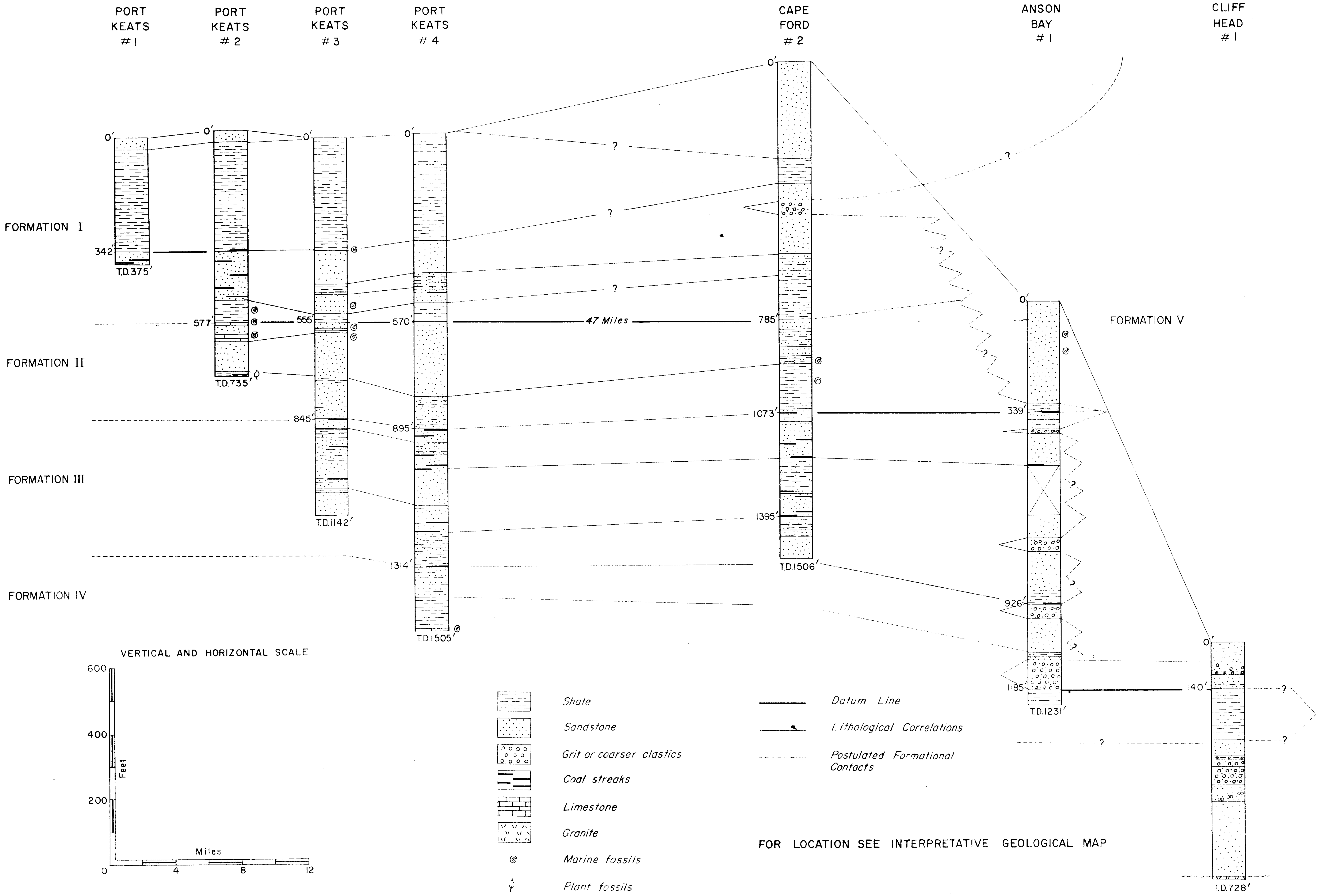
To accompany Record Nº 1963/133



To accompany Record Nº 1963/133

FIG 6

PORT KEATS COAL BORES



Bureau of Mineral Resources, Geology and Geophysics

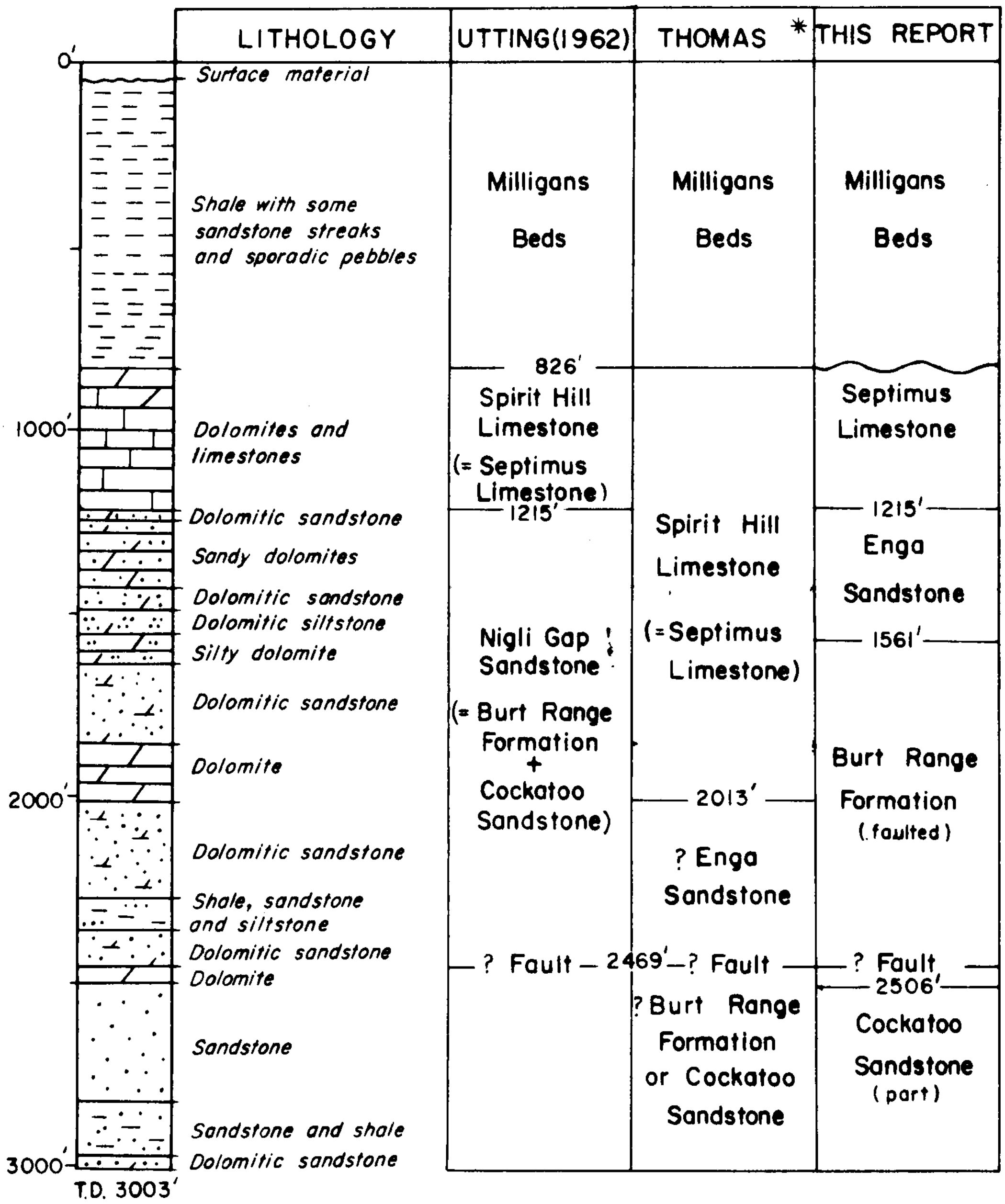
X SD 52-11-1

To accompany Record Nº 1963/133

Reduce A-C (14¾") to A-B (8")

