COPY 3

66/226
3

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

RECORDS:

1966/226

APPRAISAL OF THE LOWER PALAEOZOIC ROCKS OF THE SOUTHERN PART OF THE TASMAN GEOSYNCLINE FOR PHOSPHORITE

by

H.A. Jones

5928/65

APPRAISAL OF THE LOWER PALAEOZOIC

ROCKS OF THE SOUTHERN PART OF THE TASMAN GEOSYNCLINE
FOR PHOSPHORITE

by

H.A. Jones

RECORDS 1966/226

APPRAISAL OF THE LOWER PALAEOZOIC

ROCKS OF THE SOUTHERN PART OF THE TASMAN GEOSYNCLINE
FOR PHOSPHORITE

by

H.A. Jones

RECORDS 1966/226

CONTENTS

SUMMARY

Large phosphate deposits are commonly associated with thin sequences of dark shales and cherts and pass laterally into carbonates and red beds. The Permian Phosphoria Formation of the United States is the classic example of this type of deposit and palaeogeographic reconstructions of the Permian can be convincingly related to observable oceanographic conditions governing phosphate deposition on present day sea floors. Some ancient phosphate deposits cannot be explained in terms of the Phosphoria and there is evidence that accumulations can occur in restricted basin or even paralic environments. All high grade phosphate deposits, however, are characterized by abnormal lack of terrigenous detritus; they are associated with chemically deposited cherts and/or carbonates and frequently occur at, or shortly following, unconformities or disconformities.

A brief history of the south-eastern part of the Tasman geosyncline in the Lower Palaeozoic is given and known occurrences of phosphate and phosphate minerals in the area under consideration are recorded. Brief appraisals of the more prospective areas are made.

Heavy sedimentation, much of it of the eugeosynclinal type, occurred throughout most of the Lower Palaeozoic and in general terms the rocks laid down early in the history of the geosyncline in this area are the most prospective for phosphorite. A number of structural highs are present within the trough and some of those may have been favourable sites for phosphate deposition at any time throughout the period. Disconformities, or periods of reduced clastic sedimentation, may also occur in some of the thick, apparently continuous sequences. There are few areas where the geology is known in sufficient detail to rule out all possibility of phosphate deposits being found.

INTRODUCTION

The Lower Palaeozoic of eastern Australia was indicated as a potential phosphogenic province by R.P. Sheldon in B.M.R. Record 1966/16 on the following grounds.

(i) The chert/black shale/phosphorite suite of rocks is known to occur locally;

(ii) Tectonically it seems likely that major seaways existed in the area in the past and in some areas sedimentation was slow;

(iii) Tectonism has brought deeper water facies to the surface;

(iv) Rocks of this age were probably deposited in warm climates at low latitudes.

Sheldon's appraisal was based on the well-known studies on the Permian Phosphoria Formation in the United States and on his work on other phosphorite provinces, particularly that of North Africa and the Middle East, interpreted in the light of the Phosphoria. The same approach is used in this Record, but there is some shift of emphasis and attention is also directed towards phosphorites which do not appear to conform to the Phosphoria Formation type.

The available information on the geology of part of the Tasman geosynclinal zone has been examined for indications of lithological sequences and sedimentary environments possibly associated with phosphorite deposition. The area concerned is that underlain by Middle Devonian and older rocks outlined in figure 1.

A large amount of published and unpublished material has been studied and a bibliography of the more important sources is included in this Record. Many descriptions were written a long time ago and the information on lithologies and thicknesses must inevitably be interpreted with caution. Many papers describe poorly fossiliferous rocks which cannot be confidently correlated with sequences elsewhere. In many descriptions also the structures are so complex that no estimate of thickness can be made, and the thickness of sequences is of fundamental importance in this study. In addition very large areas have not been examined in any detail. These facts must make any assessment extremely speculative, particularly in view of the highly complex history of the geosyncline.

GENESIS OF PHOSPHORITES

Recent Phosphorites. The known sedimentary apatites being formed on present day sea floors occur in areas where deep ocean water rich in phosphorus in raised to shallower depths over continental shelves or oceanic highs. There is no general agreement on the precise conditions controlling the precipitation of the apatite, but that apatite can be formed from upwelling water, either by replacement of carbonate or by direct precipitation, is not questioned; it is suggested that increasing pH and temperature are responsible. Where the supply of terrigenous detritus is limited, and conditions do not favour the deposition of carbonate or other chemical or biogenic sediments, bedded phosphorites accumulate.

Upwelling is brought about by the divergence of two major surface ocean currents, by the divergence seawards of a major surface current flowing parallel to a continental shore (divergent upwelling), or by the deflection upwards of a bottom current by a topographic high on the sea floor (dynamic upwelling). As a result of the circulation pattern of oceanic currents, divergent upwelling is mainly concentrated along the west coasts of the continents, particularly off North and South America and South Africa. In these areas phosphorites are now being deposited on the sea floor and in some instances uplifted Tertiary phosphatic sediments on the adjacent coasts point to the continance of the conditions back into the Tertiary.

Phosphoria Formation. The large body of data now available on the Phosphoria Formation and its stratigraphical equivalents in the western United States have been interpreted in the light of these recent phosphorites and the Phosphoria is believed to have been deposited on the outer shelf and continental slope of a Permian miogeosynclinal zone in an area of divergent upwelling. The phosphorites are associated with black shales and bedded cherts and pass laterally into deep water shales towards the axis of the geosyncline and into limestones, sandstones, evaporites, and red beds towards the continent.

Using the lithological associations and the tectonic and palaeogeographic environments, of the Phosphoria Formation as a guide, exploration for phosphorite has been successfully carried out in other parts of the world. (See Sheldon, 1964, and McKelvey, 1966, for descriptions of the application of this technique to phosphate exploration).

Other Types of Phosphorite. Apatite is quite a common mineral in sedimentary rocks and minor accumulations of phosphorite have been recorded from a wide variety of lithological types including restricted basin, deltaic, estuarine and non-marine sediments. Nearly all of those do not approach economic deposits either in grade or in size, an exception being the important restricted basin phosphorites of China, but they do indicate the variety of conditions under which phosphate can accumulate and they underline the danger of treating sequences which are not of the miogeosynclinal, starved basin type as non-prospective. In addition some of the important marine phosphorite deposits of the world, including some of those of the Mediterranean province, do not appear to conform particularly closely to the Phosphoria type. Cherts or diatomite may be present, but in some cases they are not, and the same is true of shales rich in organic matter. Virtually all, however, are closely associated with calcareous rocks and it is the phosphorite - carbonate rock association which constantly recurs and has impressed many writers. Some of these phosphorites may represent the inshore calcareous shelf facies of Phosphoria type deposits, but there is no evidence that this is the case. Many are of high grade and considerable

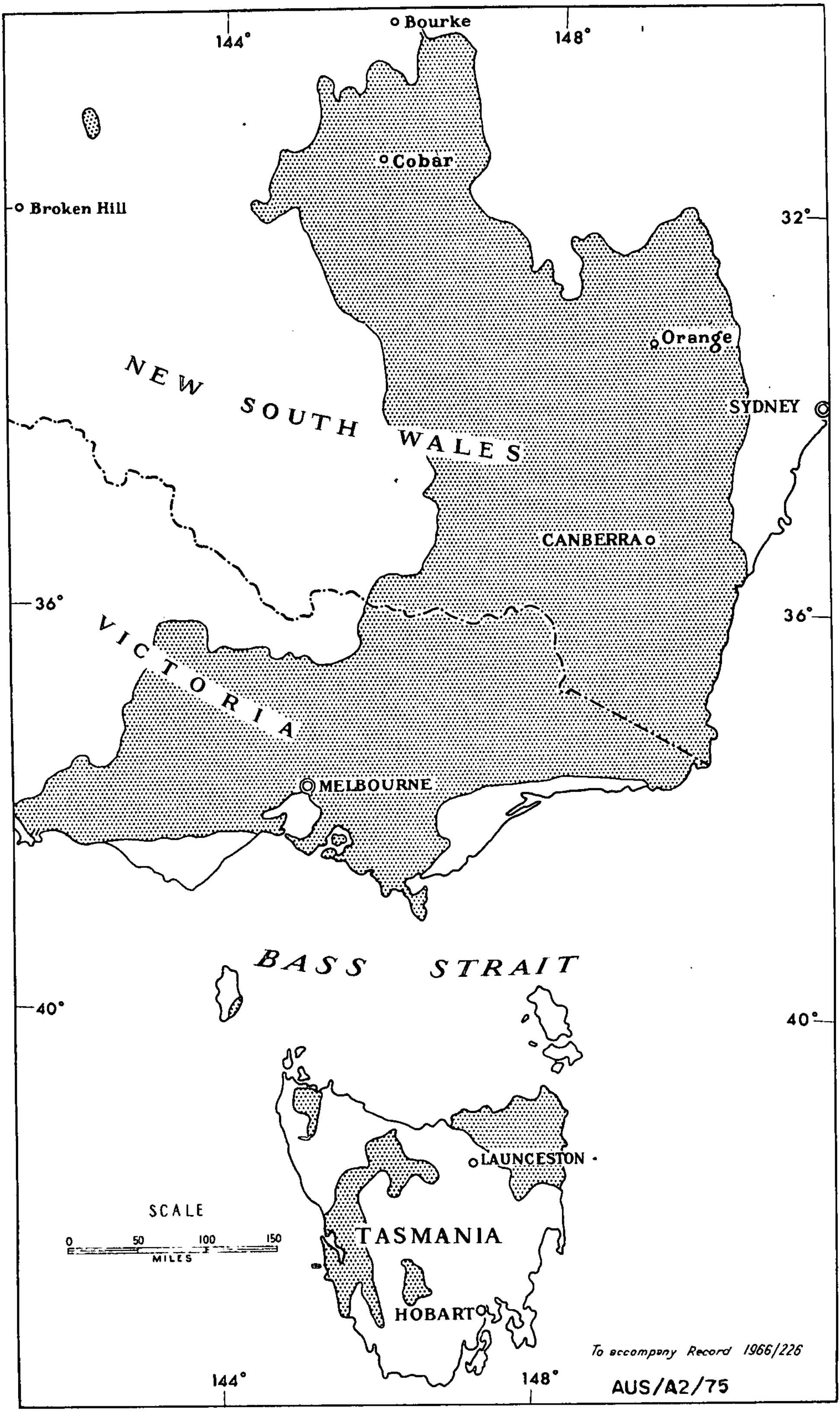

Fig.1 Locality map showing the broad outline of the lower Palaeozoic rocks in the southern part of the Tasman Geosyncline

thickness in contrast with the shelf facies of the Phosphoria. It is fundamental to the theory of chemical precipitation from upwelling currents that carbonate and phosphate deposition are to a large extent mutually exclusive and that only sparse and thin diluted nodular phosphorites occur with the limestones in the shelf areas. Some of the non-Phosphoria type deposits show evidence of extremely shallow water environments and in other cases there are indications that phosphate accumulation is controlled by bathymetry and occurs in local euxinic basins. The source of the phosphorus has not been satisfactorily explained; nutrient-rich ocean currents are probably dominant, but the influence of river waters from a neighbouring land mass undergoing intensive chemical weathering is stressed by several authors, as is the role of organisms in the extraction and concentration of phosphate. (See Slansky, 1962; Bushinski, 1964; Youssef, 1965; Pevear, 1966; for descriptions of non-Phosphoria type deposits).

APPROACH TO EXPLORATION

General aspects. Exploration for deposits of the Phosphoria Formation type has been fully described by Sheldon (1964, 1966). Basically it consists of identifying zones of miogeosynclinal sedimentation and investigating condensed sequences characterized by black shales and biogenic chert. Palaeogeographic reconstruction is important as the sedimentary basin must have been in low latitudes where the oceanic and atmospheric circulation favoured upwelling. It is difficult to construct a comparable exploration hypothesis for phosphorites which are not of the Phosphoria type because of the uncertainty concerning their genesis and their varied lithological associations. Although condensed sections and chemical sedimentation are obvious pointers, phosphorite deposition can be preceded and followed over a few tens of feet by coarse shallow water sandstones, as in the Eocene of Nigeria (Jones, 1964), or by glauconitic sandstones, as in the Upper Cretaceous of the Russian platform (Ronov and Korzina, 1960). The Sinian (Proterozoic) phosphorites of China are locally cross-bedded and are interbedded with normal coarse detritus (Bushinski 1964). Limestones (normally lime muds, sometimes shelly calcarenites, but probably rarely reef limestones) nearly always underlie the phosphorites, but may also be interbedded with them or overlie them. Many phosphorites occur at, or shortly after, important disconformities.

Relationship between phosphorites and sedimentary cycles. Whatever their origin, one thing all phosphorite deposits have in common is an almost complete lack of ordinary terrigenous detritus; they occur in condensed sections, small thicknesses of phosphorite representing long intervals of time. Thus it would be reasonable to expect that on a world-wide basis phosphorites would be more plentiful in the pre-flysch, starved basin stages of sedimentary cycles. This is in fact the case as the maximum phosphorite accumulations in Europe, Asia, North America and Africa occur preceding the Caledonian, Hercynian and Alpine orogenies in the ~~Ordovician~~-Silurian, Carboniferous-Permian and Cretaceous-Eocene periods respectively. The significance of the stratigraphic distribution of phosphorite has been elaborated by Ronov and Korzina (1960), while Pettijohn (1957) has also discussed the place of phosphorites in sedimentary cycles.

