In acknowledging the honour the Council of the Royal Society of New South Wales has conferred upon me in inviting me to deliver the Clarke Memorial Lecture, I would express the hope that, as well as placing before you a somewhat specialized subject, I may also be able to convey to you something of Clarke's versatility in geological science. Because of public interest and demand in the 1860's he perforce had to turn from geology, somewhat unwillingly at times one suspects, to mineralogy and devoted considerable attention to the gemstones of New South Wales, particularly diamonds. Clarke (1870) in his Anniversary Address to this Society, states that thousands of gemstones were being submitted to him for identification and that at times he was almost overwhelmed with letters and visitors on the subject. He was scathing about the treated fragments of bottle stoppers and other glass objects sent in at times. He evidently considered that this was done intentionally because he speaks of "the glass grinders who were sometimes more transparent than the material they manipulated", in contradistinction to the many genuine diggers who were merely mistaken and not impostors.

Clarke himself was not optimistic about the future of the gemstone industry in New South Wales. Although at the time of his death in 1878 few of our gemstone resources were known it must be made clear that, despite the variety and interest of our gemstones, no large or lucrative industry has been established. His advice to intending diamond prospectors might well serve for any prospector at any time. It is as follows—"Without wishing to dishearten any diligent man who, while anxious to serve himself, is doing his utmost to develop the resources of the country, it is surely right to warn any who have only their personal labour and privations to look to, against embarking in a search which to be successful requires ample means and union of energies and machinery" (1870). Also when informed of a discovery of sapphires near Armidale he remarked "I think our friends in New England would do better to seek for tin lodes" (1869).

On the other hand it is to be remembered that because gemstone mining was invariably carried out by individuals or small parties, an understandable secretiveness developed and official Mines Department statistics always under-estimate the true output. It is intended now to present a systematic account of New South Wales gemstones providing a brief summary of accumulated knowledge up to the present and in addition draw attention to new discoveries that have come to light since the valuable contributions of Liversidge (1888), Curran (1896), Pittman (1901) and Smith (1926).

Numbers prefixed by the letter D: are the registered numbers of Australian Museum specimens.
Diamond.

Localities. Diamonds have been found in numerous localities in New South Wales. Although mention had been made of diamonds by Hargraves (1851) and Stutchbury (1851) the first reliable identifications were made by Clarke (1860) who recorded and described six undoubted diamonds that had been brought to him; four from Sutter's Bar on the Macquarie River, one from the mouth of Pyramul Creek and one from Cahula Creek. Clarke was also the first to mention diamonds from Bingara.

The three most important diamond fields were discovered in rapid succession soon after. In 1867 a gold rush to Two Mile Flat on the Cudgegong River some 19 miles north-west of Mudgee led to the discovery of diamonds. They occurred in isolated patches of an ancient river drift, Pliocene in age. These ancient drifts known as deep leads were found 40 feet above the present bed of the Cudgegong River. This phase of the operations ended in 1870. Operations were resumed for a year in 1916 with small returns.

The Bingara Field about 5 miles west south west of Bingara was discovered in 1872 and fully reported on and mapped by Anderson (1887). The diamond bearing gravels at Two Mile Flat are Pliocene in age. Work on the field flagged considerably in 1873 because there was little interest in the stones on account of their smallness and unsuitability for jewellery. Small scale production was resumed mainly on the Monte Christo claim, and continued for some years but seems finally to have ceased in 1904.

Wilkinson (1875) made the first mention of Copeton or Boggy Camp, the most important field. Unlike Cudgegong and Bingara, diamonds were first found in recent alluvial deposits by tin miners. Subsequently it was discovered that they had been washed from nearby Pliocene stream gravels, which are frequently basalt capped and are the main source of the diamonds. As one would expect in these deep leads the alluvial deposits fall naturally into four zones, the bottom one consisting of coarse gravels known as the wash containing the bulk of the diamonds; secondly the medium sized sands and gravels known as the drift which constituted the main bulk of the deposits; thirdly, fine mud and clay, and lastly a deposit of vegetable debris on top. Sometimes the wash is so indurated by a ferruginous cement that crushing cannot be undertaken for fear of shattering the diamonds. For example at Staggy Creek and Malacca two of the diamond localities near Copeton the wash consisting of waterworn quartz, feldspar fragments, and black tourmaline is exceedingly firmly consolidated in a hard ferruginous matrix. On the other hand less ferruginous and more friable examples of the wash are known, as at Round Mount.

Anderson (1887) first mapped the sporadic deposits of diamond bearing wash and later Cotton (1914) modified and amplified this work and traced two branches of an ancient river for some 14 miles in all which in former times had flowed in a northerly direction towards Inverell, thus disproving a contention of previous workers that since Copeton diamonds are bigger than Bingara diamonds the main Tertiary stream must have flowed west from Copeton to Bingara. Production of diamonds at Copeton dwindled markedly after 1904 then again after 1922, and excepting a small resurgence during the War when African diamonds were scarce, has gradually become negligible.

Diamonds have been discovered and mentioned in other parts of New South Wales. At no great distances from Copeton diamonds have been found on Bora Creek and at Tingha. Wilkinson (1876) mentions the occurrence at Muckerawa near Stuart Town. Liversidge (1888) reported them from Oberon, Trunkey, the Lachlan River, the Abercrombie River and various localities in the Hill End district. A few stones were found in an alluvial deposit on Mount
MacDonald, near the Lachlan River some 16 miles east of Cowra (McLachlan, 1901). In the collection of the Australian Museum are three diamonds (D:34593) two of them yellow, from the "upper Lachlan River". A few diamonds have been mentioned from the Crookwell River. Two localities aroused more than passing interest some fifty years ago. These were certain areas in the vicinity of Mittagong (Curran, 1896) and Mount Werong (Pittman, 1905). A diamond weighing 28½ carats was stated to have been found at this latter locality and the stone was actually identified and inspected by the Mines Department. A certain amount of mining was done in each place for a short while. It seems however that nothing further was reported after the initial discoveries so that there are good grounds for suspecting that the diamonds produced as evidence did not actually come from these localities.