Fig. 7

SPIRIT HILL No. 1

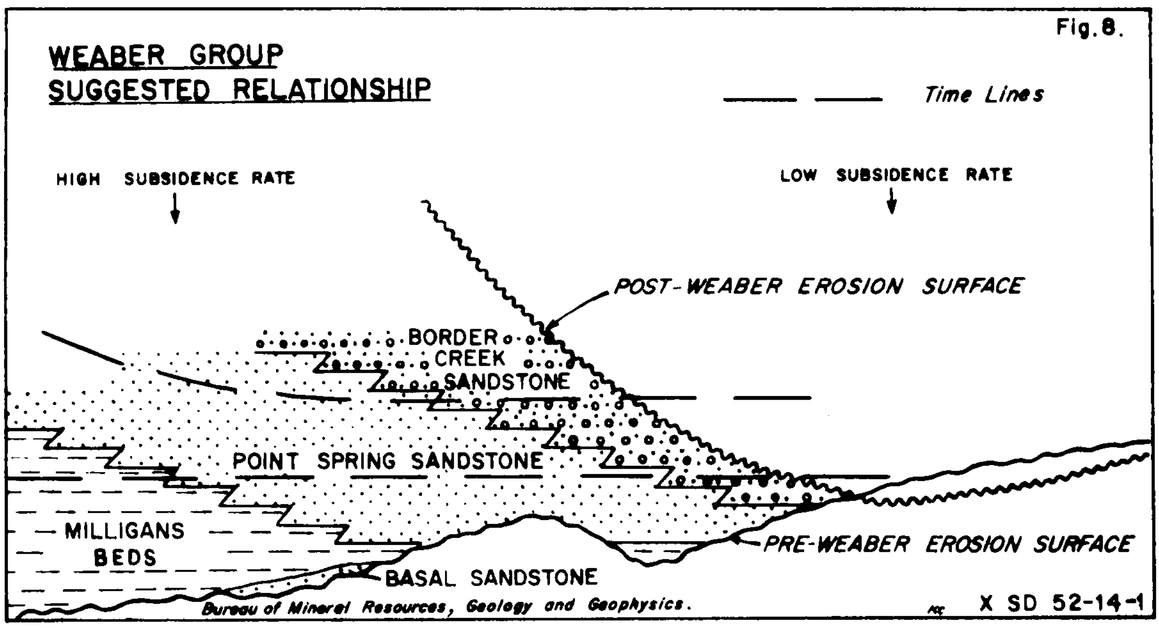


* In Spirit Hill Completion Report

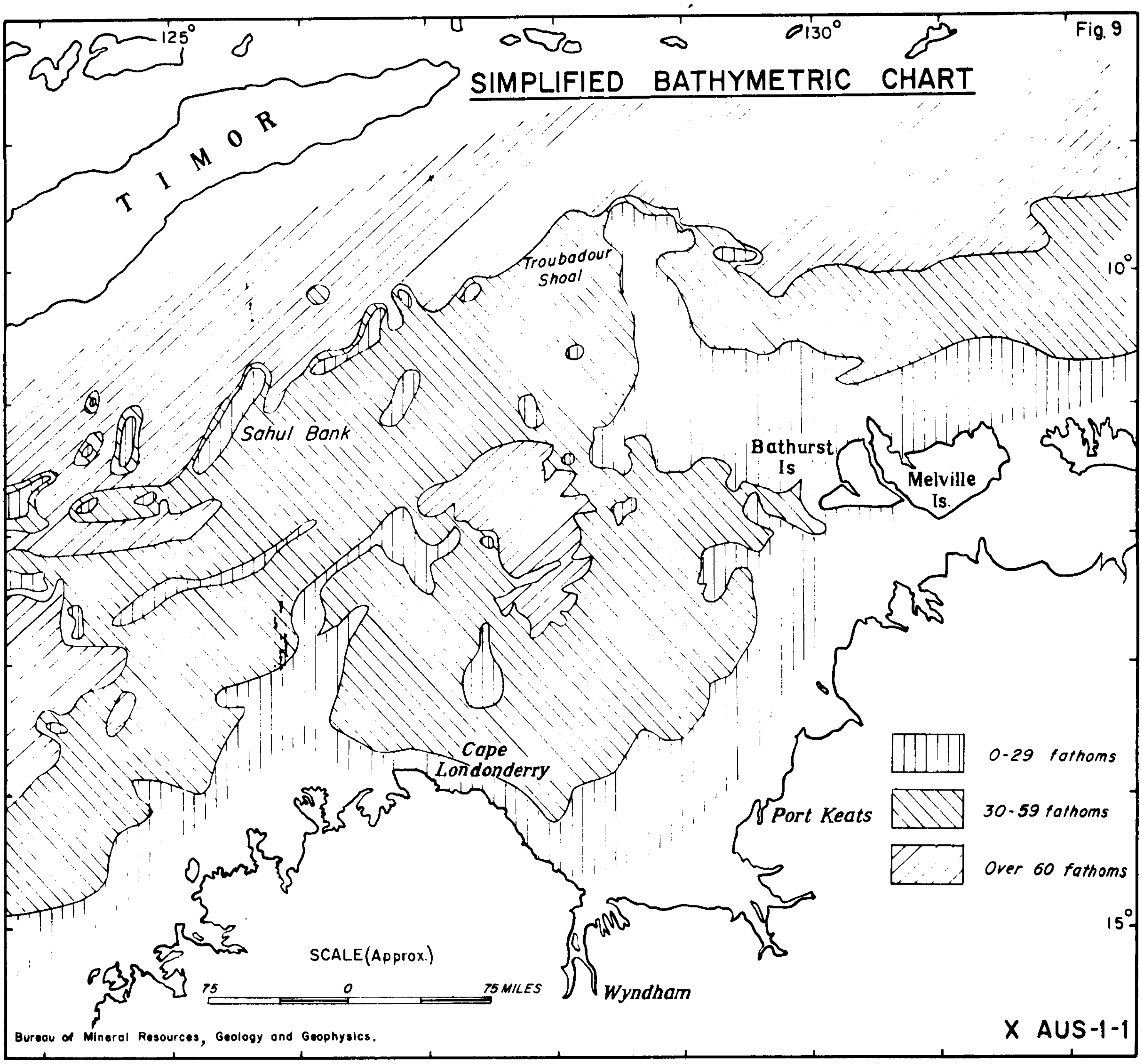
Bureau of Mineral Resources, Geology and Geophysics.