So much of the Lower Palaeozoic of the southern part of the Tasman Geosyncline is of the shale and greywacke flysch-type facies that it is of fundamental importance to establish the probable relation to these rocks of the starved basin facies prospective for phosphorites. As mentioned above, according to Pettijohn (1957) and others, the starved basin stage immediately precedes the flysch/turbidite stage in the normal sedimentary cycle. This is well illustrated in the Caledonian Geosyncline in Britain where the thick Ordovician shale and greywacke sequences overlie black shales, cherts, and spilitic intrusives in the south of Scotland and west Ireland and also in west Wales (Kelling, 1964). It should be noted, however, that these condensed successions in Britain do not include important phosphorites although all the indications are favourable for such deposits.

It is also possible that at certain times in the earth's history the seas have been unusually rich in phosphorus and phosphorites have been widely deposited independent of areas of upwelling wherever normal clastic sedimentation is inhibited. This enrichment could be the result of long continued leaching of the continents by acid ground waters followed by an arid phase in which the pH of the epi-continental seas is raised resulting in precipitation of phosphate. Such conditions possibly existed during the Ordovician in North America and Europe and during the Cretaceous/Eocene in the Tethys-West Africa province. In the latter case Sheldon (1964) demonstrated the Phosphoria-type lithological associations of the phosphorites of south-eastern Turkey and suggested that divergent upwelling was the cause of phosphorite deposition in the Mediterranean phosphogenic province. However, important phosphorites of about the same age also occur on the western flank of the African landmass in Senegal and on the southern flank in the Togoland-Dahomey basin. There is at least a possibility that an overall enrichment of the Cretaceous-Eocene epi-continental seas in phosphorus was responsible for the ubiquitous phosphorites of this period.

In this connection it is worth noting that Cambrian and Ordovician phosphate deposits occur in North Vietnam, and phosphorite, possibly also of Lower Palaeozoic age, has recently been discovered in the state of Rajasthan, India (Sheldon, in press). Thus a phosphogenic province with which the Tasman geosyncline may have been connected was in existence in south-east Asia during the Lower Palaeozoic.

<u>Geochemical and radiometric prospecting</u>. The phosphorus content of Australian soils is notoriously low. The average for the continent from more than 2000 analyses, weighted according to the area of survey, is given by Wild (1958) as 0.069 per cent total phosphate (P_2O_5). This compares with figures of 0.1 to 0.2 per cent phosphate in soils derived from glacial drift in North America and Europe. The low values in Australia are due to the lengthy period of lateritization and poor drainage which has left the soils leached of phosphate and largely independent of parent rock composition. It appears that soils from the Great Dividing Range are in general rather higher in phosphate than the average, but the few high anomalies in the south-eastern part of the Tasman geosyncline are ascribed by Wild (1958) to basic igneous parent rocks.

It is possible that high fluorine in groundwater may be related to phosphorite and it has been suggested that under certain hydrological conditions high fluorine and other halogens may be used as indicators of phosphate (Brown, 1958). A check on the analyses of high-fluorine groundwaters from the Barkly Tableland, an area where phosphatic sediments are known to occur in the Lower Palaeozoic, showed no correlation between fluorine and dissolved phosphate.

Most marine phosphorites contain significantly more uranium than the average sedimentary rock and the use of gamma ray logs in wells and portable scintillometers at the outcrop is a well-established prospecting method (Sheldon, 1964). There is an extensive literature on uranium in phosphorites and it is interesting to note that although it is generally believed that the uranium occurs in the apatite lattice as a substitute for calcium, secondary phosphate minerals such as wavellite and turquoise may also be radioactive (Altschuler, Jaffe & Cuttita, 1955; Davidson & Atkin, 1953). This is supported by scintillometer probe tests recently carried out on the Christmas Island phosphate deposits where a contrast in radioactivity was established between the C, B, and A grade material; the higher uranium values were found in the superficial "C" grade zone which consists largely of iron and aluminium phosphate minerals (Barrie, 1966). This is of significance in that it indicates that radiometric anomalies may still be present over weathering profiles containing secondary phosphate minerals.

It seems that the scale of the radiometric anomalies caused by phosphorites is usually not great enough for detection by normal airborne scintillograph surveys and reconnaissance flying over large areas is not a practicable method of phosphate exploration. None the less an airborne scintillometer might be invaluable in tracing a phosphorite known to be radioactive and in fact helicopter traverses at 150 feet have successfully delineated phosphorite outcrops in Algeria (Bollo & Jacquemin, 1963).

Field Indications. Although pelletal, oolitic or nodular textures are common among phosphorites, they vary greatly in appearance and are not easy to recognise in the field. This, and the fact that phosphorite is often softer than the associated sediments and therefore outcrops poorly, suggest that deposits can be easily overlooked during reconnaissance mapping. Although apatitic rocks tend to be inconspicuous, secondary phosphate minerals such as wavellite, turqoise and vivianite are easily recognised and in weathered and leached rocks they may be the only surface indication of phosphorite. It was the presence of radiating crystals of wavellite and pale blue turquoise in the surface rocks which led Howitt to the discovery of the Mansfield phosphorite in 1906. Another turquoise locality, Bodalla on the South Coast of New South Wales, is associated with thin beds of phosphatic shale discovered recently and currently being prospected by International Minerals and Chemicals.

Weathered surfaces of phosphorite commonly show a whitish or blue-grey bloom and this appears to be quite characteristic of certain types of phosphate rock. In a discussion of field identification methods in the Phosphoria Formation of the western United States, Gardner (1944) suggests that pelletal texture, weathering bloom, dark colour, and foeted odour when struck are all indicators of high phosphate content. He stresses, however, that some or all of these characteristics may be lacking in certain high-grade phosphorites.

Apatite has a specific gravity around 3.2 and non-porous apatite rock is therefore noticeably heavier than limestone, sandstone and shale. There are few occasions when this feature can be made use of in examining the impure and more or less porous rocks normally seen at the outcrop.

Glauconite must also be regarded as a valuable indicator in phosphate exploration. It is true, as Sheldon points out in B.M.R. Record 16/1966, that glauconitic sediments commonly are not associated with phosphorites, but the same is true of the organic shale/chert facies. The point is that glauconite indicates slow sedimentation in a marine environment, conditions which are also favourable for phosphorite deposition. In fact, of course, a number of the world's important deposits are associated with glauconite, for example the Ordovician deposits of Tennessee, the Eocene of Tunisia and Togoland, and the Cretaceous of the Russian platform. The Recent phosphorites off the Californian coast are also associated with glauconitic sands.

BRIEF HISTORY OF THE GEOSYNCLINE IN THE LOWER PALAEOZOIC

The following account is based on the descriptions of the Lower Palaeozoic history of the geosyncline given by Andrews (1937) Browne (1947, 1950) Browne (1955), Opik (1957) Packham (1960),&Voisey (1959) supplemented by data from other sources.

Cambrian. Sedimentation in the geosyncline started in the Cambrian or before, but the boundaries of the trough in the early stages are obscure. Deposition in the Adelaidean geosyncline ended with an orogeny in the Middle Cambrian and this movement may well have also brought about the subsidence to the east and initiation of the Tasman geosyncline.

The known Cambrian rocks of Victoria consist of about 2000 feet of shales of Middle and Upper Cambrian age underlain by basic volcanics and cherts. A sequence of eugeosynclinal sediments including conglomerates over 10,000 feet thick (Dundas Group) was deposited in Tasmania during the same period. In New South Wales Cambrian rocks occur at Mootwingee and west of Stuart Town in the Molong geanticline. The Wagonga Series on the South Coast (Brown, 1933) and other rocks surrounded by known Ordovician sediments near Tumut Pond (Opik, 1952) Canberra (Opik, 1957), Yass (Browne, 1955), and in the Cobar district (Opik, 1957) are possibly Cambrian also, though their age has not been proved and they may well be Ordovician.

The Mootwingee Cambrian with its shelly fauna and the conglomeratic Dundas group in Tasmania indicate that the margins of the geosyncline lay not far from these places. The Victorian Middle Cambrian beds overlying the volcanic rocks also include shelly faunas at a number of places, but there may well have been deposited at an early stage in the development of the trough for the succeeding Cambrian sediments in Victoria are uniformly fine-grained. Hills and Thomas (1954, p. 123) suggest that the sediments accumulated in shallow, enclosed, euxinic basins rather than in an abyssal environment, but none the less the absence of coarse detritus indicates considerable distance from a sediment source.

On the South Coast of New South Wales, the Wagonga Series may include Cambrian strata, but fossil evidence of its age is lacking. It consists of cherts and metamorphosed fine-grained sediments which appear to unconformably underlie Upper Ordovician. It bears some lithological resemblance to the known Cambrian of Heathcote, Victoria, and the associated flows and tuffs also have affinities with the basic and intermediate Heathcotian volcanics (Brown, 1933). On this basis the series has been assigned to the Cambrian, but a Middle or Lower Ordovician age seems possible.

In the Snowy Mountains the Tumut Ponds Beds, a thick formation of tuffaceous sandstones and shales at the base of the massive Ordovician eugeosynclinal sequence in the Adaminaby-Kiandra area, possibly extends down into the Cambrian (Opik, 1952), although Fairbridge (1953) prefers a Lower Ordovician age. The Black Mountain Sandstone, a dominantly arenaceous sequence at Canberra to the north, is also believed by Opik (1958) to be older than Middle Ordovician and possibly Cambrian. The rocks in both these areas indicate rapid sedimentation, and in the case of the Black Mountain Sandstone shallow water conditions; if they are Cambrian age they indicate very different conditions from those giving the uniformly fine-grained Cambrian of Victoria.

In the Cobar mineral field the basal sediments are again arenaceous (Weltie Sandstone, see Russel & Lewis, 1965), but not enough is known of these beds to assign a Cambrian age with any confidence. A small area of slates, greywacke and andesitic volcanics south of Wellington (the Gowan Green Group) have also been mapped as Cambrian? by the Geological Survey of New South Wales.

Ordovician. In Tasmania Cambrian sedimentation was ended by the Jukesian (Tyennan) orogeny and the succeeding Lower Ordovician Jukes Breccia and Owen Conglomerate were laid down in two troughs separated by the emergent Dundas ridge. The Lower Ordovician sediments become progressively finer in grain size and the succeeding Middle and Upper Ordovician deposits are those of a transgressive miogeosynclinal sea and comprise limestones and mudstones with a shelly fauna. The limestone-shale sequence spans Arenig to Upper Ordovician time and is up to 5000' thick (Solomon, 1965).

In Victoria conditions are very different. The Ordovician follows the Cambrian without unconformity and except for a single locality in Southern Gippsland, where shales and limestones contain a shelly Lower Ordovician fauna (Waratah Bay, see Lindner, 1963), the Ordovician consists entirely of greywackes, shales and cherts with graptolites the only fossils. Over 20,000 feet of sediment are present.

In New South Wales too the dominant lithology is that of graptolitic shales and greywackes, but here there is evidence of local highs in the Wellington and Parkes-Forbes districts with shallow water sediments and reduced thicknesses. In the case of the Wellington area the high is associated with andesitic volcanics which are also to be found in the Adaminaby area in the south. On the whole, however, volcanic rocks are not widespread in the Ordovician, although the high silica content of some of the black slates suggests that they may have been acid tuffs (Joplin, 1945).

It seems possible that the end-Cambrian Jukesian movement, prominent in Tasmania yet absent in Victoria, may be responsible for the great masses of arenaceous sediment of possible lower Ordovician age in south-eastern New South Wales (Bolton Formation and Tumut Ponds Beds) and in the A.C.T. (Black Mountain Sandstone).

Silurian. The Silurian follows the Ordovician conformably in central and western Victoria and only minor movements are indicated in Tasmania. In a number of places in New South Wales too there is no evidence of an unconformity, but over a broad belt in eastern Victoria and in central and eastern New South Wales Ordovician sediments were folded and uplifted during the Benambran orogeny. This area of folding and uplift, the Benambran anticline, covers all of eastern Victoria and far south-eastern New South Wales, but in central New South Wales splits into three lobes separated by troughs in which deposition was continuous from the Ordovician through into the Silurian (Packham, 1960).

In Tasmania the base of the Silurian is marked by a change from the carbonate environment of the Ordovician Gordon Limestone, to one of normal clastic sedimentation resulting in the Crotty Quartzite of the Eldon Group in Western Tasmania. The Eldon Group in general becomes finer grained towards the top and according to Banks (1962) deposition occurred in a mildly unstable shelf to the east or south-east of the land mass. The Mathinna Beds of north-eastern Tasmania (the partial equivalents of the Eldon Group), include turbidites and represent a deeper water off-shore facies. In both western and eastern Tasmania deposition was continuous from the Silurian through into the Devonian and there is no evidence of the Bowning orogeny of New South Wales.

