DEPARTMENT OF MINES.

MEMOIRS OF THE GEOLOGICAL SURVEY OF NEW SOUTH WALES.
E. C. ANDREWS, B.A., Government Geologist.

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THE GEOLOGY OF THE BROKEN HILL DISTRICT.

BY

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SUPPLEMENTARY NOTE ON THE GEOLOGY OF THE BROKEN HILL DISTRICT.

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A.—GENERAL STATEMENT.

I. Acknowledgments.

Cordial thanks are due to Mr. G. W. Card, Curator of the Mining-Museum, for rock determinations in the earlier stages of the Survey. It was the report on the " Quartzites " by Mr. Card which first led the Writer to pay particular attention to that interesting group of rocks, upon whose nature, even to-day, there is no consensus of opinion.

Special thanks are due also to Messrs. J. C. James, Val. Farrier, and T. Smedley Oldfield, Mining Inspectors, for the great assistance rendered by them to the Survey of Broken Hill in its earlier stages.

II. Object of Paper.

The examination of Broken Hill itself was undertaken after the completion of the Geological Surveys of the Hillgrove, Drake, Yalwal, Kiandra, Forbes-Parkes, Cobar, and Canbelego, Mineral Fields. In addition to this, numerous reconnaissance surveys had been made over the greater portion of the State, during the preparation of official reports on molybdenite, bismuth, copper, lead, and other minerals.

The information gathered thus concerning the rocks and ore deposits themselves of the areas examined gradually led to the inference that New South Wales might be divided into several mineral provinces, and that the rocks and mineral deposits of each of these, in turn, represented the end products of physical and chemical reactions belonging not only to various periods widely separated in the earth's history, but also to depths below the earth's surface widely differing from each other. The difficulty was to separate and properly correlate in space and time these various mineral fields, which, during the ages, have been bonded or welded together, and which are to-day exposed on one and the same co-extensive surface, and which thus suggest a similarity of age and of structural conditions for all.

III. Disposition of Rock Structures in New South Wales.

An examination of the rock structures of the State, checked in certain cases by the fossil evidence, indicates that the rocks of New South Wales were built outwards from the extreme west in sub-parallel strips or zones to the south-east, the east and the north, until the close of Palæozoic time. The reports of Professor Sir Edgeworth David[1], H. I. Jensen[2], and E. C. Andrews[3] illustrate the gradual growth of this idea.

This does not imply, necessarily, the extension of the Archæan nucleus, highly crumpled, beneath the folded Permian of New England, or the Devonian of the coastal area south of the Hunter River. On the other hand, the mere fact that the Permian is strongly folded in New England suggests that the closely-folded Archæan may not underlie it, inasmuch as the observed arrangement of rock groups in New South Wales indicates that the Palæozoic series, if associated intimately with the Archæan, will lie almost horizontally upon them, or show the influence of gentle folding only. This is certainly the case for the Permian, the Devonian, the Silurian, and apparently for types older than these also. A study of Australian rock associations, outside of New South Wales, also appears to support this inference.

IV. Comparison of Mineral Assemblages and Rock Structures in the Various Mineral Provinces.

In the body of this report the mineral assemblages, together with the exposed rock structures of the various mineral provinces into which New South Wales may be divided, are described, and a comparison is instituted between the individual exposures, to ascertain whether the counterparts of each may not be inferred to exist, or to have existed, within each area in vertical succession. Various portions in certain areas have been removed by denudation, as in the case of the Archæan zone of rock flowage, although preserved beneath the surface in others, as in the Permian of New England.

As the surfaces of these various mineral provinces are examined and compared, the one with the other ; as it comes to be seen that the mineral assemblages peculiar to these provinces represent the end products only of chemical reactions conducted long since in laboratories deeply seated, but, nevertheless, all at varying levels below the surface, and only exposed at the surface to-day by means of intermittent elevation and subsequent denudation, the younger groups conforming more to the appearance of the original sediments

[1] Professor Sir T. W. Edgeworth David.—(*a*) Presidential Address on "The Growth of Australia," Proc. Linnean Soc. N.S. Wales, 1893, pp. 547–607. (*b*) Presidential Address, "Notes on some of the Chief Tectonic Lines of Australia," Proc. Roy. Soc. N.S. Wales, 1911, pp. 15–76. (*c*) "The Geology of the Commonwealth" (Federal Handbook), Brit. Ass. Adv. Sci., Australasian Meeting, 1914, pp. 241–325.

[2] Jensen, H. I.—(*a*) "The Building of Eastern Australia," Proc. Roy. Soc. Queensland, July, 1911, pp. 149–198. (*b*) Some Geological Features of Northern Australia, Proc. Roy. Soc. Queensland, vol. 34, pp. 105–208, 1922.

[3] Andrews, E. C.—(*a*) "Notes on the Structural Relations of Australasia, New Guinea, and New Zealand," Journal of Geology, xxiv, No. 8, Nov.-Dec., 1916, pp. 751–776. (*b*) "Geographical Distribution of Ore Deposits in Australasia," Economic Geology, xviii, No. 1, Jan.-Feb., 1923, pp. 1–25.

from which and within which they have been formed, and betraying evidence of less alteration and of less pronounced burial than the older and less easily recognised schists and gneisses of the western areas; as the Field Geologist in his work repeatedly sees the forms peculiar to each great field, and as these facts are brought home vividly and repeatedly in his attempts to unravel their history, all these characteristic mineral groups, developed at varying depths and at widely-separated times in the history of mountain making in Australia, but now bonded together; these inliers and outliers exposed like a wondrous mosaic within a continuous surface, these claystones and conglomerates, both of the Carboniferous and of the Permian of New England, together with the coastal Devonian, all with their attendant array of batholith, boss, cross-dyke, and true fissure veins; the great inliers of slate, augen sandstone, "stretched conglomerate" of the Early Palæozoic of Cobar, with their "saddles," "pressure lenses," together with the remarkable sillimanite schists and the sills of "primary gneiss" of the Broken Hill Shield, all "injected" with pegmatite; these types, so different in age, but which, nevertheless, represent so many chance sections, just so many abyssal truncations of the ancient mountain ranges; may they not all be matched to-day in zones of descending order below the surface in any single great mountain range of to-day, such as that of the Himalaya, the Rockies, or the Andes? That is to say, may not the counterpart of the Permian and Carboniferous assemblages, exposed to-day in north-eastern New South Wales, exist many thousands of feet beneath the surface of great mountain ranges of the present day, and may not the counterpart of the Broken Hill area itself be found at much greater depths in turn, within the same ranges. If so, then homologues of the interesting structures and mineral assemblages of the provinces described in this report, but of widely-differing age, must nevertheless be intimately associated in vertical order in any great mountain range, and must pass insensibly from one to the other in one and the same vertical section. The inference is that the dyke, the true fissure vein, the "saddle," the batholith, the sandwiched sill devoid of connecting dyke or vein, and the "pegmatite injection," would all be found arranged in their proper sequence, all overlapping, nevertheless, the parallel and serried sills and the countless "injections" like microscopic sills, and like them, in turn, also showing the elongated lenticular form, would occupy, typically, positions very low in the vertical succession, the "pressure lenses" being partly with these, and partly above, connecting by means of "saddles" and allied forms to the batholiths, together with the true cross-dyke and fissure vein, and these, in turn, passing above into volcanoes arranged along earth undulations as seen in the Pacific and Malayasian Islands to-day.

Naturally, each mountain range must be considered as having vertical sections peculiar to itself, and also its own arrangement of igneous intrusions, together with characteristic minerals. For example, igneous rocks may not have the same quantitative representation in all mountain ranges. Minerals also may not be present in the same quantity. Thus iron, gold, copper, silver, lead, zinc, tin, molybdenite, and other minerals may be expected to be in varying proportions in each. In all, however, the inference is that corresponding positions in sections similarly situated will be characterised by a preponderance of certain definite intrusive forms, and of certain mineral associations with definite arrangements if such minerals and igneous rocks be present in quantities sufficient for such grouping.

B.—DESCRIPTION OF ROCK AND MINERAL ASSEMBLAGES, TOGETHER WITH GEOLOGICAL STRUCTURES OF THE PRINCIPAL MINERAL PROVINCES OF NEW SOUTH WALES.

