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Thesis for the Degree of Master of Science in Geology, University of Sydney.

R.L. Stanton, B.Sc., 1952.

Part I.
The Geology of the South-Eastern Portion of the Island of Santa Ysabel and the Island of San Jorge, with Particular Reference to the Significance of this Area in the Determination of the Geotectonic Evolution of the Solomon Islands.

in support of which is submitted

Part II.
Mineragraphic Studies of Ores from the Lloyd Copper Mine, N.S.W., and from Webb's Consols Mine, Emaville, N.S.W.
The author's thanks are due to the Government of the British Solomon Islands, Professor C. E. Marshall of this University, and to J. C. Grover, Chief Geologist, B.S.I.P., for granting him the opportunity to carry out field research in the Solomon Islands.

The determination of micro-fauna by F. K. Rickwood of this Department is also gratefully acknowledged. No identification of foraminifera has been carried out by the writer; this therefore is to be disregarded in the assessing of the thesis.

The writer would also like to thank Dr. A. B. Edwards and Mr. G. Baker, of the Mineragraphic Section, C.S.I.R.O., for their guidance in mineragraphic work.
PART I.

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The area discussed in this paper includes the south-eastern portion of the island of Santa Ysabel, and the island of San Jorge. Both of these form part of the Solomons Group.

To date, geological observation in the Solomon Islands has been meagre. The small amount of work done has been no more than reconnaissance and has been confined almost entirely to Guadalcanal. Certainly no geological work had been attempted on Santa Ysabel previous to the survey recently completed.

As the geology of this area was so little known, the main function of the investigator has been to collect and to map. Hence treatment of the subject is here largely descriptive, though the author has attempted to put forward some suggestions and ideas regarding the implications of the abundant ultramafics and their associates, and the tectonic environment of the island and island group.

The chain of islands constituting the Solomons Group is about 600 miles long, and extends south-easterly from New Britain. Although it appears to be an "island arc" it is an unusual one in that it is hardly arcuate at all. Its lack of a pronounced convexity
contrasts sharply with the flowing curves of the better-known island arc structures. There is no doubt, however, that the Solomon Islands form a double chain trending parallel to the Marshall Line in this region. The islands of Santa Ysabel and San Jorge form part of the northern chain - i.e. that closest to the continental border.

The physiography of Santa Ysabel is typical of the non-coraline islands of Melanesia, being characterised by extreme ruggedness and with the presence of deep river gorges. Such features are the result of two factors:

i. The recent uplifting of many parts of this region - a movement which in all probability is continuing.

ii. Prevailing climatic conditions - rainfall is typically tropical, occurring principally as heavy downpours of comparatively short duration.

Physiographically San Jorge differs from Santa Ysabel, due to the presence of a "blanket" of recently uplifted sediments. These are so uniformly soft that there has been little opportunity for erosion to become differential, and this has produced the unusually rounded and even outline of the island.
Covellite veins (dark) replacing chalcopyrite (medium grey) but leaving pyrite (white, centre). Pyrite was the first primary mineral to form, and was followed and partially replaced by chalcopyrite. This in turn was veined by supergene covellite.

X 174.

Webb’s Consols.
LLOYD COPPER MINE

Legend:
- Mudstone
- Andesitic tuff
- Shale
- Porphyry
- Arkose
- Mineralised area

Geological Surface Plan

Scale: 1" equals 200'; Surface contour interval, 50'

Topographical and Geological Survey by the author.
Veins of covellite (dark grey) ramifying chalcopyrite (light grey). Brilliant white mineral, upper right, is arsenopyrite. Dark material is quartz gangue.

X 174.

Webb's Consols.
3.

General Geology.

It has been suggested that San Jorge is, geologically speaking, radically different from Santa Ysabel. Except that San Jorge happens to be composed chiefly of ultramafic material and that it has an unusually heavy blanket of recent sediments, this has been found not to be so. The two islands may be treated as a single geological entity.

Basically, the islands are made up of rocks of two groups:

i. An older, folded group, consisting of shales, mudstones, pillow lavas and intrusive ultramafics. This, henceforth, will be referred to as the "older group".

ii. A younger horizontal group, resulting from under-water deposition on the older group, and subsequent even vertical uplift. The occurrence of rocks of this "younger group" is widespread but sporadic. Such unevenness of distribution is probably largely due to erosion, but results partly from the non-submergence of some portions of the older group.
The Older Group.

(a) The Sediments.

These are for the most part shales, mudstones and arkoses. As shown in Fig. 2, the formation is well developed and widely distributed, particularly on Santa Ysabel. Its most extreme development is on the north-eastern side of the island, where it forms an extraordinarily rugged terrain. This formation also forms part of the south-western region of Santa Ysabel, and as an extension of this is developed to a limited extent on San Jorge. Perusal of Fig. 2 might suggest that the projection of the sediment boundaries across Thousand Ships Bay is not altogether justified. However, a number of small un-mapped islands occur over this area, proving the presence of sediments here.

Petrographically the sediments show little variation - they are, with only minor exceptions, fine, and vary in colour from white, through cream and light brown to rare deep browns and blacks. Bedding is usually well developed, particularly to the south of Soga Point, where light and dark coloured beds, approximately four inches thick, alternate with remarkable uniformity over some hundreds of feet. (Because of this remarkable uniformity in thickness and alternation of the light and dark beds, the
Sediments of the Older Group.

Micro-photograph of coarse band in shales from Funakura Point, showing high felspar content. Composition of the specimen sectioned is:

- Groundmass (calcite 90%) — 45%
- Felspar (plagioclase 80%) — 40%
- Hornblende — 10%
- Magnetite, biotite etc. — 5%

Crossed nicols, X 100.
field name "ribbon shales" was applied to the formation.

Microscopically many of the sediments are arkoses. Plagioclase is the predominant - generally the exclusive - felspar, frequently showing excellent zoning and good crystal outlines. The fact that crystal and other fragment boundaries are sharp (rounding is quite exceptional) is probably of some significance. Commonly the groundmass, consisting of finer matter and calcareous cement, is in excess of the felspar fragments, suggesting a "poured in" type of sediment. A specimen from Fulakora Point - and as such a fair general sample - was found to have the following composition:

Groundmass (fine chlorite, sericite and calcareous matter) ----- 50%.
Felspar (predominantly plagioclase) ----- 40%.
Hornblende ----- 7%.
Magnetite ----- 2%.
Fossil remains ----- 1%.

Occasionally non-doubly-refracting silicious material is plentiful - most of this is probably fragmented sponge spicule.
The sediments carry abundant foraminifera - a brief and incomplete examination of washes and concentrates from the shales showed two distinct general assemblages, the first containing:

- Fissurina sp.
- Globigerina triloba
- Globigerina sp.
- Siphogenerina sp.
- Gyroidina sp.
- Cassidulina sp.
- Sphaeroidinella dehiscent
- Amphistegina lessoni
- Pullenia sp.
- Globorotalia menardii
- Bathysiphon sp.
- Textularia sp.
- and Ostracodes.

the second containing:

- Pyrgo sp.
- Globorotalia menardii
- Orbulina universa
- Saracenaria sp.

as characteristic forms.

It is thought that these two assemblages are Upper Miocene to Lower Pliocene.

The sediments show plentiful evidence of tectonic disturbance. Apart from folding and large-scale faulting and intrusion by ultramafics - a subject dealt with later in this paper - the rocks show much small-scale evidence of tension and compression. At Tanakau Point the dipping beds show extensive minor reverse faulting,
Position at which photograph taken  •

Direction in which photograph taken

P 1. Shales and fine felspathic sandstones, typical of the sediments of the older group. Dip of bedding E 10° S at 20°.

P 2. Slightly distorted fine sandstones of the older group.

P 3. Minor faulting (both normal and reverse) in shale and fine sandstone bands of the older group. These sediments form bold cliffs on Tanakau Point.
and along the north-east coast much minor normal, with subordinate reverse, faulting has been developed. In some localities puckering - interpreted as slump phenomena rather than drag folding - is common.

Owing to this large and small scale disruption of the formation it was not possible to ascertain its thickness in the area surveyed.

(b) The Volcanic Rocks.