In central Victoria, where the Silurian conformably overlies the Ordovician, the only evidence of the Benambran orogeny to the east is a slight lithological change from the black Ordovician shales to the greenish Lower Silurian shales and mudstones. Conglomerates are present in some places. According to Hills & Thomas (1954) however, there is a rapid increase in the rate of sedimentation as compared with the Ordovician and there is evidence of progressively shallower conditions during the period with the incoming of shelly fossils and land plants in the Melbournian. The whole Silurian succession is of the order of 20,000 feet in the Melbourne trough. Limestones are unknown and turbidite deposition seems to have occurred throughout, although the graded bedding typical of the Ordovician turbidites is confined to the graptolitic Keilorian.

In eastern Victoria, Middle and Upper Silurian rests unconformably on Upper Ordovician slates, although in most places the junction with older rocks is faulted. The succession north of Omeo consists of conglomerates followed by sandstones, limestones and shales indicating steady transgression of the Silurian sea over the Benambran anticline. A little further to the east, at Limestone Creek, the Silurian consists of thick greywackes and mudstones with subordinate limestone and sandstone (Talent, 1959).

In New South Wales the Silurian sediments are very varied in thickness and lithology and in most places include a large proportion of volcanic rocks. These variations appear to be due to the presence of a number of contemporaneous structural highs of general N-S trend. From east to west these are the Capertee geanticline (established in Middle or Upper Silurian times according to Packham, 1960), the Molong geanticline, the Parkes-Forbes geanticline, and possibly also a structure running through Condoblin. The intervening troughs where the sediments are thicker are those of Hill End, Cowra, Trundle and Cobar to the west. The last named would appear to be the continuation of the deep Melbourne trough of Victoria (Opik, 1956).

Estimates of the total thickness of the Silurian are few. In the Yass district Browne (1955) records 8300 feet of which 6000 feet is volcanic material. In Canberra the total thickness of the Silurian is less, totalling around 3000 feet excluding some of the volcanics. Opik (1958) remarks on the increase of volcanic activity during the period. These areas are on the southern continuation of the Molong geanticline and the thicknesses contrast sharply with those recorded elsewhere. Stanton (1955) for example records 20,000 feet of Lower Silurian alone in the Wisemans Creek area south of Bathurst.

Lower and Middle Devonian. Sedimentation in most of the Tasman Geosyncline ended at the close of the Silurian with the Bowning orogeny although the Melbourne and Hill End troughs were unaffected; the Lower Devonian follows the Silurian conformably in these areas and also in Tasmania, the southern continuation of the Melbourne trough. The Lower and Middle Devonian is marked by abundance of volcanic material and coral limestones.

In Tasmania both the Eldon Group and the Mathinna Beds extend up into the Lower Devonian with no change in the general miogeosynclinal conditions. The Middle Devonian Spero Bay Group on the west coast is, with the exception of the Eugenana Beds, the youngest Devonian known in Tasmania. It consists of at least 2000 feet of sandstone and limestone and the presence of conglomerates and terrestrial cross-bedding indicates a very close source of the sediments (Banks, 1962). Current direction evidence is conflicting, but this area must have lain close to the western edge of the depositional basin.

Although deposition was continuous from the Silurian through into the Devonian in the Melbourne trough of central Victoria, shallowing is indicated by the incoming of coarse-grained sediments and limestones. The presence of abundant land plants (for instance in the Walhalla Series) also points to the nearness of land and this almost certainly lay to the east along the Bowning uplift. Thicknesses are considerable; Couper (1965) for example records 16,000 feet of early Devonian and late Silurian sediments in the Yea-Molesworth area.

In eastern Victoria, where the effects of the Bowning orogeny are felt, the Lower Devonian rests with strong unconformity on the older rocks. At Tabberabberra the sequence consists of 8000 feet of coarse-grained sediments passing up into limestones and shales of Lower to early Middle Devonian age. Further to the east up to 10,000 feet of acid volcanics and subordinate non-marine sediments form the base of the post-Bowning succession and are followed by over 2000 feet of Middle Devonian marine limestones.

Lower Devonian sediments are unknown over very wide areas of central and western New South Wales and also in the south-east corner of the State. Sedimentation continued uninterrupted from the Silurian into the Devonian in the Hill End trough and in parts of the Wellington-Molong area, but the unconformable relationship of Lower and Middle Devonian on the Silurian evident in eastern Victoria can be traced northwards into New South Wales through the Tumut River area and Yass. Here, as in Gippsland, the sequence starts with volcanics and continues with fossiliferous Middle Devonian limestones. South of Yass the volcanics are about 2500 feet thick and the succeeding limestones and subordinate shales and sandstones total over 3500 feet (Browne, 1958). Farther to the west in the Cobar area the Lower to Middle Devonian Amphitheatre Beds again unconformably overlie the Upper Silurian, but in this instance do not include any volcanic rocks and consist of quartzite, sandstone and shale.

Tabberabberran Orogeny. Middle Devonian deposition ended with the Tabberabberran orogeny which probably affected all of New South Wales east of Cobar, eastern Victoria and Tasmania. The succeeding Upper Devonian sediments are lacustrine in Victoria and paralic in Western New South Wales, but marine argillaceous deposition occurred in eastern New South Wales. In general the Tabberabberran orogeny marks the end of flysch-type sedimentation in the Tasman geosyncline, the succeeding Upper Devonian and Carboniferous deposits being of molasse type.

KNOWN OCCURRENCES OF PHOSPHATE ROCK AND PHOSPHATE MINERALS

Victoria

Mansfield. The small deposits at Phosphate Hill, 3 miles west of Mansfield, were discovered in 1904 and a full description was published by A.M. Howitt in 1923. Howitt believed that the phosphates were Cambrian, but a Lower Ordovician age (Lancefieldian, Zones La 2-3) now seems assured (Thomas and Singleton, 1957). In other respects Howitt's description stands today. The phosphate is associated with black and green cherts slates and shales forming an inlier in younger Palaeozoic rocks. The strata are strongly contorted and fractured and it is not clear whether one or several phosphate beds are represented. An average thickness of the phosphate beds worked in the past is around 5 feet and analyses of the higher grade material show 15-20 per cent P_2O_5, 18-25 per cent CaO, and 5-9 per cent R_2O_3. The rock is apatitic, but veins and nodules of wavellite, and rarely turquoise, occur in the surface zone and also penetrate the fresh rock. The weathered phosphate is white, grey, or brown and friable, medium - or coarse-grained and fossiliferous; it passes down into compact dark grey or green pyritic and glauconitic (?) phosphate.

Howes Creek and Wappan. Howitt (1923) also described bedded phosphate and phosphatic breccia associated with a N.W.-trending fault about 6 miles south-west of Mansfield. Thin beds of phosphate in Silurian blue and green slates appear to control a brecciated zone extending for nearly 4 miles in a north-westerly direction in this area. The breccia is up to 5 feet in width and dips almost vertically. Analyses show P_2O_5 contents comparable to the Mansfield deposit.

Howqua River. Brecciated phosphate somewhat similar to the Howes Creek deposit was described by Skeats & Teale (1918) from just south of the Howqua River 16 miles south-east of Mansfield. This rock is light coloured and earthy at the outcrop and contains only 7 per cent P_2O_5, although the authors believed that the fresh rock might be of higher grade. The phosphate breccia is 7 feet 6 inches thick, steeply dipping, and appears to form part of the Ordovician sequence of fractured slates, shales and silicified shales.

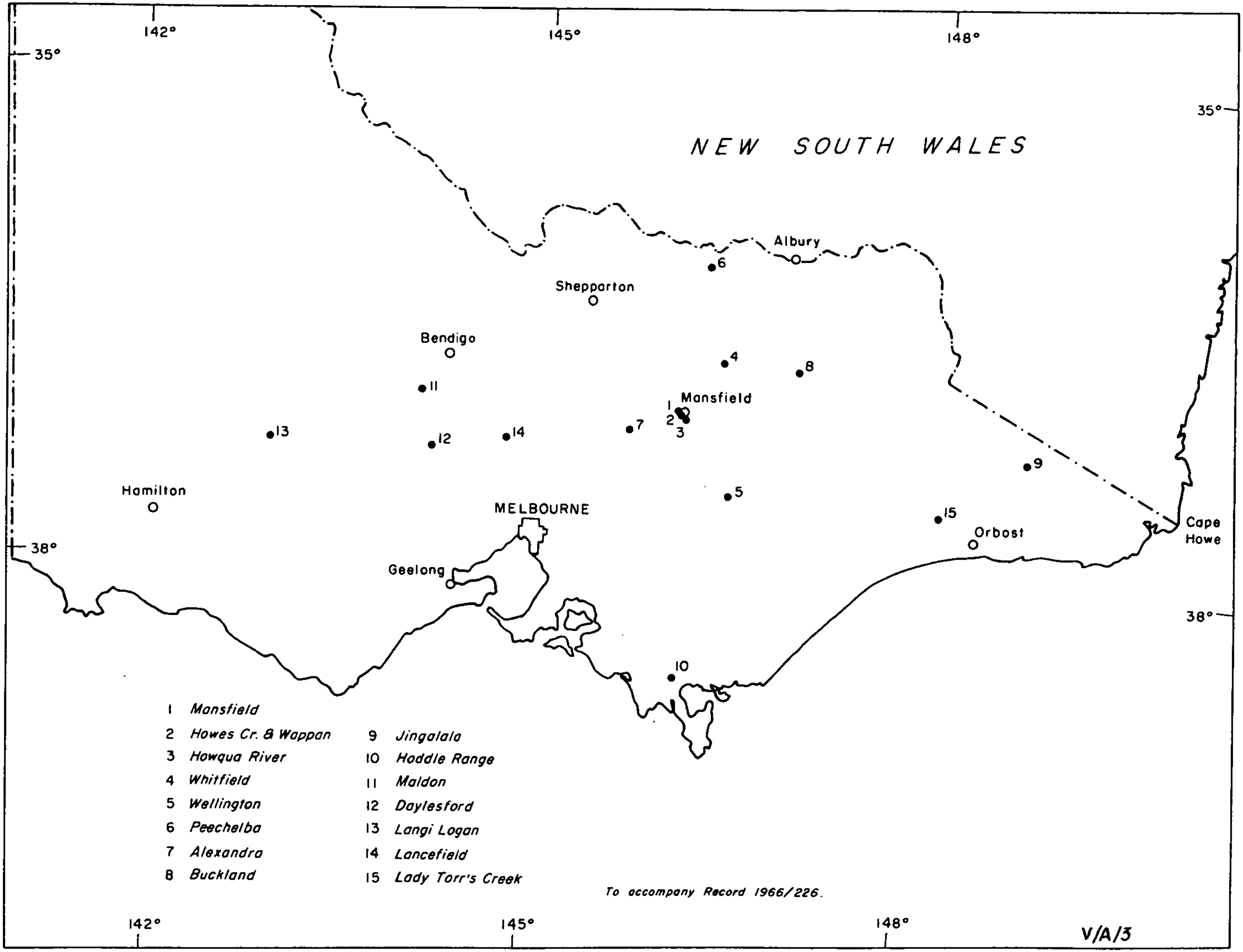

Fig. 2. Map showing location of the known occurrences of Lower Palaeozoic phosphate rock and phosphate minerals in Victoria.

Whitfield-Ovens District. Occurrences of turquoise in the Ordovician rocks to the west of Whitfield between the Broken River and King River have been known for many years and were described by Howitt (1906) and Dunn (1907). Howitt states that although he found no phosphatic beds in the turquoise belt, a sample of ironstone from a few miles farther east analysed at about 10 per cent P_2O_5. This sample would appear to come from near Whitfield. The turquoise veins occur in black graphitic and pyritic graptolite-bearing slates and in thin grey sandy slates; no cherts have been recorded.

Wellington. Several turquoise localities were recorded by Teale (1920) close to the junction of the Wellington and Dolodrook Rivers to the west of Wellington. As in the case of the Whitfield turquoise belt no beds of phosphate have been described, but Teale quotes an analysis of siliceous rock from this area giving 8 per cent P_2O_5. The associated rocks are Ordovician black slates and cherts. Slates showing varying degrees of silicification are present and Teale implies that the cherts are the result of secondary silicification rather than primary deposits. The Wellington cherts sometimes contain graptolites and no radiolaria have been noted in them.

Miscellaneous phosphate mineral occurrences. In addition to the above occurrences phosphate minerals have been recorded from Ordovician rocks at Alexandra, Buckland, Jingalala, Hoddle Range, Maldon, Daylesford, Langi Logan - Ararat, Peechelba, Lancefield and Lady Torr's Creek in the Tara Range. (Teale, 1920; Howitt, 1923). No details of those occurrences are known except that the Maldon and Daylesford mineralization occurs in Ordovician slates underlying auriferous gravels in basalt-covered deep leads. The location of these occurrences is shown in figure 2.