X SD 52-15-2

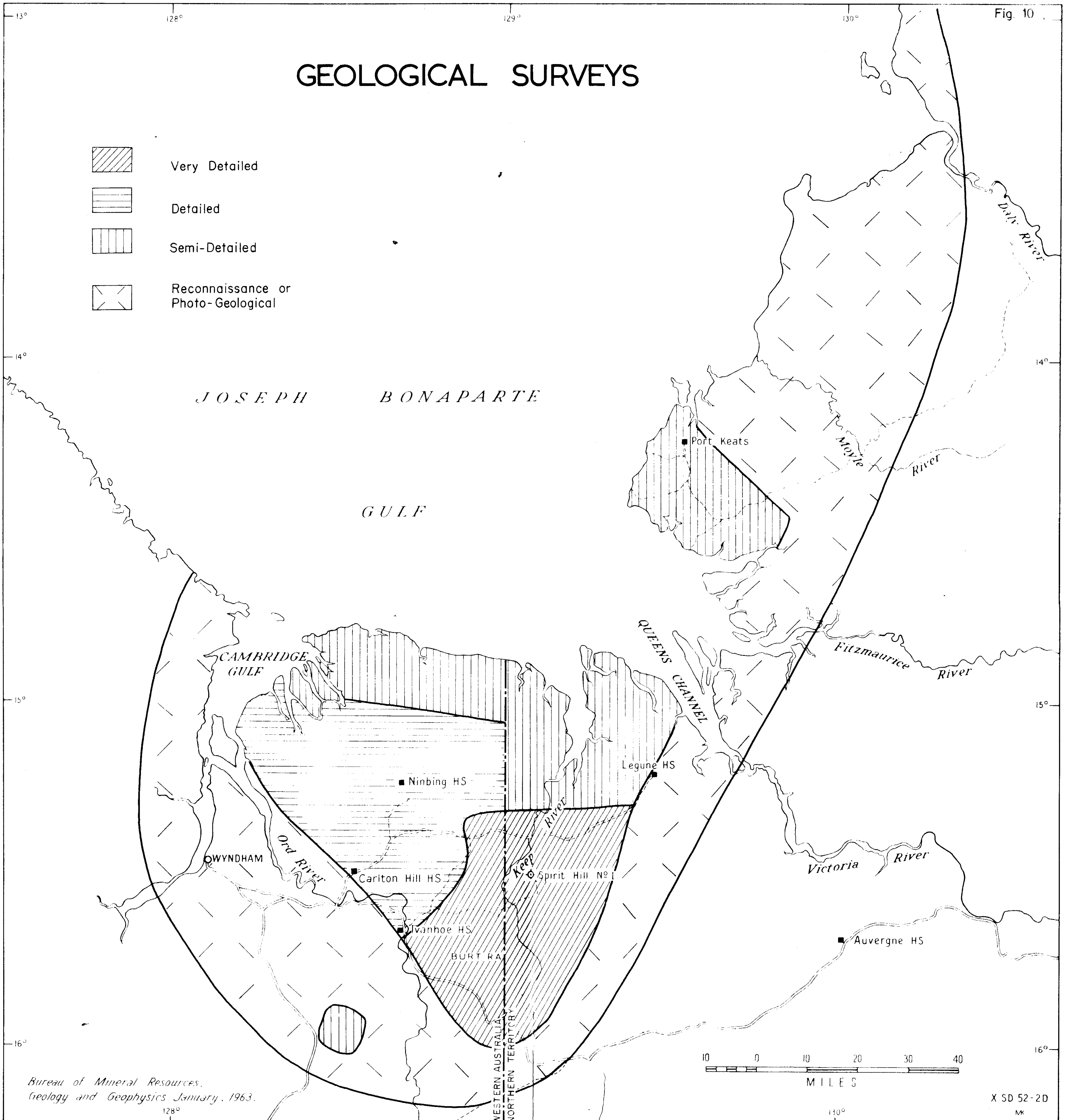
To accompany Record Nº 1963 / 133



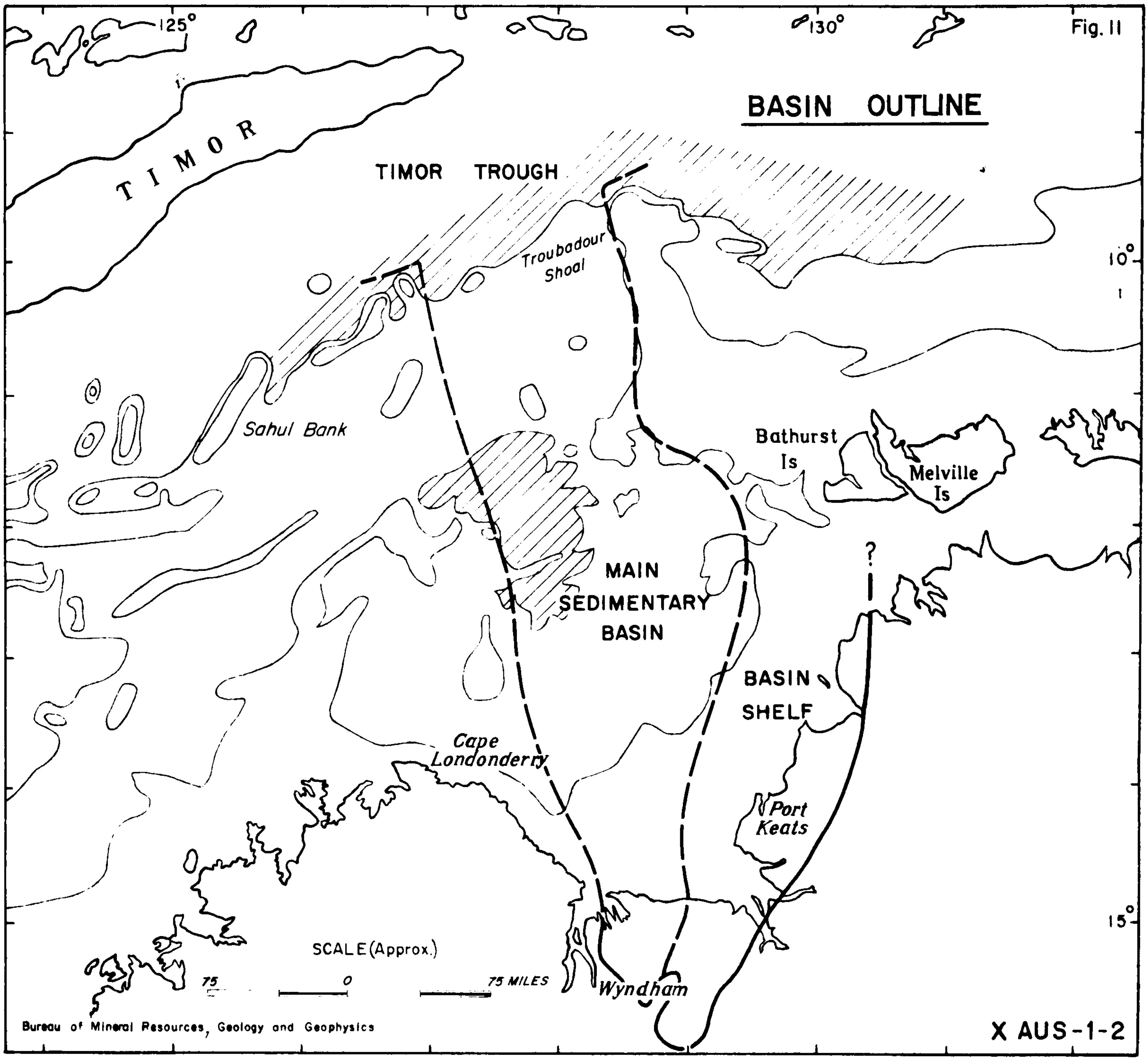
To accompany Record Nº 1963/133



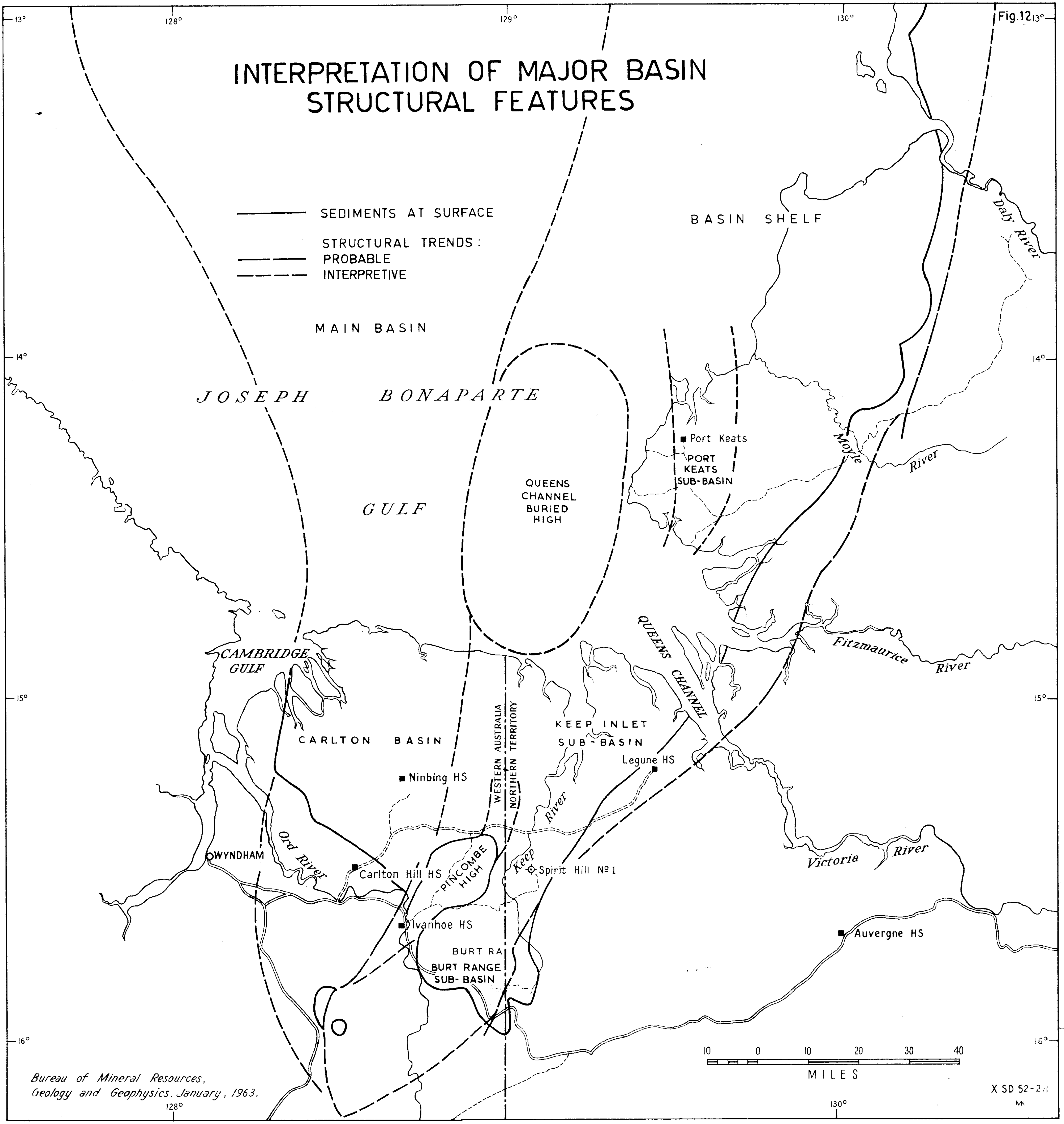