Volcanic rocks are highly developed in the central portion of Santa Ysabel. A small, isolated strip, probably occurring as a fault effect, appears between Takata Bay and Cockatoo Anchorage. No lavas have been found on San Jorge.

Owing to the severe disturbance of the sediments and the resultant complexity of dip data, and to the restricted area of survey, it is difficult to determine the relative ages of the sediments and the lavas.

The volcanic rocks almost invariably show well-developed pillow structure. Possibly the finest development of these is found in the vicinity of Pilo and Kilio Islands, near the village of Sigana. Here the pillows range in size from 6 inches to about 3 feet
in diameter and their formation is, in some cases, so extraordinarily perfect that they may be likened to "strings of sausages". In section the pillows show chilled margins, about 3 inches wide and broken by radial cooling fractures, enclosing a coarser core.

This coarser material of the cores has a typically ophitic to sub-ophitic texture and is basaltic in composition. Plagioclase occurs as sub-idiomorphic lathes enclosing augite and very rare olivine. Magnetite is always present, commonly in dendritic form. The chilled margins differ from the cores only in that they are finer-grained and that they contain some devitrified glass and microlitic material.

The lavas usually show extensive alteration, principally to chlorite, zeolite and calcite. Calcite commonly occurs in veins and is easily detected megascopically. Chlorite is developed to a greater or lesser extent in most sections, and is sometimes found completely replacing sections of basalt, and forming bright green rounded masses weighing up to several pounds. Analcite (particularly) and stilbite are common, the former often occurring as extensive veins.
The Volcanic Rocks.

Chlorite and thompsonite resulting from the alteration of pillow lava. The chlorite vein (medium grey, fair relief, upper left hand, lower right of micro-photograph) has been offset by minor faulting, and the fracture has been filled with thompsonite. The dark areas are heavily altered parent lava.

Crossed nicols, X 100.
The Volcanic Rocks.

Magnetite needles forming a lattice-work in lava from Sigana Island.

Ordinary light, X 100.
P 1., P 2., P 3.; Typical pillow lava occurrences. Masses of bright green chlorite often occur in the spaces between individual "pillows", and the lava is always finely veined by calcite.
There is, of course, every possibility that these basalts are spillites. They are undoubtedly submarine, they are characterised by pillow structure, and coloured minerals are heavily altered to chlorites. Further, the plagioclase is predominantly albitic. However, confirmatory chemical evidence is required before these lavas can be definitely classed as spillites.

(c) The Ultramafic Rocks and their Associates.

It seems fairly clear that the ultramafic rocks are intrusive into both the older sediments and the volcanic rocks, and hence that they are the youngest of the "older group". They are extensively developed on both San Jorge and Santa Ysabel, their trend roughly conforming with that of the sediments and volcanics, and with the major axis of the island. Any deviation from this seems purely local—there is a general well-marked "conformity" between intruded and intrusive rocks.

Two factors simplify the mapping of the ultramafics. Firstly they form physiographic highs, and secondly their residual soils are poor, causing the development of frequent "bare patches" (i.e. areas of coarse grass, devoid of jungle growth) over their outcrop area.
(This is particularly noticeable on San Jorge, where the sparseness of growth has, by encouraging extreme erosion, caused the desertion of the island by a formerly large native population.)

As is usual in the ultramafic association, peridotites and allied types greatly predominate over other rock groups. Frequently, however, pronounced banding has been developed, producing wide variation in rock type over small areas. Predominantly the banded rocks consist of hornblende-quartz-felspar schists and associated quartz-hornblende pegmatites. There are also very minor gabbros and micro-gabbros.

The ultramafic rocks vary over the full range dunite-olivinite-peridotite-perlmite, variation within the class resulting, in general from variation in the ratio olivine:enstatite:diopside (or diopsidic augite). Dunites are subordinate to other ultramafic types, but occur with fair frequency as small dykes. Normally they contain between 90% and 95% olivine, with very minor amounts of ortho- or clino-pyroxene. Magnetite, chromite and picotite are normally present, particularly on San Jorge, where chromite- and magnetite-dunites are common. Where picotite occurs, it is almost always
rimmed by chromite.  Olivine-chromitite and olivine-magnetitite occur in isolated pockets where there has been extreme concentration of the ore mineral.

Serpentinisation has taken place to a greater or lesser degree wherever dunites have been examined. In many cases it has been almost complete, only isolated residual cores of olivine remaining in the serpentinite. The latter are normally almost entirely antigorite and serpophite, together with primary ore, secondary magnetite dust, and occasional chrysotile and brucite.

Olivinites are rather more commonly developed than dunites. The pyroxenes are almost always enstatite, diopside and diopsidic augite, with the latter usually predominant. The ore minerals - magnetite, chromite and picotite - occur as with the dunites, and there may be isolated garnet.

Serpentinisation, though not as complete as with the dunites, is usually fairly well advanced. Blades of antigorite invade without interruption, both olivine and pyroxene, and complete bastite pseudomorphs are fairly common.

Most of the peridotites examined are harzburgites - they consist essentially of ortho- and clino-pyroxene, with subordinate olivine and ore. Although no significance is suggested for it, the proportion of picotite seems to be rather higher in the peridotites than in any of the
The Ultramafic Rocks.

Chrysotile veins in completely serpentinised dunite from Vittoria Island, showing the development parallel to the fibres of secondary magnetite. The background is of bladed antigorite.

Crossed nicols, X 100.
The Ultramafic Rocks.

Fine chrysotile veinlets in a completely serpentinised dunite from Vittora Island. The background is of meshed serpophite-antigorite.

Crossed nicols, X 100.
The Ultramafic Rocks.

Chromite (dark) forming rims round picotite (lighter cores) in harzburgite from San Jorge.

(Photography here was rather difficult because of the extreme contrast in the amount of light transmitted by the picotite and the completely serpentinised background).

Ordinary light, X 100.
The Ultramafic Rocks.

Coarse, bladed antigorite developed in a highly serpentinised olivinite from San Jorge.

Crossed nicols, X 100.
The Ultramafic Rocks.

Bastite veins in bronzite occurring in harzburgite from Tanabuli Island.

Note minor offsetting of vein due to minor movement within the bronzite grain.

Crossed nicols, X 100.
other ultramafic classes. In common with the dunites and olivinites, the peridotites are usually highly serpentinised - many harzburgite thin sections show little more than bastite and a post-olivine antigorite-serpophite mesh.

Perknites are probably the most abundantly developed class in the ultramafic group. Although the pyroxenes show some bastite veining, the perknites have resisted serpentinisation to a far greater degree than have the other ultramafics. The perknites are principally diopsidites, enstatolites, and bronzitites, with infrequent marginites. On no occasion have amphiboles been observed in the pyroxenites.

Occasionally normal gabbros and micro-gabbros occur as part of the ultramafic masses.

The hornblendic associates of the ultramafics fall into three groups:

(a) Normal diorites.
(b) Hornblende-quartz-felspar schists.
(c) Hornblende-quartz pegmatites.

Normal diorite occurs in what appears to be a small intrusion on the southern coast of San Jorge. The rock is highly altered, but the principal primary minerals are clearly hornblende and zoned plagioclase. Very minor clinozoisite is occasionally present.
The hornblende-quartz-felspar schists and the hornblende-quartz pegmatites are constant associates, and as such always form part of the ultramafic masses. The schists do not appear to have been formed by simple shearing of normal diorites. They contain a rather higher quartz percentage than the normal diorite (very little free quartz occurs in the normal rock, whereas it may be quite abundant in some sections of the schists) and are finer grained. Further, the quartz grains usually interlock and appear to have a granoblastic texture very reminiscent of quartzite.

The quartz-hornblende pegmatites occur in sporadic lenses and pods in the bands of schist. Such lenses rarely exceed 4 inches in width, but may be up to 4 or 5 feet in length. The rock is very coarse, hornblende crystals being up to 3 or 4 cms. in length.

The presence of the "granoblastic" areas of quartz in the schist and the occurrence of the rather peculiar hornblende pegmatites suggests, in part at least, an hydrothermal origin for the banded rocks.
The Banded Associates of the Ultramafic Rocks.

Hornblende - plagioclase - quartz schist, showing apparent granoblastic aggregate of quartz.

