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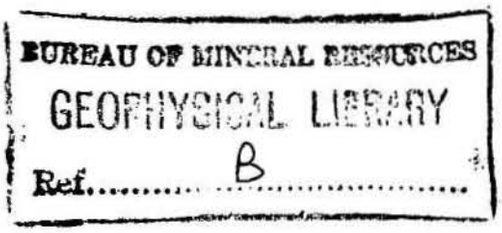

THE GEOLOGY OF THE TENNANT CREEK ONE-MILE SHEET AREA

by

P.W. Crohn and W. Oldershaw

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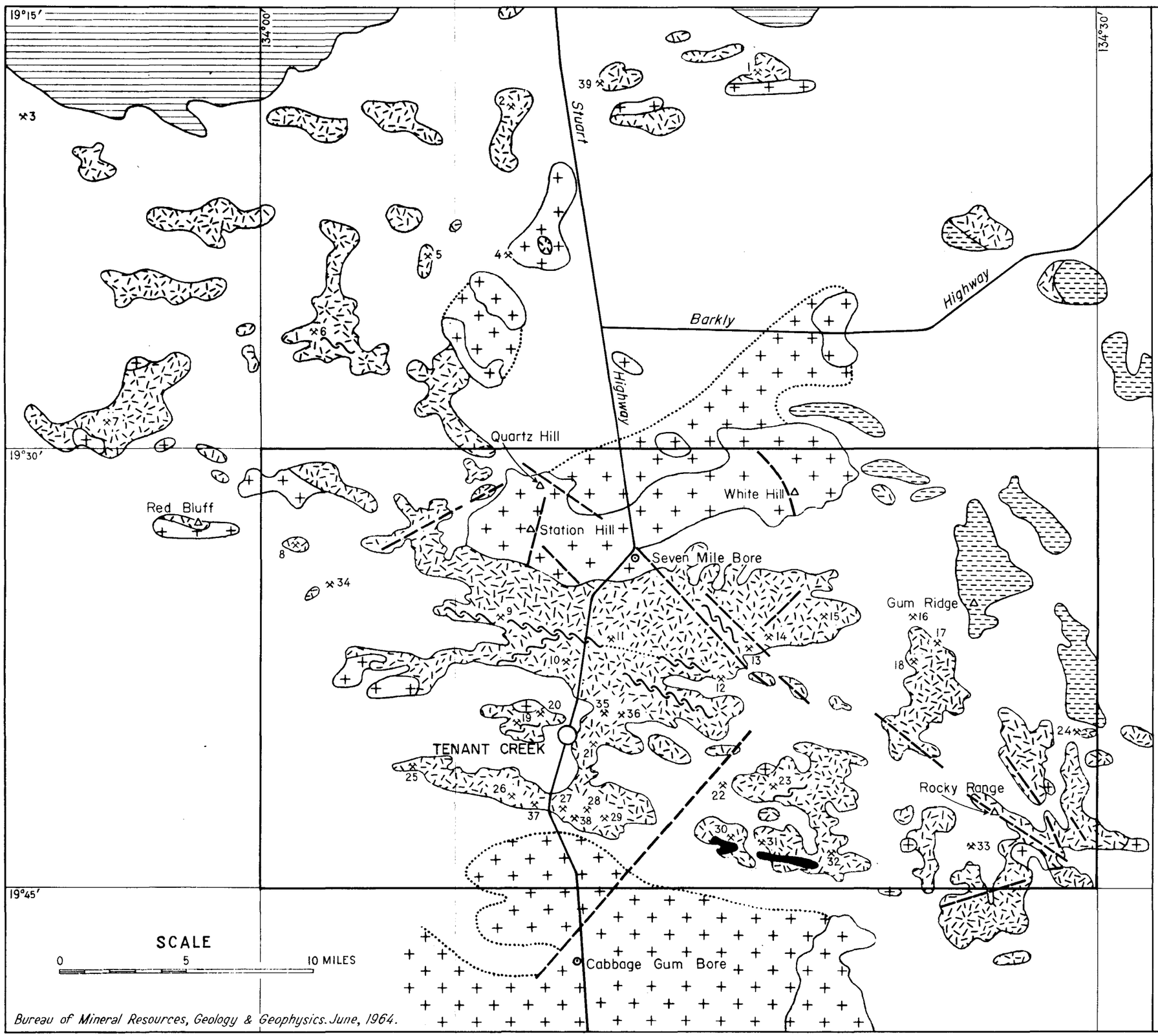
Fig. 1



REFERENCE

- Recent gravel, alluvium, sand etc.
- Gum Ridge Formation and Helen Springs Volcanics
- Ashburton Group
- Rising Sun Formation
- Warramunga Group
- Igneous rocks: granite and porphyry
- Shear zone: quartz filled
- Shear zone: other

MAJOR MINES

1	Whippet	21	Pinnacles
2	Northern Star	22	Feko
3	Last Hope	23	Golden Forty
4	Bernborough	24	Golden Mile
5	Queen of Sheba	25	Skipper
6	Orlando	26	Mount Samuel
7	Black Angel	27	Enterprise
8	Curlew	28	Eldorado
9	Mary Lane	29	Cat's Whiskers
10	Shamrock	30	Noble's Nob
11	Mary Ann	31	Rising Sun
12	Lone Star	32	Red Terror
13	Memsahib	33	New Hope
14	Mammoth	34	Ivanhoe
15	Black Cat	35	Burnt Shirt
16	Gigantic	36	Kathleen
17	Blue Moon	37	Hammerjack
18	Metallic Hill	38	Patties
19	Gibbet	39	Edna Beryl
20	Wheal Doria		

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MAP OF TENNANT CREEK AREA, SHOWING POSITIONS OF MAJOR MINES AND OUTCROPS OF MAJOR ROCK UNITS

THE GEOLOGY OF THE TENNANT CREEK ONE-MILE SHEET AREA

SUMMARY

Most of the Tennant Creek area is underlain by shale, siltstone and greywacke of the Warramunga Group (lower Proterozoic), which have undergone moderate to severe folding and shearing. These rocks are intruded by several varieties of granite, adamellite and quartz-feldspar porphyry, quartz-magnetite and quartz-hematite lodes, jasper lenses, quartz reefs, diorite and dolerite and lamprophyre dykes.

The gold and sulphide orebodies of the Tennant Creek Goldfield are confined to the Warramunga Group, and their distribution is influenced by structure and lithology. Most of the known occurrences are closely associated with the quartz-magnetite and quartz-hematite lodes, but major shear zones with only minor ironstone development may also be important loci for mineralization. The ironstones and the gold and sulphide orebodies are thought to be genetically related to the quartz-feldspar porphyry intrusions.

Rocks younger than the mineralization comprise the Rising Sun Formation (proterozoic), the Helen Springs Volcanics (Lower Cambrian), and Gum Ridge Formation (lower Middle Cambrian), as well as Tertiary to Recent superficial deposits.

The main mines currently operating on the field are Peko (copper and gold) and Nobles Nob (gold). Major discoveries of gold and copper orebodies have recently been made at the Orlando Mine and the Ivanhoe prospect. Many other mines and prospects have operated profitably in the past and some are still being worked intermittently or on a small scale.

Geophysical and geochemical methods have been successfully used in the search for non-outcropping orebodies.

INTRODUCTION

The aim of the work described in this report was to supplement previous surveys of the Tennant Creek Goldfield by re-mapping part of the field at a scale of 1 inch to 1000 feet. Air photographs at this scale were made available by Peko Mines N.L. The area was mapped during the 1958 and 1959 field seasons by P.W. Crohn and W. Oldershaw, assisted by R. Ryan in 1958 and by K. Rochow in 1959. However, major developments on the field up to the end of 1963 have been incorporated in this Record.

Previous Work

The most comprehensive previous investigation of the Tennant Creek Goldfield was by Ivanac (1954), who also summarised the results

of earlier geological work.

In 1958, the Bureau of Mineral Resources produced a set of maps at 1:63,360, showing total magnetic intensity as measured by an airborne magnetometer: the area covered by these surveys was extended in 1960. In 1955-57, a geochemical party from the Bureau sampled outcrops on the field to determine the relation of trace copper in soil and surface rock exposures to the presence of economic concentrations of copper at depth (McMillan & Debnam, 1961). In 1963 this work was supplemented by the use of a mechanical auger drill to obtain samples for spectrographic analysis.

Other investigations relating to the geology of the area include the following:

Twenty C.S.I.R.O. Mineragraphic Reports listed in the bibliography deal mostly with the mineral assemblages of specimens and drill cores from various mines, especially Peko. Edwards (1955) describes the Peko orebody, with special emphasis on its mineral composition, and two articles in the Chemical Engineering and Mining Review (Editorial contribution, 1958; White, 1962) summarise developments at the Peko Mine up to those dates. Daly (1957) summarizes the results of magnetic prospecting by the Aerial, Geological and Geophysical Survey of North Australia in this area during 1935 to 1937, and discusses the results of this work in the light of subsequent developments. Hays (1958 a and b) and Crohn (1961) give accounts of the geology and hydrology of the Cabbage Gum Basin, which has since been developed as a source of the town water supply.

History of Mining and Production

The history of the field up to 1952 is discussed by Ivanac (1954), and will not be recapitulated here. However, a number of important developments have taken place since then. In 1954, Peko began regular production of copper concentrate. For the twelve months ending 30th June, 1963, this mine produced 7200 tons of copper and 12,800 ounces of gold from approximately 159,000 tons of ore. For the same period Australian Development N.L. mined approximately 42,000 tons of ore, containing 43,600 ounces of gold, at the Nobles Nob Mine. Eldorado, the last of the remaining pre-War mines, ceased regular production in July 1958 and has since been worked on tribute on a small scale only.

During the period 1954 to 1963, a large number of prospects on the field were tested by various companies, but although encouraging results were reported in several places, only two prospects have yet been shown to contain mineable orebodies. These are at Ivanhoe, about ten miles north-west of Tennant Creek township, and at Orlando, twenty miles north-west of the township. Both these mines are being developed by Peko-Wallsend Investments Ltd.

At Orlando, regular production began towards the end of 1962,

and about 37,000 tons of ore were mined to the end of June 1963 for a yield of 19,250 ounces of gold and 280 tons of copper. At that date, published reserves amounted to 230,000 tons of ore averaging 1.2 percent copper and 11.7 dwt of gold per ton.

At Ivanhoe, a shaft is being sunk to develop the orebody at the time of writing, and the published ore reserves, calculated from diamond drilling data, are 240,000 tons of ore averaging 5 percent copper and 4 dwt of gold per ton.

Prospectors and syndicates are also active in the area. Most depend on the Government Battery (re-opened October 1958) for crushing and treatment of their ore. During the years 1958 to 1963, the following mines and prospects were worked on a small scale, many of them part-time:

Ace High, Blue Moon, Burnt Shirt, Caroline, Edna Beryl, Enterprise, Great Northern, Joker, Jubilee, Kathleen, Lone Star, Maple Leaf, Mount Samuel, Outlaw, Pinnacles, Pup, Shamrock, Susan, Trump, Wheal Doria, Whippet.

The total recorded production of the field to 30th June, 1963 amounts to about 960,000 ounces of gold and 57,000 tons of copper, of which about two thirds of the gold and practically all the copper have been won since 1952.