New South Wales

Wagonga Series. The presence of turquoise on the South Coast of New South Wales has been known since 1894 when the occurrence on the north bank of Mummuga Creek near Bodalla was recorded (Card, 1896). The turquoise occurs in the Wagonga Series of pre-Upper Ordovician age and recently thin beds of phosphate have been discovered in these rocks between Narooma and Bateman's Bay by International Minerals and Chemicals Development Corporation. This area is being actively prospected by I.M.C. and the results of this work are not yet available.

Wellington, Molong and Canowindra. Small tonnages of phosphate rock have been won in the past from a number of localities in the belt of Ordovician sediments between Wellington and Canowindra. These deposits form pockets and irregular masses in the Palaeozoic limestones and although it seems clear from the published descriptions of these occurrences that in nearly every case the phosphate originates from cave guano of geologically recent date, there is also a possibility that some phosphate has been derived from the nearby Palaeozoic rocks. For example two shafts were sunk during the last war in the Copper Hill phosphate deposit at Nandillyan, near Molong, and analyses of the decomposed slate associated with the limestones showed up to 5.5 per cent P_2O_5 (Booker, 1944).

Mootwingee. Cambrian and Ordovician fossils were first discovered in the Mootwingee Ranges west of the Darling River in 1960 (Warner and Harrison, 1961; Fletcher, 1964). The sequence includes horizons crowded with trilobites and lingullellid brachiopods and a sample of dark fossiliferous rock from a 4-inch band collected by Dr. Opik of the B.M.R. assayed at about 15 per cent P_2O_5.

Tasmania

Back Creek. Wavellite has been reported occurring on the cleavage planes of Silurian slate in the Mathinna Beds at Back Creek (Pettard, 1902). This locality, a slate quarry a few miles east-north-east of George Town, must be close to another wavellite occurrence noted by Twelvetrees (1917) who recorded boulders of slate containing spherules of wavellite on the hill slope east of Den spur near Lefroy. Twelvetrees indicates that wavellite is also found at other places extending north from the Den spur locality.

Miscellaneous phosphate mineral occurrences. Mention is made of a number of phosphate mineral occurrences in the early records (Krause, 1896; Petterd, 1902, 1910; Twelvetrees, 1917). Those which appear to be associated with Lower Palaeozoic sedimentary rocks are:- vivianite in rotten shale (Ordovician?) at North Bischoff near Waratah; vivianite at Waterhouse on the north-east coast (in the Mathinna Beds?); vivianite with barrandite at Lyndhurst also on the north-east coast and possibly in the Mathinna Beds; and wavellite in cavities in ?Ordovician limestone at Mole Creek south of Devonport.

It is of interest to note occurrences of wavellite and vivianite in the Precambrian of western Tasmania at Mt. Ramsay, 12 miles south-south-west of Waratah, and at Lucy Creek, Pieman River, 4 miles south-east of Corinna. Also an analysis of fossiliferous Permian limestone from 4 miles south of St. Marys quoted by Twelvetrees (1917) gave 3.7 per cent P_2O_5, but it is unlikely that this analysis is representative of the rock. Ordovician limestones at Railton are slightly phosphatic; an assay of 1.02 per cent P_2O_5 was quoted by Hughes (1957).

APPRAISAL FOR PHOSPHATE

General Aspects

An ancient, structurally complex, incompletely mapped area such as this must pose special problems in exploration techniques. Palaeogeographic reconstruction in search of areas suitably placed for divergent upwelling in the Lower Palaeozoic is, I believe, futile at this stage. However, there is no evidence of extensive restricted basin sediment types in the Lower Palaeozoic and the affinities of the faunas with those of the rest of the world indicate that the Tasman Geosyncline seas communicated freely with the oceans. Thus the main requisite for phosphorite deposition is present.

It is difficult to fit the Lower Palaeozoic Tasman Geosyncline in the area under consideration into the pattern of the conventional sedimentation cycles (transgression; carbonates, black shales, cherts and starved basin euxinic sediments; shales and greywackes; paralic and non-marine sediments; folding and uplift). As in the case of the Appalachian geosyncline of eastern North America it is a complex composite structure in which locations of maximum

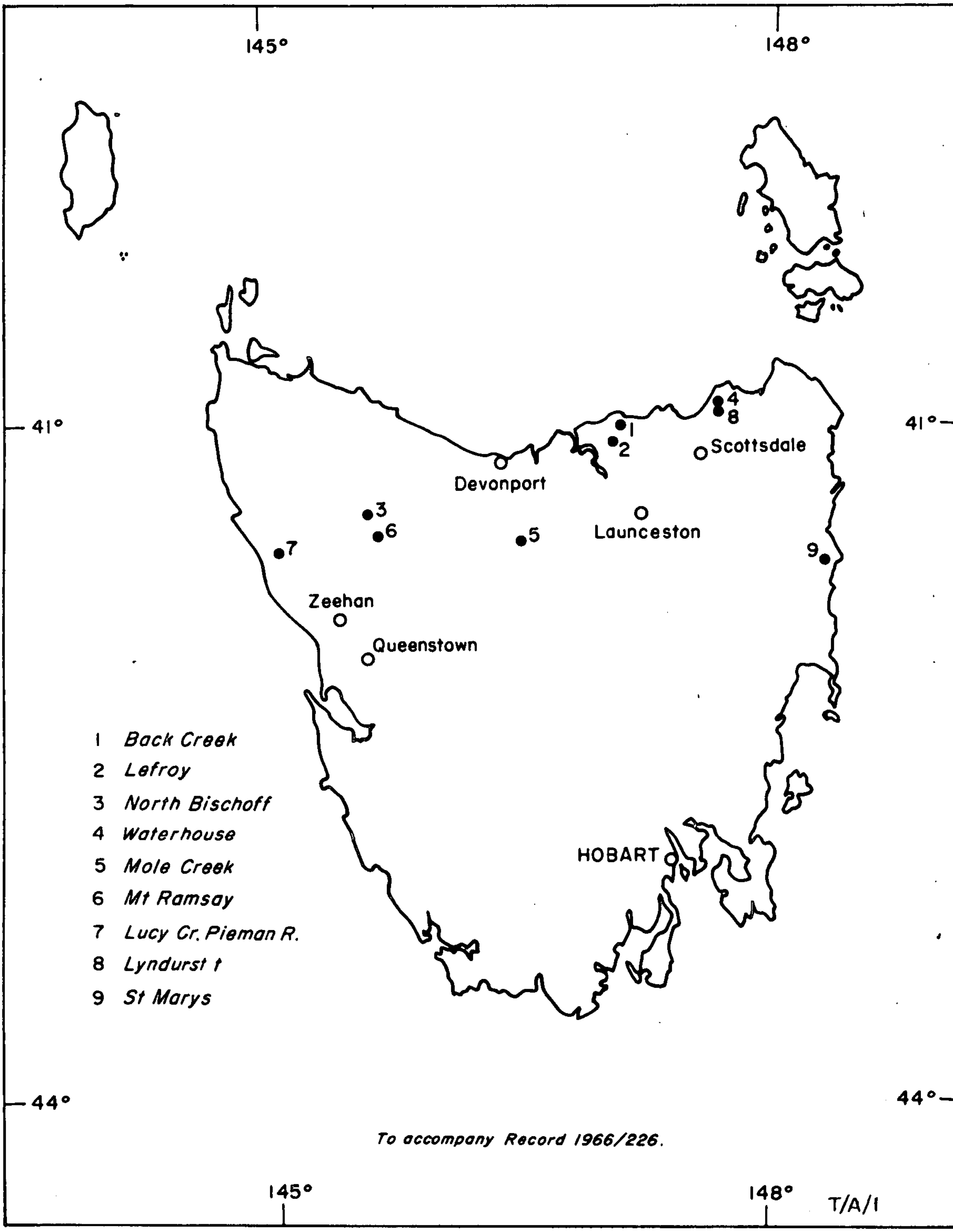

Fig. 3. Map showing the location of phosphate mineral occurrences in Tasmania.

A B

subsidence shifted during the gradual evolution and stabilisation of the whole. Three or four subsidiary cycles of sedimentation preceding the Tabberabberan orogeny can be distinguished over wide areas and wherever relatively detailed work of broad scope is carried out, for example at Yass (Browne, 1955), or Canberra (Opik, 1958), the complexity of the local Lower Palaeozoic history is brought out. Even the broad distinction between miogeosynclinal and eugeosynclinal sedimentation usually cannot be drawn because volcanic material is widespread and associated with a great variety of sediments. In contrast with the conventional cycle of sedimentation in which there is a general coarsening of sediments from the early starved basin stage through the flysch to the melasse, in the south-east Tasman geosyncline excluding Tasmania, limestones increase in importance upwards in the succession reaching their maximum development in the Middle Devonian. In general volcanic material also tends to increase in importance later in the Lower Palaeozoic. Greywacke on the other hand, dominant in the Ordovician, decrease in importance until in the Middle Devonian they are found only in the Hill End trough.

For a number of reasons the Cambrian and Ordovician seem to hold out the best prospects for phosphate deposits. Firstly, the sediments laid down early in the history of a geosyncline are, by comparison with sedimentation cycles elsewhere in the world, more likely to include phosphorites than those of the middle and later stages; moreover, the Ordovician was a period of widespread phosphorite deposition and it is possible that the Tasman geosyncline was connected with a phosphogenic province in south-east Asia at this time. The Middle Ordovician phosphorites of the Amadeus Trough and the Middle Cambrian phosphatic sediments of north-west Queensland were laid down close to the western shores of the Tasman Geosyncline sea and provide further evidence of the existence of a phosphogenic province. Secondly, most of the known occurrences of phosphate and phosphate minerals in the area under review are of this age and the shale/biogenic chert facies is also found. Admittedly, limestones are more abundant later in the Lower Palaeozoic, except in Tasmania, but these limestones are frequently biohermal and are not likely to be associated with phosphorite. And, thirdly, volcanic material is less abundant and less widespread than in the post-Ordovician.

Although for the above reasons the Cambrian and Ordovician are held to be the most prospective for phosphate, the great thicknesses of greywackes and shales, which are abundant throughout the Lower Palaeozoic and are particularly characteristic of the Ordovician of New South Wales and Victoria, are, of course, most unlikely to include phosphorites. They resemble the thick Lower Palaeozoic sequences of the Caledonian Geosyncline of north-west Europe, a basin comparable in size and time range to the Lower Palaeozoic Tasman Geosyncline and devoid of significant phosphorites throughout. Thick flysch-type sediments are characteristic of the axial part of a geosyncline during the middle stages of its development and this suggests that any phosphorites present are more likely to be found lower in the succession and nearer to the bordering land mass. Most of the sediments of the western part of the geosyncline are hidden under Mesozoic and Tertiary deposits of the Great Artesian and Murray Basins, but they emerge from beneath the younger rocks at Mootwingee and in north-west Queensland where Middle Cambrian phosphorites are known.

Finally, it must again be stressed that the south-eastern part of the Tasman Geosyncline had a highly complex history and that a number of separate basins and ridges and subsidiary orogenic cycles were developed there during the Lower Palaeozoic. Thus there are a number of belts where the Ordovician and post-Ordovician sequences are much thinner and where the monotonous greywackes and shales give place to varied lithologies including chemical sediments more likely to be associated with phosphorites. These are described in the following sections together with other areas which for one reason or another hold out some hope of containing phosphorite. The localities are described in general sequence from south to north and no order of importance is implied.

Tasmania

There are quite numerous reports of secondary phosphate minerals in Tasmania, but no phosphate rocks are known. Some of the Permian limestones are slightly phosphatic but the figure of 4 - 5 percent P_2O_5 given for a limestone 4 miles north of St. Marys (Twelvetrees, 1917; Nye, 1943) is not representative of the whole rock. Ordovician limestone from Railton, south of Devonport, contains 1.02 percent P_2O_5 (Hughes, 1957). Planet Exploration Company have held Authorities to prospect for phosphate in Tasmania and some prospecting has been carried out by other companies also.

The Lower Palaeozoic geology of Tasmania stands in most marked contrast with that of Victoria and New South Wales. The Dundas Group has some similarities with the Heathcotian Series of Victoria, (stressed for example, by Hills, 1924), but it is much thicker; the succeeding Ordovician follows a period of uplift and erosion and the thick basal conglomerates are followed by fine-grained sediments and by up to 5000 feet of limestone which was probably laid down during a large part of Ordovician time. These rocks are very different from the shales and greywackes of the mainland Ordovician, and the post-Cambrian sequence in Tasmania is in general very much thinner than it is in Victoria to the north. The Silurian and Devonian contain a high proportion of sandstones in the west (Eldon Group) but in the east the equivalent Mathinna Beds comprise greywacke and shales which are of deeper water origin.

In general terms the Lower Palaeozoic of Tasmania shows abundant evidence of deposition closer to the western margin of the geosyncline than the rocks of similar age in Victoria and New South Wales. The Tyennan Geanticline, emergent in the Middle Cambrian, may well indicate the proximity of the southern margin also.