Crossed nicols, X 100.

In the general field study of the ultramafic bodies, several features have been observed which are considered to be of some significance. A general account of these is given here to be referred to in later discussion.

(a) Although the banded rocks commonly occur within the ultramafic masses, their distribution here does not.

Wherever the banded rocks occur, their "strike" is parallel to that of the intrusive boundary. The "dip" of the bands is, most frequently, to the south-west (this is given as a general direction only) the angle varying between 40° and 25°.

(b) In one instance the banded rocks are found associated with and predominant over the ultramafics over the full width of the intrusive. The subordinate ultramafic usually occurs as veins and small contorted stringers invading the banded material. A number of specimens collected over an area approximately 2 feet square were

In the general field study of the ultramafic bodies, several features have been observed which are considered to be of some significance. A general account of these is given here to be referred to in later discussion.

(a) Although the banded rocks commonly occur within the ultramafic masses, their distribution here does not appear to be haphazard. Where these rocks do occur they are always at or close to the apparent boundary of the intrusive. It is not suggested that they form a continuous "border facies" - normal ultramafics frequently occur right to a boundary. However, except in one notable case, banded types have not been found at any great distance from the apparent intrusive boundaries. Such banding is well developed on Vittora Island, in the small ultramafic strip extending in from Tanakau Point, in the vicinity of Lepi Bay, on southeastern San Jorge, and in several other places.

(b) In one instance the banded rocks are found associated with and predominant over the ultramafics over the full width of the intrusive. The subordinate ultramafic usually occurs as veins and small contorted stringers invading the banded material. A number of specimens collected over an area approximately 2 feet square were
found to be of the following types:

- dunite, peridotite (heavily serpen tinised),
- peridotite, quartz-hornblende pegmatite,
- hornblende-quartz-felspar schist, gabbro
- and micro-gabbro,

the hornblende types predominating.

(c) With the exception of some unstressed dunite dykes, the formerly massive ultramafics have suffered intense and widespread shearing. This shearing has frequently resulted in the development of what at first sight appear to be fragmental sediments - that they might be serpentinous agglomerates has been suggested - which may, from a distance, appear to be bedded. On close inspection it is found that the apparent sediment is composed of unsheared nuclei, surrounded by intensely crushed serpentinous matter. The size of such nuclei varies enormously - from microscopic size to masses weighing many tons.

Field study suggests that, during a period of compression, two principal fracture cleavage directions were developed. As compression became more intense, fracture cleavage became shear cleavage, with movement resulting first along one shear plane, and then another, and so on. The initial development of fracture cleavage produced, in all probability, blocks having opposite angles of, say, $35^\circ$ and $145^\circ$ - rhomb-shaped in the section
parallel to the direction of compressive stress. With the development of shear cleavage and resultant movement, these rhomb-shaped blocks were "rolled" between shear planes, both shear directions contributing towards such movement. The result, it is suggested, has been the formation of intensely crushed material along and on either side of shear planes, and of rounded unsheared nuclei. On weathering the resulting rock appears very similar to a crudely stratified serpentinous pyroclast.

Probably the best examples of this occur at Tataba (particularly at the northern point of Tanabuli Island) and on San Jorge, which is composed almost entirely of ultramafic.

(d) Owing to the thick jungle growth and to the heavy cover of fallen vegetation, contact of ultramafic with bounding formations are difficult to find. However, two such contacts are known:

(i) A clean contact of ultramafic with older sediments has been found quite close to Suva village. It was noted that:

(a) The sediments lay on top of the ultramafic.

(b) Bedding of the sediments was not parallel to the contact, countering any suggestion that this contact was merely depositional.
(c) The sediments showed no sign of metamorphism, either by heat or pressure. They showed no evidence of hardening, and there had been no crushing or dragging of the sediments at the contact.

(d) The serpentinite itself was intensely fractured, but showed no change of any kind right up to the contact.

(ii) Serpentinite and pillow lava contact on Kolare Island, to the south-east of Tataba, and here it was noted that:

(a) The serpentinite was intensely crushed right to the contact.

(b) The lava showed considerable fracturing, and might be considered to have suffered minor crushing.

(c) Magnesite veins, apparently emanating from the serpentinite, occur in the lava close to the contact. The veins thin from the contact, and are rarely present more than 6 feet from it.
Portion of a magnesite vein from Kolare Island, near Tataba, where pillow lavas have been invaded by now serpentinised ultramafics. The dark material is fragmented lava, this having been shattered during faulting and later veined by magnesite apparently emanating from the intrusive.

*Approximately natural size.*
(d) Major Structures in the Older Group.

Although it is quite clear that major structures do exist in the area studied, it has been possible to gain very little quantitative knowledge of them. Because of this, the writer has considered it futile to attempt the construction of geological sections — normally regarded as the very basis of any geological account.

Later perusal of aerial photographs, which had been unavailable before and during field work, has however, revealed the probable existence of fairly open, plunging folds in parts of Santa Ysabel. If one neglects dip data and considers only outcrop patterns in the area mapped the impression gained is that this area might form part of a major fold. The strip of volcanics, trending along the axis of south-eastern Santa Ysabel, and bounded to the north-east and to the south-west by older sediments, is certainly suggestive of this. Such a possibility has always been recognised by the writer, and it does fit quite well the evidence of the aerial photographs.

If south-eastern Santa Ysabel does constitute a much-faulted and intruded fold, then this fold is probably a syncline. The shallow dips, though they
undoubtedly are all partly fault effects, are probably the more normal ones. Steep dips in the older sediments always occur close to the intrusives, and must be interpreted as being the result of fault drag.

The development of the major fault zones, now delineated by ultramafic belts, was probably initiated during a period of intense compression. These zones then constituted fairly high angle thrusts. More recently, with the relief of compression, these faults have become zones of isostatic readjustment.

It has not been possible to determine fault displacement quantitatively.
The Younger Group.

Sediments of the younger group occur sporadically over the whole of the area studied. They show extreme lithological variation, ranging from coarse conglomerates to limestones and associated reef sandstones.

The conglomerates are confined almost completely to San Jorge, and are best developed on the south-western portion of the island. Apart from their calcareous cement, they are composed almost exclusively of ultramafic fragments. The size of "fragments" varies enormously, from small pebbles to boulders of over 1,000 cubic feet in volume. Where fragments are of normal size i.e. 6 inch diameter and under, stratification is well developed, and graded bedding common.

On the northern side of San Jorge, and on the south-western part of Santa Ysabel, the coarse conglomerate is replaced by finer conglomerate, grits and sandstones. The sandstones contain abundant fragments of micro-fossils, ultramafic material, including isolated chrysotile fibre, felspar and rare ferromagnesinan fragments. The cement - which generally constitutes at least 40% of the rock - is largely calcareous.
SOUTH-EASTERN SANTA YSABEL AND SAN JORGE
SHOWING DISTRIBUTION OF YOUNGER SEDIMENTS

LEGEND

- Ultramafic Conglomerate
- Sandstone
- Limestones & associated reef sediments

Scale - 1 in 100,000
The faunal assemblage present in the finer sediments is a fairly recent one - probably post-Tertiary. Foraminifera determined:

Quinqueloculina sp.
Marginopora vertebralis
Calcarina
Baculogypsina sp.

On the work done to date this assemblage does not differ essentially from those of Recent Pacific Foraminiferal beach sands.

Limestone is abundantly developed on Santa Ysabel, both on the south-eastern peninsular and on the north-eastern part of the island. It is not highly fossiliferous and only isolated unidentifiable fragments of microforms have been observed. The most striking feature of this limestone is the occurrence within it of blebs and stringers of red silica. The silica (which is always doubly-refracting) apparently replaces the limestone, fossils and fossil fragments forming the nuclei from which replacement proceeds. The associated reef sandstones invariably contain fragments of this red silica - a useful diagnostic feature - indicating that replacement took place while the reef was still a part of the sea bed.
The limestone has, fairly frequently, suffered non-diastrophic folding. Such folds are normally found in the smaller stream gorges where the limestone has subsided to form typical small-scale gravity-collapse structures.