The mines on the field with a recorded production of more than 1000 ounces of gold to the end of June 1963 are:

	Tons ore	Oz.gold	Tons copper
Black Angel & White Devil	6400	3020	
x Black Cat	2200	1020	
x Blue Moon	3600	12360	
x Burnt Shirt	2600	2340	
Edna Beryl	2800	4420	
x Eldorado	146000	105500	
x Enterprise	10000	6600	
Golden Chance	400	1260	
x Hammerjack	5900	5220	
x Kathleen	2000	1120	
x Lone Star	9500	5570	
x Mount Samuel	3100	4170	
x Nobles Nob	380000	630000	
Northern Star	29000	9660	
Orlando	37000	19250	280
x Patties	1650	1530	
x Peko	900000	101000	56500
x Red Terror	600	1310	
x Rising Sun	10300	8000	
x Skipper Extended	2100	4250	
x Wheal Doria	2700	2925	
Whippet	16500	18370	

Mines marked x are situated within the Tennant Creek One-mile area

Physiography

The Warramunga sediments form groups of mesas (Plate I), generally with an east-south-easterly trend, separated by low flats up to two or three miles across. In areas of igneous rocks, a typical tor topography has developed. The Rising Sun Formation (Plate II) and

the Cambrian sediments have produced distinctive rounded hills with minor scarps at the levels of the more resistant beds. Some of the larger quartz reefs and quartz-hematite lodes form bold razorback ridges.

The maximum relief is about 300 feet, the highest points being Grey's Bluff, 1437 feet and Mount Samuel, 1429 feet above sea level. Many of the mesas of Warramunga sediments are recognised as remnants of an old land surface, which was characterized by a zone of iron enrichment, up to 15 feet thick, underlain by a considerably thicker leached zone; no true laterite is present. The characteristic steep sides of these mesas are due to the undercutting of this iron-enriched zone during the current cycle of erosion.

The distribution of the zone of iron enrichment is closely controlled by the lithology of the underlying sediments, for it is absent or poorly developed in the areas north and south of the New Hope Mine, and between Rocky Range and the Golden Mile, where massive siliceous beds become an important constituent of the Warramunga Group. A zone of surface silicification tends to replace the iron-enriched zone in these areas, but the equivalent of the underlying leached zone is not developed.

The remnants of the old land surface now slope generally at angles of one to two degrees in various directions. This can be accounted for either as an old peneplain, locally upwarped or block-faulted and tilted in geologically recent times, or as an originally undulating surface with a relief of at least 300 feet, whose slopes were pedimented after a change of climate.

The pediments now occupy extensive areas on the flanks of some of these mesas and in the headwater areas of major creeks rising within the ranges. The gently undulating areas on the northern flank of the Honeymoon Ranges (grid reference 2,542,500 north, 194,000 east) are excellent examples. The present creeks are incised several feet into these pediments.

The low-lying areas between the mesas are now largely occupied by wind-borne material of silt-particle size. This material probably averages five feet in thickness over most of its area, and only exceptionally exceeds fifteen feet.

True alluvium and poorly sorted creek gravels occupies considerable areas in the lower reaches of Tennant Creek, and in some of the minor creeks draining northwards from the Honeymoon Ranges. Thicknesses of more than ten feet are quite common, and some deposits are strongly cemented, as in the Mount Rugged area, the vicinity of the Arizona Mine, and the area east of the Mary Ann Mine. The maximum known thickness of alluvium is forty feet, encountered in drill holes put down in the search for underground water in the flood plain of Tennant Creek, some five to six miles west of Pigeon Holes. The present creeks are generally incised into the alluvium.

PLATE I

A. Honeymoon Ranges, general view, showing peneplain in early stage of dissection.
Neg. M/339/33.

B. Mount Rugged area, general view, showing peneplain in advanced stage of dissection.
Neg.M/339/2913.

Superficial deposits also cover a large part of the Cabbage Gum Basin, where diamond drilling in search of underground water has indicated a hundred feet of partly lateritized sands, clays, grits and gravels. These deposits must antedate the present erosion surface at least in part, and may be Tertiary in age.

The depth of oxidation of the bedrock formations is only known from mine workings and from diamond drill holes. In general, the sediments and ironstones appear to be substantially fresh at depths of 150 to 200 feet, but the sulphide bodies and breccia zones are oxidized to an average depth of 300 to 350 feet. Edwards (1955) believed that the original zone of secondary enrichment in the copper orebody at Peko was formed when the water-table stood at about 210 feet below the present surface. This zone was subsequently exposed to oxidation by a drop in the water-table to 260 feet below the present surface: but the water-table now stands at 170 feet below the surface. At Orlando, oxidation of a major shear zone with a high sulphide content is still appreciable at a depth of 600 feet.

GENERAL GEOLOGY

The major rock units in the Tennant Creek Gold field have been described by previous workers, notably Ivanac (1954). The following table is adapted from Ivanac (p.19) with some modifications:

Recent		Alluvium, creek gravels, bull-dust, etc.
Tertiary ?		Unconsolidated and poorly consolidated sands, clays, grits and gravels, in part lateritized.
Lower Middle Cambrian	Gum Ridge Formation	Calcareous sandstone, shale, and chert.
? Lower Cambrian.	Helen Springs Volcanics	Lavas and pyroclastic rocks.
? Proterozoic	Rising Sun Formation	Conglomerate, sandstone and quartzite, shale.
Igneous activity and mineralization	Late phases	Diorite, dolerite and lamprophyre dykes, ? in part post-dating Rising Sun Formation.
	Early phases	Granite, adamellite, porphyry, quartz veins, quartz-magnetite and quartz-hematite lodes, gold and sulphide orebodies.
? Proterozoic	Ashburton Sandstone and Hatches Creek Group	Sandstone, conglomerate, and quartzite.
Lower Proterozoic.	Warramunga Group	Greywacke, siltstone and shale, minor grit and pebble beds, hematite shale.
? Archaean.	Only known from diamond drill holes in Bureau of Mineral Resources Reserve No. 3 area.	Quartz-feldspar-garnet gneiss, amphibolite, magnetite schist, granitic and gabbroic intrusives.

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Archaean

No Archaean rocks are known in the Tennant Creek One-mile area, but a complex of quartz-feldspar-garnet gneiss, amphibolite, and magnetite-rich rocks, associated with granitic and gabbroic intrusives, was found in diamond drill holes put down by Australian Development N.L. in the Bureau of Mineral Resources Reserve No.3, some 20 miles west-south-west of Tennant Creek township, and these are thought to be part of an Archaean basement. The rocks are overlain by up to 80 feet of poorly consolidated grit and sandstone, and do not crop out. They give rise to pronounced magnetic anomalies, but these are due to the presence of magnetite-rich bands within the gneiss complexes, and not to quartz-magnetite lodes of the type occurring within the Warramunga Group.

SEDIMENTS

Warramunga Group

Most of the Tennant Creek One-mile area is underlain by sediments of the Warramunga Group: greywacke, siltstone, and shale, with subordinate grit and pebble beds. The thickness of individual beds averages between one and two feet, and rarely exceeds 15 or 20 feet. Graded bedding is very common. Slump structures on a small scale are very widespread and include mud-pellets, balled structures, and sole markings. Probably at least some of the pebble beds are the products of slumping on a larger scale.

All these features can be accounted for on the assumption that most of the sediments were deposited in moderately deep water and that some of the detrital material was carried into its present position by turbidity currents. Some cross-bedding, notably in the extreme south-eastern portion of the One-mile area, indicates that the depth of water was not too great to show the effects of occasional current action, but nearly all previous reports of ripple marks in these sediments should be discounted. With the possible exception of a few examples in the New Hope and Golden Mile areas, these so-called ripple marks are believed to be in part load casts and sole markings and in part structures resulting from the intersection of bedding and cleavage at low angles.

All the greywackes and some of the coarser sandy siltstones have developed joint patterns of two or more sets of joints, generally developed symmetrically to the bedding planes and varying in attitude from bed to bed. The shale and most of the siltstone, on the other hand, have developed fracture cleavage, the east-west trend of which is almost entirely controlled by regional factors and therefore remains constant over large areas.

Very few fresh specimens are available for study and most of these come from mines, where the rocks are likely to have been affected by metamorphic or metasomatic processes caused by the emplacement of iron-stone bodies and gold and sulphide orebodies. However, specimens from the Eldorado, Skipper, and Golden Forty Mines indicate that quartz and fragments of pre-existing shale are the dominant constituents of the coarser-grained sediments, while sericitic and chloritic aggregates make

up the bulk of the fine-grained ones. A few grains of sericitized feldspar are present, but are difficult to identify with certainty. Most of the rocks carry abundant magnetite, commonly as euhedral crystals, indicating epigenetic origin or recrystallization after the consolidation of the rock. This, however, may be a local effect close to orebodies.

Lithological Features and Sub-divisions

Attempts to subdivide the Warramunga Group have been only partly successful, owing to the complexity of structures and the absence of marker beds. In the northern portion of the One-mile area, a belt consisting dominantly of shale and siltstone can be distinguished, and traced from the north-west corner of the area to a point about two miles east of Mount Cleland. The boundary of this belt with the overlying shale-greywacke sequence is rarely a sharp one, although it is obvious enough on a regional scale. These relations are best exposed in the area near and to the south of Mount Cleland, where the beds are free from shearing and miner folding. In this area, the succession consists of at least 2500 feet of interbedded greywacke and shale. The greywacke near the base of the greywacke-shale succession is markedly lenticular.

The only marker bed which has been traced for any distance in the Warramunga Group is a very distinctive horizon of thin-bedded hematite-rich shale with minutely crenulated bedding-planes (Plate II) and a peculiar blocky type of outcrop, which occurs in the upper portion of the greywacke-shale assemblage. It crops out in the Mount Samuel/Eldorado area, near the Burnt Shirt and Lone Star Mines, between the Mammoth and New Moon Mines, at the Golden Mile, and at a number of other localities in the One-mile area. It crops out near the Northern Star Mine, about 15 miles north of the One-mile area.

The hematite shale ranges from a few inches to about 20 feet thick. About ten chains west of the Eldorado Mine, two bands of hematite shale are present, separated by up to 20 feet of greywacke and shale. To the east of the Burnt Shirt, two beds of hematite shale have been mapped, about 250 feet apart, and at the Golden Mile there appear to be two major and several minor beds.

In the Mount Samuel/Eldorado area, the hemolite shale has been traced with only minor interruptions for a distance of more than three miles along the strike. Near the Burnt Shirt it has been traced for at least two miles and if its faulted extensions in the Lone Star, Memsahib, and Mammoth/New Moon areas are included, for more than eight miles.

The correlation of the hematite shale within each of the major belts is regarded as being firmly established: but owing to gaps in the outcrops, the correlation between belts, though it is regarded as very probable, cannot be proved beyond all doubt.

Under the microscope, typical specimens of the hematite shale are seen to consist of alternating crenulated layers of silty shale and of black or brown iron oxides, usually less than 2 mm. thick. In general

PLATE II.