I. Western or Broken Hill Province, bounded on the East by the Darling River.

(1) Archæan Rocks and Ore Deposits of Broken Hill District.

The types of rock structures, igneous intrusions or deposits, and mineral assemblages, together with their peculiar arrangements and associations, in the Broken Hill District, is exceedingly interesting and informative, and stands in marked contrast with those of the Permian of New England, being connected therewith nevertheless, to some extent, through the forms exposed in the early, and possibly pre, Palæozoic of the Central Province, and with the Carboniferous and Devonian of New England.

Rock Structures.—Broken Hill sediments and intrusive rocks alike have been closely folded. The folds themselves appear to be relatively shallow, with steep sides and flattish summits and bases. Naturally, very many sharp types of folding are associated with these, especially in the less competent rock members. Sliding and stretching of fold limbs are pronounced features.

Forms of Igneous Rocks.—In the central and most altered portion of the Broken Hill area, the sill type, both basic and siliceous in composition, is well developed. The types are those of primary gneisses. A search for apophyses or connecting dykes was unsuccessful. The area in which this sill type is so typically developed is crowded with pegmatite injections, and is approximately twenty miles in diameter, although the more intense action is confined to an area twelve miles in diameter.

Outside this subcircular area the sill type is predominant, but some of the forms betray a tendency to give off blunt tongues working their way for short distances into the surrounding schists across the bedding planes. The true dyke type is absent, except as a product of a period when the old zone of flowage had been denuded to the zone of fracture.

The Survey of Broken Hill indicates the existence of the sills as elongated lenses, which appear to be physically discontinuous, but reveal a common origin in that the isolated lenses are arranged along the same group of bedding planes, and the igneous material appears to have travelled from one to the other lens along the same zone, and, nevertheless, to have left no track of its passage in many cases.

Other, and common, examples of igneous intrusion are the "Pressure Lenses" of pegmatite and gneiss, whose longer axes have not been developed so much at the expense of the other axes as in the case of the ordinary sills.

Forms of Ore Deposits.—The ore deposits, on casual inspection, appear to belong to two main types, namely, "Saddles" and "Pressure Lenses," associated with, and intimately related to, bands of replacement within broad zones of rock flowage. These zones of flowage, or movement, are parallel to the bedding planes.

The so-called "saddle," however, arise in great measure through the replacement of "dragfolds," the ore having been fed into the folds from a connecting zone of flowage, the latter containing many lenticular bodies of ore belonging to the type known as "Pressure lenses." Another form of replacement is noted in association with these zones of flowage whereby the schists alongside have been penetrated by emanations so as to form isolated patches of ore within them, leaving no trace of the passage of the emanations from which they have been derived. This is especially well illustrated in the gradual growth of pegmatite within the country alongside the zones of crush or flowage, the pegmatite itself appearing to be one of the advance agents of ore deposition.

The ore deposits show many features in common with the associated intrusive rocks, both in form and in composition. Thus the individual sills and "pressure lenses" of the igneous masses arranged along any single zone are discontinuous, but are arranged in such a striking manner along zones parallel to the bedding planes as to indicate an origin from a common feeding source. The physical and chemical conditions under which these were formed were such as to allow the material to travel freely along the zone, but to segregate itself into isolated patches without showing any sign to the unaided eye of its passage from one to the other. In a similar way "pressure lenses" of silica and of ore are arranged discontinuously along zones of flowage. The time factor involved in their formation appears to have been long, allowing for gradual increase of volume without rupture of the containing schists.

These peculiar forms and the arrangements of ore bodies, and even of igneous masses, in the zone of flowage, are most marked and instructive features, and they appear to be characteristically absent from the upper portion of the zone of rock fracture where branching dykes and fissure veins of the cross type are the common forms.

These types characterise the area of "injection," and appear to belong to the same great period of igneous activity.

In the sub-parallel zones outside the region of "injection," nevertheless of the same age, ore deposits containing tin and wolfram occur, but in the form of "pressure lenses" of pegmatite and as replacements arranged along bedding planes of mica-schists and silky slates.

Mineral Assemblages and Associations.—These are scarcely less remarkable than the forms of the rock structures and the mechanics of igneous intrusion.

The Schists and Gneisses.—In the central region of pegmatite "injection," the Archæan mudstones and clays have been changed to sillimanite schist containing abundant garnet, mica, and felspar. The intense chemical action of this central area, as illustrated by the great development of sillimanite blades and garnet crystals, may be noted to decrease radially in all directions outside a sub-circular area ten miles in diameter. Beyond the injected area, in a great confocal and closed curve,* the sillimanite schist is succeeded by andalusite and mica schists, with a subordiante amount of sillimanite, together with greatly reduced proportions of garnet and felspar.

Beyond this zone, which forms in turn a sub-circular area of twenty miles radius with Broken Hill as a centre, the predominating rocks are mica-schist of various types, together with silky slates, phyllites, and sandstones of a fine texture, and containing a relatively high proportion of clay. With these may be found a few belts of andalusite and chiastolite schist. All appear to be of the same age as the "injected" schists of Broken Hill proper.

The minerals such as sillimanite, andalusite, chiastolite, garnet, and felspar, were developed, in great measure, during the folding, but a considerable amount of crushing, rock flowage, and mineral formation, occurred at a later stage.

* This curve, although sub-circular, is modified by large, blunt prominences, such, for example, as The Pinnacles area.

The lodes mark a third phase in this period of mountain making, inasmuch as they form replacements and " pressure lenses " along the zones of crush, which in turn have been developed amongst the schists after the formation of sillimanite and other minerals. The lodes containing the magnetite, garnet, and apatite appear to be the oldest forms. The " pressure lense " is common in this type, and the lenses are isolated from each other in places, although it is apparent that all have been fed from a common source. In the area of " injection," the magnetite is granular and associated with garnet, whereas outside the injected area it is of course texture, of very uneven chemical composition and almost devoid of garnet.

The galena lodes associated with rhodonite, zincblende, zinc spinel and fluorspar, are confined mainly to the "injected" area, whereas, outside of this, the lodes consist mainly of galena and silver, with a gangue of carbonate of iron. Silica, as a replacement and injecting agent, is remarkably common along the main Broken Hill Lode, but is not so prominent in this connection outside the central area.

In the outer ring of mica schist, silky slate, and phyllite, the lodes contain tin and wolfram in pegmatite, in a form much akin to greisen in places.

Beyond this zone, within the slate and allied types of rock, copper and gold belts have been recorded.

The ore deposits of the " injected " area show many features suggestive of a dying phase of igneous intrusion. Beyond this central area occur the veins of galena in a gangue of iron carbonate. Their external grouping with respect to the galena, zincblende, gahnite, rhodonite, garnet, pegmatite, and quartz of the central points to a decrease of chemical action, with increasing distance from the area of maximum activity. The occurrence of the central lodes themselves in the area of " injection," but at a later stage, indicates that lode formation itself is to be regarded as a revival of igneous activity, but as marking a decadent stage.

II. Central Province.

(1) Ordovician and possibly Pre-Ordovician Rocks of Western Division of Province.

Location.—This includes the Cobar, Girilambone, Canbelego, Budgery, Nymagee, Mount Hope, Tottenham, Mineral Hill, and Bobadah areas, about 125 miles in length and 50 to 100 miles in width.

Rock Types.—These consist of Early, and possibly even Pre-Palæozoic, types, overlain by folded Silurian and gently undulating Devonian in places. The Devonian rocks consist of quartzite, sandstone, and mudstone, which show only very slight signs of alteration. The Silurian consists of blue limestone, not altered to marble, claystone, sandstone, conglomerate, and tuffaceous material. None of these appear to have been subjected to alteration.

The older types, namely, the Early Palæozoic, and possibly even Pre-Palæozoic, consist of "augen" sandstone, well-cleaved slate, phyllite, silky schist, and mica schist, cross-bedded sandstone and dense quartzite, all closely folded, with the exception of the massive quartzites, which are relatively "competent," and against which the conglomerate, the sandstone, and the slate, have been crumpled to the accompaniment of very great chemical alteration. In places these older rocks have been strongly thrust over the Silurian, which in turn is much folded but not chemically altered.