To accompany Record Nº 1963 / 133



To accompany Record Nº 1963/133



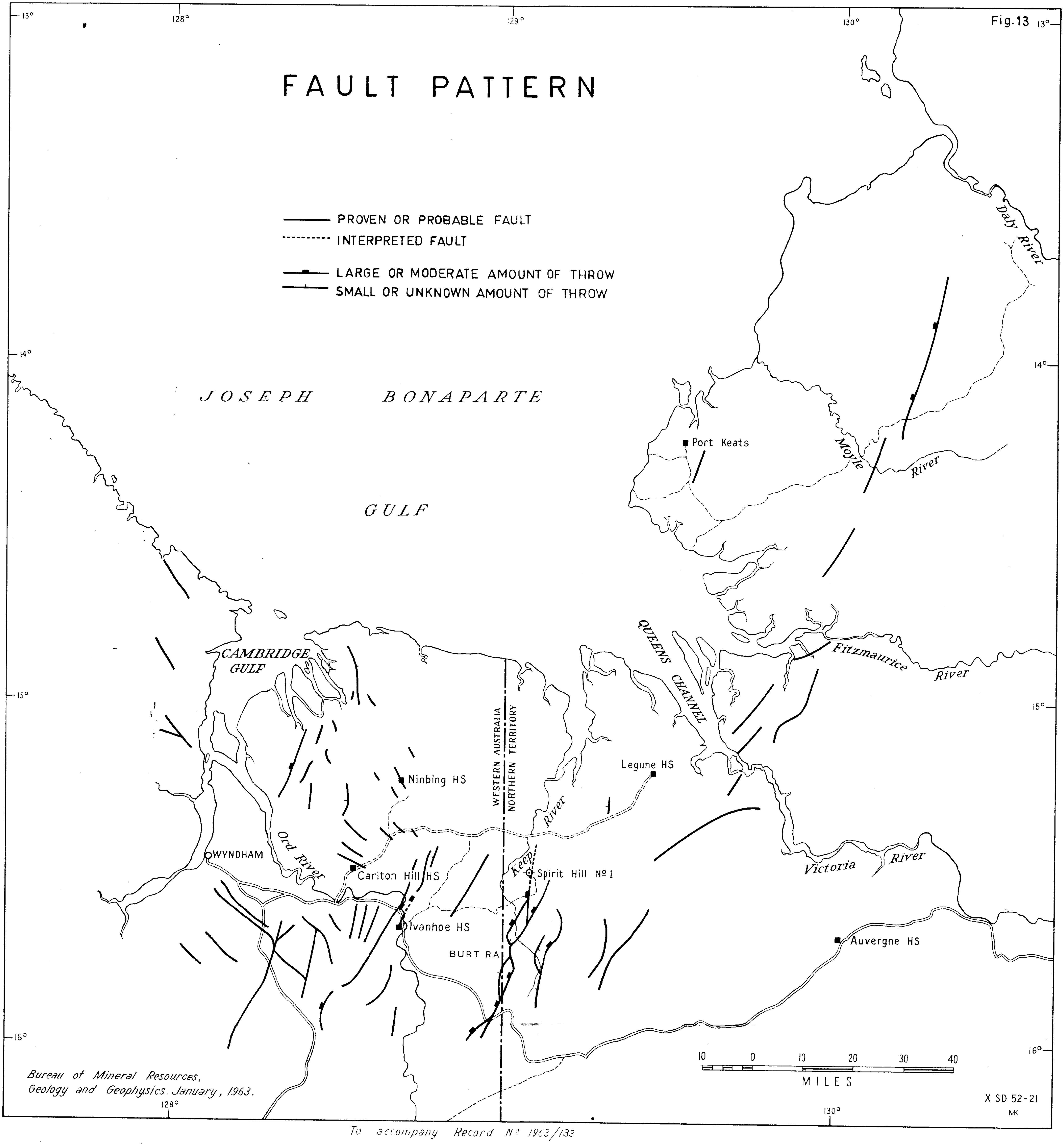
To accompany Record No 1963/133



To accompany Record Nº 1963/133