An interesting feature of this younger sedimentary veneer is the apparent facies change progressing from south-west to north-east. On the southern coast of San Jorge the coarsest sediments occur, whereas on the north-east coast of this island, and on the south-west portion of Santa Ysabel their finer equivalents are developed. These then appear to give way to limestone and reef sandstones.
Position at which photograph taken

Direction in which photograph taken

Younger sediments - looking downstream on the Lana River. Boulders of partly silicified limestone. About one hundred yards upstream from here, the limestone forms a deep gorge in which gravity-collapse structures have developed.
MEMORANDUM TO Miss E. M. Dinley, FISHER LIBRARY

Under separate cover I am forwarding the original and one copy of the thesis submitted by I. G. White and accepted in satisfaction of the requirements for the Degree of Doctor of Philosophy.

[Signature]
ASSISTANT REGISTRAR.

8th July, 1955
SWW/MM
Sediments of the Younger Group.

Typical "reef sand" found closely associated with, and frequently included by, limestone of the younger group (as distinct from sandstone occurring as a finer stratigraphic equivalent of the San Jorge conglomerate). This sandstone contains a high percentage of felspar - principally plagioclase. An approximate composition is:

- Groundmass (80% calcite) --- 45%
- Felspar (70% plagioclase) --- 30%
- Lava fragments --- 10%
- Pyroxene (80% enstatite) --- 10%
- Fragmented micro-fauna --- 5%

Crossed nicols, X 100.
Sediments of the Younger Group.

Limestone (fine material, centre and sides of micro-photograph) showing development of secondary calcite veins. Secondary silicification has also taken place in this section (not included in photograph) foraminifera usually acting as nuclei for its development.

Crossed nicols, X 100.
Sediments of the Younger Group.

Chryseotile fragment included in sandstone of the younger sediments. The bright material of the groundmass is calcite.

An approximate composition of the rock sectioned is:

Groundmass (calcite, kaolin etc.) — 50%

Fragmented micro-fauna (principally foraminifera) — 30%

Ultramafic fragments — 20%

Crossed nicols, X 100.
The Younger Sediments.

Fragments of micro-fossils occurring in limestone of the younger group. Silica (near white) has replaced the calcium carbonate of the fossils, and with these acting as nuclei, is now replacing the fine limestone between them.

Ordinary light, X 100.
The Younger Sediments.

Sedimentary breccia occurring with limestone of the younger group. The coarse fragments are of red silica derived from the limestone itself - the inclusion of this material is a characteristic feature of these reef sandstones and breccias.

Approx. natural size.
Sedimentation and the Tectonic Evolution of Santa Ysabel and San Jorge.

There seems little doubt that the Solomons Group occurs in a major orthogeosynclinal (engeosynclinal) marginal belt.

Upper Miocene - Lower Pliocene sedimentation in the Santa Ysabel area probably resulted from the removal of detritus from the linear islands to the south e.g. Guadalcanal, and may have taken place in a deep neritic environment. The fact that sorting is often poor, that there is always a high proportion of matrix to coarse matter and that there has been practically no alteration of angular felspar fragments suggests fairly rapid sedimentation. There is, however, fair development of bedding, and it could not be suggested that sedimentation approached very closely the "poured in" type, so typical of greywacke formation. The non-inclusion of lava fragments from the pillow formations indicates a later date for the formation of these. It has been recognised that the later and most acute stages of the orogenic cycle may be marked by submarine outpourings and the formation of great thicknesses of pillowed basalts or "greenstones", and although the evidence here is admittedly far from conclusive it is probable that the shale formation preceded the development of the pillow lavas. Following
the outpouring of basalt, the two units were folded.

At this stage too, major fault lines, paralleling the general regional trend, probably began to develop. These then became the loci of emplacement of the ultramafic masses which now trend north-west - south-east in sympathy with the regional structure.

Movement along the faults did not cease with the emplacement of these ultramafics - there is conclusive evidence that it continued, sporadically, and that it is still occurring at present. This evidence is provided by the younger sediments.

Although their (the younger sediments) existence above sea level requires epeirogenic uplift it might be suggested that this was non-differential over a wide area, and was in no way related to the faulting now discussed. Such a suggestion, however, does not take into account the extraordinary nature of the ultramafic conglomerates of San Jorge, or the rapid facies change developed in the younger sediments.

The fragments constituting the conglomerate are so coarse (sizes of up to 1,000 cubic feet have been mentioned, and larger boulders are reported to occur) that their transportation by moving water could not be seriously suggested. However, that they were deposited under water is shown by the bedding (commonly graded)
of the (comparatively) finer material. It is probable that deposition took place from, and close to, a fault face i.e. while San Jorge was formerly submerged, it constituted the sea floor immediately adjacent to the north-eastern face of a now submerged land mass. This north-eastern face formed part of a fault zone in which ultramafic material had been emplaced and along which there was sporadic movement.

Following the normal pattern of sedimentation the coarsest and most dense material accumulated close to the source of detritus, the finer and chemical types developing further away. The presence of huge angular boulders within the conglomerate is probably due to marine erosion, which caused dislodgment of masses of material from the shoreline fault zone. (This shoreline was probably largely made up of cliffs, and as such was similar to the southern coast of San Jorge today). It is suggested that the boulders, once dislodged, rolled down the underwater fault face, and came to rest in the normal water-sorted conglomerate. They are therefore a type of "eratic". Graded bedding in the less coarse material resulted from sporadic movement along the fault. Either as the result of large-scale, or prolonged intermittent movement this hypothetical southern land mass has now been submerged, and San Jorge and Santa Ysabel elevated.
Position at which photograph taken

Direction in which photograph taken

Outcrop of ultramafic forming the cliff shoreline of southern San Jorge.
Spectacular evidence of present day movement is provided by the almost submerged village of Voki, at the head of Cockatoo Anchorage. Situated within an ultramafic belt, the village subsided about 5 feet some three years ago, necessitating the rebuilding of many of the native houses.

It is suggested that the present fault movements are of isostatic readjustment.

Sediments of the "younger group" have been found at all elevations to 2,000 feet, and it is probable that they occur at even greater heights. There has therefore been an uplift of at least 2,000 feet since Pliocene time.

These younger sediments are, then, the result of the familiar "cannibalistic" action of the geosyncline. It is, at the present time, "feeding upon itself" to produce a second cycle of sediments.

Summary of Section.

In this section it has been concluded that:

(a) The oldest sediments found on San Jorge and southeastern Santa Ysabel are Upper Miocene to Lower Pliocene in age.

(b) They were followed by the extrusion of pillow lavas of basaltic (possibly spillitic) composition.

(c) Both sediments and lavas were folded in a post
Lower Pliocene movement.

(d) Fault zones were developed at some stage during folding, and along these ultramafics intruded.

(e) Uplift of the area followed, with consequent erosion and the deposition of a "veneer" of later sediments.

(f) Isostatic readjustment along the fault zones of (d) has continued for the present, and still continues.

This has produced some peculiarities, and rapid variations in the later sediments.
The village of Woki, on the shore of Cockatoo Anchorage. Situated within an ultramafic belt, the village subsided approximately 5 feet about three years ago, indicating that the fault zones, along which the ultramafic rocks have intruded, are still active.
The Regional Tectonic Environment of the Solomon Islands, with Particular Reference to the Santa Ysabel-San Jorge Area.

Glaessner (1950) has tentatively included the Solomon Islands in the Outer Melanesian Zone. Carey defined an "Inner Melanesian Arc" as "the arc of the Main Cordillera of New Guinea" with its assumed western and eastern extensions, and Glaessner considers that the latter coincides with the Outer Melanesian Zone. The latter also remarks that "The Melanesian structures possess a number of distinctive features. They are characterised by the prevalence of sigmoidal trends and the corresponding lack of an ordered outward convexity of the island arcs; occurrence of rounded deep nuclear basins; lack of separation of volcanic and non-volcanic arcs." Of the Solomons he says - "The volcanoes are ranged along the axis of the Solomons Group. It is not possible to differentiate here between a volcanic and a non-volcanic arc and there is no distinct direction of convexity as in other island arcs".

This last statement the present writer considers to be not altogether accurate - perhaps because it was a little premature - and in the following an attempt is made to show that the Solomons Group falls, to a greater extent
than Glaessner admits, into the pattern of a normal double island festoon.