Carbine Group. The Upper Proterozoic - ? Cambrian rocks of the Corinna area north-west of Zeehan include dolomites, cherts and argillites at the top of the succession. Thick volcanics are also present.

According to Spry (1962, 1964), the succession is as follows:

Savage Dolomite 400+

Delville Chert 200'?

Unconformity ?

Bernafai Volcanics 1300'

Corinna Shale 1000'

Donaldson Group 1900'+

Interview Slate and Quartzite 5000'?

Unconformity

Whyte Schist

The Delville Chert is a black, slaty rock and Spry considers that it is of secondary origin and represents silicified dolomite and slate. However, there is some evidence of chemical sedimentation and the pre-Dundas Group rocks in this area may conceivably include phosphorites. Although the Corinna sequences are unmetamorphosed, the structures are so complex that correlation over even short distances is difficult or impossible. Another unfavourable factor is the possibility that glacial conditions obtained at approximately the time these rocks were laid down. The Zeehan tillite appears to be Permian but the King Island tillite may be equivalent to the Sturt Tillite of South Australia and contemporaneous with the upper part of the Carbine Group.

Dundas Group. The greater part of the Dundas Group represents eugeosynclinal flysch-type sedimentation which is most unlikely to include phosphorites. However, the basal part of the sequence in the Zeehan - West Coast Range area, overlying the Mount Read Volcanics, shows some indications of having been deposited in a pre-flysch euxinic basin possibly favourable for the accumulation of phosphorites. There is some doubt about the stratigraphic position of these rocks, the Crimson Creek argillites, (see discussion in Campana, 1961) but despite the fact that they are of considerable thickness (perhaps up to 10,000 feet according to Bisset and Gulline, 1961), they do include black shales and cherts, and phosphorites may be present also. Quite large areas of Crimson Creek Formation are shown on the Zeehan 1 inch to 1 mile map mainly to the north and east of Dundas and in discontinuous patches from Zeehan to the coast at Trial Harbour. Dips are steep and the formation is often poorly exposed.

Black shales and cherts, commonly associated with volcanic breccias and greywackes, have also been recorded in the Middle and Upper Cambrian near Waratah and in the Lower Gorge near Penguin on the mid-north coast. In the Leven Gorge, Banks (1957) shows a section of about 4,500 feet of Cambrian rocks which include over 600 feet of thinly bedded cherts and argillites.

The presence of abundant spilitic rocks and other volcanics suggest that many of the cherts may be of volcanic origin; others appear to be the result of secondary silicification of slates. These facts, combined with the considerable thickness of the sequences are not encouraging from the point of view of phosphate search. None the less, the coarser grained clastics are mainly concentrated in the upper part of the Dundas Group and its equivalents, and the lower part of the sequences may be phosphatic in part.

Gordon Limestone. The long period of carbonate sedimentation represented by the Gordon Limestone, which occupied much of Ordovician time, indicates a return to a depositional environment starved of terrigenous detritus following the basal conglomerates and succeeding sandstones and mudstones of the lower part of the Ordovician. The presence of calcareous algae in some of the limestones indicates shallow water and cross-bedding and ripple marks also occur. No bioherms are known and much of the limestone appears to be a chemical deposit laid down in warm shallow waters close to the margin of the craton (Carey, 1953). A fairly large number of analyses of Ordovician limestone have been carried out (Hughes, 1957), but with the exception of a sample from Railton mentioned above which assayed at 1.02 percent P_2O_5, only traces of phosphate were found and there are no records of phosphatic nodules.

From a palaeogeographic standpoint the most likely site of phosphate accumulation in the Ordovician would appear to lie between the shallow carbonate shelf on which the Gordon Limestone was deposited and the deep water greywacke/shale belt of the Victorian Ordovician. A small part of this area may be represented by the shelly Ordovician of Waratah Bay (see a previous section) but the greater part must lie under the Bass Strait.

Mornington Peninsula and Waratah Bay

The Ordovician rocks of the Mornington Peninsula are exposed in an anticlinal structure lying between the Heathcote and Mount Wellington axes. Keble (1950) recorded 15,000 feet of Ordovician sediments on the peninsula, but Hills & Thomas (1954) suggest that the Ordovician totals only about 10,000 feet and represents a condensed succession in comparison with the much thicker sequences at Bendigo and Ballarat to the north-west. There is little evidence, however, of slow deposition and chemical sedimentation. Theoldest rocks exposed in the core of the anticlinorium in the Mornington Peninsula, at McIlroy's quarry, consist of dark graptolitic shales of low Lancefieldian age, and these are succeeded by some thousands of feet of dominantly arenaceous strata, the Kangerong Formation, which includes current bedded sediments. The Kangerong Formation is overlain by more Lancefieldian shales and sandstones and by later Ordovician formations of similar lithology. Cherts present in the Ordovician are believed by Keble to be the result of the silicification of shales and not original chemical deposits. The Silurian consists of varigated shales and sandstones with local evidence of very shallow water conditions. Thus, although there is some evidence that the Ordovician and

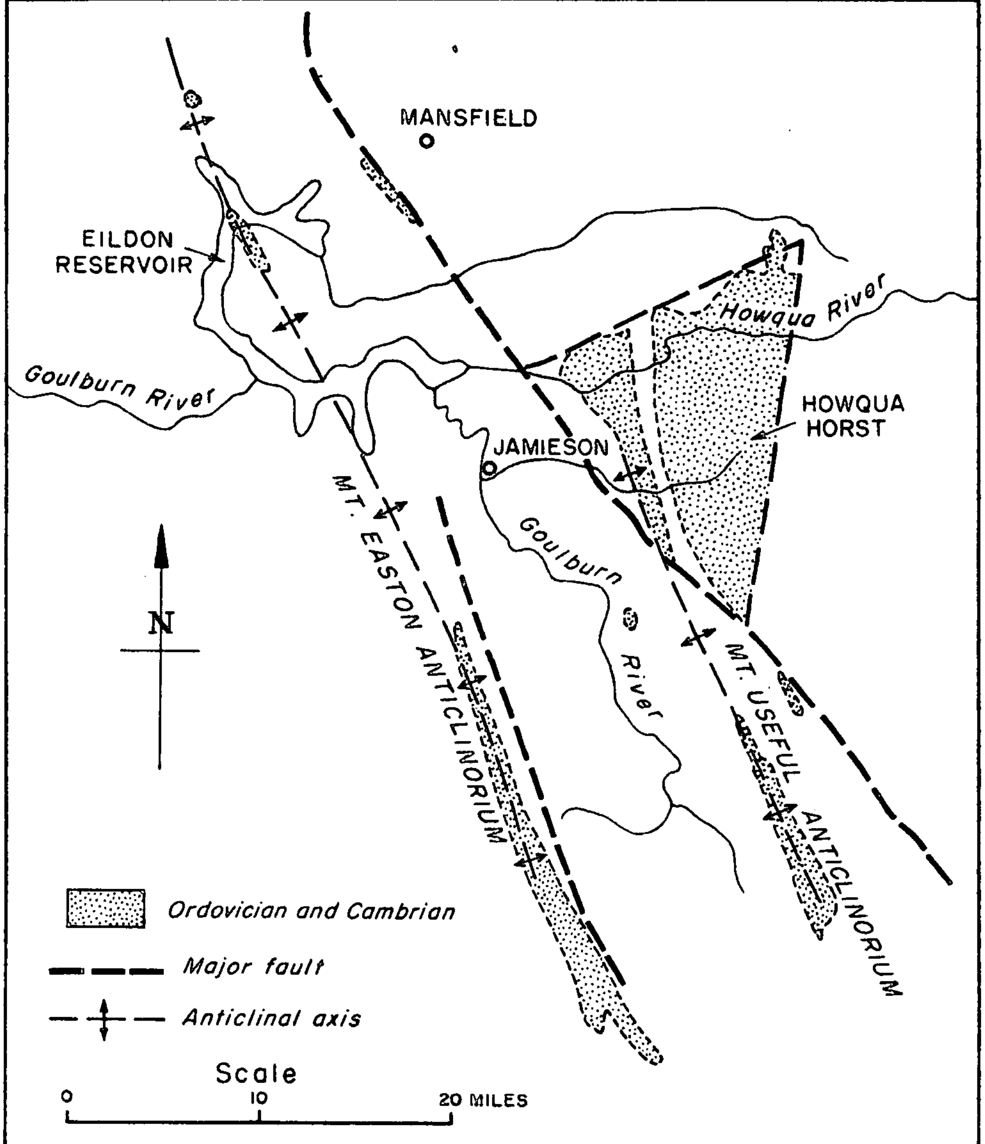

Fig. 4. Sketch of the Mansfield-Howqua River area showing the distributions of the Pre-Silurian rocks and the main structures. (After Thomas, 1947).

To accompany Record 1966/226. J 55/A6/1

Silurian were deposited on one of the Lower Palaeozoic geanticlinal axes, there is no indication of the presence of lithological associations prospective for phosphorites.

The Digger Island Formation at Waratah Bay includes limestones and calcareous shales with a shelly basal Ordovician fauna, the only known occurrence of shelly Ordovician in Victoria (Lindner, 1953). The Waratah Bay Ordovician occurs in another of the Lower Palaeozoic anticloria which is linked by Thomas (1939) with the Mount Eastern anticlorium to the north. The Digger Island Formation is 120 to 130 feet thick and is separated from the altered volcanics of possible Cambrian age below and the Devonian Bell Point Limestone above by faults. Part of the northern outcrop has suffered contact metamorphism from a basic intrusion and the whole formation is more or less sheared. Lindner describes the limestones as being nodular but there is no indication of the presence of phosphorites.

Mansfield - Howqua River Area

The Lower Ordovician phosphorites of Mansfield form only a small structurally complex inlier, but the cherts and black shales associated with them suggest that a fairly extensive phosphate province may be present. Lower and Middle Ordovician rocks occur in the cores of anticlinoria and along fault lines at a number of places in the Mansfield - upper Goulburn River district and in the Howqua River horst, where phosphatic sediments have also been recorded. (Harris & Thomas, 1938, 1940, 1942; Howitt, 1923; Teale, 1919; Thomas, 1947; Whitelaw, 1916). The main areas of Ordovician rocks are shown in figure 4. Detailed mapping is required to elucidate the structures which are much complicated by faulting. Although individual beds of phosphorite, if present, could well be repeated by folding or faulting, the complexity of the structures and the steep dips are major disadvantages from the point of view of working a deposit. International Minerals and Chemicals are currently prospecting this area for phosphate.

Whitfield - Tabberabbera Belt

To the east of the Devonian and Carboniferous rocks of the Mount Howitt Range, Ordovician rocks again appear. At the northern end of this belt, in the Whitfield, Edi, Myrrhee area, are the well-known turquoise localities. To the south the Ordovician rocks to the north of Tabberabbera described by Talent (1963) consist of claystones, siltstones and subordinate sandstones and include a belt about one mile wide of black fine-grained sediments and cherts. The latter are of Upper Darriwilian to Upper Eastonian age and the promising lithology suggests that the belt of sediments following the regional strike between Whitfield and Tabberabbera deserves investigation. This is rugged country whichhas not been mapped in detail and as in the Mansfield - Howqua River area, careful and painstaking mapping is necessary. International Minerals and Chemicals have recently relinquished a lease they held over much of this area.

Central and Western Victoria

From a theoretical standpoint the extensive areas mapped as Lower Ordovician to the west of the Heathcote axis would appear to hold out some prospects for phosphorite. They lie to the west of the axial part of the geosyncline and of the main Benambran orogenic belt and the sediments may have been laid down close to the western margin of the depositional basin. Part of the succession may extend down into the Cambrian (Singleton, 1965) and the rocks are coeval with phosphatic sediments elsewhere in the basin. However, despite the close folding there is no doubt that considerable thicknesses of sediments are present. At Bendigo, Hills and Thomas (1954) have described 12,000 feet of Lower and Middle Ordovician, and at Ballarat, 10,000 feet of Lancefieldian (and older ?) sediments are known. These thick and monotonous sequences of greywackes and slates are most unprospective for phosphorite and apart from isolated occurrences of phosphate minerals at Ararat, Daylesford and Maldon there is no record of phosphatic sediments anywhere in this belt. At the extreme western limit of the Ordovician outcrop in Victoria, on the Glenelg River, impure dolomitic limestones and calc-silicate metamorphic rocks have been recorded (Wells, 1956). The succession includes black slates and microcrystalline quartzites which may have originally been chert but thick greywackes are also present. There is considerable metamorphism and the structures are complex but indications of chemical sedimentation are present and there is a possibility that phosphorites may be associated with the sediments.

South Coast of New South Wales

Phosphatic sediments are known in the Wagonga Series of pre-Upper Ordovician age which outcrops along the South Coast of New South Wales between Narooma and Batemans Bay. These rocks have been described by Brown (1928, 1930, 1933) and are usually regarded as Cambrian although they may be younger. They consist of phyllites and schistose fine-grained sediments, and black radiolarian cherts with which thin phosphatic sediments and veins of turquoise are associated. Some of the rocks appear to be conglomeratic, but the pebbles and larger fragments in some cases may be concretions or consist of disrupted boudins. Brown remarks on the very distinctive lithology of these rocks which is quite different from that of the Upper Ordovician graptolitic slates and greywackes to the west. They bear some resemblance to the Lancefieldian sediments of Mansfield and to the Neranleigh - Fernvale group of the Brisbane Schists which are also phosphatic locally (Denmead, 1928; Brooks and others, 1960).