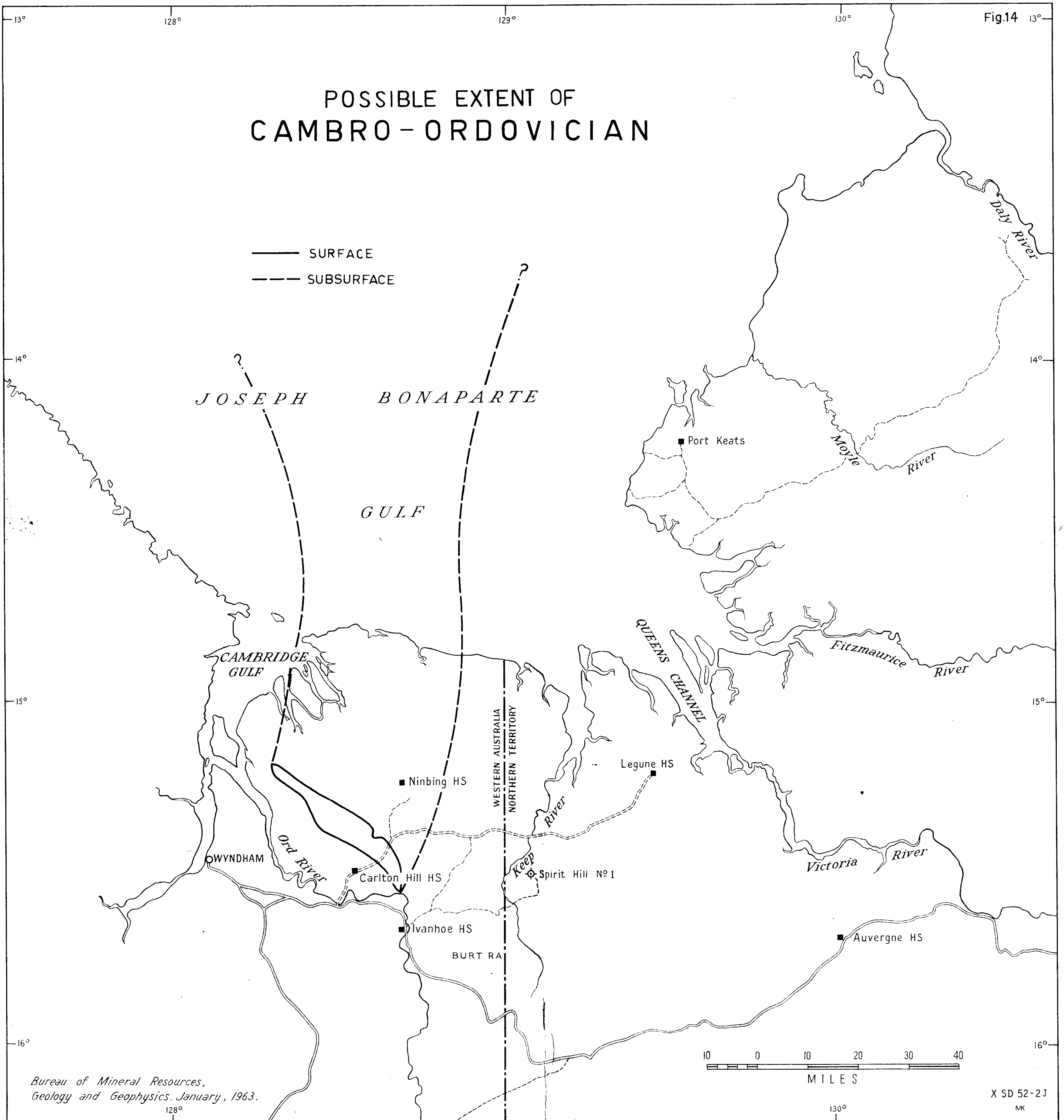
Fig. 13

FAULT PATTERN

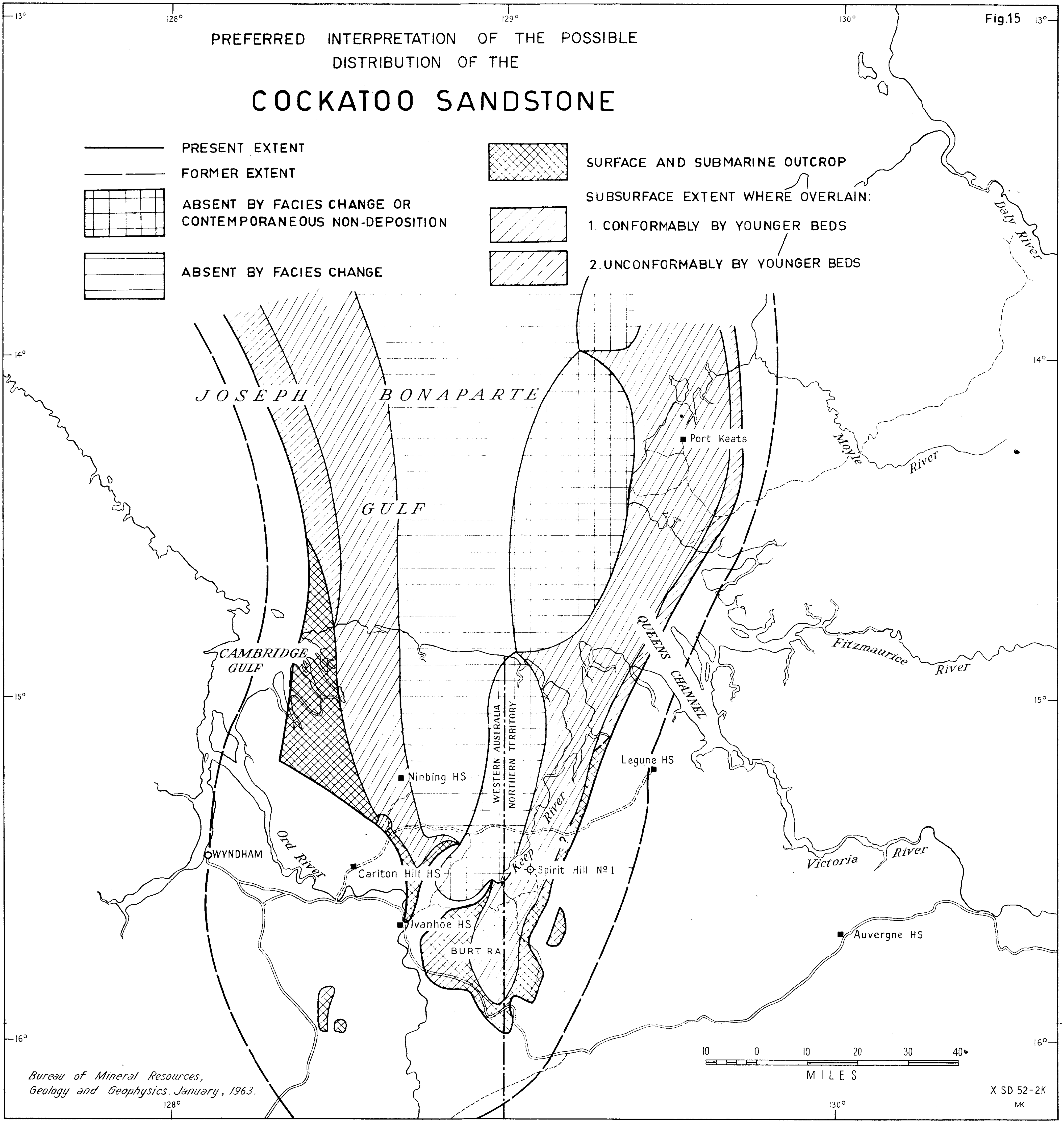


Bureau of Mineral Resources, Geology and Geophysics. January, 1963.