Rock Structures.—These consist of broad folds in the more competent members, and of close folds in the slate, sandstone, and conglomerate. Faults with large throws, and mainly of the overthrust type, are common. These consist partly of flowage, and partly of fracture, types.

Forms of Igneous Intrusions.—Very little definite evidence of igneous intrusion belonging to the zone of flowage within this region has been noted. The ages of the infrequent granite masses and of the great lenses of quartz-felspar porphyry, extending from Mount Boppy to Mount Hope and Mineral Hill, a distance exceeding one hundred miles, are not known.

Forms of Ore Deposits.—These form a very interesting series, consisting of gold-quartz "saddles," mainly of replacement, and associated with zones of crush and rock flowage. A fine example is the Mount Boppy "saddle." Other types include pyritic replacement of slate and schist, the replacement following closely the folded bedding planes throughout all their details of contortion. Examples are the Budgerygar copper deposits. Lenses of gold-bearing quartz containing copper, together with "pressure lenses" and replacements of copper in slate, occur also along broad zones of compound faulting. The main examples of these are, the Great Cobar, Nymagee, and Mount Hope, types. Low-grade impregnations of copper have been recorded also from the porphyry south of the Mount Hope Mine.

Mineral Groups and their arrangement.—The Great Cobar deposits consist of "pressure lenses" and large replacements of slate, copper pyrites, galena, and zincblende, in a gangue of magnetite and pyrrhotite, together with silicate of iron, disappearing on the hanging-wall side into the country rock by selective replacement along the bedding planes of slate.

The Nymagee ore deposits are similar to those of Cobar.

The characteristic mineral of replacement, however, is free silica, both in the form of chert and of ordinary quartz, the replacement having proceeded generally from an extremely great number of veinlets in the form of net-works arranged principally in two sets at right-angles to each other. With these also are associated large lenticular replacements of quartz and large " pressure lenses " arranged along definite zones of crush. Discontinuous lenses of magnetite, linearly arranged, are associated with these quartz bodies.

In a general way, the gold deposits appear to occur in the central portion of the area, the copper-gold deposits lying both east and west of the gold-quartz " saddles."

Tin has been recorded from this district, but is extremely rare. Bismuth is reported from the Great Cobar Copper Mine. Molybdenite has not been recorded.

The nature and occurrence of the magnetite, pyrrhotite, and quartz, gangue indicates an origin from igneous emanations.

2. Ordovician Rocks and Ore Deposits of Eastern Portion of Province.

Location.—These groups occur as inliers associated with younger rocks in the large Parkes-Forbes-Peak Hill District, also the Trunkey, Cadia, Upper Shoalhaven, and probably also the Hill End-Hargraves areas. These may be taken as the types. Exposures of these rocks of this age occur in other portions of the Province.

Rock Types.—The Forbes-Parkes area may be taken as the type. Here Ordovician rocks are composed of slate, phyllite, mica-schist, massive sandstone, and quartzite, the types of fine texture being crowded with small veins and " pressure lenses " of quartz arranged along bedding planes.

Rock Structures.—The slate and schist are closely folded, whereas the massive sandstone and quartzite are not so affected.

The area is referable partly to the Lower Zone of Fracture and partly to the upper portion of the Zone of Flowage.

The Silurian rocks associated with the Ordovician consist of unaltered blue limestone, claystone, sandstone, and conglomerate, arranged in broad, open folds only.

The Devonian tuffs, claystone, sandstone, and quartzite lie almost horizontally upon the truncated edges of the close folds of the Ordovician rocks, and show little or no sign of chemical alteration.

In some of the other fields of this eastern portion of the Province the Devonian and the Silurian rocks show very little chemical alteration, but they show the effect of close folding.

Forms of Igneous Intrusion.—At Forbes-Parkes a granitoid intrusion of the miarolitic type occurs in the Ordovician, suggestive of a large sill. Devonian quartzites lie almost horizontally upon its denuded surface.

Sills of basic composition occur also in the Ordovician of this area.

W. R. Browne* describes a very large and interesting group of Ordovician rocks in the Cooma District. The sedimentary rocks consist mainly of slate, schist, and quartzite. These have been intruded by gneisses of varying composition, which appear to be of the sill type. Other intrusives also do occur of non-gneissic type, but these may possibly be of much later age than the gneissic sills.

Forms of Ore Deposits.—These consist of " Pressure lenses " of magnetite and hæmatite, " saddles " of gold-quartz, " pressure lenses " of gold-quartz in zones of flowage and crush, quartz veins following bedding planes, and replacements of slate also following bedding planes.

Mineral Groups and their Arrangement.—Magnetite and hæmatite in lenses, and partly as replacements, are common, as also are copper pyrites and pyrrhotite with quartz and gold with quartz, while lead and zinc sulphides are not uncommon. Tin, wolfram, molybdenite, bismuth, and other minerals, generally associated with these, are almost absent.

3. Devonian Rocks and Ore Depcsits of Coastal and Plateau areas south of the Hunter River.

Location.—The coast and the Eastern highlands south of the Hunter River.

Rock Types.—These consist in the main of claystone, limestone, tuffs, sandstone, conglomerate, and quartzite.

Forms of Rock Structures.—Folding of pronounced character occurs in places, as among the thin limestone beds of the Yass district, described by L. F. Harper.† Very little chemical alteration is to be noted in these sediments.

The structures and the rock types are those characteristic of the upper zone of rock fracture.

* W. R. Browne, " The Geology of the Cooma District, New South Wales." Proc. Roy. Soc. N.S.W. 48, pp. 272–122, 1914.

† L. F. Harper, " The Geology of the Murrumbidgee District near Yass." Records Geol. Surv. N.S. Wales, ix, Pt. 1, 1909.

Forms of Igneous Intrusion.—The most common type is the Batholith or Boss, with numerous associated tongues following the bedding planes of the intruded sediments. Dykes of the true cross-type are also common, and are composed of pegmatite, of granite, or of more basic rocks.

Carne's clear description and accompanying section of the Wolumla Batholith* shows the tendency of igneous rocks as opportunity offers to form sills or laccoliths. Its summit, broadly, is sub-horizontal or undulating, and it has penetrated the surrounding sediments in the form of sills and tongues.

Another example of these Post-Devonian and Pre-Permian granitoid intrusions is the Bathurst Batholith, consisting of a granite of varying composition and which has driven tongues and sills into the surrounding sediments. Many peculiar sills also are associated with the siliceous portions of this granite, whereby sub-tabular masses of quartz, garnet, lime-silicate, and molybdenite have followed the bedding planes of the associated sediments or contemporaneous lava flows.†

Mineral Groups and their Arrangement.—The typical forms are true fissure veins of gold-quartz, silver-lead, or copper pyrites, in claystone, felsite, porphyry, and other rock types. The deposit of galena with silver, zincblende, and copper pyrites, at Sunny Corner appears to belong to this period.

Pipes, dykes, and impregnations of molybdenite and bismuth, also tin and wolfram, are associated intimately with the siliceous types of granite intrusion.

Molybdenite and bismuth are associated with abundant garnet and quartz within the granitoid margin at Whipstick. Molybdenite in garnet and quartz, in the form of sills, is associated with the siliceous phase of the granite at Yetholme, near Bathurst. Tin and wolfram are peripherally arranged round and within certain siliceous granites. So far as examinations have been conducted, these granites appear to have been truncated apically rather than deeply, and the mineral "pipes," together with the other types of deposit associated with the granite, appear to have been deposited near the original roofs of the intrusions.

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* Ann. Rept. Dept. Mines, N.S. Wales, for 1897, p. 162.

† The late W. J. Clunies Ross expressed the opinion to me verbally in 1896 that the Bathurst Granite might be found hereafter to be in great measure a laccolith or one at least whose main tendencies were to follow the bedding planes, the whole mass having been forced between the combined Silurian and Devonian to the east, on the one hand, and the older slates and associated schists on the west on the other. No detailed field work has been done whereby this idea might be tested.