Brown (1933) indicates that the Wagonga Series extends along the strike for about 150 miles from north of Batemans Bay to the Victorian border, but a much more restricted outcrop is shown on the Geological Survey of New South Wales maps (Fig. 5). The series is well exposed along the shore but the regional strike cuts the coastline at only a small angle, and as inland exposures are few, much of the section is hidden. The rocks are strongly contorted and sheared, with intense minor folds and crumpling superimposed on the major structures. Some degree of metamorphism is shown by all these sediments and this suggests that beneficiation of low grade apatitic rock would not easily be accomplished. The steep dips, tight folds, and abundant fractures also reduce the possibility of finding an economic deposit.

International Minerals and Chemicals currently hold a Mineral Exploration Licence for Phosphate in this area.

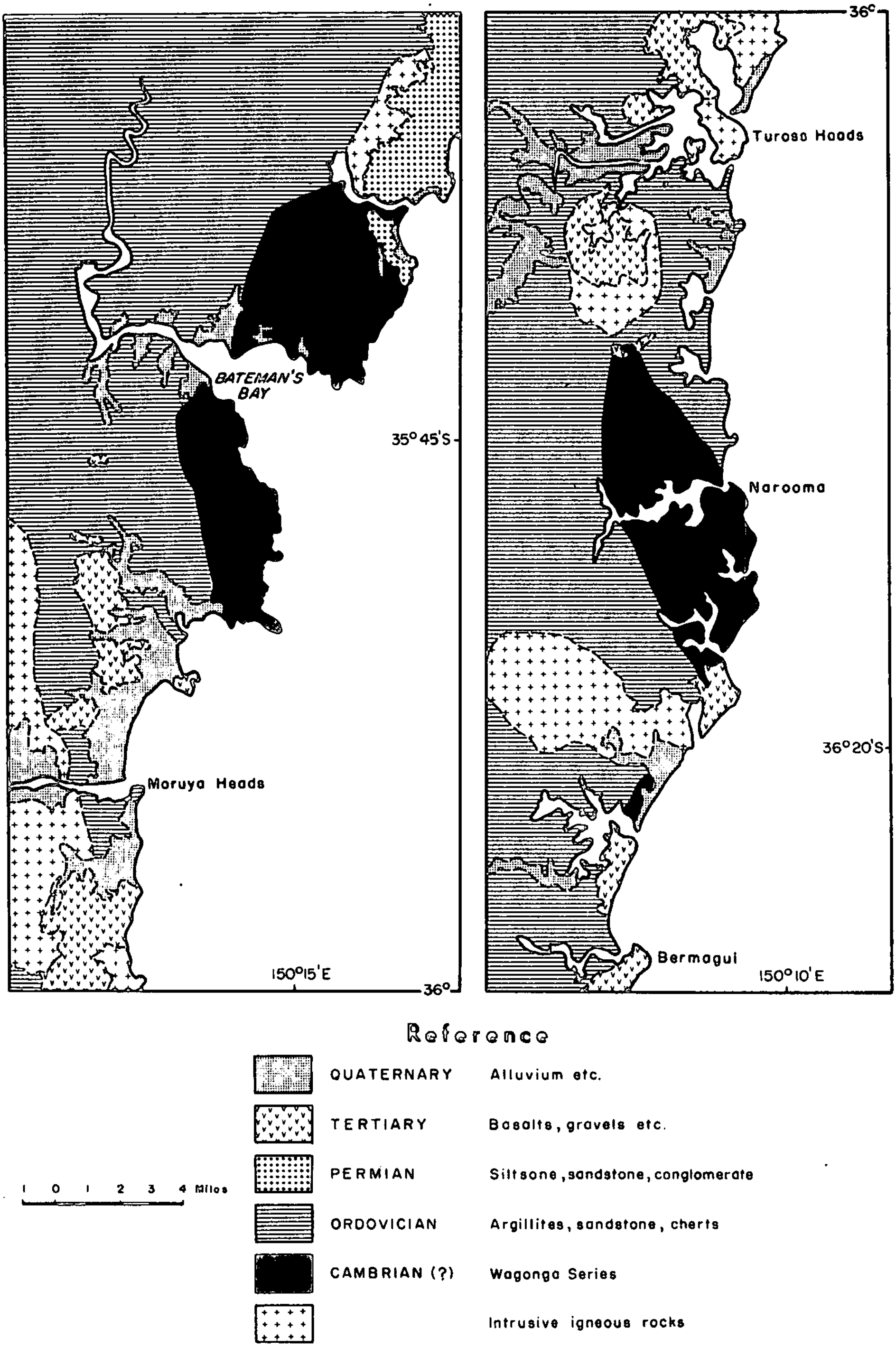

Fig. 5. Simplified geological map of part of the South Coast of New South Wales showing the outcrop of the Wagonga Series

Geology from Geological Survey of New South Wales
1: 250000 Geological Series Ulladulla and Bega Sheets

To accompany Record 1966/226

N/A/5

Cooleman Caves, New South Wales

The Cooleman Plain is situated near the A.C.T. border about 40 miles south-west of Canberra (Fig. 6). The geology of the area has been described by Stevens (1959) and Walpole (1952); Upper Silurian limestones, cherts, slates and sandstones are surrounded by Devonian volcanics, granitic rocks and Ordovician sediments. Many of the junctions are faulted. The area is of interest because of the limestone/chert/slate association. Changes in lithology and thickness are rapid in the Silurian. According to Stevens the succession in ascending order is as follows;

1. Cooleman Limestone. Massive fossiliferous limestone with thin shales and occasional cherts. Thins from a maximum of about 2000 feet in the south-east to about 200 feet in the extreme west. In the eastern part of the area the Cooleman Limestone is represented by the Pocket Beds, a series of shales, slates, limestones, cherts and tuffs. The limestones contained corals. Total thickness appears to be several thousand feet.

2. Blue Waterhole Beds. Sandstone, shales, cherts, and limestones with a maximum thickness of about 2000 feet in the central part of the outcrop south of "Coolamine". Sandstone and shales predominate in the west and coralline cherts increase in importance eastwards. East of Cooleman Gorge the Blue Waterhole Beds appear to pass laterally into limestone (the Wilkinson Limestone).

The presence of abundant coral fauna in this limestone is not encouraging from the point of view of phosphate prospects. Corals also occur in the cherts of the Blue Waterhole Beds and it is clear that much of the chert is in fact replaced limestone. However, the banded nature of the cherts and their relation to the unaltered limestone suggest that some of these are original chemical or biochemical deposits and that in other beds silicification was penecontemporaneous with limestone deposition.

Sampling of the Cooleman Group sediments revealed no phosphatic rocks and scintillometer traverses were negative; however, although outcrops are quite good in this deeply dissected country, it is possible that phosphatic sediments are in fact present in this less well exposed areas. There is little chance of a large deposit being present.

Ordovician of the Canberra area

The geology of the Canberra district has been described by Opik (1958). The succession is as follows:

DEVONIAN VOLCANICS

---------- UNCONFORMITY ----------

U. Sil.	Red Hill Group	Yarralumla Fm. 500'	Calcareous and tuffaceous shale
		Deakin Volcanics	
	Fairbairn Group	600' +	Mainly volcanics
M. Sil.	Mt. Pleasant Porphyry St. Johns Church Beds	300'.	Volcanics and tuffaceous sediments
L. Sil.	Canberra Group	City Hill Shale, 350'+.	Calcareous shales.
		Riverside Fm. 600'"	Volcanics and calcareous shales, sandstones and tuffaceous sediments
		Turner Mudstone 200'	Calcareous shale with sandstone and thin tuffs
	State Circle Shale, 200'.		Shales and fine-grained sandstones.
	Camp Hill Sandstone	40'	Sandstone, originally calcareous, ripple marked.

-------- UNCONFORMITY --------

U. Ord.	Acton Shale	200'+	Siliceous black shale.
M. Ord	Pittman Formation	700'	Sandstones, shales and cherts.

-------?------------ UNCONFORMITY --------?----------

Pre M. Ord.	Black Mountain Sandstone	1500'+.	Sandstones and very subordinate shales

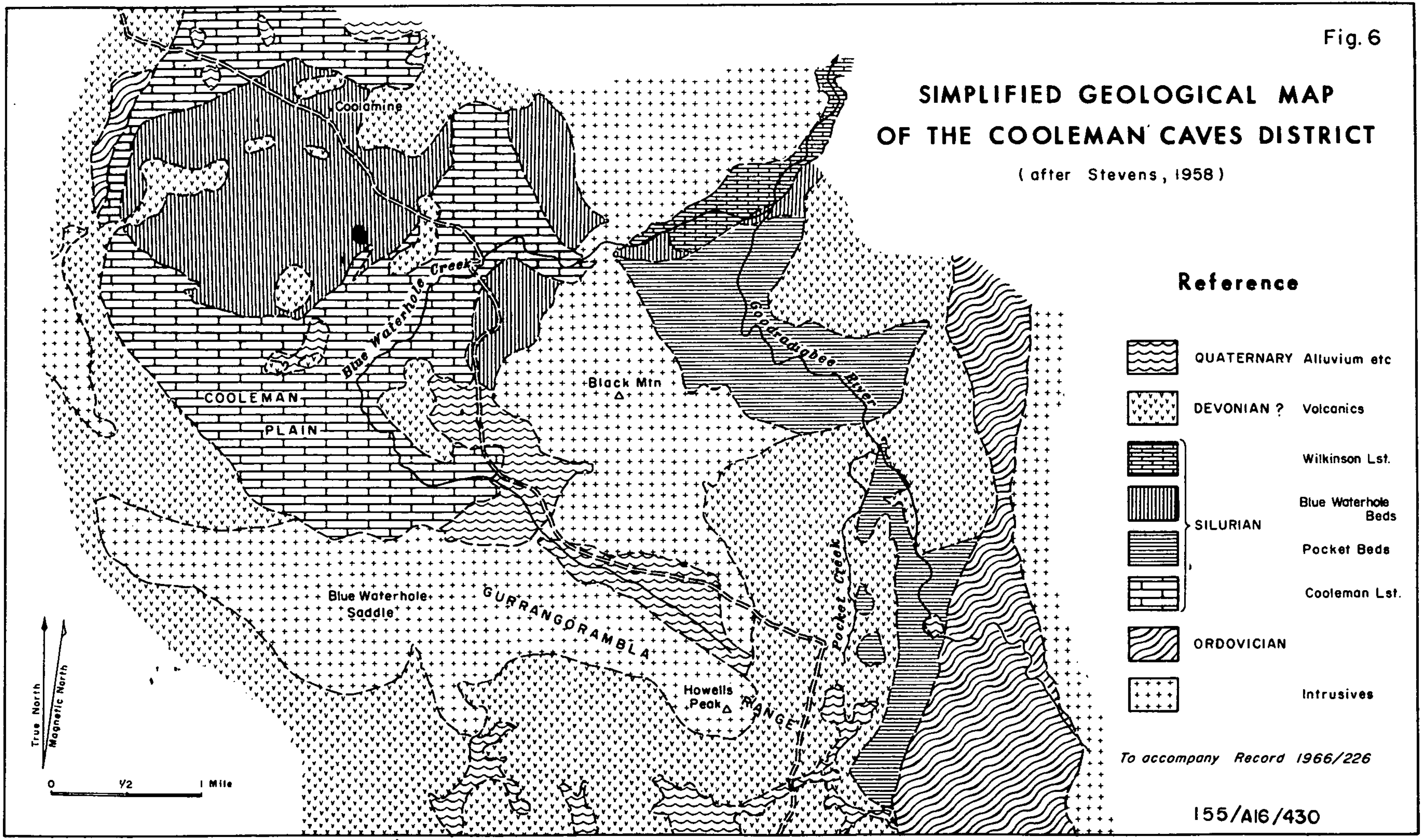
Fig. 6
SIMPLIFIED GEOLOGICAL MAP
OF THE COOLEMAN CAVES DISTRICT
(after Stevens, 1958)
Coolamine
Blue Waterhole Creek
Goodradigbee River
COOLEMAN
PLAIN
Black Mtn
Blue Waterhole
Saddle
GURRANGORAMBLA
RANGE
Howells
Peak
Pocket Creek
True North
Magnetic North
0
1/2
1 Mile
Reference
QUATERNARY Alluvium etc
DEVONIAN ? Volcanics
Wilkinson Lst.
Blue Waterhole Beds
SILURIAN
Pocket Beds
Cooleman Lst.
ORDOVICIAN
Intrusives
To accompany Record 1966/226
155/A16/430

Although the Ordovician sequence may not be complete owing to post-Black Mountain Sandstone and post-Acton Shale erosion, there is no doubt that the Pittman Formation and the Acton Shale represent nearly all of Middle and Upper Ordovician time. Their combined thickness is of the order of 1000 feet only and an extremely slow rate of deposition is indicated. Outside the immediate area of the Canberra Rift many thousands of feet of sediments were deposited during this period and the existence near Canberra of this condensed sequence which includes black shale and cherts is significant from the point of view of phosphate search. The overlying Silurian sediments are also relatively thin, but the increasing dominance of volcanics during the period make it less prospective for phosphate.