(i) Distribution of Vulcanicity.

Geographically, the island group plainly comprises two distinct chains. The more northern chain includes Choiseul, Ysabel, San Jorge and Malaita Islands, and the Nggela Group. The southern chain includes Shortland Islands, Vella Lavella, Kolombangara, New Georgia, Russell Islands, Guadalcanal, Savo and San Cristobal. In spite of Glaessner's assertion that the volcanoes are arranged along the axis of the Solomons Group, they (active and recently extinct volcanoes) are distributed throughout, and are restricted to, the islands of the southern festoon. To the writer's knowledge no volcanoes occur on any of the islands of the northern festoon.

Further, the southern group is distinctly andesitic. All of the active volcanoes are andedite producing, as have been recently extinct ones, such as Savo. It may also be significant that on Guadalcanal there are well developed dioritic intrusions.

(ii) Distribution of Serpentinites.

As has already been pointed out, the dominating feature in the geological "make-up" of Santa Ysabel and San Jorge is the abundance of serpentinites.

Further, the writer, in a short reconnaissance of the Nggela Group found these islands to be,
geologically, precisely similar to Santa Ysabel. Extensive areas of ultramafic occur particularly in the northern half of this group.

Ultramafic is reported to occur on Choiseul; it may occur in the more southern part of Malaita (this is doubtful information as it is merely the result of questions put to natives of Malaita) but is absent from the middle and northern regions of the island. (F.K. Rickwood, verbal communication).

Restricted development of ultramafic has been reported from Guadalcanal (P.J. Coleman, verbal communication). However, the present writer considers that these may form portion of an "old" serpentinite belt.

In the light of present (though admittedly limited) knowledge of the Solomons, it appears that there has been post-Lower Pliocene formation of ultramafics in the islands of the northern chain. There is as yet no evidence of this in the southern chain.

(iii) Folding and Metamorphism.

Fairly open folds have been developed in the sediments and lavas of Santa Ysabel, San Jorge, Malaita and the Nggela Group. Little is known of the geology of Choiseul, but it is probably safe to say that the degree of folding in the northern chain is:

(a) Nearly uniform throughout the group.
(b) Has nowhere been sufficiently intense for the development of phyllites or schists (other than those forming part of ultramafic masses for which a special origin is postulated).

Apart from the occurrence of volcanoes, little is known of the geology of the islands of the southern chain - with the exception of Guadalcanal. If Guadalcanal is representative of these, (and as it falls in the same volcanic and seismic zone there is every possibility of this) the southern group is characterised by:

(a) Fairly open folding.

(b) Limited plutonic intrusion of granitic type.

In summary, it has now been demonstrated that:
(a) The Solomons Group is composed of two rather straight, but distinct, island chains.
(b) Vulcanicity is distributed throughout the southern chain, but is absent from the northern.
(c) Serpentinites have been extensively developed in the northern group, where in some localities at least, they are associated with active faulting. Serpentinites occur to a very limited extent in the southern group, but may be considerably older than those of the northern chain.
(d) Folding is uniformly open (this probably to the greatest extent on Malaita) in the islands of the northern chain and regional metamorphism is absent. Of the southern chain, Guadalcanal exhibits folding of about the same intensity and absence of metamorphism.

(e) Normal plutonic intrusions (i.e. as distinct from sub-silicic ones) are conspicuously absent in the northern chain, but are known to occur in the southern.

The contrast in the geology of the two island chains seems to indicate strongly the existence of two distinct tectonic features. Furthermore these features correspond remarkably well to the classical descriptions of inner and outer island arcs. The best-known island arcs — those of the East and West Indies — certainly have a far more distinct convexity than the Solomons, but apart from this possibly superficial discrepancy, the geotectonics of the three areas is really very similar.

The most detailed analyses of island arc structure have been those by Umbgrove and Hess, of the East and West Indies respectively. In both areas double festoons occur, the inner island chains being characterised by vulcanicity, andesitic affiliations, and positive gravity anomalies, the outer by the presence of linear alpine serpentinites and negative gravity anomalies. Inner island arcs are regarded by both authorities as being due
to the rise of an inner geanticline. In contrast, the outer arc is the product of a downbuckle - the "tectogene" of Heinesz and Kuenen - the characteristic structural picture being due to deformation of "geotectocinal" sediments and intrusion of ultramafics during development of the tectogene.

There is little doubt that the southern Solomons chain fits very well the normal pattern of inner volcanic arcs. The only obvious discrepancy is the lack of pronounced curvature, though as this is probably the central portion of a recurved arc, such a linearity might be expected.

The geological features of the northern chain seem to be typical of those of normal outer arcs, with perhaps one exception. Whereas sediments of outer arcs are usually intensely folded, they are here thrown into only shallow open flexures. However, this is easily explained if one postulates the present time as being an "interdeformational" period.

In his investigations of the West Indies, Hess has found evidence suggesting two periods of deformation of the tectogene, these being separated by an "interdeformational" period. Initially, normal geosynclinal accumulation of sediments takes place. In time,
tectogene formation commences, causing comparatively
gentle folding of the sediments involved in the jaw
of the forming downbuckle. It is near the close of
this first folding period that ultramafics intrude.

A period of quiescence follows, during which the
structure partly emerges above sea level, and erosion
and sedimentation take place. The geosyncline has
now become cannibalistic and is feeding upon itself.
Considerable thicknesses of sediment may accumulate
during this period, and with continued epeirogenic
uplift, these may be raised above sea level.

The second deformation follows, involving older
sediments, ultramafics and younger sediments.

It is now suggested that the present may be a
period of quiescence between the two deformations.
The outer arc of the Solomons certainly shows all the
features cited by Hess as those of an outer strip prior
to the second folding period. Older, fairly gently
folded eugeosynclinal sediments are the rule, and these
have been faulted and intruded by ultramafics. Younger
sediments have accumulated, and with continued vertical
uplift, they continue to form.

The theories of Hess and Heinesz regarding the
mechanism of island arc formation are so hypothetical
that the present writer hesitates to accept them.
However, Hess and Umbgrove have, on factual evidence, traced a definite sequence in the development of island arcs. Although comparatively little evidence has been collected in the Solomons so far, it seems very possible that these islands show a similar pattern of development, but that they are as yet "tectonically incomplete".

No mention is made by Hess of interdeformational isostatic readjustment. This is very evident on Santa Ysabel and San Jorge, and further study over a wide field may show it to be a general feature of this stage of outer arc formation.

**Summary of Section.**

In this section it has been proposed that:

(a) Glaessner's statement that (of the Solomons):
"It is not possible to differentiate here between a volcanic and a non-volcanic arc ----" is of doubtful accuracy.

(b) Although the Solomons Group shows no pronounced convexity, in all other features its pattern of development is similar to that of the better-known island arcs.

(c) The "outer arc" of the Solomons is now passing through the "interdeformational period" of Hess.
Ultramafic intrusions of the alpine type present such an enigma that the features of any new occurrence are always worth assessing. However, the serpentinites of Santa Ysabel and San Jorge conform so well to the classical descriptions that they do little more than bolster an already remarkable reputation for consistency in mode of occurrence.

The petrography of the Santa Ysabel-San Jorge occurrence is completely normal except in that pyroxenites are perhaps unusually abundant. Contact features - lack of thermal metamorphism, absence of contortion in invaded rocks etc. - are very much the same as those observed in other parts of the world. The intrusions are closely (spatially) associated with a considerable thickness of basaltic (spilitic?) pillow lavas, a feature of world-wide occurrence. Further, their form of intrusion and tectonic relationships are precisely those of almost all other alpine type intrusions.

There is one feature of these Santa Ysabel intrusions which, however, might be examined more closely. This is the occurrence and distribution
of the banded associates of the ultramafics.
The origin of these predominantly hornblendic rocks
and the reason for their occurrence close to the
intrusive borders, is not at all clear.

As their explanation undoubtedly involves an
understanding of the mechanism of ultramafic intrusion,
the problem is a difficult one.