An extremely interesting feature of these " pipes " and sills is the physical discontinuity of individual ore or gangue patches, but their evident derivation from a common source, thus indicating the intercommunication between the pipes, in one direction at least, at a period immediately prior to their deposition as ore or gangue masses.

The gold, lead, and copper, appear to have been deposited at some slight distance from the granite intrusions.

III. New England Province.

(1) Carboniferous Rocks and Ore Deposits.

Location.—According to Benson,* the Carboniferous, together with the Devonian, occupies a great proportion of the Western and Southern Divisions of the area.

Rock Types.—Conglomerate, sandstone, tuffs, contemporaneous lavas, claystone, radiolarian chert, and limestone, are common.

Forms of Rock Structures.—Steep folding is common, attended with intense compression, in places, of the less competent rock members. Faults of the fracture type appear to be common. Very little indication exists of rock flowage phenomena, although the slates of Hillgrove and of associated areas may belong to the Carboniferous.

The rocks of the Carboniferous and Devonian described to date appear to illustrate reactions within the zone of fracture, nevertheless, many thousands of feet below the original surface.

Forms of Igneous Intrusions.—Large lenses of Serpentine in the Carboniferous have been described by Benson.*

The arrangement, appearance, and mineral composition of the infrequent bosses of granitoid rocks within the Carboniferous are suggestive of types which were associated with the folding which closed the Permian Period.

Forms of Ore Deposits.—Chromite segregations occur in the Serpentine. Gold and copper veins are also associated with the Serpentine intrusions. True fissure veins of gold-quartz are common also. The gold-quartz veins of Hillgrove, Copeland, Gloucester, Stewart's Brook, Moonan Brook, Nundle, and other fields in the Carboniferous or Devonian rocks of New England may be of Closing Carboniferous or of Closing Permian Age.

Mineral Groups and their Arrangement.—Chromite, copper, and gold, with quartz, are associated with Serpentine. Scheelite appears to be associated with basic dykes; gold quartz in true fissure veins appears to occur at some slight distance from the igneous intrusions.

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* Benson, W. N. Proc. Linnean Soc. N.S. Wales, xxxviii, xl, xlii, xliii, xlv.

(2) Permian Rocks and Ore Deposits.

Location.—The folded Permian rocks of the New England Province occur mainly in the north-eastern portion.

Rock Types.—These comprise conglomerate, sandstone, tuffs, lavas, indurated claystone, and limestone. Very little chemical alteration of the rocks has been noted, even in rocks which have suffered flowage, as in the exposures near Warwick, just north of the New South Wales Border which appear to have suffered heavy over-thrusting at relatively shallow depths. The rock types belong mainly to the zone of fracture, probably from 5,000 to 10,000 feet at least below the original surface which was in existence while the deep-seated folding was in progress.

Forms of Rock Structures.—According to the reconnaissance work of the writer, it would appear that the Permian sediments were deposited upon the truncated edges of the steeply-folded Carboniferous and Devonian. The folding of the Permian is interesting, for whereas in the north-eastern portion of the New England Province it is very pronounced, nevertheless, in a southerly direction the folds pass gradually into mere warpings beyond the Hunter Valley, while in the western portion of the province the folds pass, by way of the western warp of the Nandewars, into the sub-horizontal strata underlying the Great Inland Plain. A great arch of Permian sediments over Central New England apparently has been removed by denudation, leaving large inliers of Carboniferous and Devonian, together, possibly, with Pre-Devonian types.

Forms of Igneous Intrusions.—The earlier igneous intrusions which accompanied the folding at the close of the Permian consisted of large bosses of quartz-diorite and other granitoid types. These were succeeded and intruded by batholiths and bosses of siliceous granite. These in turn were intruded by more siliceous granites of irregular and radiating form, all being associated with an array of pegmatite, pegmatitic quartz, and aplite dykes of the cross type. A considerable development of greisen was formed also along the marginal areas of certain siliceous granites. A series of lamprophyric and doleritic dykes, together with subordinate rhyolitic forms, appear to mark a closing phase of the intrusions. The pegmatite and pegmatitic quartz veins are intimately associated with the siliceous granites themselves, but the basic dykes are developed characteristically at a slight distance from the granites.

These intrusions are associated only with the folded areas. The batholiths, apparently, had flattish or undulating roofs. An excellent example of this type is illustrated by the Mole Tableland Massif. So far as is known at present, many of the granite masses have only been apically truncated by denudation. A splendid example of such truncation or stripping is the siliceous granite of Wunglebong, near Tenterfield.

Forms of Ore Deposits.—Tin and wolfram occur in " pipes " and irregular masses; also as impregnations, fissure veins, and stock-works. These are associated intimately with siliceous granites, being either within or near their margins.

Molybdenite and bismuth occur in " pipes " and impregnations within the margins of granites, which are not quite as siliceous as the tin-wolfram types of granite. Certain granites and pegmatites, consisting mainly of quartz and felspar, contain molybdenite, bismuth, tin, and wolfram as accessory minerals.

True fissure veins of the cross type, containing tin and wolfram, are abundant, and differ materially from the sill type.

Gold, silver, lead, copper, and zinc, in gangues of quartz, occur as fissure veins more or less tabular, and of the cross type. These are developed typically in claystone, tuffs, and other sediments of fine texture, and are associated, characteristically, with basic cross-dykes. Examples :—The silver veins of Rivertree and of Boorook, the gold-copper veins of Drake, the gold-quartz veins of Pretty Gully and of Tooloom, the gold-quartz veins of Kookarabookra, the silver veins, with or without zinc, of the Emmaville district, the lead-zinc veins of Howell, containing sulphide of tin, the gold-quartz veins of Solferino and Lionsville, and the silver-lead-zinc veins of Silver Spur, immediately north of the New South Wales border.

Mineral Groups and their Association.—Tin, wolfram, molybdenite, and bismuth, together with their associates, are arranged marginally to siliceous granites, being distributed along the main axis of folding in central positions within this mineral province. The other types, such as the true fissure veins of quartz containing gold, silver, copper, lead, zinc, arsenic, and other minerals, are arranged on outer arcs. This suggests the high probability that the tin group has a tendency to be deposited near the apices or roofs of the siliceous granites, while the main gold, silver, copper, and other veins, of commercial importance, were deposited above and beyond them in turn, and have been destroyed by denudation, leaving only the outer rings of these minerals as less important remnants of a once-great heritage of this important mineral group.

C.—CORRELATION AND ECONOMIC SIGNIFICANCE OF OBSERVATIONS.

Rocks and their Structures.

Zone of Fracture.—The laccolith, the batholith, the boss, together with certain intrusions of irregular shape*, may be expected to occur typically in the zone of fracture. With these the dyke of cross type, the true fissure vein, the contact deposit, and the " pipe," are typically developed.

Zone of Flowage, and Zone of Combined Rock Flowage and Fracture.—In the zone of flowage the intrusion is typically the sill type, or a series of lenses arranged end-to-end like strings of elongated beads. This applies also to the types of ore deposits, such as " pressure lenses," " saddles," or quartz lenses in the form of strung beads of distorted form. In the portions still deeper below the surface the sills are sandwiched and packed together, the whole mass being filled or " injected " possibly with millions of tiny lenses or sills arranged along planes of bedding and schistosity, all being typically discontinuous as individuals, but evidencing a common feeding source.

Large masses of gneiss or granitoids may be expected in the zone of flowage as the result of replacements and digestion of intersill rocks. Later granites also in the form of bosses may be formed after the denudation has brought the flowage types into the zone of fracture.

Each group overlaps the other in vertical succession, but in any great growing mountain range there may be expected an orderly succession upwards from the " injection " of the zone of flowage to the volcano and the lava flows of the warped and undulating surface of the mighty plateaus which form its uppermost portions.

Forms of Ore Deposits.—Where igneous emanations containing valuable minerals in commercial quantities have accompanied periods of folding, it is to be expected that tin, wolfram, molybdenite, bismuth, and minerals commonly associated with these will be found, both marginally arranged around the upper portions of siliceous granites, and also to a lesser extent above the roofs of same. Above the granites of more basic type, or away from the siliceous granites themselves, gold, silver, copper, lead, zinc, and other materials, may be expected, especially in the form of true fissure veins in slate, claystone, limestone, tuffs, and quartzite.