Opik's measured section of part of the Pittman Formation indicates rhythmic sedimentation typical of turbidites, except for the presence of cherts, and it is difficult to explain the condensed nature of the sequence in this type of lithology. It seems likely that the Canberra area stood above the general level of the floor of the Tasman Geosyncline during the Ordovician and therefore received only a fraction of the sediment deposited elsewhere. Even so, sandstones predominate in the measured section. Limestones are absent and no phosphatic sediments have been recorded.

It is most unlikely that any significant deposit of phosphorite is present in the Canberra rift, but the area provides evidence of considerable local thinning of the sequence in the Ordovician, which, if repeated elsewhere in the geosyncline may be associated with phosphorite deposition.

Jenolan Caves area

The Silurian Caves Limestones near Jenolan is underlain by a considerable thickness of slates, and a thick, thinly bedded chert sequence. The geology of the area was described by Sussmilch & Stone (1915) and a number of University of New South Wales theses have added to the information available. A reconnaissance of the area in November, 1966, did not reveal any sediments with more than 1 percent P_2O_5. The thick cherts west of Jenolan Caves are quite barren of phosphate while the dark slates to the south and east are interbedded with greywackes which in places show typical turbidite sedimentary structures. Some of these coarse-grained sediments had been mapped as "porphyrite" by Sussmilch & Stone, and surprisingly traces of phosphate occurred in these rocks more often than in the shale.

Apart from the association of limestone cherts and shales, interest was aroused in the area because of a mention of patchily coloured argillites with spots and lenses of light and darker material (Gulson, 1963) which is suggestive of some phosphorite textures. Some turbidites south of Jenolan are patchily coloured and possibly the above account refers to similar rocks. The presence of turbidites and volcanics and the thickness of the sequence are unfavourable for phosphorites and it is unlikely that a large deposit is present in the Silurian rocks of the Jenolan Caves area.

Forbes - Parkes

West of the Cowra trough Ordovician rocks again appear and outcrop intermittently along a N-S belt for about 100 miles between Narromine and Grenfell. Nothing has been published on the Forbes-Parkes area since the description of the goldfield by Andrews (1910). This area is of interest because, like the Wellington - Molong belt, it probably formed a structural high during the Lower Palaeozoic and the Ordovician and Silurian sediments include limestones, shales and cherts. In addition, the steep dips and intense folding so common in rocks of this age in the Tasman geosyncline give place in the vicinity of Forbes to gentle open folds. A number of traverses in the Forbes-Parkes district showed that some, at any rate, of the cherts are the result of the near-surface silicification of limestone and no phosphate sediments were seen. However, very large areas are blanketed by a thick waste sheet and only a small part of the succession is exposed.

Wellington - Molong

It seems unlikely that the cave guano type deposits in the limestones of the Wellington - Molong - Canowindra belt, will prove to be of any economic importance. However, the outcrop of the Ordovician marks the axis of a geanticline active throughout most of Ordovician and Silurian times and despite the abundance of intermediate volcanics in the Ordovician near Wellington, the more varied lithology and reduced thickness of the Lower Palaeozoic in this belt deserves, and has received, close attention from the point of view of phosphate search. Australian Fertilizers, Anaconda and International Minerals & Chemicals all hold phosphate exploration licences in this area.

There is a considerable volume of published material on the geology of the Wellington - Canowindra region and some additional information is contained in unpublished university theses (Adamson & Trueman, 1963; Basnett & Colditz, 1945; Joplin & Culey, 1938: Joplin and others, 1952; Matheson, 1930; Packham, 1958; Packham & Stevens, 1955; Ryall, 1965; Stanton, 1955; Stevens, 1950, 1951, 1952, 1953, 1954, 1957; Stevens & Packham, 1953; Strusz, 1959; Walker, 1959). Although the sequences are thinner here than in the Hill End trough to the east and in the Cowra trough to the west, they are still of quite substantial thickness. Reliable estimates are few; Matheson (1930), quotes over 20,000 feet of Silurian rocks at Wellington and Stanton (1955) records 20,000 feet of Lower Silurian conformably overlying 15,000 feet of Upper Ordovician south of Bathurst. It seems possible that the thicknesses recorded at Wellington are exaggerated as Packham (1958) suggests that the sedimentary series above and below the volcanics are in fact one and the same. In the case of Stanton's estimate of thicknesses at Burraga, this region is to the east of the Molong geanticline and the Ordovician and Silurian probably thin significantly westwards. Considerable changes in thickness over quite small areas are characteristic of this region; for example the Upper Ordovician sediments overlying the Cargo Creek Limestone thin from about 4000 feet south of Cargo to about 700 feet inclusive of volcanics to the west of Cudal, some 10 miles to the north (Stevens, 1957); also Packham (1958) notes that the Silurian Panuara Formation thickens from about 700 feet south of Orange to 4800 feet west of Cudal.

Facies changes in this region are also marked and add to the difficulties of stratigraphic correlation. These rapid lateral changes in lithology are well shown, for example, by the Silurian Panuara Formation west of Orange (Walker,

1959) and by the Ordovician Cliefden Caves Limestone and Malongulli Formation north-west of Mandurama. Although the bulk of the Ordovician limestones are shelly and coralline, for example see Steven's (1952) description of the Cliefden Caves Limestone, interbedded chert nodules provide some evidence of chemical sedimentation elsewhere. Banded black shales and cherts are also recorded by Stevens (1950) from inliers of Ordovician rocks 3 miles east of Cargo.

Other areas of possible Cambrian rocks in N.S.W.

On the basis that the Cambrian and lowermost Ordovician are known to include phosphorites elsewhere in the Tasman geosyncline, rocks of this age deserve special attention. Thus in the Tumut area Opik (1952) believes that the sandstones and shales at the base of the thick eugeosynclinal Ordovician sequence may extend down into the Cambrian. One of the soil analyses showing relatively high P_2O_5 quoted by Wild (1955) also occurs near Tumut and this area should be investigated. Again Browne (1955) says that some beds surrounded by Ordovician strata near Jerrawa, 12 miles east of Yass, are lithologically similar to the distinctive Wagonga Series of the South Coast. It is possible that they too are phosphatic.

Strata of Cambrian age may also occur in the Cobar Belt and although there is no record of limestone shales and cherts in this basal arenaceous sequence the possibility that these rocks were laid down to the west of the axis of the geosyncline, perhaps close to the shelf of the western continent, increases the chances of phosphorite occurring somewhere in the sequence.

Rocks of undoubted Cambrian and lowermost Ordovician age occur in the Mootwingee Ranges north-east of Broken Hill. Part of the succession quoted by Fletcher (1964) is as follows:

U. Cambrian to	Shales, sandstones and conglomerates
L. Ordovician	Shales and siltstone
U. Cambrian	Greywacke, conglomerate calcareous and feldspathic siltstone
M. Cambrian	Shales and marls with limestone
M. to L. Cambrian	Shale and tuffs with glauconite
L. Cambrian	Acid volcanics, tuffs, shales and cherts.

Opik (1961) notes that the regional structure of the Mootwingee series and the underlying Cambrian rocks is that of a westerly dipping monocline and that the strata thicken towards the west also. The inlier of Precambrian to the east of the Mootwingee Lower Palaeozoic would appear to have been emergent at the time of deposition of these rocks, many of which have a very shallow water aspect, while the continental mass bounding the geosyncline also could not have been far distant to the west.

In the upper part of the series a thin bed crowded with phosphatic brachiopods occurs, while the presence of glauconite in the Middle to Lower Cambrian is also noteworthy. It is unlikely that significant phosphate deposits will be found in the small area known to be underlain by Cambro-Ordovician sediments for there is evidence of shallow water environment and abundant detritus in the upper part of the series and of considerable volcanic activity in the lower part. None the less, the presence of abundant lingulellid brachiopods provides more evidence of the phosphate potential of the Cambro-Ordovician.

CONCLUSIONS

Most of the areas in Tasmania, Victoria, and New South Wales to which attention has been drawn have already been prospected in greater or lesser detail by one or more of the mining companies engaged in phosphate search. Some of this work has been done by geologists with wide experience in phosphate exploration in Australia and overseas and it is unlikely that a large and obvious deposit has been overlooked. None the less the difficulty of recognizing phosphate in the field cannot be overstressed; the recent discovery of phosphatic sediments in the well-exposed Triassic sandstones within a few miles of the centre of Sydney underlines this point. There are few areas where the rocks are well enough exposed and known in sufficient detail to rule out all prospects of important phosphate deposits being present.

In general the Lower Palaeozoic of this part of the Tasman Geosyncline is characterized by heavy sedimentation and these thick sequences do not hold out good prospects for phosphorite. There is some evidence of thinner starved basin type deposition in the Proterozoic-Cambrian succession of Tasmania and the Cambro-Ordovician succession of Victoria and New South Wales and these rocks may include phosphate deposits. With regard to the thick Ordovician to Middle Devonian sequences, there are two factors concerning their phosphate potential which must be borne in mind. The first is that it is well established that subsidence was by no means regular throughout the geosyncline; the typical thick eugeosynclinal deposits, although widespread, are not universal. There are a number of belts, of which the Wellington-Molong geanticline is the best known, where the thinner successions and varied lithologies indicate that the floor of the trough had considerable relief. Some of these rises may have been suitably placed for phosphate deposition and they deserve careful exploration, particularly where Ordovician or older rocks are exposed.

The second factor concerns the possibility that significant discontinuities, or periods of reduced sedimentation, remain undetected in apparently continuous and thick rock sequences. The fossil record is not often complete enough to discount this possibility and cessation of clastic sedimentation for a small fraction of the time represented by many successions might allow important phosphate development. Other evidence of chemical sedimentation, particularly carbonates and cherts, should give a pointer to conditions of this sort.

To summarize in general terms, it appears that the south-eastern part of the geosyncline considered in this Record was situated close to the axial zone of the main trough during the Lower Palaeozoic, and that the most likely sites of phosphate deposition are buried under younger rocks to the west and north-west. In the area of outcrop the Cambrian and Lower Ordovician hold out the best prospects for phosphorites but local structurally controlled phosphogenic provinces may have developed elsewhere in the succession. Some of these areas of non-eugeosynclinal deposition are known, others may be present also. Thin shales and cherts which indicate starved basin conditions may be difficult to recognize in normal eugeosynclinal sequences; non-biohermal limestones are more easily recognized in the field and are also important indicators of chemical sedimentation with which phosphorites may be associated.

REFERENCES

ADAMSON, C.L. & TRUEMAN, N.A., 1963 - Geology of the Cranky Rock and The Needles proposed dam storage areas, Canowindra. Dept. Mines N.S.W. Rept. No. 11

ALTSCHULER, Z.S., JAFFE, E.B., & CUTTITA, F., 1956 - Geology of uranium and thorium. Proc. Int. Conf. Peaceful Uses of Atomic Energy, Geneva 1955, vol. 6.

ANDREWS, E.C., 1910 - The Forbes-Parkes Goldfield. Dept. Mines N.S.W. Geol. Surv. Min. Res. No. 13.

ANDREWS, E.C., 1938 - The structural history of Australia during the Palaeozoic. J. Roy. Soc. N.S.W., vol. 71.

BANKS, M.R., 1957 - Middle and Upper Cambrian in Tasmania. In Opik & others. The Cambrian geology of Australia. Bur. Min. Resour. Aust. Bull. 49.

BANKS, M.R., 1962 - The geology of Tasmania. J. Geol. Soc. Aust. vol. 9, pt. 2.

BARRIE, J., 1966 - The geology of Christmas Island Bur. Min. Res. Aust. Rec. (in preparation)

BASNETT, E.M., & COLDITZ, M.J., 1945 - General geology of the Wellington district, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 79.

BISSET, A.H., & GULLINE, A.B., - The Proterozoic - Upper Cambrian succession in west Tasmania. Aust. J. Sci. vol. 23, no. 10.

BOLLO, R., & JACQUEMIN, M., 1963 - La recherche de phpsphates par radiometrie aeroportee. Geophysical Prospecting, vol. 11, pt. 4.

BOOKER, F.W., 1944 - Prospecting for phosphate rock at Nandillyan, near Molong. Dept. Mines N.S.W. Minute 44/1813M (unpub.).

BROOKS, J.H., & others, 1960 - The geology of Queensland - Precambrian. J. Geol. Soc. Aust., vol. 7.

BROWN, I.A., 1928 - The geology of the South Coast of New South Wales, part 1. Proc. Linn. Soc. N.S.W., vol. 53.

BROWN, I.A., 1930 - The geology of the South Coast of New South Wales, part 2. Proc. Linn. Soc. N.S.W., vol. 55.