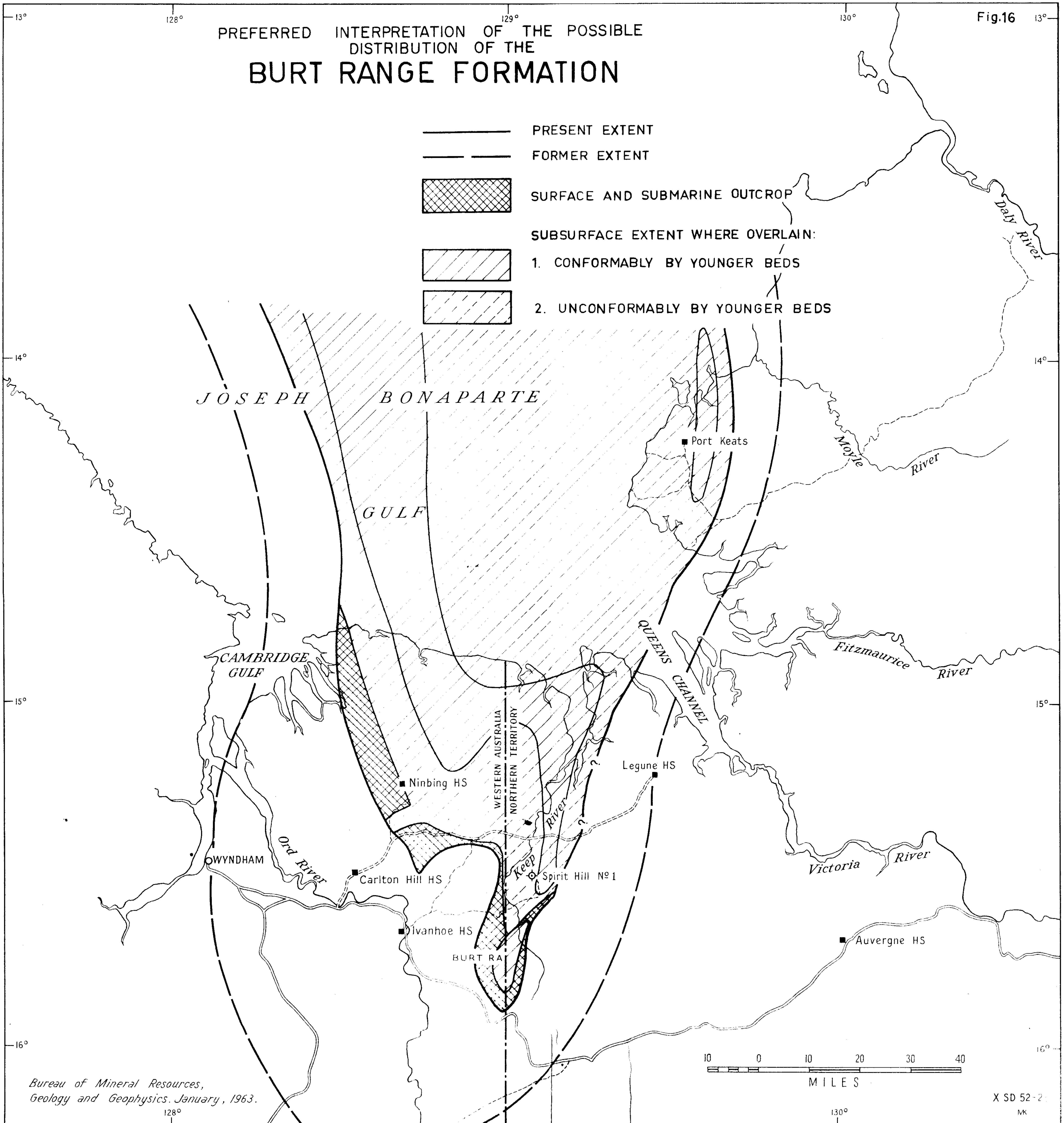
To accompany Record No 1963/133



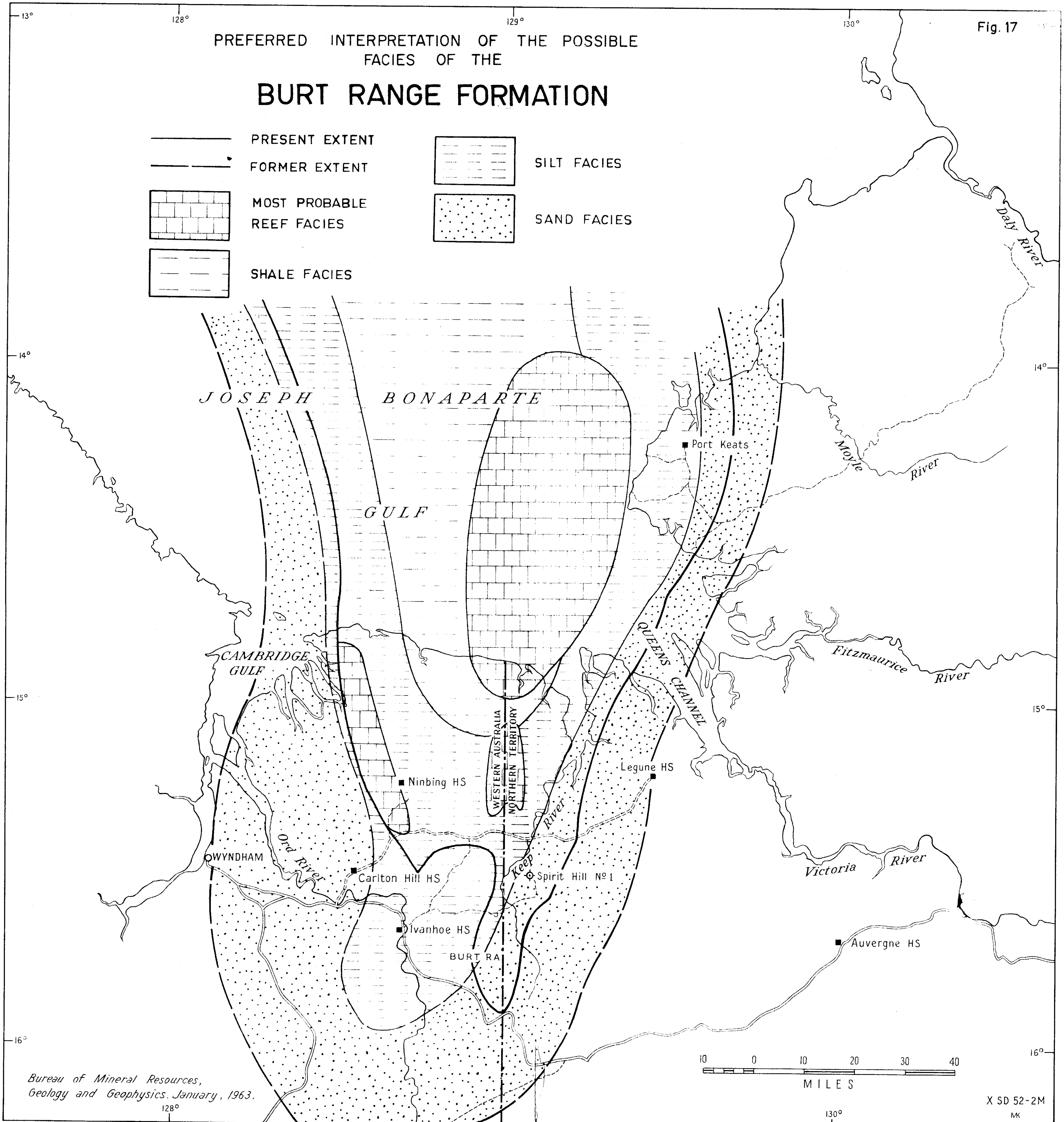
To accompany Record № 1963/133



To accompany Record Nº 1963/133



To accompany Record Nº 1963/133

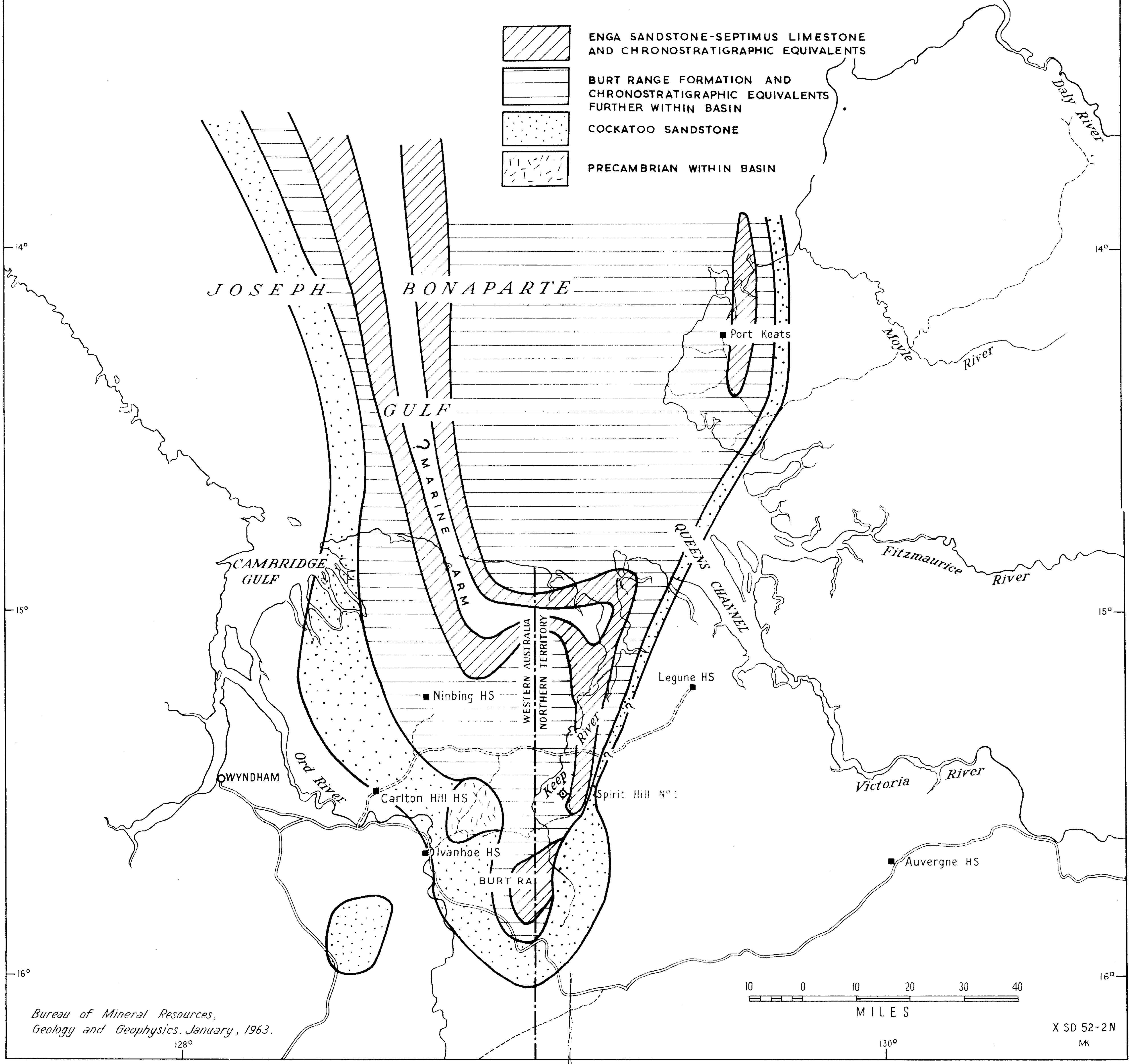