A. Rising Sun Formation, south of Red Terror Mine, showing typical rounded hills.
Neg. M/339/23.

B. Typical Hematite Shale, vicinity of Big Ben Mine, showing regularity of layering. Neg. M/339/16.

the thinnest layers show the most intense crenulation. Some of the silt layers are graded, having a bottom zone of angular and sub-angular quartz grains, which passes up into a zone of minute quartz granules set in a matrix of sericite flakes. There is a well-marked foliation parallel to the axial plane cleavage. The quartz grains are elongated and the sericite flakes mostly extinguish parallel to the cleavage.

The layers of iron oxide are very constant, and even the thinnest of them can generally be traced right across the thin section. Some of the thinner ones consist of a single line of minute granules of iron oxide, but the thicker layers generally consist of a continuous band of opaque black hematite. The layers may occur singly or in groups, and do not appear to alternate systematically.

Some specimens also contain small octahedra of hematite after magnetite, which may form up to about 15 percent of the rock by volume. The octahedra range up to 3 mm., in diameter, and many are fractured. Small quartz aggregates may occupy the pressure shadows adjoining the octahedra in the plane of the foliation.

In other occurrences, lenses of magnetite, now largely altered to hematite, take the place of the magnetite octahedra. They are conformable with the bedding, but are quite distinct from the crenulated layers. They may also be broken or deformed by minor thrust faults and shears.

The crenulated layers are regarded as syngenetically precipitated iron oxides, but the magnetite octahedra and lenses must have been introduced or at least reconstituted after the consolidation of the rock. From a study of the distribution of trace elements (see section on quartz-hematite and quartz-magnetite lodes), they are thought to have originated by reconstitution of syngenetically precipitated iron compounds.

Other isolated thin-banded shales with crenulated bedding planes lack the high hematite contents of typical members of this group, although they are comparable in all other respects. Such rocks are especially prominant near the eastern extremity of the Burnt Shirt line of outcrops, and they are tentatively regarded as the leached equivalents of the hematite shale.

The sediments in the Warramunga Group vary laterally as well as vertically. To the south-east of the New Hope Mine and to the south of the Golden Mile, about 3000 feet of sandstone with only minor shale overlie shale and siltstone similar to those of the Mount Cleland area. However, the sandstone of these areas is more massive than the greywacke found in the remainder of the One-mile area and shows marked cross-bedding, which is rare elsewhere. It was mapped as part of the Rising Sun Formation by Ivanac (1954), but is undoubtedly part of the Warramunga Group. It probably underlies the beds of the Golden Mile area which consist of about 1000 feet of interbedded greywacke and shale, with at least two strongly developed horizons of hematite shale.

The massive sandstone may thus be equivalent to part of the

greywacke-shale assemblage occurring in other parts of the One-mile area, but was probably deposited in shallower water.

Beds containing pebbles or angular rock fragments have been recorded at widely separated localities. At 2,542,000 north, 187,000 to 188,000 east, east of the Caroline Mine, one such bed with a maximum thickness of some 50 feet has been traced along the strike for more than 2000 feet. This bed, thickest at the western end and gradually thinning to the east, consists largely of boulders and angular fragments, up to 18 inches in diameter, in a matrix of sandy siltstone or shale. Most of the boulders are similar in composition to the typical greywacke, siltstone and shale of the Warramunga Group, and were probably derived largely by pene-contemporaneous erosion from lower parts of the succession and transported by turbidity currents. Some are bent and show signs of plastic deformation. There are however, a few pebbles of igneous rocks, and a few others which have been cut by quartz veins and which must have been derived by normal erosion processes from already consolidated rocks.

About half a mile north of Mount Cleland, three shale beds in a succession of interbedded shale and greywacke contain sporadic subangular to subrounded pebbles up to three inches in diameter. Similar beds have been noted near the Mary Ann and Hidden Mystery Mines, and at 2,545,700 north, 202,000 east, about one mile north-west of the Mammoth Mine. At this last-mentioned locality, some of the pebbles appear to have been derived from pre-existing igneous rocks.

At most of these localities, several pebble beds occur within a few hundred feet of each other, and all appear to lie at roughly the same stratigraphic horizon. They are thought to have been laid down by turbidity currents, like the beds at the Caroline Mine, but on a smaller scale. The proportion of rock fragments is not generally high enough to warrant the use of the term slump breccia, and there are some examples of rocks intermediate between this type and a normal conglomerate with well-rounded and well-sorted pebbles.

At 2,534,500 north, 211,500 east, for example, a 50 foot section of well-bedded siltstone and fine-grained greywacke contains sporadic pebbles, up to three inches in diameter, of slightly indurated greywacke and shale. Where two such pebbles have been brought into contact by the compaction of the matrix, they are flattened at the interface, and were therefore still plastic at the time of deposition. A similar bed, containing slightly more occurs at 2,529,500 north, 210,500 east. These occurrences are therefore still consistent with a picture of extensive transport of material by turbidity currents, the original derivation of the material being by slumping or by intermittent erosion, e.g., by seasonal flood conditions.

At 2,534,500 north, 224,500 east, and at 2,532,000 north, 228,000 east, in the vicinity of Rocky Range, on the other hand, a shale-greywacke succession contains sporadic pebbles which appear

to be more normal conglomerates. Although these occurrences are not continuous, they all appear to lie within a restricted stratigraphic section, just below the first massive greywacke.

Rocks exceptionally rich in chlorite, sericite, and less commonly talc have been recorded from numerous localities, including the lower levels of the Peko Mine, the Skipper, Golden Forty, Pinnacles, and Shamrock Mines, and the contact zone of the large porphyry mass about half a mile south of the Pinnacles Mine. Some of these rocks contain disseminated euhedral magnetite crystals and many of them show sufficiently strong parallelism of the constituent minerals to warrant the names of chlorite schist, talc schist, ect. All these schists appear to be derived from shale of the normal Warramunga type by recrystallization with hydrothermal activity accompanying the emplacement of the porphyries and ironstones or the gold and sulphide orebodies.

At Mount Samuel, Eldorado, Noble's Nob and Red Terror and near the Gibbett Mine, parts of the Warramunga Group contain concentrations of ovoid bodies (Plate IIIa) which were first thought to be of organic origin, but are now believed to be sand volcanoes, formed during compaction (Oldershaw, 1961). The sand volcanoes in the Mount Samuel/Eldorado area appear to be restricted to two or possibly three greywacke beds, twenty feet stratigraphically below the hematite shale, but at Noble's Nob and Red Terror the relationship is less close. At the Gibbet Mine, the bed of sand volcanoes is not associated with any hematite shale; and many occurrences of hematite shale are not associated with any beds containing sand volcanoes.

Whenever they are formed, the ovoids appear to lie on the fine-grained upper layers of greywacke beds. The top surface of each individual body is dome-shaped and has an apical depression which is probably the outlet of some duct or pipe. The ovoids are mostly one to two inches long, but range up to four inches and down to a quarter of an inch. Their width is generally about two thirds of their length, but this ratio varies considerably, depending apparently on the amount of deformation undergone by the rock, as the elongation is always parallel to the trend of nearby fold axes. The height of these bodies is generally about one quarter of their length.

Thin sections of several bodies have shown an internal stratification parallel to the domed upper surface. The central pipe, leading to the apical depression, is composed of relatively coarse grains, and the average size of the particles in the stratified portion of the ovoid decreases from the centre outwards. The fact that the stratification appears to continue into the surrounding rock strongly suggests an origin similar to that of sand volcanoes, but their distribution in a small number of well-defined horizons still requires explanation.

The minor structures described as ripple marks by previous workers are now thought to be either pene-contemporaneous features, such as load casts and sole markings, or the effects of minor disturbance of

PLATE III

A. Sand Volcanoes, 300 yards south of Red Ned Mine.
Neg. M/339/26.

B. Pseudo-ripple marks in Warramunga sediments, half a mile north-east of Red Terror Mine.
Neg. M/339/20.

the bedding planes by movement on closely spaced shear and cleavage planes cutting the bedding at low angles (Plate IIIa and Fig.2). The latter type of structure may be comparable to drag-folding on a small scale, except that the movements are localized on cleavage planes instead of being continuously distributed.

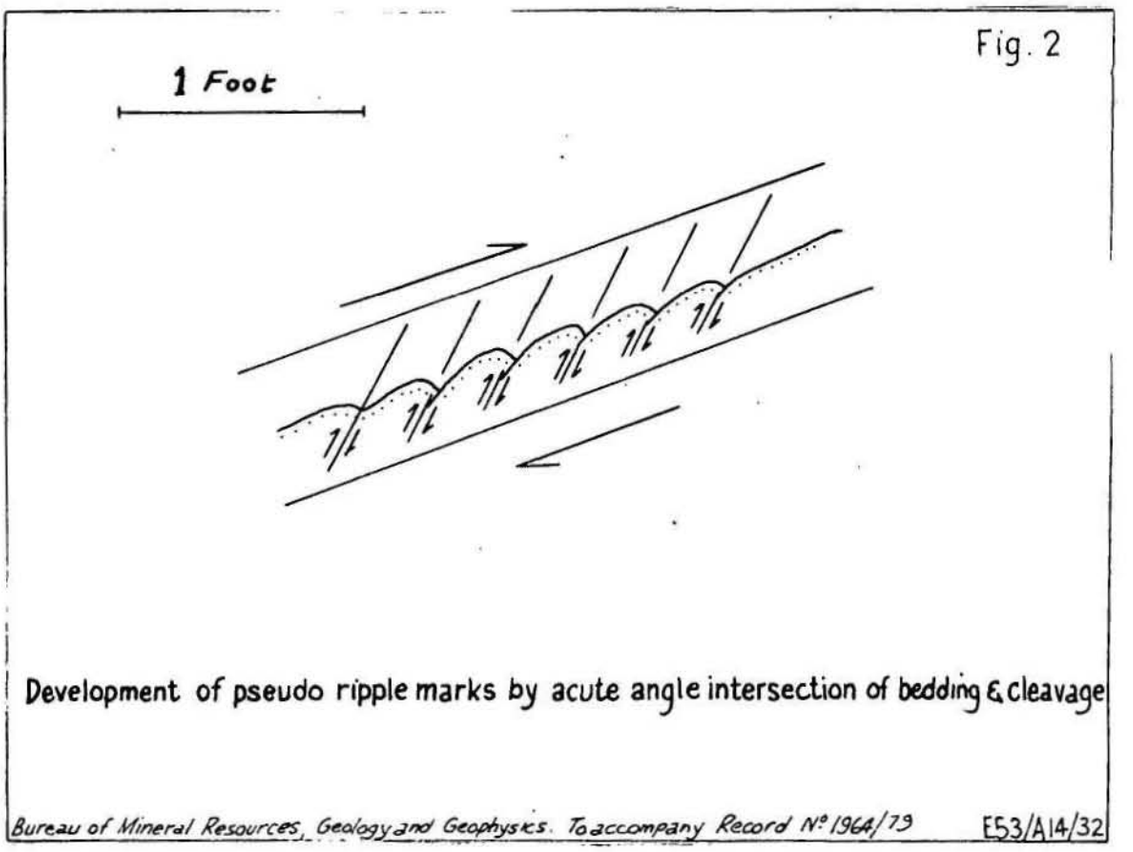


Fig. 2
Development of pseudo-ripple marks by acute-angle intersection of bedding and cleavage.