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* " Igneous Rocks and their Origin," 1914, by R. A. Daly, p. 84, in regard to " chonolith."

In the upper portion of the zone of flowage, " pressure lenses " of lead-zinc, copper, gold-quartz, and iron-oxide as magnetite or hæmatite, may be expected. In this region also the gold-quartz " saddle " is typically present. Especially are these minerals to be expected associated with slate or its equivalent near zones of crush. In the still deeper portion of the zone of flowage, lenses of magnetite and hæmatite, gold-quartz " saddles," and " pressure lenses," and replacements of dragfolds, associated with zones of crush, may be expected. Lead, zinc, and copper deposits, with gold and silver, may be expected in this form.

Intense silicification may be expected in this deeper region, the silicification typically following the planes of bedding.

Application to Western and Central Divisions.—The accompanying brief statement is an attempt to indicate the types of minerals which may be expected to occur in commercial quantities in these two important districts. These are regions of very sparse settlement in sub-arid and arid areas, and are not adapted to closer settlement. It is, moreover, an attempt to indicate the futility of prospecting for certain minerals which cannot be expected to occur commercially in the zones partly of rock flowage and partly of rock fracture.

Broken Hill or Western Division.

The minerals which the Australian prospector apparently expects to find in commercial quantity at Broken Hill are :—

1. Coal and crude petroleum.
2. Tin, wolfram, molybdenite, bismuth.
3. Arsenic and antimony.
4. Magnesite.
5. Iron and manganese.
6. Chromite and the platinoid minerals.
7. Gold, silver, lead, zinc, and copper.

1. *Coal and Crude Petroleum.*—The rocks in this district are both too old and too altered to yield commercial coal.

The rocks are too altered also to contain oil, nor is there any evidence of past life in the rocks to justify the presence of organisms to lead to the common belief that commercial supplies of crude petroleum do exist, or ever did exist, in this region.

2. *Tin, Wolfram, Molybdenite, and Bismuth.*—There is an abundance of siliceous granite, especially in the form of lenticular greisen and pegmatite, and as the latter types are generally recognised as definite indicators of the minerals in question, and, moreover, as abundant rich specimens of tin and wolfram have been found, it has been thought that Broken Hill would prove to be a rich field for these minerals.

On the other hand, an examination of the district indicates the absence of siliceous granites in the form of batholiths and bosses apically truncated. The roots only of these ancient tin-wolfram containers have remained, while the great batholiths and bosses themselves have been removed by denudation. Inasmuch as the tin, wolfram, molybdenite, and bismuth, which usually accompany these siliceous granites were accustomed to gather above and around the apices and upper portions characteristically of the intrusions, there is little expectation of discovering important deposits of these minerals in the denuded stumps and roots only of the granites. Small working parties only may be expected to work these tin and wolfram deposits so as to produce a small margin of profit.

3. *Arsenic and Antimony.*—Arsenic and antimony may be considered in a similar manner. The region is too deeply seated to expect commercial deposits of these minerals.

4. *Magnesite* only occurs sporadically as a superficial alteration in the form of small nodules, and not in commercial quantities.

5. *Iron and Manganese.*—A careful examination of the area indicates the abundant presence of small lenses and patches of magnetite, together with a minor proportion of hæmatite. There is no probability of discovering masses of iron ore, by boring or other prospecting work, greater than those already known. There is, therefore, no expectation of commercial supplies of iron oxide from Broken Hill, although the area represents the zone of combined flowage and fracture, and is exactly the type of place where huge "pressure lenses" and replacement masses of iron oxide might have been expected.

Similarly for manganese.

6. *Chromite and Platinoid Minerals.*—The not uncommon occurrence of serpentine with small rich veins or patches of the platinoid metals has led to the belief that a great industry would be opened up in this connection in the future at Broken Hill. The not uncommon exposures, however, are so small, and

the platinoid deposits, as judged by the numerous outcrops and deposits already prospected, contain such small tonnages individually that there is little or no expectation of the discovery of commercial bodies of the platinoid minerals.

The case for chromite might be considered similarly.

7. There remain the minerals, gold, silver, lead, zinc, and copper.

Field work has shown that one very large "dragfold" in the Broken Hill area has been replaced in great measure by galena and zincblende, with a subordinate amount of silver, gold, and copper. This body, namely, the Main Broken Hill Lode, is associated with a wide zone of crush in the centre of an area thoroughly "injected" with pegmatite. Along this continuous zone of crush, various "pressure lenses" of ore have been found, both as outcrops and as underground bodies. "Pressure lenses" also of certain gangue minerals, namely, pegmatite and garnet, are not uncommon. The extension north and south of the Broken Hill lode consists of lenses and of replaced "dragfolds" arranged along a definite and continuous zone, but the individual lenses, consisting generally of quartz and siliceous galena and zincblende, are physically discontinuous. In like manner, the small replaced dragfolds associated with this zone are discontinuous. This zone is absolutely barren in places for lengths of many hundreds of feet, and this discontinuity applies to vertical as well as to longitudinal extension.

Outside the Broken Hill Lode itself, but within the "injected" area, very numerous "pressure lenses" and replacements of folded country, but individually small, have been noted. Most of these have been prospected to a moderate depth. Examples of these are the numerous deposits, known as the Rupee, Piesse's Knob, the Round Hill, the Nine Mile, the Centennial, Hardy's, the Great Western, the Little O.K., the Little Broken Hill, the Laurel, and other lines.

Outside of this "injected" area very numerous lodes of galena and silver have been worked, notably the Apollyon Valley, the Silverton, the Thackaringa, the Daydream, the Purnamoota, the Umberumberka, and the Mount Robe areas.

The history of prospecting operations shows that the whole of the Broken Hill Shield has been searched for ore deposits. A geological survey has now been made of the central area of the Shield. As a result the evidence is fast accumulating to the effect that, over an area exceeding 1,000 square miles, one large body of ore, namely, the Main Broken Hill Lode and its extensions, has been found, but that hundreds of small deposits have been worked. With the exception of the Main Lode and the Pinnacles, the ore deposits of the district are too small to warrant the attention of large companies, or, indeed, the attention of other than small working parties. The examination of the structure of the field indicates that the probability of the existence of another large ore deposit worthy of the attention of large companies is certainly much less than 1 in 200. There is no surface indication of such, and, indeed, the surface indications are such as to point to the great improbability of any of the mines, other than the Main Broken Hill itself, being connected in any way with a large body underground.

The chance of finding an additional large commercial body, beyond Broken Hill Lode and its extensions, is therefore too speculative to warrant the attention of large companies.

These remarks are intended to be applied only to the Broken Hill Shield proper, an area of 2,000 square miles. Beyond this area again, beyond the area of " injection " and of the outer arcs of the lead, tin, and wolfram, copper and gold deposits of commercial importance may be expected. This area is in decided need of a detailed geological survey, and until this is done it cannot rightly be said that the Broken Hill Field has no expectation of containing other great mineral deposits in addition to the Main Lode and the Pinnacles.

(*b*) *Western Portion of the Central Province.*

This is generally known as the Greater Cobar district. The older rocks are in the zone partly of rock flowage and partly of rock fracture. Batholiths and bosses are typically absent, as are also basic and siliceous dykes of cross-type and true fissure veins developed across the strike of the country.

The Silurian rocks have been strongly folded in places, but they appear not to contain ore deposits of commercial importance. This is due, apparently, to the influence of the dense basement of older rocks.

The Devonian lies almost horizontally upon the truncated edges of the older rock basement.

Prospectors generally appear to consider that both this and the Broken Hill areas have only been " scratched " and that they will be found to contain commercial deposits of petroleum, tin, wolfram, bismuth, molybdenite, arsenic, and antimony, iron, manganese, the platinoid minerals, together with gold, silver, copper, lead, and zinc.

(1) *Crude Petroleum.*—The oldest rocks of the district are too much altered for the storage of any crude oil which may possibly have been present in them, and the Silurian and Devonian groups, which are associated with these older rocks, do not contain signs of abundant organisms sufficient to justify the expectation of oil within them. Their structures also are not favourable for the retention of oil.