To accompany Record No 1963/133

Fig 18

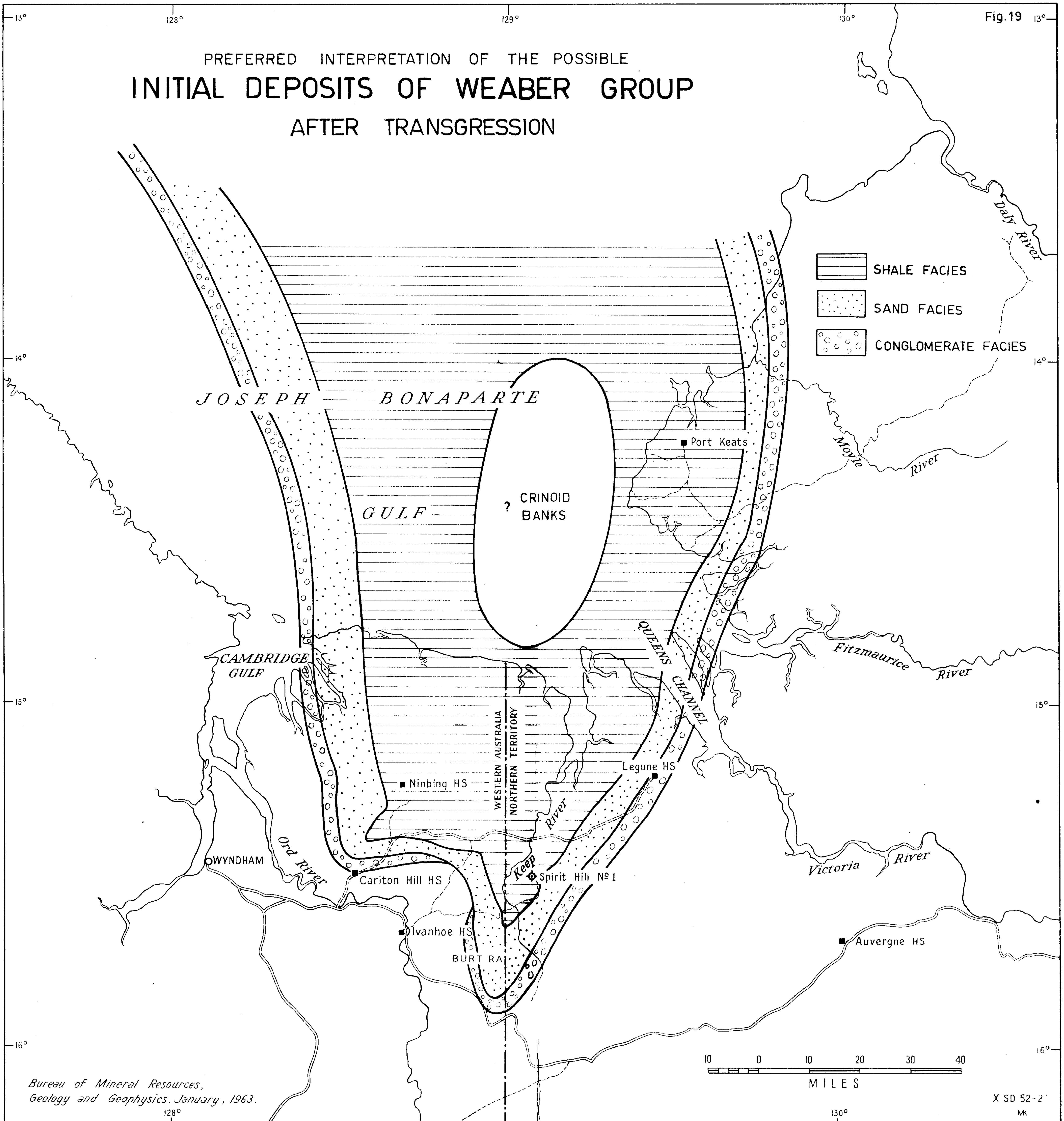
PREFERRED INTERPRETATION OF THE POSSIBLE EROSIONAL SURFACE IMMEDIATELY PRECEEDING TRANSGRESSION OF

MILLIGANS BEDS



Bureau of Mineral Resources, Geology and Geophysics. January, 1963.