Despite the efforts of Hess and other protagonists
of the idea of an ultramafic "magma" the former
existence of such a liquid seems more than doubtful.
Bowen and Tuttle have shown experimentally that a low
melting point serpentinous liquid is incompatible with
the principles of physical chemistry, and the former,
some 20 years ago, suggested that peridotites might
intrude as a low temperature "mush" of olivine crystals
and intergranular liquid.

A proponent of the idea of ultramafic magma might
suggest that the banded rocks of Santa Ysabel and San
Jorge constitute a kind of sporadic border phase,
resulting from the chilling and concurrent shearing
of the intrusive. However, at least 90% of the banded
material consists of hornblende, plagioclase and minor
quartz - a composition which certainly does not support
the border phase idea. Alternatively it might be
suggested that the banded material represents xenolithic
matter - blocks of sediment and lava picked up by the
intruding ultramafic - partly assimilated by and crushed
with, the including intrusive. A rather different mode of formation, based on the work of Bowen and Tuttle, is tentatively put forward by the present writer. Four assumptions are first made:

(a) That the movement of the ultramafic material was guided by fault zones, the width of such zones corresponding, very approximately, to the present width of the intrusion. Movement within the zone took place along a great number of minor fractures, rather than along a small number of large breaks.

(b) That the ultramafic was intruded in the form of a "mush" as visualised by Bowen.

(c) That the enclosing geosynclinal sediments contained a high water content.

(d) That intrusion took place above the critical temperature of water (a probable range of 200° C. to 400° C. is mentioned by Turner and Verhoogen).

It is now suggested that following the initiation of faulting, squeezing of ultramafic material into the zone of intense breakage commenced. The main body of intrusive was preceded by a mass of veins fingerling into the sediment or lava above, but, owing to the density difference between intruded and intruding rock, there was no rifting and foundering of the roof.
Rather the intrusive acted almost as an hydraulic ram, and was probably aided in this capacity by large volumes of water above critical temperature. This high temperature vapour may have occurred partly as an envelope, bounding the intrusive, and forcing its way ahead into the roof of shattered sediment or lava, and to a lesser extent, into the wall rocks. Now water above its critical temperature has recently been found to be a good solvent of silica — certainly a far better one than was formerly suspected. It is thought that it may have performed the following functions:

(a) Transformed dunite to pyroxenite, and vice versa, producing dunite veins in pyroxenite and pyroxenite veins in dunite, as has been carried out experimentally by Bowen and Tuttle. Such veining is particularly noticeable in the Kaipite River section, and in the border areas of the ultramafics.

(b) Transformed the sheared material immediately above the ultramafic, and, less constantly the wall rocks, to plagioclase-hornblende-quartz rocks and in some cases produced coarse quartz-hornblende pegmatites.

(c) Caused a serpentinisation of the ultramafics, according to the equation:

\[
5\text{Mg}_2\text{SiO}_4 + 4\text{H}_2\text{O} \rightarrow 2\text{Na}_4\text{Mg}_3\text{Si}_2\text{O}_9 + 4\text{MgO} + \text{SiO}_2
\]

Olivine introduced \(\rightarrow\) Serpentinite removed in coln.
The excess MgO may then have combined with CO₂ in solution, with the ultimate formation of magnesite veins, such as those occurring in the lavas of Kelare.

The banded associates of the serpentinites are, then, possibly transformed wall and roof formation. The peculiar Kaipite River section is now interpreted as being on the "roof" of the main serpentine belt of south-eastern Santa Ysabel, where a downward irregularity occurs.

It is fully realised that in making such postulates as these, the author is treading on very insecure ground. However, much of the idea rests on a sound experimental basis - the highly hypothetical suggestions, regarding the origin of the banded rocks stem from those features of them which are normally taken to be typical of hydrothermal activity, and from the writer's belief that water above its critical temperature is a powerful agent in the transformation of rock material.

**Summary of Section.**

In this section:

(a) A mechanism has been suggested for the intrusion of the ultramafic rocks occurring in the Santa Ysabel-San Jorge area.

(b) Very tentative suggestions have been advanced concerning the origin of the banded associates of the ultramafic rocks.
41.

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A Mineragraphic Study of the Ore of the Lloyd Copper Mine, with Particular Reference to its Constitution and Paragenesis.

Introduction.

It is surprising that, although it was formerly one of the largest producers of copper in N.S.W., there was very little scientific investigation of the Lloyd Copper Mine orebody during its productive life. A very brief description of the salient features of the geology of the orebody was included by J.E. Carne in his "The Copper Mining Industry and the Distribution of Copper Ores in N.S.W." (1908), but this formed only a minor part of an article principally devoted to milling practice and general mining economics.

In 1948 the present writer, as a member of the Investigation Staff of Broken Hill South Ltd., carried out detailed geological mapping and the structural analysis of the mine area. The results of this work were submitted as a confidential mine report. Later, some of the ideas embodied in the first report were revised, and a short account of the more recent analysis has been submitted as a contribution to the 1953 Empire Mining Congress geological symposium "The Geology of Australian Ore Deposits."
Following this geological work, the author has continued the investigation of the orebody by carrying out mineragraphic studies of the ore itself. The aim of this work has been to determine:

(i) The constitution of the ore.
(ii) The paragenesis of the sulphide and associated minerals.
(iii) The temperature at which the ore was deposited.

The following is an account of this.

Description of the Ore.

A megascopic examination of the ore shows the sulphides to have two general modes of occurrence:

(i) As blebs and splashes in milky quartz, the latter in the form of veins and stringers ramifying into the host rock.

(ii) As replacements of the host rock. Massive sulphide ore is commonly very finely banded in pyrrhotite: chalcopyrite, and close examination shows this to be due to preservation of the schistosity of the host material - a chlorite schist.

Although previous assays did not suggest the presence of a great variety of minerals, polished section work has shown the ore to contain a considerable assemblage.
Pyrite. This is not very abundant, occurring as isolated cubes and anhedral grains in the other sulphides, (chiefly pyrrhotite and chalcopyrite) and more frequently forming vein filling in cracks transecting the other sulphides, in which case it is intimately associated with quartz.

Pyrrhotite. Next to chalcopyrite, pyrrhotite is the most abundant sulphide present. The pyrrhotite tends to develop rather elongated, near-parallel aggregates of grains, suggesting replacement of silicate laminae (probably micaceous) formerly present in the host rock. The pyrrhotite shows a marked preference for areas of quartz (this generally occurs as slightly elongated to equidimensional grains), the quartz grains frequently being ringed by areas of pyrrhotite. The bounding pyrrhotite passes to chalcopyrite.

Chalcopyrite. This is the most abundant sulphide. It is frequently moulded round pyrrhotite, and may include it or be included by it. However, where chalcopyrite appears to be included in pyrrhotite, under crossed nicols it is seen always to occur between grains - it is never found included within an individual pyrrhotite grain. Fairly frequent "caries" texture, though by no means conclusive, suggests some replacement
of pyrrhotite by chalcopyrite and sphalerite. Evidence of exsolution of chalcopyrite from sphalerite, though rare does occur. Occasionally chalcopyrite forms emulsion textures in larger sphalerite grains, and in isolated instances drainage of chalcopyrite to segregation veins has taken place.

**Sphalerite.** This occurs far less frequently than chalcopyrite or pyrrhotite, though it is much more abundant than the pyrite. Occasionally uninterrupted lines of sphalerite run through chalcopyrite and pyrrhotite. However, the sphalerite is found chiefly as small blebs included in the chalcopyrite, and in fairly large masses of meshed chalcopyrite and sphalerite. It is probable that the frequent small inclusions are exsolution bodies — they frequently show the typical star shape of sphalerite exsolving from chalcopyrite — and it may be that the mesh/masses represent larger, partially developed exsolution bodies of sphalerite, forming between the grains of the former solvent, chalcopyrite. Isolated fine veinlets — possibly segregation veinlets — completely or partially transect some areas of sphalerite. The relationship of sphalerite to the other sulphides is very similar to those of chalcopyrite.
Arsenopyrite. This occurs most frequently as small, anhedral grains in pyrrhotite throughout which it is sparsely disseminated. It occurs very sparingly in chalcopyrite and sphalerite, and is on occasions apparently a vein filling, intimately associated with quartz and pyrite. In one instance where arsenopyrite occurs as grains within a quartz vein, it protrudes into embayments in the veined pyrrhotite, suggesting the replacement of the pyrrhotite by arsenopyrite. Where associated with pyrrhotite, the arsenopyrite may occur within or between pyrrhotite grains.