(2) *Tin, Wolfram, Molybdenite, and Bismuth.*—Very small quantities of tin and bismuth have been recorded from the district, but the general absence of siliceous granites and their associated pegmatites, intrusive quartz porphyries, greisens, and pegmatitic quartz, indicates decidedly that these minerals and their associates do not occur in commercial quantity.

(3) *Arsenic and Antimony.*—The general absence of these in commercial quantity is indicated much as in the Broken Hill district.

(4) *Iron and Manganese.*—Iron oxides outcrop only as very small lenses, and an examination of the geological structures indicates that the value of the expectation of finding commercial bodies of magnetite, hæmatite, or other iron oxide, is negligible.

The field examination also indicates the general absence of commercial bodies of manganese.

(5) *Chromite and Platinoid Minerals.*—The general absence of Serpentine and allied rocks suggests the hopelessness of expecting commercial quantities of these minerals in this area.

(6) There remain gold, silver, copper, lead, and zinc.

Until a detailed geological survey has been made of this important area, it would be impossible to say that it possesses no large bodies of commercial importance of these minerals in addition to those already worked. The numerous "zones of crush" are in need of examination for possible surface traces of important deposits of gold-quartz, "saddles," "pressure lenses," for replacement deposits of copper, lead, and zinc, with gold and silver by-products.

It would appear also that no serious attention has yet been paid to the long line of porphyries extending from Mount Hope to Mount Boppy as possible containers of low-grade copper as secondary enrichments at shallow depths.

D.—Table of Ore-Production from Broken Hill.

Year.	Crude Ore mined.	Value of Product, including Ore, Bullion, Concentrates, and Refined Products.	Year.	Crude Ore mined.	Value of Product, including Ore, Bullion, Concentrates, and Refined Products.
	tons.	£		tons.	£
1885	3,000	42,866	1905	1,339,034	1,977,198
1886	14,750	228,519	1906	1,252,136	2,187,931
1887	51,880	470,290	1907	1,652,891	5,111,815
1888	125,984	744,000	1908	1,447,504	3,215,325
1889	*161,500	1,725,213	1909	1,030,287	2,611,189
1890	*192,546	2,628,536	1910	1,243,684	3,033,541
1891	471,101	3,960,676	1911	1,484,397	3,832,431
1892	403,132	2,479,692	1912	1,639,659	4,436,759
1893	†.........	2,979,309	1913	1,744,177	4,967,959
1894	642,822	2,167,635	1914	1,441,966	4,221,179
1895	‡517,565	1,644,563	1915	1,504,603	3,341,921
1896	820,366	3,010,462	1916	1,020,027	4,479,514
1897	1,011,961	3,352,462	1917	1,031,359	5,148,316
1898	890,809	3,447,728	1918	1,251,161	6,232,931
1899	1,263,107	5,364,022	1919	415,400	2,562,748
1900	1,424,028	4,004,790	1920	38,661	282,516
1901	1,278,622	2,665,028	1921	317,333	1,743,586
1902	1,114,864	2,202,311	1922	640,064	3,615,980
1903	1,100,514	2,711,234			
1904	1,342,276	§............	Grand total ...	33,325,170	£108,793,175

* B.H.P. only. Other figures not available. † No returns crude ore mined. ‡ B.H.P. only.
§ No returns value.

E.—DESCRIPTION OF COLOURED PLATES.

The minerals represented in colour on Plates I to VIII inclusive have been obtained from the Main Broken Hill Lode, while those represented on Plate IX are from the Broken Hill Consols Lode.

The accompanying notes, dealing with Plates I to VIII, thus refer only to the minerals formed in the zone of maximum chemical activity.

The notes by Mr. George Smith on minerals from the Broken Hill Consols Lode, and figured on Plate IX, refer to minerals formed under less intense chemical activity, and appear to represent a decadent phase of the chemical action which produced the Main Broken Hill Lode itself. The magnetite-garnet-apatite deposits, together with those consisting of galena-fluorspar with quartz, galena with iron-carbonate and quartz, and the tin-wolfram types in greisen and tourmaline pegmatite, are not illustrated.

The location of the mineral assemblage, known as the Broken Hill Lode, is very peculiar. It represents the product of chemical and physical activity, generally supposed to be characteristic of zones deeply seated beneath the earth's crust. It is surrounded by schists, igneous rocks, and ore deposits, which show much less decided traces of chemical and physical activity than those which are found near and within the Broken Hill Lode proper. This Broken Hill mass may have been dragged, in part, over less deeply seated rocks of the same mountain area, or it may represent, in part, an original centre of maximum chemical and physical activity with surrounding zones in which the chemical and physical action was less pronounced in proportion to the distance, measured radially, from the Broken Hill Lode as a centre. The planes of cleavage and schistosity in the extensive area around Stephen's Creek are prevailingly of low angle, and suggest generally a great overthrusting, or dragging, in this portion of the area. The arrangement of the rocks, both along the Apollyon Valley, and along the western portion of the Great Western Fold, suggests very pronounced gliding action of fold limbs on each other. This idea is strengthened by a knowledge of the existence of sillimanite schist on the eastern side of the Apollyon crush, and of granite sills with blunt apophyses on the west. The galena-fluorspar veins, west of the Mount Robe Fold, also suggest the transport of more deeply-seated masses over a less deeply-seated series.

The order observed in the numbering of the plates approximately accords with the sequence of the mineral introduction. Thus the Broken Hill Lode appears to have been pre-determined by emanations along a zone of crush and of drag-folding, whereby "pressure lenses" of pegmatite, with or without green felspar, were developed along the crush zone, and in part also as replacements of the schist alongside the zones of crush. A marked replacement of colloidal silica replaced this penetration of the sediments by the pegmatite. Rhodonite, manganese garnet, fluorspar, gahnite, galena, zincblende, silver, copper, and iron sulphides, with traces of other minerals, such as cadmium, were developed later, and partly at the expense of the earlier pegmatite. The silica appears to have replaced the schists and pegmatite in places for considerable distances beyond the limit of the commercial bodies of ore. Silica of opalescent appearance, and apparently of later development than the rhodonite, garnet, and gahnite, is shown in the numerous veinlets which form networks throughout the garnet sandstones.

All the minerals figured on the plates represent the actual dimensions of the specimens.

PLATE I.

Pegmatite with green felspar, replaced in part by galena, zincblende, garnet, and quartz.

The principal mineral represented in the plate is a green felspar of the orthoclase type. With it are associated garnet, as crystals and grains, well-cleaved galena, zincblende, and bluish opalescent quartz.

In the north-west corner a large grain or small crystal of manganese garnet may be distinguished, with rounded faces and younger than the green felspar crystal which encloses it. Bluish opalescent quartz in considerable quantity is figured on the plate, and of later age than the pegmatite and the garnet. Tiny veinlets and threads of crystalline galena are figured traversing the felspar crystals, the main bunches of the sulphides appearing, however, as replacements of the cementing material between the larger crystals of felspar. It may be noted that the sulphides have eaten their way into the crystals of felspar in the form of blunt wedges, terminating apically along the cleavage planes, and passing thence as films and threads of the sulphides along the cleavage planes themselves.

PLATE II. (JUNCTION NORTH MINE.)

Rhodonite crystal with galena and garnet.

The mineral figured illustrates a large crystal of rhodonite, which has been detached from its setting of galena, garnet, and other minerals. Originally this rhodonite crystal was isolated from other rhodonite and garnet crystals within this galena matrix, much as plums are isolated from each other within a pudding. The crystal faces are brilliant, and have not been corroded but they are incomplete, being deeply furrowed with pits, grooves, and sub-angular channels, the facets, however, not sharply intersecting each other in geometrical lines, but as rounded chamfers and channels. The galena is very well cleaved, of coarse texture, and shows brilliant faces. It does not appear to have penetrated the rhodonite crystal along cleavage planes. Both rhodonite and galena appear to have grown simultaneously, the pitting, channeling, and grooving of the rhodonite being due to the simultaneous intergrowths of the two minerals with mutual crystalline expansion. The surface of separation between the rhodonite and galena is extremely sharp, but in places the stripped faces of the rhodonite show the attachment of a film, almost negligible in thickness, of amorphous galena, connecting the coarsely crystalline galena with the pitted and channeled rhodonite. Grains of garnet may be seen in the cubical galena.