![Text-fig. 1.—Diamond localities on or near the Macquarie, Cudgegong and Turon Rivers and their tributaries. (X) marks Calula Creek from which Clarke identified a diamond from an indefinite locality.](image)

One very interesting feature of recent years has been the recovery of diamonds by Wellington Alluvials Ltd., in their gold dredge on the Macquarie River some ten miles south-east of Wellington. This is the only locality in New South Wales for some years whose yield of diamonds has been of any economic significance. Starting with a production of 130 carats in 1950 the figure for 1954 up to the end of September was 1301 carats. There are two types of stones. A hard "Australian type" diamond corresponding to those from Copeton and a softer diamond, equivalent in hardness to the South African stones. The hard types show no particular crystal shape. Of the stones showing crystal shape the commonest forms are octahedra and flattened octahedral twins. Some show very sharp edges and corners and probably originate near Wellington. The stones range from straw to clear blue-white, all intermediate shades being represented. They are associated with plentiful corundums of no commercial value. The diamonds are essentially industrial
stones but about 5% can be cut as gemstones. It is of interest to note that the present site of this dredging is quite near Suttor's Bar, one of the localities from which Clarke originally recorded diamonds. Those localities already mentioned on or near the Macquarie, Cudgegong and Turon Rivers no doubt have contributed to the concentration of diamonds now being worked.

**Origin.** Considerable interest in the past has been evinced concerning the origin of the diamond in New South Wales. Taylor and Thompson (1870) in their description of the Cudgegong field expressed the view that the diamond had originated in the ancient drift itself. This seems to have been based on the following evidence—1. Diamonds are only found in the present bed of the Cudgegong where gold diggers had previously discharged the older Pliocene drift into the river. 2. The diamonds are never waterworn whereas the associated gemstones are. 3. The diamonds are not uniformly distributed in the drift as the other gems but generally occur in rich patches. Clarke (1870) seems to have given this view some credence stating “... infiltration, decomposition and reconstruction of carbonaceous materials of whatever age under the influence of chemical transformation may be producing diamonds at this moment where the needful conditions exist.” Originally Wilkinson (1887) subscribed to this view but after having personally examined the Copeton occurrence he came to the conclusion that the diamonds had originated in the nearby metamorphosed Palæozoic sediments.

In 1870 diamonds were discovered in a basic igneous rock forming the filling of volcanic necks at Kimberley, Orange Free State, South Africa. This notable discovery strengthened the belief that perhaps basic and ultrabasic rocks might be the original source of the diamond in other parts of the world. Twelve miles south of Bingara at Ruby Hill, a volcanic pipe containing fragments of breccia was described by Pittman (1901) and Card (1902). In 1889 a few diamonds were supposed to have been recovered from the breccia. Interest became keener when eclogite fragments were identified later on because shortly before, Bonney (1900) in England had described small diamonds embedded in a fragment of eclogite one of the constituents of the volcanic breccia in South Africa. No further finds of diamonds, however, were made at Ruby Hill.

In 1904 Messrs. Pike and O'Donnell were prospecting a basalt covered deep lead at Oakey Creek on the Copeton field. While driving a tunnel under the basalt, three dykes of decomposed dolerite were encountered. In those parts of the nearby wash which were richest in diamonds an abundance of dolerite fragments were found. Subsequently a diamond was discovered embedded in solid dolerite. Pittman (1904) stated that it was embedded to the extent of two-thirds of its bulk. It was also stated that another diamond was found in a heap of dolerite that had weathered in the open and that indentations on the surface of this second diamond contained fresh dolerite. A good deal was written on this discovery by Pike and David in various newspapers at the time. It was taken abroad by David (1906a, 1906b) and shown to various eminent geologists at the British Association for the Advancement of Science meeting and the International Geological Congress meeting in Mexico, none of whom had any doubts about its authenticity. Cotton (1914) was also convinced of the genuineness of the specimen. These are the facts connected with this discovery and while it must be admitted that general doubts are expressed by geologists and mineralogists at the present day, this may be because of the entire absence of confirmatory evidence following the initial discovery.

**Associated Minerals, Quality and Size.** In the deep leads diamonds are associated with waterworn fragments of other minerals such as pleonaste, topaz, quartz, zircon, black tourmaline, garnet, cassiterite, spinel and rarely sapphire. Various colours have been noted. The most common colour is a not very
pronounced yellow, actually an off-colour. Sometimes they are a pronounced yellow. Porter (1898) recorded purest white, black, bronze, blue tint, green tint, rose, deep and light orange, lemon and straw. It was stated by Davies and Etheridge (1886) that defects such as "black specks", "cleavage", macles (or twinned xls) and "flats" were found less often than in Cape diamonds. This meant that in general New South Wales stones were of good quality. However they were generally small. Although it was stated that one 5½ carat stone was found at Cudgegong, over the whole field the average number to the carat was four stones. At Bingara the average was five per carat and in places the stones were so small that the average per carat was 20. The Copeton stones in general were larger, frequently averaging three per carat. T. Heath of Copeton in a personal communication states that the largest diamond was an eight carat fractured white. He also mentions a 12 carat piece of bort. However, on account of their superior hardness they came to be sought mainly for industrial purposes. Relatively few gems have been cut and these mainly in the early days of production.

Hardness. Atkinson (1886) first stated that New South Wales diamonds were harder to cut than those from elsewhere. This was apparently noticed as stones from Bingara first reached the London market. This report did not state whether the difficulty was encountered in sawing or grinding. This has been generally accepted as a fact and some confirmation of their superior hardness has come from the experience of Australian industry during the war. (Chalmers, 1946). One cannot be absolutely definite on the basis of such general statements, because hardness in diamond is a vector property, that is it varies with direction and no properly designed experiments based on rate of cutting and grinding or on the degree of micro-indentation have been carried out on New South Wales diamonds. One reads contradictory statements in literature. Kraus and Slawson (1939) state generally that it is impossible to cut, grind or polish diamond in a direction parallel to the octahedron faces. On the other hand Grodzinski (1952) has found it extremely difficult to saw New South Wales diamonds in a direction parallel to the cube face, yet in abrasion tests on ordinary scaifes approximately in a cube plane these diamonds were no more resistant than Brazilian stones. He expresses the opinion that the greater resistance of New South Wales stones may be because they are full of small "naats" (knots) which owing to their different orientation may hinder the polishing action.