BROWN, I.A., 1933 - The geology of the South Coast of New South Wales, with special reference to the origin and relationships of the igneous rocks. Proc. Linn. Soc. N.S.W., vol. 58.

BROWN, P.M., 1958 - The relation of phosphorites to ground water in Beaufort County, North Carolina. Econ. Geol. vol. 53.

BROWNE, I.A., 1955 - A study of the Tasman Geosyncline in the region of Yass, New South Wales. J. Proc. Roy. Soc. N.S.W., vol. 88.

BROWNE, I.A., 1958 - Stratigraphy and structure of the Devonian rocks of the Taemas and Cavan areas, Murrumbidgee River, south of Yass, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 92.

BROWNE, W.R., 1947 - A short history of the Tasman Geosyncline of eastern Australia. Science Progress, vol. 35.

BROWNE, W.R., 1950 - see David, T.W.E., 1950.

BUSHINSKI, G.I., 1964 - On shallow water origin of phosphorite sediments. In van Straaten (ed.) Developments in Sedimentology, vol. 1. Deltaic and shallow marine deposits.

CAMPANA, B., 1961 - Comment on the note of Bisset and Gulline. Aust. J. Sci., vol. 23, no. 10.

CARD, G.W., 1896 - Mineralogical and petrological notes. Geol. Surv. N.S.W. Rec., vol. 4, pt. 1

CAREY, S.W., 1953 - Geological structure of Tasmania in relation to mineralization. Fifth Emp. Min. Met. Congr., vol. 1. Geology of Australian ore deposits.

COUPER, J., 1965 - Late Silurian to early Devonian stratigraphy of the Yea - Molesworth district, Victoria. Proc. Roy. Soc. Vic., vol. 79, pt. 1.

DAVID, T.W.E., 1950 - (ed Browne, W.R.) Geology of the Commonwealth of Australia. London.

DAVIDSON, C.F., & ATKIN, D., 1953 - On the occurrence of uranium in phosphate rock. XIXth. Int. Geol. Congr. Section 11, pt. 11.

DENMEAD, A.K., 1928 - A survey of the Brisbane Schists Proc. Roy. Soc. Qld., vol. 39

DUNN, E.J., 1907 - The Edi turquoise field, King River. Geol. Surv. Vic. Rec., vol. 2.

FAIRBRIDGE, R.W., 1953 - Australian Stratigraphy Nedlands, W.A.

FLETCHER, H.O., 1964 New linguloid shells from Lower Ordovician and Middle Palaeozoic rocks of New South Wales. Aust. Mus. Rec., vol. 26, no. 10.

GARDNER, L.S., 1944 - Phosphate deposits of the Teton Basin area, Idaho and Wyoming. U.S. Geol. Surv. Bull. 944-A.

GULSON, B.L., 1963 - Geology of an area S.E. of Jenolan Caves, N.S.W. Univ. N.S.W. B. Sc. Hons. thesis (unpub.)

HARRIS, W.J., & THOMAS, D.E., 1938 - Notes on the geology of the Howqua Valley. Min. Geol. J., vol. 1, no. 2.

HARRIS, W.J., & THOMAS, D.E., 1940 - Notes on the geology of the Upper Goulburn Basin. Ibid., vol. 2, no. 3.

HARRIS, W.J., & THOMAS, D.E., 1942 - Geology of the Upper Goulburn Valley. Ibid., vol. 2, no. 6.

HILLS, C.L., 1924 - An outline of the economic geology of Tasmania. Proc. Aust. Inst. Min. Met., vol. 52.

HILLS, E.S., & THOMAS, D.E., 1954 - Turbidity currents and the graptolitic facies in Victoria. J. Geol. Soc. Aust. vol. 1.

HOWITT, A.M., 1906 - Report on the Edi-Myrrhee turqoise belt. Geol. Surv. Vic. Rec., vol. 1 pt. 4.

HOWITT, A.M., 1923 - Phosphate deposits in the Mansfield District. Geol. Surv. Vic. Bull. 46.

HUGHES, T.D., 1957 - Limestones in Tasmania. Geol. Surv. Tas. Min. Res., no. 10.

JONES, H.A., 1964 - Phosphate deposits in Abeokuta Province. Geol. Surv. Nigeria Rec., vol. 7.

JOPLIN, G.A., 1945 - Petrological studies in the Ordovician of New South Wales. III. Proc. Linn. Soc. N.S.W., vol. 70.

JOPLIN, G.A., & CULEY, A.G., 1938 - The geological structure and stratigraphy of the Molong-Manildra district. J. Roy. Soc. N.S.W, vol. 71.

JOPLIN, G.A., & others, 1952 - A note on the stratigraphy and structure of the Wellington-Molong-Orange-Canowindra region. Proc. Linn. Soc. N.S.W., vol. 77.

KEBLE, R.A., 1950 - The Mornington Peninsula Geol. Surv. Vic. Mem. 17.

KELLING, G., 1964 - The turbidite concept in Britain. In Bouma, A.H. & Brouwer, A. eds. Developments in sedimentology vol. 3. Turbidites.

KRAUSE, F.M., 1896 - An introduction to the study of mineralogy for Australian readers. Melbourne.

LINDNER, A.W., 1953 - The geology of the coastline of Waratah Bay between Walkerville and Cape Liptrap. Proc. Roy. Soc. Vic., vol. 64.

MATHESON, A.J., 1930 - The geology of the Wellington district, N.S.W., with special reference to the origin of the Upper Devonian series. J. Proc. Roy. Soc. N.S.W., vol. 64.

McKELVEY, V.E., 1966 - Successful new techniques in prospecting for phosphate deposits. (Reprinted in) Australian Mining, 15 March 1966.

NYE, P.B., 1943 - Phosphate deposits in Tasmania. Bur. Min. Res. Aust. Rec. 1943/28 (unpub.).

OPIK, A.A., 1952 - Interpretation of the stratigraphy of the Palaeozoic sedimentary rocks of the Adaminably tunnel lines, Snowy Mountains. Bur. Min. Res. Aust. Rec. 1952/12.

OPIK, A.A., 1957 - Cambrian palaeogeography of Australia. In: The Cambrian geology of Australia. Bur. Min. Res. Aust. Bull. 49.

OPIK, A.A., 1958 - The geology of the Canberra district. Bur. Min. Res. Aust. Bull. 32.

OPIK, A.A., 1961 - Cambrian and Ordovician sequence of the Mootwingee Range, north-eastern New South Wales. Bur. Min. Res. Aust. unpublished memorandum.

PACKHAM, G.H., 1958 - Stratigraphic studies in the older Palaeozoic rocks of the Tasman Geosyncline in central-western New South Wales. Univ. of Sydney Ph.D thesis (unpub.).

PACKHAM, G.H., 1960 - Sedimentary history of part of the Tasman Geosyncline in south-eastern Australia. XXI Int. Geol. Congr., pt. 12.

PACKHAM, G.H., & STEVENS, N.C., 1955 - The Palaeozoic stratigraphy of Spring and Quarry Creeks, west of Orange, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 88.

PETTERD, W.F., 1902 - The minerals of Tasmania. Papers & Proc. Roy. Soc. Tas. 1900-01.

PETTERD, W.F., 1910 - The minerals of Tasmania. Ibid., 1910.

PETTIJOHN, F.J., 1957 - Sedimentary rocks. New York.

PEVEAR, D.R., 1966 - The estuarine formation of United States Atlantic coastal plain phosphorite. Econ. Geol., vol. 61.

RONOV, A.B., & KORZINA, G.A., 1960 - Phosphorus in sedimentary rocks. Geochemistry No. 8.

RUSSELL, R.T., & LEWIS, B.R., 1965 - Gold and copper deposits of the Cobar district. Eighth Commonwealth Min. & Met. Congr., vol. 1. The geology of Australian ore deposits.

RYALL, W.R., 1965 - The geology of the Canowindra east area, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 98.

SINGLETON, O.P., 1965 - Geology and mineralization of Victoria. Eighth Commonwealth Min. & Met. Congr., vol. 1, The geology of Australian ore deposits.

SKEATS, E.W., & TEALE, E.O., 1918 - On a new phosphate deposit in the Howqua district, near Mansfield, Victoria. Proc. Aust. Inst. Min. Eng., no. 32.

SHELDON, R.P., 1964 - Exploration for phosphorite in Turkey - a case history. Econ. Geol., vol. 59.

SHELDON, R.P., - in press Exploration for phosphate in the eastern hemisphere.

SLANSKY, M., 1962 - Sedimentologie et recherche des gisements sedimentaires marins de phosphate. In Amstutz, G.C. ed. Developments in Sedimentology, vol. 2 Sedimentology and ore genesis.

SOLOMON, M., 1965 - Geology and mineralization of Tasmania. Eighth Commonwealth Min. & Met. Congr., vol. 1, The geology of Australian ore deposits.

SPRY, A., 1962 - The geology of Tasmania - Precambrian rocks. J. Geol. Soc. Aust. vol. 9, pt. 2.

SPRY, A., 1964 - Precambrian rocks of Tasmania. Part IV. The Zeehan-Corinna area. Papers Proc. Roy. Soc. Tas., vol. 98.

STANTON, R.L., 1955 - The Palaeozoic rocks of the Wisemans Creek - Burraga area, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 89.

STEVENS, N.C., 1950 - The geology of the Canowindra district, N.S.W. Part 1. The stratigraphy and structure of the Cargo - Toogang district. J. Proc. Roy. Soc. N.S.W., vol. 82.

STEVENS, N.C., 1951 - Id. Part II. The Canowindra - Cowra - Woodstock area. Ibid., vol. 84.

STEVENS, N.C., 1952 - Ordovician stratigraphy at Cliefden Caves, near Mandurama, N.S.W. Proc. Linn. Soc. N.S.W., vol. 77.

STEVENS, N.C., 1953 - A note on the geology of Panuara and Angullong, south of Orange, N.S.W. Ibid., vol. 78.

STEVENS, N.C., 1954 - Studies in the Palaeozoic geology of central-western N.S.W. Univ. of Sydney Ph.D thesis (unpub.).

STEVENS, N.C., 1957 - Further notes on the Ordovician Formations of central New South Wales. J. Proc. Roy. Soc. N.S.W., vol. 90.

STEVENS, N.C., 1959 - Palaeozoic geology of the Cooleman Caves district, New South Wales. Proc. Linn. Soc. N.S.W., vol. 83.

STEVENS, N.C. & PACKHAM, G.H., 1953 - Graptolite zones and associated stratigraphy at Four Mile Creek, south-west of Orange, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 86.

STRUSZ, D.L., 1959 - The geology of the parish of Mumbil, near Wellington, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 93.

SUSSMILCH, C.A., & STONE, W.G., 1915 - Geology of the Jenolan Caves district. J. Roy. Soc. N.S.W., vol. 49.

TALENT, J.A., 1959 - Notes on Middle Palaeozoic stratigraphy and diastrophism in eastern Victoria. Min. & Geol. J., vol. 6.

TALENT, J.A., 1963 - The Devonian of the Mitchell and Wentworth Rivers. Geol. Surv. Vic. Mem., no. 24.

TEALE, E.O., 1919 - Diabase and associated rocks of the Howqua River area. Proc. Roy. Soc. Vic., vol. 32.

TEALE, E.O., 1920 - A contribution to the Palaeozoic geology of Victoria. Ibid., vol. 32.

THOMAS, D.E., 1939 - The structure of Victoria with respect to the Lower Palaeozoic rocks. Min. Geol. J. vol. 1.

THOMAS, D.E., 1947 - The geology of the Eildon Dam Project. Geol. Surv. Vic. Mem., no. 16.

THOMAS, D.E., & SINGLETON, O.P., 1957 - The Cambrian stratigraphy of Victoria. In Opik, A.A. & others. The Cambrian geology of Australia. Bur. Min. Res. Aust. Bull., no. 49.

TWELVETREES, W.H., 1917 - Phosphate deposits in Tasmania. Geol. Surv. Tas. Min. Res., no. 3

VOISEY, A.H., 1959 - Australian geosynclines Aust. J. Sci., vol. 22

WALKER, D.B., 1959 - Palaeozoic stratigraphy of the area to the west of Borenore, N.S.W. J. Proc. Roy. Soc. N.S.W., vol. 93.

WALPOLE, B.P., 1952 - Wee Jasper - Cooleman caves area. Bur. Min. Res. Aust. Rec. 1952/63 (unpub.).

WARNER, R.A., & HARRISON, J., 1961 - Discovery of Middle Cambrian fossils in New South Wales. Aust. J. Sci., vol. 23.

WELLS, B.E., 1956 - Geology of the Casterton district. Proc. Roy. Soc. Vic., vol. 68.

WHITELAW, O.A.L., 1916 - The topography, geology, and mines of the Woods Point district. Geol. Surv. Vic. Mem., no. 13.

WILD, A., 1958 - The phosphate content of Australian soils. Aust. J. Agric. Res., vol. 9.

YOUSSEF, M.I., 1965 - Genesis of bedded phosphates. Econ. Geol., vol. 60.