Structural Features

Structurally, the Warramunga sediments of the Tennant Creek One-mile area are divisible into two main areas, separated roughly by the line of the Quartz Hill/Rocky Range fault (Fig.4). West of the fault, the dominant structures in the Warramunga sediments are folds with roughly east-west axes. Dips average about 60° but in places reach 90° and may even be overturned. Most of the folds are roughly symmetrical; however, in the Mount Samuel/Eldorado area a local steepening of dips to the north has produced a major monoclinal structure in an area of dominantly gentle dips.

In the Mount Samuel/Eldorado area, pitches are dominantly to the east at angles of up to 20°, but in the Peko and Golden Forty areas they are predominantly to the west at angles of up to 30°. Other areas show variations in pitch with rapid reversals.

In some areas, two periods of deformation are indicated by the presence of minor folds, pitching down the dips of the limbs of the major folds. These take the form of 'bruch-falten', associated with oblique shears and can be traced into clean breaks along the strike of the shears in places (Fig.3).

Throughout the area, folding in the incompetent shale tends to be tighter and more complex than in the greywacke.

East of the Quartz Hill/Rocky Range fault zone, folding is generally more open, and dips are most commonly in the range 30° to 45°.

The regional strike of the cleavage throughout the area is about 80°, with predominantly northerly dips. Local variations of this attitude are not uncommon, but cannot generally be related to any changes in the strike and pitch of the beds or of the nearby fold axes.

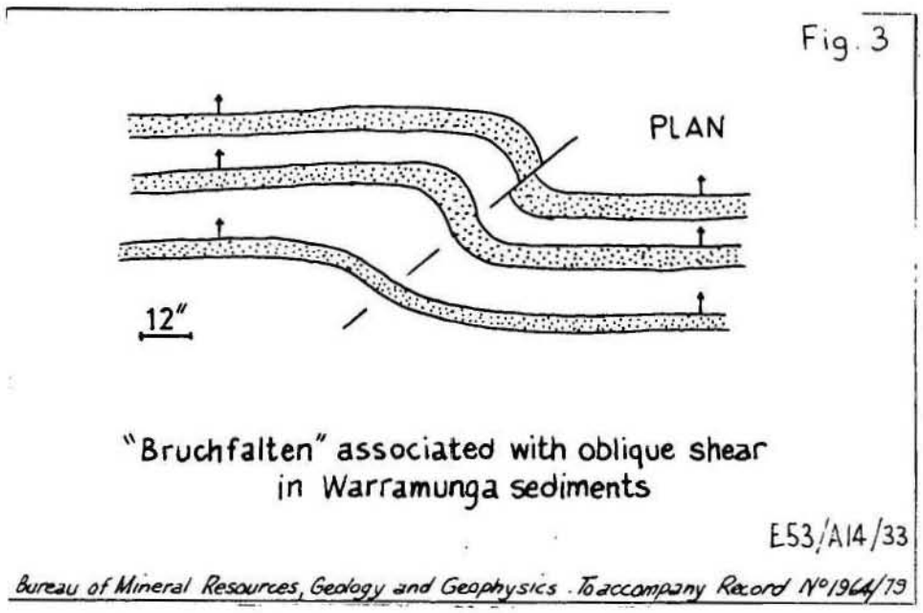


Fig. 3

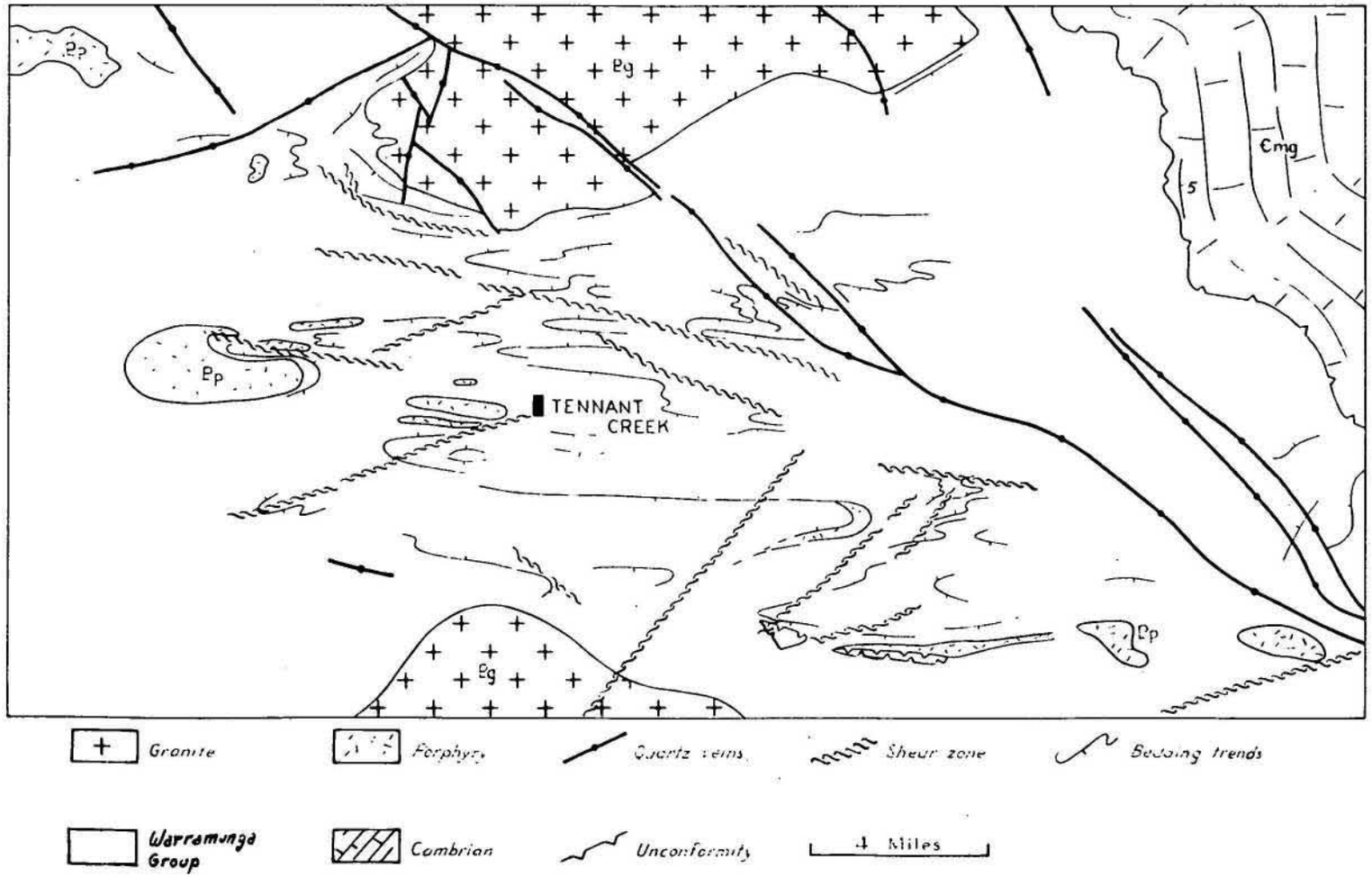
"Bruchfalten" associated with oblique shear in Warramunga sedimentary rocks.

Shears and faults are common. They range from clean breaks to zones of brecciation and mylonitization more than a hundred feet wide, and the resultant displacement may be anything from a fraction of an inch to several hundred feet. Many of them have subsequently been filled by quartz reefs or quartz-hematite lodes. The shears and faults can be grouped into well-defined sets, which together make up a remarkably symmetrical pattern (Figs 4 and 5). Prominent quartz-filled shears trend north-east and north-west, prominent shears associated with ironstone and occasionally with gold and copper orebodies trend east-west, east-north-east and west-north-west, and assorted minor sets of shears trend north-north-east and north-north-west.

The most prominent of these sets has a north-westerly trend and includes the zone of quartz reefs which extend intermittently from Quartz Hill to Rocky Range, a distance of about 30 miles. Near the Memsahib Mine, this zone splits into two main branches, about a mile apart, each of which is itself a composite structure. A distinct en echelon arrangement of the individual quartz veins can be recognised south of the Renate Mine and in the vicinity of the Rocky Range Trig.

Fig.4

SIMPLIFIED STRUCTURE OF TENNANT CREEK



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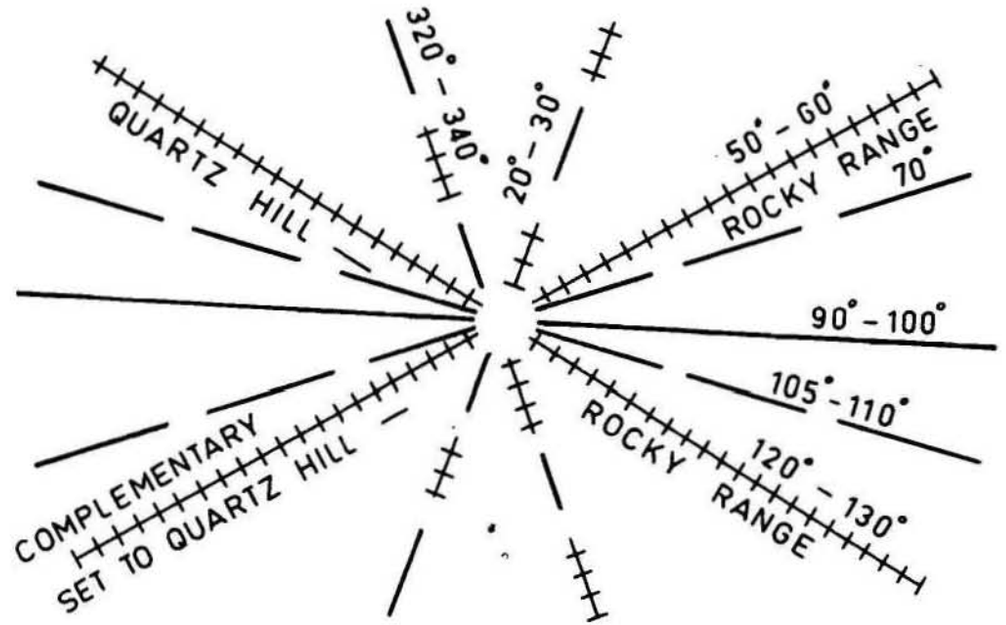
E53/A14/35