Opal

Prior to the discovery of the extensive fields of Queensland, New South Wales and South Australia, isolated occurrences of precious opal in small areas were known only from Czechoslovakia (formerly Hungary), Mexico and Honduras. For many centuries dating back to the time of the Romans it was known only from Hungary and was highly prized. All these occurrences are in igneous rocks.

Localities. In New South Wales there are three isolated occurrences of precious opal in igneous rocks. The opal deposit seven miles west of Trunjey on Rocky Bridge Creek a tributary of the Abercrombie River, was reported on by Wilkinson (1877) who stated that the matrix was a soft decomposed vesicular basalt, and by Curran (1896) who regarded it as an acidic or andesitic lava. H. F. Whitworth informs me that specimens in the Mining Museum examined by Card are certainly olivine poor Tertiary basalt. L. J. Lawrence has shown me a specimen in which light coloured common opal, showing occasional play of colour fills vesicles averaging 5mm. in length, in a light grey friable rock which, though very decomposed, in thin section is seen to be a basalt. Obviously it can be said that the matrix is variable. The field is of no economic significance.
Pittman (1907) noted the occurrence of precious opal filling vesicles in trachyte at Tooraweanah, Warrumbungle Mountains.

In 1901 opal from Tintenbar, five miles north-west of Ballina was first noted but it was not until 1919 that the field was discovered to have serious possibilities. Precious opal occurs in cavities in a decomposed basalt and also as pieces varying in size from a pea to a large walnut, loose in the soil where they have been detached from the parent rock by weathering (Morrison, 1919). In Tintenbar opal the colours stand out in a transparent matrix but the marked tendency of the stone to craze, before very long led to the cessation of all work on the field.

In the principal opal fields of New South Wales the occurrence is quite different and of a type noted nowhere else in the world. It occurs in sediments of lower Cretaceous age and is unconnected with any igneous activity. All these sedimentary occurrences whether in Queensland, New South Wales or South Australia have certain features in common. The opal deposits are found dominantly in beds of clayey sandstone always in arid or semi-arid regions in plain country broken only by low flat topped hills. The deposits are seldom found at depths below the surface exceeding 100 feet. It might be mentioned in passing that the matrix of Queensland opal differs from that of the other two states due no doubt to the fact that in Queensland the age of the host rocks is Eyrian (Early Tertiary). These overlie the Cretaceous rocks unconformably. A most notable feature of opal, is that unlike most other gemstone occurrences these opaliferous sediments extend over vast distances. Known opal deposits in New South Wales occur over an area of some 2,000 square miles but of course not all of the opal is the precious variety.

At White Cliffs, where opal was first discovered in 1889, a thin bedded fine grained siliceous sandstone occurring at depths of from 25 to 40 feet below the surface is the important marker horizon although it carries no opal. This “bandstone” as it is called is both underlain and overlain by a fine grained clayey sandstone. In the underlying beds the greatest abundance of opal is found. The precious opal is found in thin veins of potch or common opal. It is distributed quite irregularly within the potch horizons which follow the bedding planes of the sandstone and also fill joints. Precious opal also is found replacing the fossil fauna of the Cretaceous sediments. Invertebrate forms thus completely replaced include molluscs (both pelecypods and brachiopods), crinoids, belemnites, the internal skeleton of Cretaceous cuttle-fish and vertebrate remains such as teeth, ribs and limb bones of Cimiliosaurus a small form of the well known Plesiosaurus, a marine reptile equipped with paddle-like limbs as a means of propulsion. Opalized wood is also found.

Opal pseudomorphous after other minerals also occurs, the best known examples being the well known opal “pineapples” in which the opal has replaced the mineral glauberite (Anderson and Jevons, 1905).

At Lightning Ridge, originally known as Wallangulla, most noted for black opal, at which organized mining began in 1903, the host rock is the same as at White Cliffs but here there are four separate levels of the silicified “bandstone” and beneath each one is the white clayey sandstone containing the precious opal. Here, instead of occurring as seams and joint fillings, as at White Cliffs, it is found principally as isolated nodules known as “nobbies”. These are usually most abundant near the roof of each “level” of the host rock, known to the miner as opal dirt. Many of these nobbie have the form of a miniature volcanic peak and show well marked striations. O. le M. Knight (personal communication) expresses the opinion that these were called “nobbies” by the miners because of this prominence or “nob”. One gets the strong impression that these are replacements of organic forms but no suggestion has yet been
made by palæontologists as to what the original form might have been. In some parts of the field, shafts have been sunk as deep as 90 feet.

White Cliffs and Lightning Ridge are the only two New South Wales opal fields of importance. With these must be included their logical extensions such as Purnanga some 40 miles north of White Cliffs and Grawin some 29 miles south west of Lightning Ridge. However, Lower Cretaceous sediments cover large areas in the north-west of the state. Traces of precious opal have been recorded in outlying parts of the state such as at Milparinka (Slee, 1895). The Australian Museum has in its collection opal specimens from Brindagabba near Hungerford on the Queensland border. All this evidence suggests that careful prospecting might disclose other opal bearing areas in the state.

Mode of Formation. Under the climatic conditions prevailing in Lower and Middle Miocene time in the Tertiary, widespread lateritization took place in Australia particularly in the inland parts of the continent. Much silica was released in the process. The most marked climatic feature was the alternation of tropical wet and dry seasons. In the wet periods the water table was lowered and because it was an era of almost perfect peneplanation and consequent poor drainage, the groundwater remained in constant contact with the underlying rocks and exercised its maximum solvent action. In the dry periods capillary action brought dissolved silica and other substances to the surface where they were deposited and replaced other rocks to form the dense hard siliceous deposits named the duricrust by Woolnough and popularly known as "grey billy" or "billy", that cover vast areas of inland Australia. This was originally thought to be of Cretaceous Age and was called the Desert Sandstone, but is now considered to have formed in the Miocene. An admirable summary of these matters is given by Kenny (1934).