Niccolite. (Breithauptite?). The presence of niccolite (possibly breithauptite, NiSb) in the ore has been suggested by Edwards (verbal communication). Only two small areas of the mineral have been found, these being characterised by their rather bright pink colour, definite anisotropism, and strong pleochroism.

Native Bismuth. Although it usually occurs as small grains, native bismuth is found disseminated throughout a number of sections.

Bismuthinite. Almost always associated with, and usually surrounding, the highly reflecting native bismuth, is grey bismuthinite. This is most frequently found within the chalcopyrite, but association with pyrrhotite is not uncommon. The native bismuth may occur as
shapeless blebs within the bismuthinite, or as small grains attached to the boundaries of the bismuthinite.

Gold. Five small, highly reflecting particles—probably gold—have been found included in chalcopyrite.

Paragenesis of the Ore.

Polished section examination suggests that there has been only one period of sulphide mineralisation in the formation of the Lloyd Copper Mine ore.

Subhedral pyrite was the first sulphide to form, followed by pyrrhotite which:

(a) Included and partly replaced pyrite.
(b) Replaced former micaceous bands in the host rock, and attacked to a restricted degree, quartz grains occurring in the micaceous bands of the parent schist.

The pyrrhotite therefore now partly isolates the quartz grains, and forms a sub-parallel, banded ("palimpsest") structure.

The pyrrhotite was probably followed by gold (which is included in chalcopryite) and then by chalcopryite and sphalerite—deposition of this latter two was simultaneous (as a solid solution) and was followed by exsolution of sphalerite—the solute—from chalcopryite—the solvent.
Both of these attacked the pyrrhotite and quartz which:

(a) Show "caries" structure.
(b) Are often isolated as small grains in the chalcopyrite and sphalerite.

The occurrence of fine chalcopyrite veins in the sphalerite might suggest the later deposition of the former, the veins being indicatives of replacement. However, other evidence of exsolution, and the known structural similarity of chalcopyrite and sphalerite suggests that the "replacement" veins may in reality be segregation veins.

It may be that the three sulphides - pyrrhotite, chalcopyrite and sphalerite - were initially in solid solution. If such a solid solution did exist, unmixing of sphalerite probably took place first at a temperature of about 550° C. This was followed by unmixing of the pyrrhotite - chalcopyrite solid solution, and later by limited exsolution of chalcopyrite from sphalerite, within the range 350° C. -400° C.

There is insufficient evidence to determine the place of bismuth and bismuthinite in the sequence. The bismuthinite may have resulted from the alteration
of the native bismuth, only residual small grains of this now remaining.

Following the deposition of the chalcopyrite-sphalerite, the emplaced sulphides suffered minor cracking (probably as a result of slight earth movement). These cracks apparently developed before the period of deposition of the arsenopyrite, as this, in addition to replacing pyrrhotite, chalcopyrite and sphalerite, occurs in veins developed in the cracks. Other vein minerals are niccolite (breithauptite?), quartz and pyrite, the latter possibly resulting from redeposition of pyrite replaced by later sulphides.

Deposition of quartz occurred before and throughout ore mineralisation.

Temperature of Ore Deposition.

That deposition of sulphides in the Lloyd Copper Mine orebody began at a high temperature is indicated by the following:

(i) The presence of abundant pyrrhotite, suggesting an initial temperature of deposition of the order of 600° C.

(ii) The common occurrence of exsolution bodies of sphalerite in chalcopyrite. Unmixing of sphalerite from chalcopyrite takes place at about 550° C.
Continuation of ore formation until a temperature of the order of 350°-400° C was reached is suggested by the limited development of exsolution bodies and segregation veins of chalcopyrite in sphalerite. Such poor development indicates very rapid chilling at this point.

The last phase of ore deposition was the solidification of native bismuth. It is probable that this was included, as small molten droplets, in the sulphides which had been precipitated at higher temperatures. Primary ore deposition was therefore complete at 271° C, the freezing point of bismuth.

In view of the ease and rapidity with which minerals precipitated from the solid solution segregate into granular structures during laboratory experiments with natural exsolution intergrowths, it seems that the solutions from which the Lloyd Copper Mine ore was precipitated arrived at the point of deposition at a temperature well above that of the host rock, and that chilling was rapid.

It has been demonstrated that sulphide deposition commenced at about 600° C, and that it went on, for a short time at least, at a temperature of the order of 350°-400° C. It has also been noted that there has been excellent preservation of textures developed in
the 500°-550° C range. Therefore it seems probable that the temperature range 600°-350° C was covered quickly, and that the deposition of the sulphides and associated minerals was correspondingly rapid.
Final stages of the exsolution of sphalerite from chalcopyrite, Lloyd Copper Mine ore. The sphalerite has almost completed migration to the grain boundaries of chalcopyrite. Sudden chilling has just prevented the complete obliteration of the exsolution texture.

Light grey - chalcopyrite.
Medium grey - sphalerite.
Black - quartz gangue.

X 140.

Lloyd Copper Mine.
Chalcopyrite (off-white) moulded onto cubic pyrite (brilliant white). The dark grey material is quartz, black unreplaced host rock.

X 120.

Lloyd Copper Mine.
Elongated aggregates of pyrrhotite grains (rather lighter grey than background, and including much unplaced matter) within chalcopyrite (general grey background).

X 120.

Lloyd Copper Mine.
Late quartz veins, transecting chalcopyrite and emanating from large, earlier-formed quartz grain.

X 115.

Lloyd Copper Mine.
Quartz (dark grey) replacing host rock (black), and itself being replaced by chalcopyrite (white).

X 130.

Lloyd Copper Mine.
Pyrrhotite (light grey) including numerous small pieces of unreplaced host rock (black). The pyrrhotite has itself been replaced by quartz (dark grey veins) and by pyrite (white vein material). Chalcopyrite forms lower part of micro-photograph.

X 160.

Lloyd Copper Mine.
The Constitution and Paragenesis of Ore from Webb's Consols Mine, Emmaville, N.S.W.

Introduction.

Developed as a silver mine, Webb's Consols lode was discovered in 1884, and was described by E.F. Pittman in "The Mineral Resources of N.S.W." in 1901.

The ore was reported by Pittman to consist of "argentiferous fahlerz, galena, zinc blende, copper pyrites, arsenical pyrites and iron pyrites". Of the orebody, he remarked "These minerals occur together in veins several inches in thickness, but as a rule they form minute veins along the bedding planes and joints of the indurated claystone gangue, and also intersecting the latter in other directions. The lode-stuff has, therefore, the character of a typical stockwork-

The specimens examined and now described are, for the most part, massive sulphides, those clearly visible macroscopically being chalcopyrite, galena, and arsenopyrite. The general appearance of the ore suggests open space deposition (e.g. within a stockwork) rather than replacement.

Microscopic examination of polished sections has revealed the presence of a far greater variety of minerals than Pittman suspected. The most noteworthy
of these is stannite. To the writer's knowledge this is the first occasion on which stannite (among other less noteworthy minerals) has been observed in the Webb's ore, and its presence here is now placed on record. Further interest in the stannite occurrence lies in its (the stannite's) development as a product of unmixing from sphalerite. Extraordinarily fine exsolution textures have been developed, involving chalcopyrite, sphalerite and stannite.

It is interesting to note, too, that although Pittman thought the orebody to be devoid of secondary enrichment, microscopic work has shown considerable development of the supergene sulphides chalcocite and covellite, and of martite.

Description of Ore.

The minerals identified in polished section are as follows:

Magnetite. The occurrence of magnetite (martitised) is doubtful. The mineral occurs exclusively in arsenopyrite, always in fair proximity to the borders of this.

Arsenopyrite. This is the most abundant sulphide, and deposited next in succession to magnetite, the arsenopyrite exhibits sharp crystal outlines where it contacts with other sulphides. Fair zonal structure
in the arsenopyrite is revealed by etching with 1:1 nitric acid.