PLATE III. (NORTH MINE.)

Crystalline Rhodonite with galena, zincblende, and calcite.

This specimen is a fragment of a large mass of crystalline rhodonite from the North Mine, exceeding 100 lb. in weight.

In the centre and lower, or southern, portion of the plate, flesh-coloured rhodonite with well-developed cleavage planes is figured. In the north-eastern and northern portion, crystalline calcite is shown, and in the extreme north-western portion massive cubical galena with intergrowths of bright yellow chalcopyrite is figured. The chalcopyrite is also shown in the central portion of the extreme lower or southern limit of the figure.

The rhodonite is dotted with grains and crystals of manganese garnet, and with smaller octahedra of gahnite, all with rounded faces, and apparently the result of simultaneous intergrowths of rhodonite, garnet, and gahnite. The calcite also contains these minerals. The rhodonite is seen in the figure to be traversed by irregular veins and splashes of calcite partly developed along cleavage lanes and partly as later growths at the expense of the rhodonite host.

PLATE IV.

Rhodonite crystals with zincblende and calcite.

The rhodonite exists as long prisms, pale in colour, in a setting of granular and cleaved calcite.

The calcite contains granules and rounded crystals of garnet.

Zincblende, brilliant in colour, well-cleaved, but extremely dark, is developed as grains and patches throughout the calcite, and in association with the rhodonite, either enveloping it or intruding it along cleavage planes and joints. This zincblende appears to have a high content of iron, together with other minerals. Copper pyrites occur as brilliant yellow grains and small patches occur, as intergrowths or inclusions within the zincblende.

PLATE V. (JUNCTION NORTH MINE.)

Garnet crystal with galena.

The garnet shows most brilliant faces, being those of construction or growth rather than those of corrosion. The crystal faces are built up, as it were, of parallel plates rising one above the other in small but irregular steps. All the edges of the crystal faces, and of the steps, are well rounded. Pitting, of definite crystalline form, is well marked. This garnet crystal is one of a group which occur as isolated individuals set in a paste or matrix of coarse crystalline galena, the latter being sharply marked from the garnet, or else separated therefrom by the merest film of amorphous galena. As in the case of the rhodonite described in Plate II, the garnet and galena appear to be intergrowths fromed simultaneously during the general process of replacement and expansion by which the lode itself was formed.

PLATE VI. (BRITISH MINE.)

Galena and zincblende with garnets.

The specimen illustrates massive and crystalline galena intimately associated with intergrowths of garnet crystals, garnet sandstone, copper pyrites, and quartz. In the lower right-hand corner garnet sandstone is figured, finely granular in texture, and dark in colour by reason of galena growths within it, both as tiny veinlets and as extremely numerous specks and granules.

In the centre of the plate, garnet is figured having a finely-granular texture as a nucleus, and bordered by darker garnet crystals of similar chemical composition.

Both patches of garnet sandstone mentioned here are separated from the enclosing galena by an irregular aureole of opalescent quartz, brilliant yellow grains, and splashes of chalcopyrite and resinous crystals of manganese garnet with rounded and subdued outlines. These are all indicated in the Plate.

The galena is coarse in texture and well cleaved, and contains abundant specks and threads of chalcopyrite, together with massive zincblende shown in the upper right-hand portion of the figure overlying the well-cleaved galena.

PLATE VII. (BRITISH MINE.)

Crystals of garnet with galena and opalescent quartz.

The garnets show well-developed crystal faces, and appear to be simultaneous intergrowths with the enclosing galena, which is massive and well-cleaved. Brilliant yellow chalcopyrite is shown a little to the left of the centre of the figure, and opalescent quartz occupies the lower left-hand or western portion of the plate.

In these specimens, as indeed throughout the whole of the Broken Hill Lode minerals, there is no sign of distortion by flowage or pressure after the formation of the minerals, the faces being as perfect as when they were originally formed.

PLATE VIII. (NORTH MINE.)

Garnet sandstone invaded by veins of opalescent quartz.

Garnet sandstone has been recorded from the Broken Hill Main Lode as pipes or irregular and bent tubes or cylinders as much as 100 feet across and 700 feet in length. The plate represents a fragment of a large specimen obtained from an extensive exposure in a North Mine stope. The garnet sandstone is light in colour and finely granular in texture. As in the case of most of the garnet sandstone of the Broken Hill Lode, the sandstone is friable, having very little cement, and specimens must be handled with care, otherwise they break down easily by attrition.

The quartz is younger than the garnet sandstone, and has intruded it as numerous threads, veinlets, and patches, giving to the stope face the appearance of a brecciated mass of garnet sandstone. An interesting feature in regard to the younger opalescent quartz is that specks and granules of galena, together with copper pyrites, follow the planes of contact between the garnet sandstone and the quartz, the tiny veinlets of quartz themselves passing into the garnet sandstone as long threads or lines of these sulphides.

PLATE IX.

Description of Minerals from the Broken Hill Consols Mine.

By Mr. George Smith, Inspector of Mines.

No. 1.—Crystal of native silver projecting from an amorphous base of the same material. As described elsewhere, this was originally enclosed in calcite which had been dissolved and partly removed, leaving the silver in masses of interlaced crystals. These crystals rarely exceeded two inches in length, nearly all were thin and wire like and therefore not equal in size to some of the American occurrences of similar character. They were bright and showed no signs of leaching or tarnish. The quantity of silver in this particular deposit amounted to several hundred weights. The assay value varied from 97·20 to 99·86 per cent.

No. 2.—Native silver in calcite with siderite. This specimen is from a deposit found just below No. 1, but in unaltered calcite. There were no definite crystal forms and the deposit, somewhat smaller than No. 1, had the same silver value. There were no associated minerals. The calcite and siderite often occurred in alternate bands typical of fissure lode structure, but the silver was confined to the calcite, generally in the middle band. No impregnation of silver in the vein material was seen in this zone, with the exception of films of pyrargyrite, which were plentiful in the cleavage planes of siderite in certain areas.

It was different in the oxydised zone, where the siderite had been changed to limonite which, when adjacent to the rich ore bodies, was thickly impregnated with cerargyrite, though a few feet away it might be practically barren. The silver ores in the oxydised zone had been originally deposited in the same pure concentrated forms as those found below; it was due to leaching action that they were decomposed and partly removed. The silver so dissolved did not travel far as it was found redeposited in close proximity as chloride or iodide, both of which were present in profusion. The original deposits of these higher levels were mainly dyscrasite, when found they were in all stages of alteration. Native silver did not occur with these secondary minerals.

No. 3.—Compound terminated prism of dyscrasite associated with calcite and siderite. Similar crystals were found in small isolated deposits in the deeper levels enclosed in calcite. Very perfect crystals of the lower silver values were met with, but, being brittle, with a basal cleavage, they were often found broken. They represented varieties ranging approximately from 73 to 84 per cent. of silver (Ag_3 Sb to Ag_6 Sb.) The silver present compared with the antimony was most frequently in multiples of three, Ag_3 Sb, Ag_6 Sb, Ag_9 Sb, Ag_{12} Sb, Ag_{18} Sb, Ag_{15} Sb was not met with. The high values were in crystalline arborescent groups. The large masses of dyscrasite were found in the oxydised zone only. They consisted of aggregates of crystalline grains of a tin-white color, with brilliant metallic lustre; the prisms, however, were dull silver-white. While the latter were only found in calcite, the largest mass was without any accompanying vein material; it had been deposited directly on the footwall. There were thus at least three types; all readily tarnished on exposure from yellow to brown. The coloring on the specimen illustrated is due to this cause.