During the passage to the surface of these solutions, silica in colloidal form, that is silica gel, was deposited in favourable environments in the Cretaceous or Tertiary sediments through which they passed. This eventually consolidated to form opal. There is no direct evidence of what caused the formation of the silica gel in nature. Kenny (1934) has suggested that the original clay content of the replaced rocks may have dissociated into bauxite and opaline silica, or that the clay may have acted as a precipitating agent for silica. Leechman (1951a) has pointed out that on the basis of the great number of experiments that have been carried out by various workers on the formation and nature of silicic acid gels it could have been due to the ascending solutions of silicates in the groundwater coming into contact with descending acidic solutions. Dwyer and Mellor (1934) as result of X-ray studies of the structure of opal have shown that opal formed from groundwaters such as White Cliffs and Lightning Ridge have not been subjected to heat during their geological history so that it can be assumed that all solutions involved were of a low temperature type.

Solidification of the silica gel then took place as evaporation proceeded, but the greater part of the opal so formed is "potch" or common opal. Leechman (1951a) has dealt very fully with the influence that the nature and concentration of solutions has on the formation of common opal and those types of "potch" that show the first traces of colour patches. Here we are only concerned with precious opal that shows the well known brilliant play of colours. It can be said with certainty that a very long period of gelation is required to give time for incipient crystallization to begin within the gel.

Play of Colours. There is a long standing belief that opal is amorphous i.e. lacks any trace of internal crystalline structure. This statement is still found in text books and is still taught to students. However, as long ago as twenty years, X-ray studies by Levin and Ott (1932, 1933), and Dwyer and Mellor (1932) showed that opals contain crystallites of cristabolite one of the
naturally occurring forms of silica. It is also still stated that the play of colours in opal are interference colours caused by the presence of minute cracks within the opal that developed during the contraction of the gel as it solidified. Leechman (1951b, 1954) pointed out that whereas interference colours are a mixture of various colours in the spectrum which remain when one particular component colour is eliminated, the colours of an opal are monochromatic that is, they are pure single colours not mixtures of colour, which suggests that they are due to white light being broken up into its component colours. Raman and Jayaraman (1953) have shown by X-ray examination that, as Leechman had already suggested, the key to the explanation of the cause of the colours is the finely stratified nature of crystalline structures within the opal. They have shown that these structures consist of alternate layers of two crystalline modifications of silica of slightly different refractive indices. These modifications are low-tridymite and high-cristobalite. Spectroscopic examination of the play of colours reflected from these stratified structures prove them to be pure monochromatic hues, and therefore not caused by interference. It is pointed out that the high degree of perfection of the reflections from opal show that the alternate layers occur in great numbers and are spaced regularly, the magnitude of the spacing being of the same order as the wave length of light. The magnitude of the spacing indeed corresponds more to the smaller wave lengths of light which explains why the smaller wave length colours, violet, blue and green are seen more frequently than the higher wave length colours, red and orange. One of the most convincing proofs that the colours of opal are caused by the inherent structure of the mineral was first afforded by Dwyer and Mellor (1932) who found that heating opal at 1000°C for eight hours did not destroy the colours. Raman and Jayaraman proved this also by heating opal to such an extent that it disintegrated and yet the colours were not destroyed.

Unfortunately Raman and Jayaraman are not very explicit about the localities of the opal specimens examined. Dwyer and Mellor (1932) found that a very definite X-ray pattern due to high-cristobalite was found in New South Wales opal of volcanic origin from Rocky Bridge Creek and Tintenbar. This indicates a higher temperature of formation than in those from groundwater solutions, as one would expect. However, there is no doubt that crystalline structures do exist in the latter type as well, even if more rudimentary. Raman and Jayaraman have stated that because of the diffuseness of the X-ray patterns in gem opal, and one assumes he is speaking of our Australian opal formed from ground waters, the task of identifying the layered tridymite-cristobalite structures is more difficult.

It is thus clear that before opal can form, a number of highly critical conditions have to be fulfilled and hence noble opal takes its place amongst the precious stones because of its comparative rarity, even though it may lack durability.

It is not intended to deal with the history of the New South Wales fields. The fascination of opal has given rise to popular informative books on the subject to which the reader is referred (Wollaston, 1924, and Murphy, 1948). Croll (1950) deals with the history, economic aspects and marketing. A good account of the history of Lightning Ridge with a detailed map is given by Knight (1953).

SAPPHIRE.

Stutchbury (1851) mentioned sapphire from the Cudgegong River. Clarke (1853) mentioned sapphire (including the green variety) as occurring generally in New England particularly in Tilbuster Creek. The numerous localities from where sapphire has been noted in New South Wales are listed by Liversidge (1888), Curran (1896) and Pittman (1901). As in the case of diamond, sapphires
are found either in deep leads of Tertiary age frequently capped by basalt, or in recent deposits derived from the denudation of the Tertiary leads. The most important locality is Sapphire, in the New England district some 15 miles north-east of Inverell. Other important localities are Bingara, Cope's Creek, Dundee, Glen Elgin, Gwydir River, Nundle, Peel River, Oban, Puddledock, Emmaville, Tingha, Abercrombie River, Two Mile Flat, Oberon and Mount Werong.

The first commercial mining seems to have been undertaken by C. L. Smith on his property at Argyle, near Sapphire in 1919 (Cambage, 1919). Prior to this, however, occasional stones had been sent out for cutting by such enthusiastic and discerning collectors of minerals and gemstones as the late D. A. Porter and the late George Smith. The principal sapphire bearing ground has been proved for a distance of one mile along a dry stream bed. They are found on the surface and down to a depth of three feet to four feet the average thickness of payable dirt being 18 inches to two feet. It is probably that most of the material has been redistributed by the erosion of Tertiary deep leads. Associated gem minerals at Sapphire are pleonaste and yellowish-brown to colourless zircons. Zircons are the most common associated minerals from all New England localities.

An early report of Curran's that a sapphire had been found embedded in basalt has been substantiated by other discoveries but there is always the possibility that they may have been caught up by molten basalt flows the eruption of which was later than the formation of the deep leads.

As Pittman has pointed out sapphire of first class gem quality occurs but rarely in New South Wales. Pure blue stones have generally such a deep tint that they appear almost opaque when cut. At Sapphire in addition to dark blue stones, parti-coloured blue and green, blue and yellow, and green and yellow stones are found. Quite attractive golden yellow stones are also found. Some bluish green stones in the collection of the Australian Museum collection were not entirely clear but had rather a misty appearance. A number of stones from Reddistone Creek, eight miles west of Glen Innes were examined and had the same general characteristics as the stones from Sapphire. A cursory microscopic examination of the small number of cut stones available showed such features as minute vesicular inclusions symmetrically arranged, hair-like crystals of rutile and colour banding, but further work would have to be done before any of these could be established as positive diagnostic characteristics for New South Wales stones.