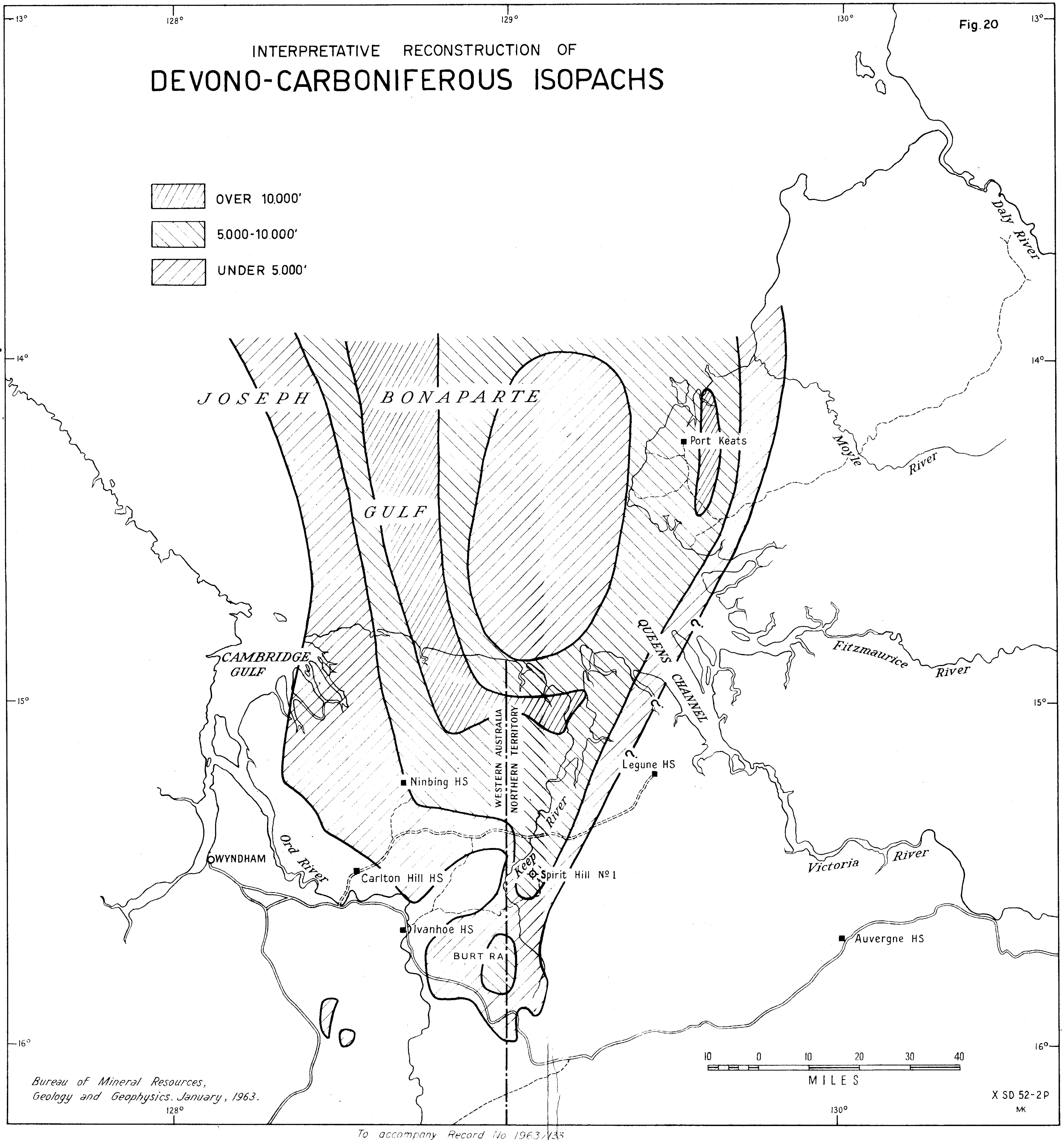
To accompany Record No 1963/135



To accompany Record No

Fig. 20

INTERPRETATIVE RECONSTRUCTION OF DEVONO-CARBONIFEROUS ISOPACHS



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X SD 52-2P

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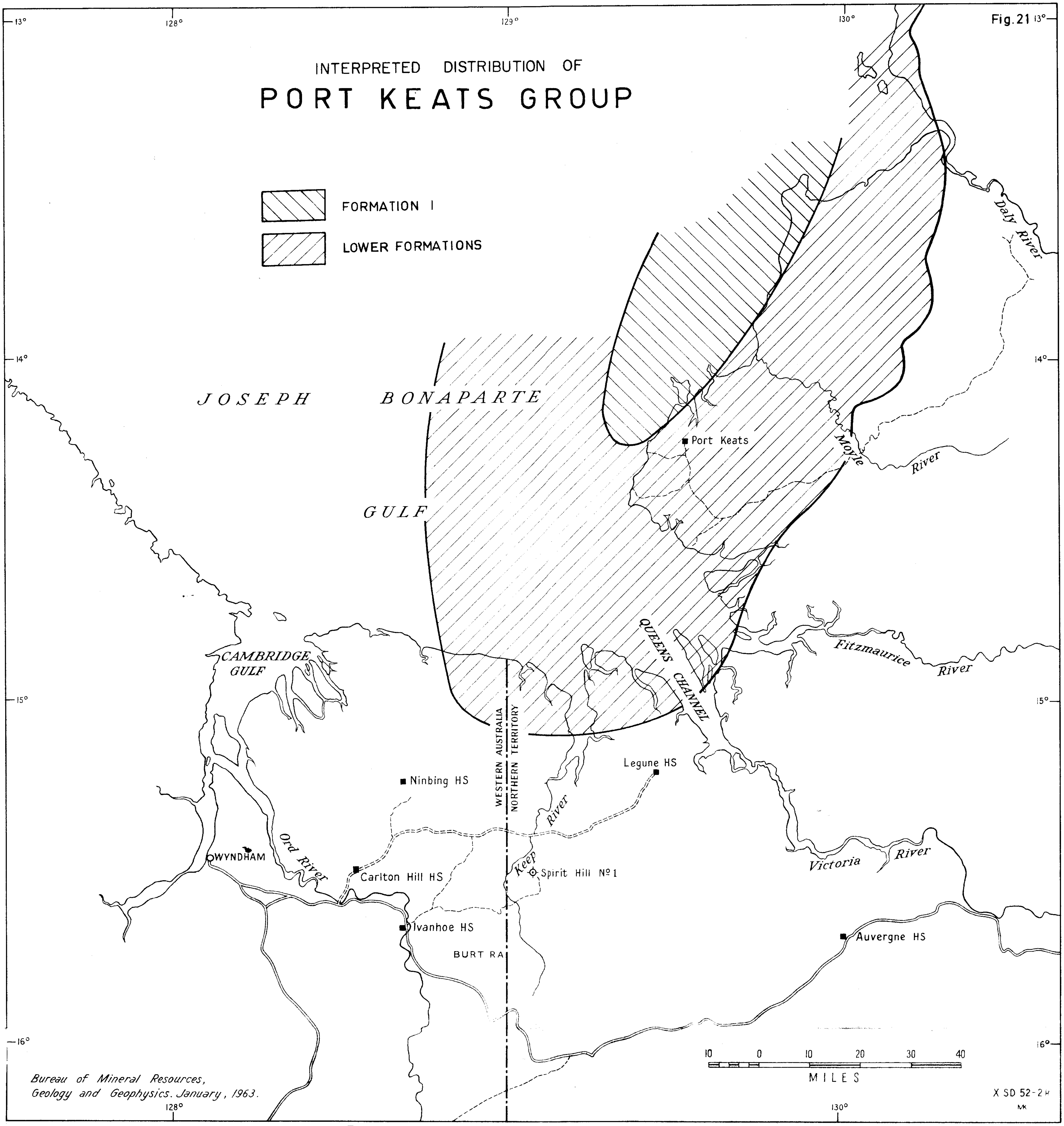
To accompany Record No 1963/135



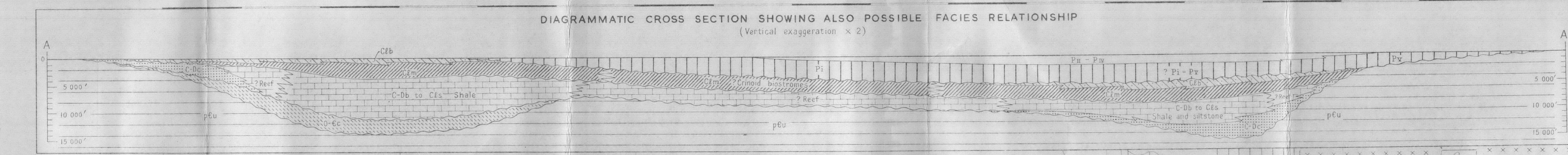
To accompany Report No. 1963/135

Sheet a

BONAPARTE GULF BASIN

INTERPRETATIVE SOLID GEOLOGY

5 0 5 10 15 20
MILES




Sheet b
JOSEPH
BONAPARTE
GULF
CAMBRIDGE GULF
QUEENS CHANNEL
MEDUSA BANKS
Victoria River
Little Fitzmaurice River
DIAGRAMMATIC CROSS SECTION SHOWING ALSO POSSIBLE FACIES RELATIONSHIP
(Vertical exaggeration x 2)
B
B1
Reef
Shale
? Reef C-Db to Cls
Shale and siltstone
pЄu
5 000'
10 000'
15 000'
X SD 52-1B


BONAPARTE GULF BASIN
SURFACE GEOLOGY
MILES
QUATERNARY
Undifferentiated
Unconformity
? CRETACEOUS
? Darwin Formation
Mullaman Group
TRIASSIC
Formation I
Formation II
PERMIAN
Formation III
Formation IV
? PERMIAN
Keep Inlet Beds
Formation V
Port Keats Group
Shown only on 'SURFACE GEOLOGY' maps
Shown only on maps of INTERPRETATIVE SOLID GEOLOGY
? Unconformity ?
? UPPER AND LOWER CARBONIFEROUS
Border Creek Sandstone
Point Spring Sandstone
Milligans Beds
Weaber Group
Nigli Gap Sandstone
Position uncertain
Shown as Cockatoo Sandstone on INTERPRETATIVE SOLID GEOLOGY map, Sheet b.
LOWER CARBONIFEROUS
Septimus Limestone
Enga Sandstone
? LOWER CARBONIFEROUS AND UPPER DEVONIAN
Burt Range Formation
Burt Range - Cockatoo Undifferentiated
Cockatoo Sandstone
"C-D" Group
ORDOVICIAN AND UPPER AND MIDDLE CAMBRIAN
Carlton Group
? LOWER CAMBRIAN
Antrim Plateau Volcanics
PRECAMBRIAN
Unmetamorphosed sediments
Metamorphosed sediments
Granite
? PRECAMBRIAN
Gabbro and dolerite
Built up area
Homestead
Highway
Secondary road
Minor road or track
River or creek
Hill feature
Swamp
Mine
Aerodrome or landing ground
Geological boundary, position accurate
Geological boundary, position approximate
Strike and dip of beds
Syncline, position approximate
Fault, position accurate
Fault, position approximate
Abandoned hydrocarbon bore-hole
Water bore-hole
Coal bore-hole
Stratigraphic test bore-hole
Section location
Elevation control by Department of Interior.
Projection Transverse Mercator, Australia Series, Zones 5 and 4.
Control and detail after National Mapping 1960 provisional 4-mile planimetric map.
Bureau of Mineral Resources, Geology and Geophysics. April 1963.
XSD 52-1A
Sheet a
TIMOR SEA
ANSON BAY
Daly River
Reynolds River
Hyland Bay
JOSEPH BONAPARTE GULF

Sheet b

X SD 52-1A