Fig. 5



QUARTZ FILLED SHEARS

MINERALIZED SHEARS

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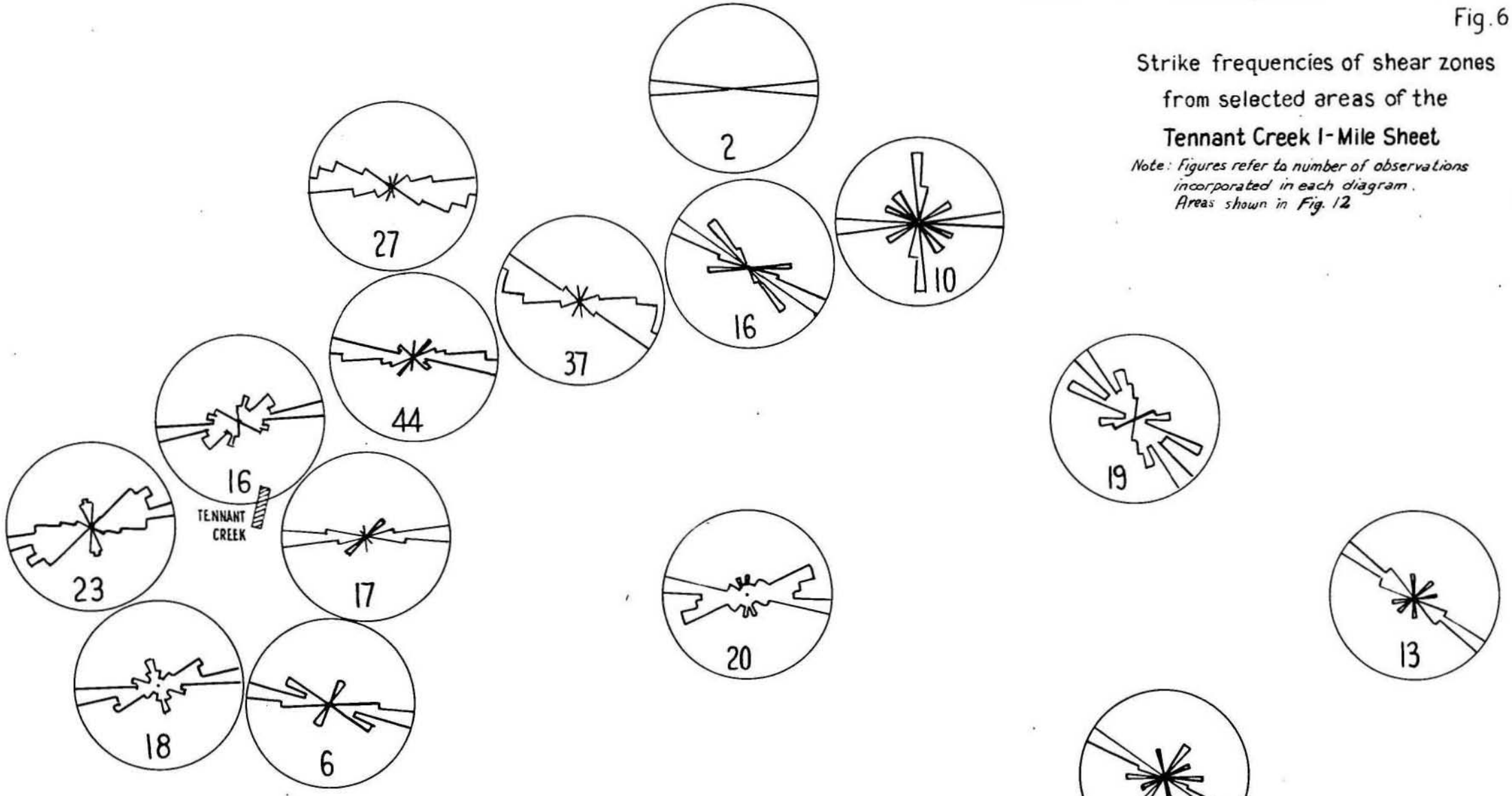
E53/A14/34

Fig. 6

Strike frequencies of shear zones from selected areas of the **Tennant Creek 1-Mile Sheet**

Note: Figures refer to number of observations incorporated in each diagram. Areas shown in Fig. 12



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E53/A14/36

Point. A strong north-north-west branch zone can also be traced for about five miles near Rocky Range.

Complementary north-easterly zones are developed at Quartz Hill and north of the Mammoth Mine. In addition, a strong non-outcropping north-easterly shear zone has been delineated by diamond drilling in the Cabbage Gum Basin, about ten miles south of Tennant Creek township: the trend coincides with a prominent linear feature on the air photographs, and can be traced for about 10 miles at least as far as the Peko Mine.

Evidence of the movement on some of these shears is rather conflicting. Displacement of the granite contact near the old Telegraph Station and of the hematite shale marker bed near the Mammoth Mine indicates an apparent throw of about one and a half miles, east block north, for the main Quartz Hill/Rocky Range fault zone. However, parts of the zone show a left-hand echelon pattern, which suggests a movement in the opposite sense, and a branch fault north-east of Rocky Range, trending 140°, shows an apparent throw of nearly two miles, east block south, measured from the displacement of a conglomerate horizon at the base of a succession of massive greywackes. Unless repeated movement has taken place, these observations could only be reconciled on the assumption that the movement on these faults was largely vertical, east block down, and probably amounted to not less than 5000 feet.

Although quartz-filled shears are very striking features of the regional geology of the Tennant Creek Gold field, they are less important economically than those shears which have localized the emplacement of the ironstone lodes, and the gold and sulphide orebodies.

The most widespread set strikes between 090° and 100° and accounts for nearly half the shears observed in the One-mile area (Fig.5), although most of them could only be traced for short distances. Shears trending 105° to 110° are less numerous, but they include some very large structures, traceable for many miles, notably the Mary Lane/Mary Ann shear-zone with its probable extension into the vicinity of Red Bluff to the west and the Lone Star Mine to the east. In the Mary Lane area, shears of this set trend roughly parallel to the southern margin of the Station Hill granite complex, to which they may be related (Fig.6).

In the Lone Star/Memsahib/Mammoth area, numerous small shears, some of them mineralized, also trend at 120°, parallel to the Quartz Hill/Rocky Range fault-zone, and to a lesser extent this trend is also represented in other parts of the area (Fig.6).

In the south-east corner of the One-mile area, two miles south of the New Hope Mine, a strong fault, striking at 075°, has been traced intermittently for more than three miles. East-north-easterly shears (average strike 060 to 070° form a subordinate but significant set in the Gibbet/Wheal Doria, Pinnacles, and Golden Forty areas. In addition, some areas show subordinate sets striking north-north-east (average 020

to 030°) and north-north-west (320 to 340°), which include both quartz-filled and mineralized members.

Ashburton Sandstone and Hatches Creek Group

The Ashburton Sandstone crops out to the north of the Tennant Creek One-mile area on the northern margin of the Tennant Creek Goldfield, and the Hatches Creek Group occupies a similar position on the south flank of the field.

Reconnaissance trips to the area north and north-east of the Last Hope Mine, about 30 miles north-west of Tennant Creek township, tended to confirm Ivanac's (1954) suggestion that the Warramunga sediments in this area pass conformably up into the Ashburton Sandstone. There is undoubtedly a steady increase in the proportion of sandstone to shale as this boundary is approached, and the sandstone becomes more siliceous, better sorted, and more strongly cross-bedded, resembling in these respects the rocks in the south-eastern portion of the Tennant Creek One-mile area. Nevertheless, the shape of the Warramunga/Ashburton contact as shown on Ivanac's map suggests an unconformity, and the question can only be resolved by detailed mapping of several miles of this boundary.

Smith et al. (1961) record an angular unconformity between the Warramunga and Hatches Creek Groups. The Ashburton Sandstone and Hatches Creek Group are very similar lithologically and structurally, and it is tentatively suggested that they might be equivalent, at least in part. If this is so, unconformity is likely to be found at the base of the Ashburton Sandstone.

Rising Sun Formation

This Formation crops out over an area of approximately six miles by a quarter of a mile, elongated in a general east-south-easterly direction, to the south of the Noble's Nob, Rising Sun, and Red Terror Mines, and there is a small outlier about one mile north of Rocky Range. The Formation is composed largely of conglomerate, quartzite and grit in the lower portion, with sandstone, siltstone and mudstone becoming more important in the upper portion. It rests with a strong angular unconformity on an eroded surface of porphyry and Warramunga sediments.

Structurally, the main mass forms a syncline with its axis parallel to the long dimension of the outcrop, but its southern margin is strongly faulted and in places the entire southern limb appears to have been faulted out. Minor faulting at right angles to the axis is common. Dips range from 20° to 30° in the northern limb of the syncline, but are less regular in the southern limb, where the beds are locally overturned. The maximum exposed thickenss is about 200 feet, but the original thickness may of course have been very much greater than this.

The Formation may be divided into three main portions. The basal portion consists dominantly of conglomerate with associated grit and sandstone, about 60 feet thick in the east and thinning to about 30

PLATE IV

A. Rising Sun Formation unconformably overlying weathered porphyry. Matrix of the basal bed of conglomerate consists of re-worked quartz and feldspar grains derived from the porphyry.
Neg. M/339/2918

B. Typical granite tors near Station Hill.
Neg. M/339/21.

feet two miles westward. As the unit thins, the proportion of conglomerate decreases from about 70 percent to less than 40 percent, and the size of the boulders also decreases.

Typical sections through the lowest portion of the Formation at the two localities are as follows:

Eastern Locality	Western Locality
30' conglomerate with minor grit and quartzite.	20' conglomerate and grit.
4' white cross-bedded quartzite.	7' cross-bedded sandstone.
20' conglomerate, including 6' bed of grit, commencing 2' above base.	- - -
2' basal grit with scattered pebbles.	0' - 2' basal grit with scattered pebbles.
- - - - - - - - - - - -	- - - - - - - - - -
porphyry.	porphyry.

The basal grit contains well-rounded quartzite pebbles in a matrix of subangular quartz and feldspar grains with some interstitial clayey material. This has been regarded by a number of previous workers (e.g., Ivanac, 1954) as evidence of porphyritization of a conglomerate, but careful examination disclosed a sharp boundary against the underlying porphyry, and the material, except for the pebbles, is thought to be derived from the underlying porphyry by a process of re-working with a minimum of transport (Plate IVa).

Some of the thicker conglomerate beds have been traced along the strike for several hundred yards, but some beds were seen to lens out from a thickness of five feet within a distance of less than 50 yards.

The pebbles in the conglomerate range up to about 18 inches in diameter, and are largely sandstone and quartzite, similar to the Ashburton and Hatches Creek Formations. Some are fragments of a pre-existing conglomerate, and one was found to contain angular fragments of quartz, jasper, flint, and shale.

Although conglomerate and grit alternate repeatedly in this part of the Formation, there is no gradation in grain-size, although a few large pebbles occur in the grit beds.

The white cross-bedded sandstone band occurring within the conglomerate can be followed almost continuously to the western limit of the exposures. It is in places recrystallized to quartzite. The grit overlying it is generally poorly cemented and poorly sorted and lenses out rapidly along the strike.

The grits and conglomerates are overlain by a series of predominantly red and purple coloured siltstone and sandstone, at least 90 feet thick. The sandstone is fine to medium-grained, poorly sorted, and in part has a fine-grained clayey matrix. Beds are from two to nine inches thick, and commonly show ripple marks with an east-west

orientation. Interbedded with them is thin-bedded siltstone which includes a small proportion of mudstone. The beds are severely contorted and in places crushed and sheared. At one point, a lamprophyre dyke, three feet thick, is intruded along a bedding plane.

The uppermost division of the Rising Sun Formation consists of quartzite with a maximum exposed thickness of about 50 feet. Except for their silicification, these beds are very similar to the underlying thin-bedded sandstone.