While most sapphire come from the New England district there are other localities mentioned by Liversidge (1888) and Curran (1896), such as Tumberumba and Wingecarribee River.

Curran made special mention of opaque to translucent bronze coloured chatoyant corundum at Wingecarribee. In recent years material of this type from Anakie, Queensland, which when cut provides black star sapphires, has aroused a great deal of interest in America. It is interesting therefore to note that such material occurs not only at Wingecarribee but at practically every locality where gem-quality transparent sapphire occurs in New South Wales. Recently a large flattened piece of opaque blackish-bronze chatoyant corundum weighing 1149 carats (7 1/8 oz.) was acquired by A. W. Rouse, a Sydney gemmologist. The exact locality has not been disclosed but it is definitely from New South Wales. This stone can be divided into three areas from each of which there is a possibility of cutting a large black star sapphire.

Ruby and Spinel

Ruby from Two Mile Flat was analyzed by Thomson, the result being given by Liversidge (1888), but in the absence of specific data it is impossible to vouch
for the correctness of the numerous references by earlier workers to these two gemstones.

No cut rubies from New South Wales are known to the writer. The occasional small waterworn fragments of pale pink transparent corundum that occur in gem gravels from localities such as Tumberumba—Jingellic (D:27773) and Burmah (Heiser's Mine), Sapphire (D:27772) are not true ruby. Fluorescence and specific gravity tests show it to be pink corundum. Small red octahedra of spinel mentioned by Smith (1926) are associated with the pink corundum fragments from these two localities and their identity has been confirmed by specific gravity tests. It seems certain that much of the material from the stream gravels stated in the past to have been spinel or ruby is actually garnet or zircon.

**BERYL AND EMERALD**

Beryl is a widespread mineral in the Emmaville and Torrington districts where it occurs in pegmatites associated with bismuth, wolframite, cassiterite, monazite, uranium minerals, quartz, feldspar and mica. The occurrence of beryl with special reference to gem material has been described by Smith (1926). The most transparent crystals were discovered associated with quartz, feldspar and mica at Hefferman's Wolfram Mine, three miles west of Torrington. Some fine pale yellowish green cut stones from this locality are in the collection of the Australian Museum. The largest (D:27793) weighs 73 carats and is remarkably free from flaws. Another deep green cut stone (D:15571) in this collection, though somewhat flawed, weighs 88.5 carats. It came from the Emmaville district. Waterworn-beryls are found in stream gravels in the New England district. Because of the columnar nature of the original crystals the waterworn pebbles have an elongated form. There is one crystal of gem quality golden beryl (D:31706) in the collection from Emmaville. There has never been commercial mining of beryl for gemstone purposes in New South Wales, but a short lived emerald industry on a very small scale was embarked upon in the Emmaville district some sixty-five years ago. The emeralds were first recognized by D. A. Porter in 1890, the locality being a tin mine known as de Milhou's Reef, M. L. 90, Ph. Wellington North, Co. Gough, 5 miles 70 chains, 12° east of north of Emmaville.

Small emerald crystals were noted in pockets which occurred at intervals in a dipping quartzose vein. Associated minerals were cassiterite, topaz, fluorite, arsenopyrite and quartz. The vein was mined in an endeavour to find these pockets at depth. A full description was given by David (1891). Three small scale ventures were attempted between 1890 and 1909 but only a few miners were employed at any one time. New South Wales emeralds are somewhat pale, compared to stones from Siberia, Colombia and South Africa. Under the Chelsea Filter they were pink, but a much paler tint than emeralds from these other localities. Tests with Clerici's solution showed the specific gravity to be less than that of Colombian emerald. The refractive index of New South Wales emeralds is 1.575 which is lower than that of Siberian and South African stones determined for comparison. The general rule is that pale emeralds, no matter what the locality, have slightly lower density and refractive index than deep coloured stones.

**TOPAZ.**

An early reference to topaz (Paterson, 1811) is so vague as to be valueless and so ambiguous that it seems likely that the specimens came from Port Dalrymple (Launceston) and not from New South Wales. Stutchbury (1851, 1853) recorded topaz from the Cudgegong and Castlereagh Rivers.
Like beryl, topaz is found either in situ or as waterworn fragments in the Emmaville-Torrington districts. It is found in pegmatites associated with granite intrusions. Associated minerals in situ are bismuth, fluorite, cassiterite, arsenopyrite, beryl and emerald. The most notable occurrence is in the stream gravels of the Oban River, Mitchell River and Nowlands Creek forming an area of considerable extent lying to the east of Guyra and Ben Lomond. This occurrence with special reference to gem material has been described by Smith (1926). While no steady mining of topaz seems to have been carried on, its interest as a gemstone was recognized. Sixty ounces of topaz were recorded as having been won presumably in conjunction with tin-mining (McLachlan, 1899).

There is a popular erroneous belief that all topaz is yellow and the fact that this misconception still prevails is an indication that our own magnificent Oban topaz is not nearly well enough known. Oban topaz is mostly light blue, brilliant and absolutely flawless, and large waterworn pebbles and crystals have yielded some superb stones of unusually large size. It may also be colourless and sometimes has a faint pinkish brown tint. The largest cut stone in the Australian Museum is a superb specimen (D:15768) weighing 184 carats (1.2 oz.). The largest crystal in the Museum collection (D:38854) weighs 1½ lb. It is a pronounced blue colour, and is only part of a large crystal stated to have come from Kerrabee, on the Goulburn River, 20 miles south of Merriwa but this is unlikely to be its original source. It may conceivably have come from Mudgee or Gulgong. Liversidge (1888) mentions portion of a blue-green crystal from Mudgee weighing several pounds, in the Melbourne Technological Museum, and two others of the same colour, one weighing 11oz. from Gundagai and the other from Gulgong weighing 1lb. 2oz. There is no detailed description of these occurrences in literature, and the fact that such outstanding specimens were once found at these localities is almost forgotten. Pale blue topaz under short-wave ultra-violet rays occasionally fluoresces a faint, patchy pale yellowish green.