Pyrite. This follows arsenopyrite in a sequence of deposition, and is only very sparsely developed. It is usually found as cubes, though occasionally as subhedral grains, where the pyrite is moulded round arsenopyrite. Pyrite is frequently extensively incised by chalcopyrite, and where replacement is well advanced, the original cube may be represented by only small pyrite residuals. Less extensive replacement of pyrite by sphalerite and stannite also occurs.

Chalcopyrite. Second in order of abundance to arsenopyrite, chalcopyrite, with sphalerite and stannite, follows pyrite in order of deposition. Chalcopyrite may occur as exsolution bodies in the sphalerite, though the reverse is more often the case. The chalcopyrite is moulded on to, and extensively veins (probably open space rather than replacement veins), arsenopyrite. Replacement of arsenopyrite by chalcopyrite occasionally has taken place along crystal directions in the former. Chalcopyrite is moulded round and replaces pyrite, and it may replace or be included by galena.
Sphalerite - Stannite. These are grouped as they almost invariably occur together and apparently are closely related genetically. The sphalerite, as has already been mentioned, is usually developed as a result of exsolution from chalcopyrite, and its relationships with both earlier and later hypogene minerals are very similar to those of chalcopyrite. However, the sphalerite is characterised by its almost universal inclusion of stannite, the stannite probably being a product of exsolution from the sphalerite. The stannite, in some cases, shows a distinct "drainage" texture, suggestive of movement to the grain boundaries of the sphalerite. Most frequently the stannite forms exsolution rims round the sphalerite, the inner part of the ring showing the same "drainage" texture. Associated sphalerite and stannite often replaces arsenopyrite, the resultant pattern suggesting replacement along arsenopyrite cleavages and zone boundaries. Occasionally the sphalerite and stannite are in turn selectively replaced by chalcosite.

Tetrahedrite and Bornite. These are among the least abundant of the hypogene sulphides, and occur exclusively in, or at the grain boundaries of, chalcopyrite. Though showing little evidence of this, they may have been
formed by early exsolution from chalcopyrite, having more or less completed migration to grain boundaries. Alternatively the tetrahedrite and bornite may have replaced chalcopyrite.

**Galena.** Next in abundance to chalcopyrite, galena occurs as coarse grains containing numerous small inclusions of what may be pyrargyrite. Galena may include chalcopyrite, sphalerite and stannite, though in some cases chalcopyrite is moulded round well developed galena crystal faces. Where the latter is the case, sphalerite - stannite, and infrequently tetrahedrite, occur at the galena - chalcopyrite interface, the grains having straight edges where they contact galena.

The most striking feature of the galena is its selective replacement by chalcocite, and the formation of even rims of the latter round the margins of galena grains. Where replacement is complete, galena cleavages are frequently preserved in the chalcocite.

**Cassiterite.** Very minor quantities of needle tin occur in the ore.

**Native Bismuth.** Isolated specks of native bismuth occur most frequently included in chalcopyrite.
Pyrargyrite. In replacing it, the chalcocite has not only preserved the cleavage of the galena but has also revealed the presence in it of what is probably pyrargyrite. Where no replacement has taken place the included pyrargyrite cannot be distinguished from its host. Where, however, replacement has taken place, pyrargyrite appears as minute unreplaced grains within the chalcocite. Initial development of pyrargyrite has probably been by exsolution from the galena.

Secondary Minerals.

Martite. This is developed to a limited extent within the primary magnetite.

Covellite. This replaces chalcopyrite and to a lesser extent, sphalerite. Replacement has taken place along fractures, and round grain boundaries, and where chalcopyrite veins arsenopyrite, such veins are often partially or wholly replaced by the covellite.

Chalcocite. This replaces galena exclusively, often forming remarkably even rims round the unreplaced galena. Where replacement is extensive, only a small nucleus of galena remains in the chalcocite, and occasional complete replacements occur.
Paragenesis of the Ore.

Although, as a result of their comparative rarity in the ore, the positions of bismuth, bornite, and tetrahedrite are rather doubtful, the sequence of the other minerals is fairly well defined.

The probable order of deposition of the sulphides and associated minerals is:

Magnetite
Cassiterite
Arsenopyrite
Pyrite
Tetrahedrite, Bornite
Chalcopyrite - Sphalerite - Stannite
Galena - Pyrargyrite
Bismuth

Overlapping within the sequence occurs to some extent, but is most pronounced where indicated.

Temperature of Ore Deposition.

Commencement of deposition at some temperature above 500° C is suggested by the presence of cassiterite and magnetite. Rather sudden quenching at a temperature between 350° and 400° C is indicated by the well preserved chalcopyrite - sphalerite exsolution texture.

The Webb's Consols ore was, therefore, deposited under rather similar conditions to those of the formation of the Lloyd Copper Mine orebody.
BIBLIOGRAPHY.


Schmeiderhohm, H. & Randohr, P., 1931. "Lehrbuch der Erzmikroskopie, II."


Micro-photograph showing the replacement of galena by chalccsite. Galena (white, with triangular pitting) now occurs as unreplaced nuclei within the replacing chalccsite (grey, surrounding galena). Sphalerite and stannite, formerly included by the galena, remain unreplaced by the chalccsite. In replacing the galena, the chalccsite has preserved the cleavage of the host — the cleavage cracks are now filled with a poorly reflecting mineral — possibly anglesite. The brilliant white mineral at top left of photograph is arsenopyrite, partially replaced by sphalerite-stannite.

Magnification, X 85.

Webb's Consols.
Arsenopyrite (brilliant white) replaced by galena, which in turn has been completely replaced by chalccosite, with the preservation of the galena cleavage. Sphalerite-stannite have not been replaced by chalccosite. The arsenopyrite was probably first partially replaced by sphalerite-stannite, then by galena, this then including the sphalerite-stannite. With the replacement of the galena, the latter combination is now included by chalccosite.

Webb's Consols.
Sphalerite (dark grey) and stannite (light grey) replacing arsenopyrite (near white). Dark material on right of photograph is quartz gangue.

X 140.

Webb's Consols.
Sphalerite-stannite intergrowths replacing arsenopyrite along probable cleavage planes. Sphalerite (darker grey) - stannite (light grey) intergrowth shown best just to right of centre of photograph.

X 145.

Webb's Consols.
Zonal structure developed in arsenopyrite of Webb's Consols ore

Etched with 1 : 1 HNO₃.

X 94.

Webb's Consols.
Exsolution of chalcopyrite (light grey) from sphalerite (dark grey), showing stages in the development of segregation veins of chalcopyrite.

Dark material - quartz gangue.

X 115.

Webb's Consols.
FIGURES 1 & 2.

To accompany Part 1 of Thesis for the Degree of Master of Science in Geology, The University of Sydney.

R.L. Stanton, B.Sc., 1952.
THE BRITISH SOLOMON ISLANDS
SHOWING THE POSITION OF THE ISLANDS OF SANTA YSABEL AND SAN JORGE AND THE AREA SURVEYED BY THE AUTHOR

Fig. 1.
This shows the distribution of the rocks of the "Older Group" - i.e. the Upper Miocene - Lower Pliocene sediments, the basaltic pillow lavas, and the intrusive rocks. Formation boundaries have been determined, in the field, by coast and stream section observation. Later, interpolation of boundaries between points of observation was made using un-controlled aerial photographs.

Geophysical checking of boundaries has also been carried out. The writer has made a number of magnetometer traverses (compass, tape and field survey, instrument stations every 200') to check surface observation - for example, traverses were made between Takata Bay and Tataba, and between Woki and Fulakora Point. Details of the geophysical work have not been given in this paper, but may be published in a later one.
Sediment (Principally shale and mudstone)
Pillow Lava
Ultramafic and associated banded rocks
Banded and veined rocks of the Alipine River area
Diorite Intrusion

GEOLOGICAL MAP OF SOUTH-EASTERN SANTA YSABEL AND SAN JORGE
SHOWING THE DISTRIBUTION OF SEDIMENT, LAVA AND ULTRAMAFIC ROCK

LEGEND

The outline of this map has been drawn from aerial photographs produced by the RAAF. Although photographs are uncontrolled, it has not been possible to correct hill or preserve accurate scale. This map is however more accurate than any other available.