J. D. Dana (A System of Mineralogy, Appendix I), states that T. Petersen endeavored to show that there are two native compounds of silver and antimony, Ag_2 Sb_2 and Ag_6 Sb_2, and all recorded analyses which did not correspond with these formulae should be considered erroneous or due to mixtures. No explanation was offered in support of this opinion. More recently, T. L. Walker (Contributions of Canadian Mineralogy, 1921, Department of Mineralogy and Petrography, University of Toronto, Canada) thinks it probable that dyscrasite is made up of entectic intergrowths of silver and silver antimonide. He supplies two plates illustrating miscropcopic sections, which show a mechanical mixture of the two minerals, and apparently upon this occurence he deduces the theory that dyscrasite containing the higher proportions of silver should be regarded as a mixture. In the case of the Consols deposits no mixture was seen, and the quantity of pure material available for investigation was very great. All the analyses quoted by the writer were of crystallized types, in every case these were found to be pure, and their composition corresponded to a chemical formula. There seems no more reason to doubt that the higher values were as definitely chemical combinations of silver and antimony as were the poorer varieties.

No. 4. Stephanite.—This is also practically pure; unlike the other minerals figured, it occurred in small vughs. A few well formed hexagonal prisms were obtained, but the specimen illustrated consists of an aggregate of tabular crystals. Viewed from one direction they show a brightness of lustre which could not be reproduced in the plate.

Though found in different parts of the mine (all within a small area), the total quantity of this mineral amounted in weight to a few pounds only. The quantity of antimonal silver sulphide of any kind, except tetrahedrite, was very small, though the amount of antimony present, free or combined, was considerable. The bulk was combined with silver as antimonide (dyscrasite) and an attempt to explain this combination of weaker affinities was made in the Trans. Am. Inst. Mining Engineers, 1897 (XXVI, pp. 69–78.) There were no mineral associates with the stephanite. Galena, blendeand pyrites, which so often accompany the rich silver sulphides of other mines, were absent.

It is believed by some authorities that the Consols lode is closely related to the main Broken Hill lode, and at one time (1897) a rich branch was followed for some distance eastward from the Proprietary Mine, which was thought to be the actual connection. The respective lodes, however, are of entirely different types, the general conditions differ widely, and though the minerals would be expected to vary in the circumstances, one might expect some resemblance if such a connection existed. The Consols lode fissure was followed in mica schist some hundreds of feet towards the Proprietary Mine, but it was not ore-bearing at any point within that distance. All the silver deposits occurred in that portion of the lode which was enclosed by amphibolite. Those who believed in the connection offered no explanation why such minerals as rhodonite, gahnite, and blende should be absent from the Consols, while they are so plentiful in the main lode. Embolite, so common in the latter, formed the enriching material in the Proprietary end of the supposed connecting link, but it did not occur in the Consols, conversely cerargyrite, which was found in large quantities in this lode, was never detected by the writer in the main lode in tests extending over several years.

[9 coloured plates.]

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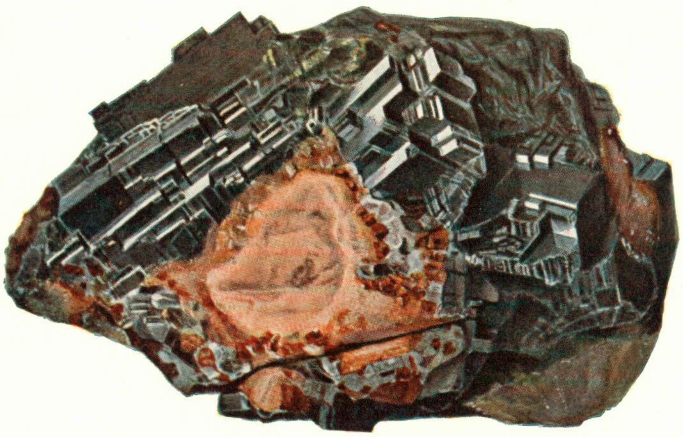
Pegmatite with green felspar, replaced in part by galena; zincblende, garnet, and quartz.

**Rhodonite crystal with galena and garnet,
Junction North Mine.**

Crystalline rhodonite with galena, zincblende, and calcite, North Mine.

Rhodonite crystals with zincblende
and calcite, North Mine.

Garnet crystal with galena,
Junction North Mine.



Galena and zincblende with garnet, British Mine.

Crystals of garnet and opalescent
quartz, British Mine.

Garnet sandstone, invaded by veins of opalescent quartz, North Mine.

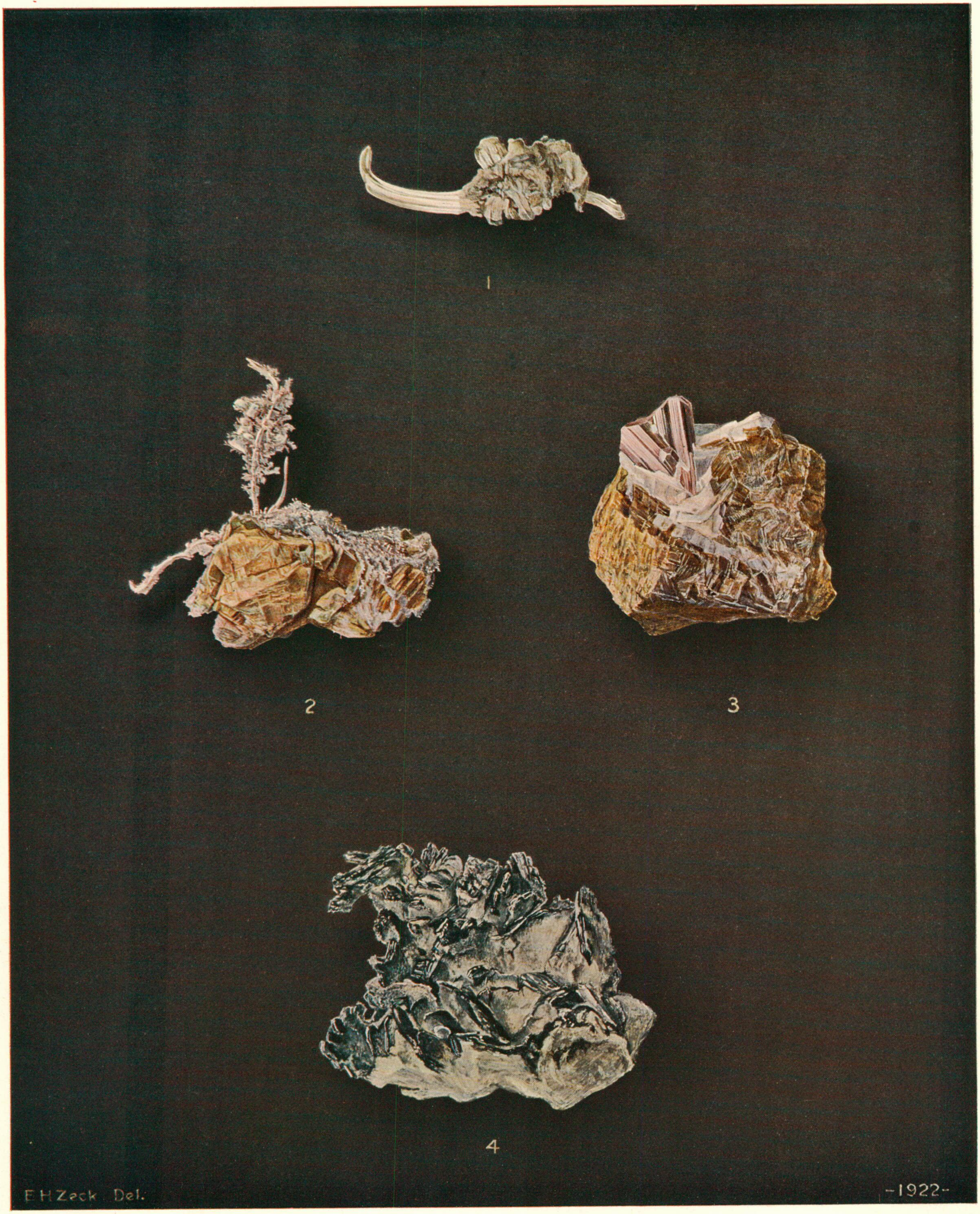


Fig. 1, 2, Native Silver; 3, Dyscrasite; 4, Stephanite, Broken Hill Consols Mine.

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