**Zircon and Garnet.**

Zircon is particularly abundant in the gem gravels of the New England district. The following observations have been made on material in the Australian Museum collection. From Nundle the prevailing colour is yellowish brown ranging from very pale to very deep shades. Prisms and pyramids are seen on crystal fragments, but no marked cleavages are apparent. All
zircons from this locality fluoresce yellow under a short-wave ultra-violet lamp. The fainter the colour the brighter yellow and more luminous the fluorescence. The darker the stone the more dull and patchy the fluorescence becomes. Many waterworn fragments from more northern New England localities, Rocky River, Uralla, Bald Nob, Sapphire, and Inverell were also examined. Three principal colour varieties occur in each of these localities, deep red or deep reddish brown, brownish pink, and colourless to faint yellow. There is a gradation in colour from the deep red to brownish pink. The pale yellow to colourless varieties, under a short-wave ultra-violet lamp, fluoresce bright luminous yellow. The brownish pink stones fluoresce a golden brown, dull and patchy in appearance. The red stones do not fluoresce at all. The pale yellow to colourless varieties, predominate in material from Inverell. These frequently occur as slightly waterworn crystals showing prisms and pyramids. At times perfect basal and prismatic cleavages can be seen. Deep red to reddish brown varieties predominate in material from the Rocky River, Uralla, and in crystal fragments pyramids are the most prominent faces. A perfect basal cleavage and an imperfect prismatic cleavage are sometimes seen. All of these varieties showing the same types of fluorescence have been noted in gem gravels from Berrima and Trunkey. These zircon concentrates are obtained from streambeds, while washing for alluvial cassiterite, and the greater portion of them consist of fragments too small to cut as gemstones, but an occasional most attractive cut red or yellowish brown zircon from New South Wales is seen. The largest waterworn fragments (D:27764) each weighing 10 to 30 carats are from 12 miles south-east of Oban. They are dark red. Two contributing factors to the abundance of zircon are that it is a mineral of high specific gravity and would stay behind in the wash, and also it is a very stable mineral not subject to alteration. Other localities for zircon in the New England district are given by Porter (1888) and Smith (1926).

A few quite attractive cut stones of the garnet varieties almandine, pyrope and eossinite in the Australian Museum collection, all come from Oban. Both Porter (1894) and Curran (1896) have mentioned a locality 12 miles form Bingera on the Tamworth road, from which good pyrope garnets were cut. New England pyropes closely resemble the red zircons, and can easily be mistaken for them unless confirmatory tests are carried out. The occurrence of gem quality almandine in the Barrier Ranges seems to have first been recorded by Wilkinson (1887) who mentions it as occurring at Poolamucca, Corona and Silverton.

**Quartz.**

Smith (1926) has dealt fully with quartz occurrences, particularly in the New England district and much of this material would no doubt prove suitable for gemstones. Except where otherwise mentioned reference herein is made only to specimens in the Australian Museum collection.

**Rock Crystal.** Spectacular clear large crystals of quartz have been found in the past in various mines at Kingsgate, associated principally with bismuth and molybdenite. Miss F. S. Sachs, of the Australian Museum, formerly resident at Kingsgate remembers a 25lb. crystal of perfectly clear quartz from the Arsenic Shaft. She still has in her possession a clear flawless mass weighing nearly 2lb. from this shaft. While material of this quality would be eminently suitable for gemstones, no cut stones from this locality are in the Museum collection. The largest cut stone is from Oban and weighs 188 carats (1·2 oz.).

Fine groups of flawless transparent crystals come from the Conrad Mine, Howell and from Nundle.

An interesting occurrence of gem quality quartz was discovered in recent years by L. J. Lawrence, to whom I am indebted for the following information.
While crystallized quartz is generally not present in the Yerranderie lodes there were one or two places where small outcrops were prospected in the hope of finding sulphide ores. In one of these an early generation of imperfect quartz crystals has apparently grown in vughs in the lode material. Deposited on the ends of many of these imperfect crystals are a second generation of doubly terminated quartz crystals of perfect transparency and flawlessness. These can be collected loose in the dump of waste material from the excavation of the lode. Special attention is drawn to two fine crystals (D:38344–5) and a stone (D:38576) cut from another crystal.

**Brown and Yellow Quartz.** The principal varieties are citrine (light golden yellow) and cairngorm (deep brownish yellow) both perfectly transparent. Gradations of colour between these two extremes are also seen. Smoky quartz shows all these colours but in addition lacks perfect transparency mostly in only a very slight degree. The faint misty appearance is well known and can best be described as smoky. It is often difficult to decide by inspection before cutting whether the stone will be perfectly transparent or smoky. A waterworn pebble of pale brown smoky appearance from Kookabookara collected by A. E. Gardner furnished a fine perfectly clear citrine of 20 carats when cut.

Much of what is called smoky quartz from the New England district is really perfectly transparent brown quartz, with little yellow in it. It grades from light to dark, and it is incorrect to call it either citrine or cairngorm. O. le M. Knight has cut a fine 100 carat stone of pale brown quartz from a waterworn pebble which showed exactly the same colour before cutting. A number of coloured varieties are found at Oban including dark brown (D:13391), light brown with a suggestion of violet (D:30014) and pale yellow (D:13047–9). Medium brown crystals were found at Hart's Mine, Torrington (D:27107). Many fine groups of clear pale brown quartz, often associated with molybdenite came from Kingsgate. In two such groups (D:30276, D:31231) the crystals are quite large some measuring 6in. by 3in. A medium brown material, with a mere suggestion of violet, as in the material from Oban, comes from Maurer's mine, near Kingsgate and from Tingha. Light brown specimens also came from Tingha. Two notable cut specimens are light brown quartz (D:15682) weighing 147 carats from Oban and a striking deep golden brown cairngorm (D:20995) weighing 13 carats from Giant's Den near Bendemeer. In most of these localities waterworn pebbles as well as crystals are found.

[Text-fig. 3.—X near the Lachlan River is the Mount MacDonald diamond locality.]
has remarked that large crystals of smoky quartz are common almost throughout New England.

It should be noted that heat treatment of certain types of smoky and brown coloured quartz will produce citrine, but it is not known if this process has been applied to New South Wales varieties.