The general indications are therefore that the basal part of the formation was laid down in shallow water and the upper part in moderately deep calm water. The decrease in thickness of the conglomerate from east to west, together with the decrease in pebble size, indicates a source of supply from the east.

The rocks at 2,531,000 north, 218,000 east and 2,526,000 north, 224,000 east, shown as parts of the Rising Sun Formation on Ivanac's map, are regarded here as parts of the Warramunga Group.

However, two small outliers of conglomerate occur on low ridges about one mile north-east of Rocky Range Trig. Station. These beds are lithologically indistinguishable from the basal beds of the Rising Sun Formation at the type locality, indicating that the Formation was originally much more widespread. In addition, rocks comparable to parts of the Rising Sun Formation in lithology and structure have been recorded in the Davenport Ranges, some 80 miles south-east of the type locality (Smith, 1960), and from an area on the south-west flank of the Ashburton Ranges, about 50 miles north-west of the type locality (J. Elliston, Peko Mines N.L., personal communication).

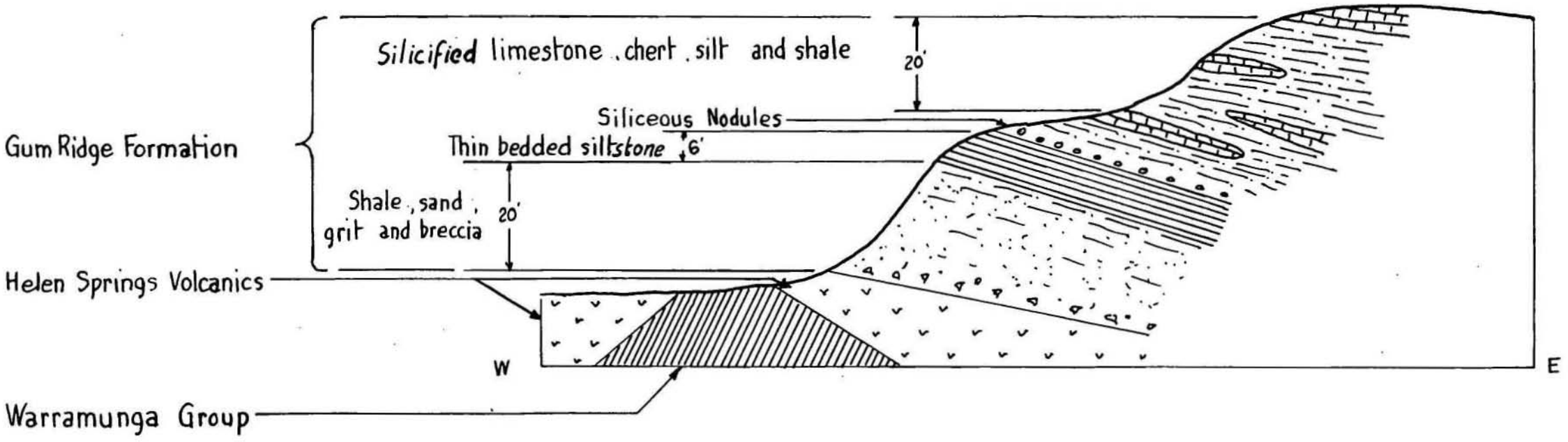
At all these localities, the Rising Sun Formation rests unconformably on older sedimentary and igneous rocks, but is itself moderately folded and faulted. It may be cut by quartz veins, especially in the vicinity of major faults, but is not otherwise mineralized.

Helen Springs Volcanics and Gum Ridge Formation

The present survey has confirmed Ivanac's description (1954, pp. 28-32) of the Helen Springs Volcanics and the Gum Ridge Formation.

The Gum Ridge Formation consists of siliceous shale, chert and siliceous limestone, with a basal sequence of sandstone, grit and sedimentary breccia (Fig. 7). The maximum exposed thickness of the whole formation is about 40 feet. The basal members of this formation are derived from the immediately underlying older rocks, so that sedimentary breccias containing fragments of greywacke and shale in a sandy matrix occur in areas where the formation rests directly on Warramunga rocks, whereas quartzite and grit overlie the Helen Springs Volcanics. About half-way up the sequence, a thin-bedded fossiliferous siltstone serves as a useful marker horizon and also indicates the vertical transition from coarse to fine-grained sediments. Trilobites become abundant for the first time within this siltstone.

Fig. 7



Generalised section through Gum Ridge Formation

Chemical deposits are locally important in the upper, fine-grained sedimentary succession. The individual beds do not persist along the strike, but commonly lens out rapidly. Siliceous lenses and nodules within these beds are especially rich in fossils, mainly trilobites and hyolithids; brachiopods and sponge spicules are also locally abundant.

GRANITIC ROCKS AND PORPHYRIES

Within the Tennant Creek One-mile area, the Warramunga sediments are intruded by a pene-contemporaneous consanguineous series of igneous rocks, ranging from massive and foliated granites and adamellites through granite porphyry and quartz-feldspar perphyry dykes and plugs to ignimbrites filling volcanic pipes. The occurrence of an ignimbrite containing minerals identical with those of the adjoining porphyry (the Airport Porphyry) shows that the prophyry intrusions were very high level intrusions, and that some of them reached the surface. As the prophyrics appear to be genetically related to the granites, and were emplaced pene-contemporaneously, it follows that the granites were also high-level intrusions.

The two largest of these intrusions are the Station Hill/White Hill complex in the northern portion of the One-mile area, and the Cabbage Gum complex on the southern edge of the area.

The possibility that igneous rocks of two ages may be included in this series has been advanced by some workers, e.g. Owen (1942), and is supported by the presence in the Caroline boulder bed of pebbles resembling the sheared porphyries occurring elsewhere in the area. However, wherever the contacts of an igneous body have been examined, the relationship between these rocks and the Warramunga sediments appears to be intrusive (Plate VIIIa).

Station Hill/White Hill Complex comprises some of the best exposures of igneous rocks in the Tennant Creek One-mile area. It covers an area of approximately 15 by 8 miles, elongated roughly east-west, and contains four major granite types:- massive porphyritic, foliated, equigranular coarse-grained, and aplite. The complex is cut by quartz veins and dolerite dykes and contains numerous small xenoliths and some infaulted wedges of sedimentary material. It is intruded into the shales at the base of the Warramunga succession, which dip away from it on all sides, so that it appears to occupy the central portion of a large dome-like structure. However, although its outline is roughly concordant to the invaded sediments, it commonly transgresses the bedding on a small scale. One sample of granite (E53/14/1) has been dated by the K/Ar method as 1630 million years old (Walpole & Smith, 1961).

Massive Perphyritic Granite. The most abundant rock type within this complex is a massive porphyritic granite, generally red, which forms about 60 percent of the outcrops in the Station Hill area (Plate IVb) and almost all in the White Hill area.

PLATE V.

A. Foliated porphyritic Granite. Primary foliation shown by vertical elongation of minerals. Sheer foliation, marked by biotite schlieran dips steeply to the right.
Neg.M/339/26.

B. Baveno habit microcline crystals weathered out of foliated porphyritic granite Quartz Hill area.
Neg.M/339/2919

The rock consists of rounded to irregularly shaped phenocrysts of red microcline microperthite 5 to 10 mm. across, euhedral to subhedral greyish-white oligoclase 2 to 3 mm. across, grains of clear glassy quartz, and flakes of dark green or black biotite. The granite is markedly constant in appearance over wide areas, though it becomes finer-grained to the west of Station Hill. It contains very few inclusions or xenoliths, but the chilled marginal parts contain a few drusy cavities and pegmatitic segregations.

Under the microscope, only the oligoclase is seen to be euhedral. The microcline and quartz crystals are irregular in shape and many are coarsely and irregularly intergrown, though not on the scale or style of graphic intergrowths. The size of the plagioclase crystals is remarkably uniform over the whole extent of the granite, but in the chilled marginal parts the quartz and microcline crystals are much smaller than in the rest of the granite.

Most of the microcline ($2V=90^{\circ}$) shows characteristic cross-hatching. Film microperthite texture is well developed, but in some crystals the exsolved albite films, instead of being parallel, are so irregular as to resemble a graphic intergrowth. All the microcline crystals have very irregular shapes, even the phenocrysts. Some phenocrysts show carlsbad twinning, and, unlike the others, are free of inclusions of quartz and sericitized oligoclase. Most of the untwinned microcline crystals contain irregularly shaped inclusions of quartz, many of which are in optical continuity with each other and show undulose extinction. There are also inclusions of sericitized oligoclase, some of which are also in optical continuity with each other. The margins of the microcline crystals are very irregular, especially against quartz. Some contiguous microcline crystals are separated by zones of clear albite, some by zones of granular albite. Others are separated by clear quartz or by quartz granules. One microcline crystal is rimmed against contiguous oligoclase by a thin irregular band of fresh microcline in optical continuity with the original crystal.

Quartz occurs as irregularly shaped poikilitic crystals of varying size, which contain inclusions of microcline and plagioclase. Strain shadows are well developed and the inclusions appear to be the loci for many of them. A few crystals are granulated along their margins. Some of the quartz crystals appear to have euhedral crystal faces against microcline.

Oligoclase occurs as euhedral sericite-covered crystals, some of which show albite twin lamellae and extinction angles of 5° to 10°. None of the crystals are zoned. The sericite flakes and epidote granules appear to be arranged in a rectangular pattern, probably because saussuritization is controlled by the cleavage.

The major mafic mineral was biotite, but most of it has been converted to penninite. The original biotite cleavage is marked by iron staining and trails of minute granules of hematite. Colourless and pale

green epidote and patches of black iron oxide occur along the cleavages and around the flakes of biotite. Minute needles of apatite and rounded grains of zircon are scattered through the rock.

The porphyritic granite in the central part of the Station Hill outcrop area, just to the east of Station Hill, is coarser-grained than the rest of the granite and is strongly foliated (Plate Va).

Most of the minerals form large crystals. Oligoclase, showing extinction angles of 10° to 12° occurs as euhedral crystals 3 to 5 mm. across, quartz forms ovoid blebs up to 10 mm. long, and microcline occurs as rounded phenocrysts from 15 to 30 mm. across. As the foliation increases, the perthite phenocrysts are more distinct and rounded. In some parts, the microcline phenocrysts have been weathered out of the granite and can be seen to consist of euhedral Baveno crystals 20 to 30 mm. long with slightly rounded corners (Plate V). Some of the microcline phenocrysts are mantled with oligoclase, giving a rapakivi texture. Around some microcline crystals the oligoclase mantle is a continuous zone, around others it is a zone of minute euhedral crystals of sericitized oligoclase.

The most striking feature of this granite is the intense foliation. A primary foliation (probably a flow foliation) strikes 070° to 080° and is generaly vertical or steeply dipping. The quartz crystals have been granulated and streaked out into ovoid blebs and trails of granules, the biotites are bent and streaked out into long trails, and some of the albite lamellae in the saussuritized oligoclase are bent. However, in spite of this well-marked foliation, there is no segregation into mafic and leucocratic layers. This primary foliation is intersected by thin, straight biotite schlieren, also striking 070° to 080°, but dipping at slightly different angles. This is probably a later shear foliation.