Amethyst. Notable occurrences are at Glen Elgin and Oban in the New England district. A fine cut stone (D:15684, weight 39 carats) comes from the latter locality. Curran (1896) mentions good specimens which provided fine cut stones from between Oberon and O'Connell's Plains. In latter years W. Nicholls, of Rylstone, collected amethyst from this same district, on Sidmouth Valley Creek, near Newstead, Tarana.

Text-fig. 4.—Gemstone localities in the southern part of New England. Giant's Den, an ill-defined locality, is regarded as part of the Watson's Creek tin field. Nundle is on the Peel River. The stream flowing north and north-west from Uralla is Rocky River. P.X is Puddledock.

Quartz with inclusions. Many attractive cabachons of rutilated quartz from Tingha are known. Smith (1926) has given a full list of the localities from which quartz containing inclusions of various minerals have been recorded. Most of these are represented in the Australian Museum collection. Special mention might be made of columnar crystals of black tourmaline included in medium brown quartz (D:27107) from Hart's Mine, Torrington, and the examples of molybdenite, bismuth, bismuthinite and arsenopyrite in quartz from Kingsgate.

TURQUOIS.

The only occurrence of this gemstone in the state is fully described by Curran (1896) from a locality near Bodalla on the South Coast. Ida Browne (personal communication) informs me that the turquois occurs in black cherts in the Wagonga series, tentatively regarded as Cambrian. She has given
further details of the location of the mineral in the Bodalla district. Two localities are mentioned, both in Ph. Wagonga, Co. Dampier. The first is 3\(\frac{1}{2}\) mile south 20° east of Wagonga Trig. Station. The other is 1\(\frac{1}{2}\) mile north of Mummuga Creek, Por. 171, north of Por. 28, about one mile upstream from the Prince’s Highway crossing of the creek.

Two small polished stones (D:10114) show it to be an excellent blue colour, devoid of any green tint and somewhat paler than the best Persian material.

**TITANITE**

Some years ago H. Hore of Broken Hill sent some yellowish green crystal fragments to H. F. Whitworth, of the Mining Museum, who identified the mineral as titanite. The writer has spent a few hours at the locality twice in recent years. The mineral occurs in an amphibolite mass on Huonville Station, some 11 miles south-east of Broken Hill. This amphibolite mass is shown on the Zinc Corporation geological map of the Broken Hill district (King and Thomson, 1953), the grid reference being 30,000 E : 46,000 S. Under the microscope the rock is seen to consist mainly of green to bluish-green hornblende. What small amount of plagioclase feldspar is present, is extensively altered to platy penninite and zoisite. A certain amount of prospecting has been done by numerous individuals, and all evidence of the original outcrop has been removed and a shallow excavation no more than 6 feet in depth and some 20 feet in diameter now exists. Some further digging in the excavation revealed a mass of unknown dimensions and shape that has intruded the amphibolite. For purposes of description it can be regarded as a pipe like mass. It is a mineral assemblage porous in nature, consisting principally of interlocking, slender, fresh, twinned albite crystals averaging 2mm. in length, transparent slender crystals of dark green epidote averaging 3mm. in length, magnetite and a large amount of yellowish green, pleochroic, fibrous, actinolite which has imparted a green colour to the assemblage. The actinolite has almost completely replaced a pronouncedly bluish-green hornblende. Remnants of this are scattered throughout the fibrous aggregates of actinolite. Microscopic examination shows small crystals of titanite also present. A good deal of this material has been excavated previously, and lies on dumps, and in this most of the actinolite has been removed by weathering. In the weathered mass the albite and epidote crystals are more easily visible. Associated with the albite-epidote-titanite assemblage are untwinned tabular crystals of albite ranging in length from 5mm. to 1·2cm. Crystals of 7mm. are quite common. These occur as compact masses in veins or as interlocking crystals apparently lining very shallow cavities. Calcite is associated with the albite in various ways. The most striking occurrence of calcite is in the form of large dark green cleavage masses found only on the dumps. The colour is imparted by an abundance of slender hair-like crystals of actinolite included in the calcite. Isolated crystals of the untwinned albite, of the same dimensions as above mentioned occur completely enclosed by the green calcite. These are often completely hollow only a thin outer shell remaining and in the cavities are deposited columnar crystals of epidote, and slender fibrous crystals of very pale yellowish actinolite. Platy masses of ilmenite intergrown with magnetite are occasionally found encrusting the calcite cleavage faces.

Associated with the albite-epidote assemblage are compact pale greenish-grey masses of very small calcite crystals with clayey material. Fibrous actinolite identical with that in the albite-epidote-titanite assemblage and lamellar chlorite masses are abundantly scattered throughout the matrix. The large untwinned albite crystals are also embedded in it. Actually large fragments of titanite were not seen in this matrix from the central pipe but were seen in whitish to yellowish earthy weathered fragments of it on the dumps.
One crystal of albite was noted with a small fragment of titanite attached. The titanite occurs in crystal fragments usually 4-8 mm. long but fragments 2-5 cm. are sometimes seen. It frequently has a tabular habit and is sometimes sandwiched in between platy masses of ilmenite intergrown with a little magnetite. The titanite is also recovered as loose fragments in the dumps and in the soil in the immediate vicinity of the excavation.

From its occurrence in the pipe it seems as though the calcareous clayey material may be deuteric in origin having infiltrated cavities in the porous albite-epidote-titanite assemblage. Small remnants of the latter are frequently embedded in it. On the other hand there is evidence of some of the calcareous material having been re-deposited at a much later period as a secondary travertine or kunkar by solution of the primary calcite by circulating groundwater. In one specimen it exhibited a compact nodular structure, undoubtedly secondary in nature. Near the surface in the sides of the excavation seams of earthy travertine have been deposited along joint planes in the amphibolite.

If, as seems likely, the calcareous clayey matrix is deuteric in origin and bearing in mind that the whole primary assemblage is not massive but porous in nature, it is conceivable that crystals of titanite, epidote, actinolite and albite loosely attached in their original matrix could have been removed by deuteric solutions and embedded as deposition took place. On the other hand if some of the calcareous matrix is secondary it is conceivable that near the surface of the outcrop, titanite, albite, epidote and actinolite could have been in a detached state due to weathering and could have been embedded in the travertine as it was deposited from solution.