The foliated granite contains numerous mafic xenoliths. Some parts are so contaminated as to contain up to 30 percent of xenoliths. Most of the xenoliths are disc-shaped and oriented parallel to the foliation. They range in size from a few inches to two or three feet long, and they vary from highly feldspathised 'ghost xenoliths' to discs of fine-grained biotite schist.

Fresh muscovite flakes and disc-shaped rosettes of radiating acicular dark green tourmaline crystals up to 5 cm. long occur in the foliation planes and in tension cracks of this granite. This suggests that the foliation antedates the late-stage hydrothermal reactions in the granite.

The foliated granite, uncharacteristically, occurs in the centre of the complex: in most granite complexes, the foliation and contamination increase towards the margin of the mass. The foliated granite differs considerably from the non-foliated granite in grain-size, appearance, and content of xenoliths, but no intrusive contacts were found between the two granites. Instead, the massive porphyritic granite

was found to be weakly foliated in places, and in a few localities was seen to grade into the foliated porphyritic granite. Generally, however, most of the contact or transition zone is covered by soil or rubble. The foliation appears to be independent of the shape of the foliated porphyritic granite mass and of the whole granite complex, and is sub-parallel to the regional cleavage.

Foliated Porphyritic Granite (Second Phase). The central part of the foliated porphyritic granite was invaded by two masses of foliated granite. One of these occurs as a small north-westerly-trending pod of fine-grained granite at 2,550,800 north, 190,500 east, and is distinguished by the presence of ovoid quartz crystals whose long axes plunge steeply southwards. The other, at 2,550,200 north, 189,300 east, has a chilled marginal zone 30 yards wide and a sharp planar contact dipping 30° towards 190° against the surrounding earlier foliated Porphyritic Granite. However, the contact could not be traced more than 200 yards and the full extent of the intrusion could not be determined. The foliation of both granites is parallel and independent of the contact between them, suggesting that the second phase intruded the first phase before the granites were foliated.

Coarse-grained Granite. The central part of the Station Hill outcrop area contains several small intrusions of a coarse-grained inequigranular granite.

This contains crystals of microcline from 1 to 4 mm. across, and a few phenocrysts up to 10 mm. Subhedral to euhedral oligoclase crystals (extinction angles 5° to 10°) range from 2 to 3 mm. across. The mafic minerals are aggregated into clots and consist mainly of fresh biotite with some magnetite and apatite. Quartz-microcline graphic intergrowths occur, and are commonly radially disposed around small kernels of microcline. Other microcline crystals appear to be interstital between euhedral quartz grains.

This coarse-grained granite usually has sharp, slightly chilled smooth contacts against the adjoining earlier phases of the granite complex, commonly the foliated granite.

Fine-grained Granite. The fine-grained granite is the youngest member of the Station Hill/White Hill igneous complex. It crops out over an area of about two square miles along the south-western margin of the Station Hill outcrop area, and over smaller areas along the north-western margin. Smaller pods, dykes, and veins of this granite intrude all the earlier members of the complex. Contacts are sharp and well-marked. The south-western mass contains inclusions of the adjoining porphyritic granite.

Typically, this fine-grained granite is an inequigranular rock with an average grain size of 0.5 to 2 mm. None of the minerals are euhedral, and quartz-microcline intergrowths are common.

The Station Hill and the White Hill areas contain veins of this

fine-grained granite. Where the veins cross non-foliated granite, they are not foliated themselves, but they are foliated where they cross foliated granite and they contain disc-shaped aggregates of radiating tourmaline needles.

Xenoliths. In places the foliated porphyritic granite contains up to 30 percent of its volume of fine-grained mafic xenoliths, streaked out parallel to the primary foliation. These xenoliths range from discs of fine-grained biotite schist to 'ghost xenoliths' crowded with feldspar and quartz porphyroblasts (Plate VIa).

Under the microscope, the mafic xenoliths are seen to consist of a mosaic of minute interlocking granules of quartz, microcline, and albite-oligoclase, and flakes of sericite, together with oriented streaks or schlieren of small fresh parallel flakes of biotite and some muscovite. Accessory magnetite, zircon, and apatite are common.

The quartz, microcline, and plagioclase also form poikiloblastic phenocrysts up to 10 mm. across. They have very irregular margins, enclosing numerous granules of the mosaic. One large microcline aggregate consisting of minute interlocking irregularly shaped crystals of microcline, was seen.

The fine-grained mafic xenoliths do not resemble any of the country rock exposed round the granites. Probably the xenoliths were incorporated into the granites at considerable depth, where the high temperature, content of volatiles, and long period of alteration allowed the development of the large feldspar porphyroblasts. None of the exposed contact rocks show such extensive alteration and feldspathization.

The foliated porphyritic granite in the centre of the complex is the richest in xenoliths, whereas the marginal granite contains very few xenoliths, even of the contiguous metasediments. Some of the arenaceous xenoliths in the porphyritic granite show intense contortion (Plate VIb), which may be a result of mobilization.

Contact Metamorphism. The sediments in contact with the Station Hill/White Hill granite complex are only lightly metamorphosed. The contacts are mainly concordant and the metasediments dip radially off the granite. The sediments are mostly fine-grained siltstone and alternations of siltstone and shale.

In some places, the contact rocks contain thin quartz - tourmaline veins and quartz-feldspar-tourmaline veins, but generally new minerals are not developed, and the rocks are merely hardened either by baking or by silicification.

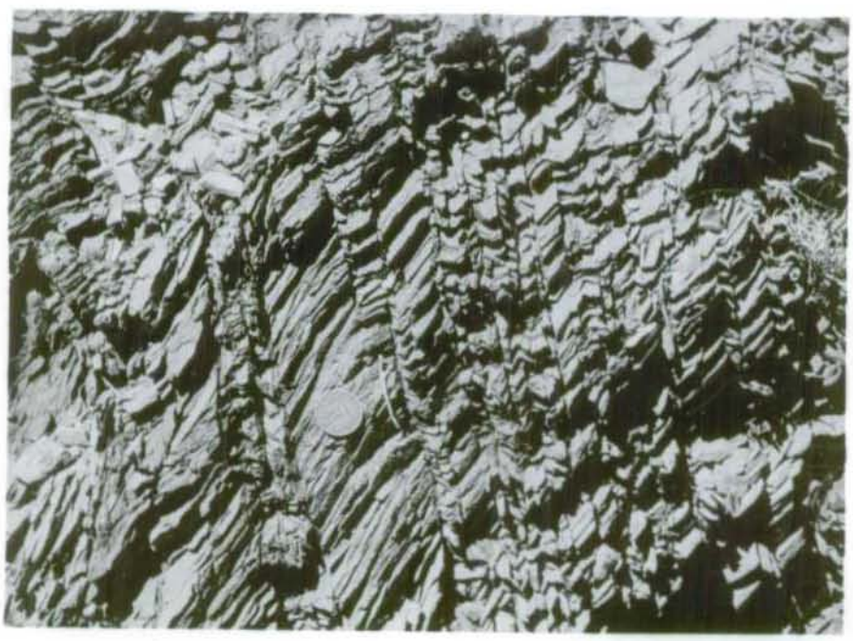
Under the microscope, most of the siltstone is seen to have been re-crystallized into mosaics of interlocking minute grains of quartz with varying amounts of sericite scattered through the rock. There is usually a relatively high proportion (about 5%) of minute octahedra of magnetite. Small fresh poikiloblastic crystals of biotite and small rounded grains of green tourmaline are also scattered through the rocks. A siltstone

PLATE VI.

A. Mafic xenolith in foliated porphyritic granite, showing development of poikiloblastic feldspars.
Neg. M/335/30

B. Contorted arenaceous xenolith in porphyritic granite. White Hill area.
Neg. M/339/30.

PLATE VII



A. Chevron structures in Warramunga sediments at north-east margin of Station Hill granite complex.
Neg. M/339/2912

B. Jubilee Porphyry, showing bavono habit microcline crystals.
Neg.M/339/11.

near the White Hill granite contact contains irregular veins of fine-grained kaolinite and ovoid pods composed of minute grains of green tourmaline.

The sericitic siltstone and shale contain minute irregular quartz grains scattered through a matrix of oriented fresh sericite flakes. These sericitic rocks contain less magnetite, biotite, and tourmaline than the quartzose rocks.

The hardening and recrystallization of the contact rocks may be due to mobilization and recrystallization of quartz by the heat of the nearby granite. On the other hand, the presence of scattered tourmaline shows that boron-rich emanations from the granite were permeating the rocks, and these could also have introduced silica. The contact rocks at the eastern and western extremities of the granite also contain limonite-filled casts of pyrite cubes.

A few of the contact rocks are veined. The most common veins consist of quartz and contain tourmaline crystals growing normal to the vein walls. These veins have been found in sediments up to three miles from the nearest granite outcrops. Quartz-feldspar-tourmaline veins also occur in the contact rocks. Some of the sericitic rocks appear to have been invaded along irregular fractures by volatiles which altered the sericite to kaolinite, thus forming 'veins' of kaolinite. These veins consist of large flakes of kaolinite and some illite set in a siliceous matrix. Some veins have ferruginous borders.

Some of the veining is irregular, but most of it follows the steeply dipping east-west regional cleavage, which appears to be independant of the shape of the granite and the changing trends of the contact metasediments.

Structural Relationships. The granite appears to have pushed the surrounding metasediments aside, for the metasediments to the west of Station Hill appear to diverge north-eastwards and south-eastwards around the granite, and dip off it. However, neither the western extremity of the granite nor the actual divergence of the metasediments is exposed.

The contact rocks are well exposed along the north-west margin, where they contain numerous drag folds overturned to the north-east, which plunge down the regional dip of the beds. Chevron structures about fractures striking 030° to 040° were also noted (Plate VII). Drag-folds and chevron structures were also found along the south-west margin; but the strata along the south-eastern margin dip gently off the granite at angles of 30° to 60°.

Although the granite appears to have pushed the sediments aside, the cleavage of the contact rocks trends 070° to 090°, parallel to the regional cleavage. This cleavage appears to antedate the emplacement of the last phase of the granite, as numerous veins of quartz and aplite, and a few Baveno porphyry dykes, have been injected along the cleavage planes. It is therefore suggested that the cleavage of the sediments and the foliation of the granite were developed contemporaneously during

the final stages of consolidation of the granite.

Cabbage Gum Complex

The Cabbage Gum Complex, apart from a few small outcrops of porphyritic adamellite, is known only from diamond drill intersections. However, in addition to the porphyritic adamellite, an augen gneiss and a medium-grained gneissic granite have been recognised as major phases, and quartz-feldspar porphyry, aplite, and dolerite as minor ones. The complex also contains several major inclusions of Warramunga sediments and is cut by quartz veins and by a major north-easterly shear zone, as described in a previous section.

The porphyritic adamellite corresponds closely to the foliated porphyritic granite (first phase) of the Station Hill area in mineral composition and in the distinctive appearance of the microcline phenocrysts. However, no equivalents to the augen gneiss or the gneissic granite have been noted elsewhere in the One-mile area. Because of the lack of outcrops, the age relationships of the three major phases could not be determined. The aplite can be seen in some of the drill cores to be small irregular intrusions into the granitic phases, and the dolerite is thought to occur as dykes the granitic members of the complex.