The titanite is scarce and mostly translucent and flawed. An occasional fragment transparent enough to yield a gemstone is found. O. le M. Knight has been able to obtain three cut stones from fragments obtained after several hours of collecting. The largest is a yellowish green stone, 1 carat in weight, showing the characteristic pronounced fire due to its high dispersion.

Prehnite.

Although prehnite comes into the category of an ornamental stone rather than a precious or semi-precious stone, it is of considerable interest on account of the abundant occurrence of material suitable for cutting at Prospect, close to Sydney.

The Prospect intrusion is a multiple sill and much of its nature and its wealth of minerals has been revealed by extensive quarrying. After the intrusion of a basic magma which cooled quickly in contact with the overlying Wianamatta shales to form a fine grained olivine analcite basaltic phase, there occurred a further intrusion of a body of magma which cooled more slowly and separated into two phases due to gravitational differentiation. These two phases consolidated to form olivine analcite dolerite one being more olivine rich and basic than the other and possessing picritic affinities. This latter is a porous rock. In both of these phases a wealth of secondary minerals principally calcite, hydrated silicates and zeolites has been deposited from deuteric solutions. Most notable of all these is prehnite, Prospect being one of the world's most famous localities for this mineral. It occurs most frequently in botryoidal masses. These are often deposited in vughs and crevices in both of the two dolerite types. In one instance the picritic phase is seen to have suffered the most severe attack by the deuteric solutions. Most attractive rich green curved crystal aggregates of prehnite grading into true botryoidal structure, have almost completely replaced the dolerite, little being left of the matrix other than masses of earthy chlorite, occasional fragments of pyroxene and slender needles of apatite. In addition to varying shades of green, pale fawn, lemon yellow,
rich golden brown, grey and almost colourless prehnite is found. It is mostly translucent, transparent material seldom being seen. Some two years ago A. Billett, lapidary at the Australian Museum, found that most attractive cabochons could be cut from all these types. Although the hardness of prehnite is only 6 to 6.5 somewhat below that required for good durability, it takes an excellent polish. Despite the fact that it is very cracked and flawed it shows a remarkable toughness and shows no tendency to fracture during the grinding and polishing process.

CONCLUSION.

In conclusion let it be repeated that, especially at the present time, the economic significance of New South Wales gemstones is negligible. Even at its period of greatest activity, at about the turn of the century it was never of great significance.

The following figures taken from Belshaw and Jackson (1950) indicate the position. The official record of Australian diamond production is 208,001 carats valued at £156,031, of which 205,543 carats valued at £147,949 came from New South Wales. By far the largest portion of this came from Copeton. It is recorded that the Bingara output amounted to only £24,000. Belshaw and Jackson have advanced reasons as to why these figures may be underestimated by as much as 100%, but even then diamond mining could not be regarded as an industry of marked economic significance. Although opal mining is by far Australia's most important gemstone industry it is relatively insignificant, forming less than 0.05% of Australia's total mineral production. The value of New South Wales production is £1,600,000, more than half the total Australian production of £2,200,000. In recent years New South Wales production has been almost negligible. Australian production now comes mainly from South Australian fields. The total recorded value of New South Wales sapphire produced between 1919 and 1936 is £35,800, all from New England. By far the greatest number came from Sapphire. The total value of emeralds produced was only some £10,000.

It should be noted that excepting opal the great bulk of New South Wales gemstones has been associated with alluvial cassiterite in New England and won in the process of tin mining. Undoubtedly part of the reason for the relative scarcity in other areas of the state is because there alluvial tin mining is on a much smaller scale. Although diamonds associated with alluvial gold were and still are being won from deep leads adjacent to the present day Macquarie-Cudgegong-Turon River systems, they never seem to have been recorded from other important alluvial gold fields elsewhere in the state.

However, the many interesting scientific aspects of New South Wales gemstones make them a worthy subject of study. Gemstones are particularly pure varieties of minerals and hence lend themselves to chemical studies. They very often show great perfection of crystalline form and hence have always been sought after for crystallographic studies. Since one of the necessary properties of a gemstone is perfect transparency either in the rough or cut form they form ideal subjects for optical studies.

Throughout the last twenty years a separate science known as gemmology has emerged as a branch of mineralogy. The stimulus has come as much from scientifically minded members of the jewellery trade as from mineralogists. One interesting field that is now almost solely the province of the gemmologist is the study of minute inclusions of other minerals, liquids and gases that frequently are found in minerals. A transparent cut stone lends itself admirably to microscopic examination of such features.
As might be expected gemmology is in a very advanced stage in Great Britain, America and certain European countries. The study of gemmology in Australia received a great impetus some nine years ago when the Gemmological Association of Australia was founded, which now has amongst its membership many enthusiastic and competent gemmologists. It is felt that we are on the threshold of a new era in gemmology when the refined and accurate techniques of other countries will be applied to the study of our native gemstones.

In the preparation of this lecture numerous gemmologists have given generous assistance. Arthur Wirth has done a good deal of experimenting in recent months with Clerici's solution used as a heavy liquid for the determination of specific gravities. He made these solutions available, which proved invaluable in accurately determining small fragments of gem minerals. O. le M. Knight (1951) some years ago designed and constructed a most accurate balance of unusual design for the rapid determination of specific gravities and was good enough to place it at my disposal. Use was made of specimens from the collections of both these gentlemen.

Bearing in mind the object of the Royal Society of New South Wales which includes "studies and investigations in Science and especially on such subjects as tend to develop the resources of Australia and to illustrate its Natural History and Productions", it seems that a survey of the gemstones of New South Wales has been an appropriate subject to place before you in honouring the memory of the Rev. W. B. Clarke. One might end suitably by quoting the words of a past President of the Royal Society, Professor Smith who in 1871 commented on the change of title of this society from Philosophical Society to Royal Society in the following words—"A strictly Philosophical Society might be expected to confine its attentions to matters of speculation and pure science, while in our circumstances it is expedient to devote our energies more to applied science and matters of obvious practical utility not however refusing to entertain questions of speculative philosophy when competent members bring them under our notice. Following the example of the Royal Society of England we can embrace the whole range of human knowledge and skill, avoiding only such topics as usually end in angry controversy."

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