Other Granitic Rocks

A small isolated mass of porphyritic granite crops out about one mile north-east of the New Hope Mine, and some other occurrences of both porphyritic and fine-grained granite are associated with the quartz-feldspar porphyry outcrops between two and three miles east of this mine. Their relations to the porphyry could not be determined, however.

In addition, a large granodiorite mass occurs some ten miles south-south-east of Noble's Nob, outside the limits of the Tennant Creek One-mile area, but this was not investigated in detail during the present survey.

Porphyries and Ignimbrites

By contrast with the granites, the porphyries generally occupy smaller areas with a maximum extent of about three by one miles, the best examples being north of the Curlew Mine, at the Jubilee Mine, in the vicinity of the Aerodrome, south of the Red Terror Mine, to the east and south-east of Peko, and in the New Hope area.

Some of the smaller masses of porphyry are very strongly sheared, and in hand-specimen are not always distinguishable from the grits of the Warramunga Group. In the field, however, they can generally be identified by their uniform appearance over much greater widths than any attained by beds of the Warramunga Group and by their transgressive contacts.

Nearly all these bodies are elongated east-west, parallel to the dominant strike of the Warramunga sediments, and the direction of shearing is generally also parallel to this direction. The transgressive relationships of these bodies are usually most obvious at the east and west tips, where the sediments have been forced apart and shattered.

In some of the larger masses only the margins have been sheared, leaving a relatively fresh core of bluish-grey or greenish-grey rock studded with glassy quartz and white or flesh-coloured feldspar. The sheared phases are generally more strongly weathered and are reddish-brown in colour.

The Baveno Porphyries. Because of their content of Baveno-habit microcline phenocrysts, several of the porphyries in the One-mile area, notably those from the areas north of the Curlew Mine and west of the Jubilee Mine, are thought to be closely related to the porphyritic phases of the Station Hill granite complex. These have been called the Baveno porphyries. The porphyry occurrences in the New Hope area also include some rocks of this type, but fine-grained and sheared phases predominate.

At the Jubilee Mine, these porphyries form two concordant ovoid intrusive bodies, about two by one miles in area, in the cores of domal structures in the Warramunga metasediments. At the porphyry contacts, the metasediments have been silicified and in part replaced by iron oxides, resulting in the development of prominent quartz-hematite reefs, from 10 to 30 feet thick, within the contact aureole.

A number of petrologically similar porphyries crop out in the area between the southern margin of the Station Hill granite area and the Mary Lane and Hidden Mystery Mines. These porphyries are mostly in the form of dykes 10 to 40 feet thick, which coincide in strike with the trend of the surrounding metasediments and also with the outline of the granite complex. They may thus be part of an incompletely developed system of ring dykes. They are generally sub-vertical, and commonly lens out rapidly along the strike. In places, the planes of weakness originally invaded by the dykes were subsequently invaded by quartz veins which attain thicknesses of up to 20 feet where the dykes lens out.

However, not all the dykes of this area conform to this pattern. Thus at 2,549,300 north, 186,000 east, one well exposed dyke has been traced for nearly two miles in an easterly direction, parallel to the cleavage of the metasediments rather than their bedding, and the eastern portion cuts across the contact of the Station Hill granite complex and passes almost through the centre of a body of fine-grained granite.

All the Baveno porphyries are distinctive porphyritic fine-grained rocks containing large baveno crystals of microcline 10 to 20 mm. long, ovoid corroded quartz crystals 10 to 20 mm. long, and subhedral crystals of plagioclase (Plate VIIb).

The phenocrysts of microcline are all euhedral baveno crystals with slightly rounded corners. They contain a few inclusions of quartz and plagioclase, and in some of the dykes the microcline is heavily saussuritized. The microcline crystals in the Baveno porphyry near the Jubilee Mine contain irregularly shaped gas cavaties that have been subsequently filled with dark green chlorite. There is not much perthite texture.

The quartz phenocrysts consist of large, single, slightly strained crystals which have been rounded and deeply embayed by magmatic corrosion. The quartz phenocrysts are more numerous close to the margins of the intrusions, where they consist mainly of small slightly corroded euhedral bipyramids.

The plagioclase occurs as irregularly shaped crystals and aggregates of small crystals. Most of these are saussuritized, so that albite-twinning extinction angles are difficult to measure, but the composition appears to be albite-oligoclase.

There is little mafic material, except for a few biotite flakes, magnetite granules, and rounded zircons. There is a marked increase in the amount of magnetite in the marginal parts of the Jubilee porphyry.

The groundmass is very fine-grained and consists of minute granules of quartz and microcline, flakes of sericite, and minute granules of what appear to be radially intergrown quartz (? crystobalite) and microcline. The groundmass is markedly finer grained near the margins of some of the phenocrysts.

Quartz-Feldspar Porphyries. The great majority of the porphyries in the Tennant Creek One-mile area are here grouped together as quartz-feldspar porphyries, although detailed petrological examination might enable further subdivisions to be made.

These rocks form dykes, small plugs, and large lenticular intrusions, up to three miles long, intruded into the Warramunga shale and greywacke (Plate VIIIa). The intrusions differ in their resistance to erosion according to their size and degree of shearing, and many of the dykes have been reduced to aggregates of quartz grains in an almost structureless red clayey matrix.

The contact metamorphic effects of these intrusions are generally slight, and even the larger bodies are surrounded by zones of silicification only about 50 yards wide. In some areas, notably along the southern margins of some of the larger intrusions, such as the Aerodrome porphyry, prominent jasper reefs have been formed by the introduction of silica and iron oxides into favourable beds. Xenoliths are very abundant in some of these porphyry bodies, e.g., at 2,535,000 north, 206,000 east. Most of them are sharply defined angular fragments of Warramunga greywacke and shale and are little altered.

Most of the quartz-feldspar porphyries consist of irregularly shaped corroded phenocrysts of quartz, microcline, and euhedral plagioclase, set in a fine-grained matrix which ranges from dark grey to red, depending on the degree of weathering (Plate VIIIb).

Quartz forms the most common phenocrysts and occurs as large, irregularly shaped, deeply embayed and corroded single crystals up to 5 mm. in diameter. Near the margins of the porphyry intrusions, however, corroded euhedral bipyramids of quartz (after beta quartz) are more common.

The microcline phenocrysts consist of irregularly shaped deeply corroded crystals of fresh, cross-hatched microcline, (2 V = 90°), up to 5 mm. in diameter. Little perthite was found. The microcline contains inclusions of quartz, plagioclase, and many chlorite-filled gas or fluid cavities. The marginal parts of some porphyries contain clear sanidine (2 V = 15° to 30°), crowded with minute rod-like orientated opaque inclusions.

The plagioclase occurs as euhedral sericite-covered phenocrysts from 1 to 3 mm. across. A few fresh plagioclase crystals with well developed albite twinning appear to be albite-oligoclase, having extinction angles of 12° to 15° and a refractive index below that of canada balsam.

There is not much mafic material - a few magnetite octahedra scattered through the matrix, a little chloritized biotite, and some apatite and zircon.

The matrix is very fine-grained and consists of minute intergrown granules of quartz and microcline, and flakes of sericite and chlorite. Many of the granules consist of radiating intergrowths of quartz and microcline. In places there is a well-marked flow foliation.

A few specimens from the central, unsheared portion of the Aerodrome porphyry were found to contain specks of disseminated sulphides (chalcopyrite and pyrite), and at several other localities, notably about three quarters of a mile south of the Pinnacles Mine and to the east of the New Hope Mine, the weathered porphyries contain cavities partly filled by limonite (Plate VIIIb), which may be, at least in part, residual after the leaching of sulphide minerals. On the other hand, they may be formed by the leaching out of weathered feldspars. The possible significance of this will be more fully discussed in a later section.

Some of the porphyries contain minor amounts of tourmaline, and in one of them, about two miles east of the Rocky Range Trigonometric Station, the original feldspar is almost completely tourmalinized, leaving the original quartz as the only remaining primary mineral. However, as this porphyry is situated almost at the junction of two major quartz-filled shear zones, the alteration may be related to the period of mineralization responsible for the emplacement of these reefs rather than to that of the porphyry itself.

An unusual variant of the porphyries occurs in the vicinity of the Black Angel Mine, some 25 miles north-west of Tennant Creek township. Here, several bands of porphyry, up to 3000 feet long and 100 feet wide, trend roughly north-west, parallel to the locally dominant trend of the Warramunga sediments. These porphyry bands are characterized by the presence of exceptionally large rounded quartz phenocrysts, and were mapped as conglomerates by Ivanac (1954, p.23), although their true nature had been recognized by Owen (1942).

The quartz phenocrysts in these rocks range from 2 mm. to 2 cm. across and are deeply embayed and corroded ovoid crystals. The smaller

PLATE VIII

A. Part of Town Hill Porphyry contact showing xenoliths and marginal thrusts. Neg.M/339/5.

B. Photomicrograph of Quartz-feldspar-porphyry.
Q - quartz (note corrosion).
M - microcline.
A - altered plagioclase.
Neg.M/339/1584.

phenocrysts are mostly corroded bipyramids, but some of the larger phenocrysts have several crystal faces and probably were more complex crystals. These phenocrysts are set in a fine-grained matrix of quartz, sericite, and magnetite. Unusual features are the high proportion of quartz and magnetite, the almost complete absence of feldspar, and the linear orientation of the quartz ovoids.

A few irregularly shaped felted masses of small sericite flakes found in the thin sections are probably altered feldspar crystals.

The matrix consists of minute irregularly shaped intergrown crystals of quartz, flakes of sericite, and granules of magnetite. In parts the matrix has been recrystallized into a mosaic of poikiloblastic quartz with sericite and magnetite inclusions. The magnetite content of the matrix varies, and in places the magnetite has aggregated to form orientated mafic clots consisting of up to 60 percent of magnetite. A few oriented ovoid xenoliths of fine-grained quartzite, consisting mainly of poikiloblastic quartz crystals, also occur.

It is tentatively suggested that the lenticular outcrops, the orientation of the quartz phenocrysts, and their intense corrosion (suggestive of high content of volatiles in the magma), can most readily be accounted for on the assumption that the porphyry is some form of volcanic vent filling.

Ignimbrites. Two outcrops of ignimbrite have been found in the Tennant Creek area. One is a thin lens along the south-eastern margin of the airport porphyry; the other is a north-westerly lenticular mass, nearly two miles long, near the Bernborough Mine.

The airport ignimbrite consists essentially of irregularly shaped fragments of quartz, sanidine, and sericitized plagioclase of various sizes up to 1 mm. The fragments are of euhedral crystals, of corroded crystals, and triangular fragments or shards, with concave faces, of quartz and sanidine.

The groundmass forms approximately 20 percent of the rock and consists of a very fine-grained mosaic of quartz and sericite.

The sanidine of the fragments is identical with that in the adjacent Airport porphyry and contains the characteristic oriented opaque rod-like inclusions. Thin sections taken across the porphyry/ignimbrite contact show it to be marked by a 1 mm. band of minute magnetite grains, and both the marginal portion of the porphyry and the ignimbrite are crowded with larger magnetite grains up to 0.25 mm. in diameter.

The ignimbrite is probably a remnant of a volcanic pipe filling. The similarity of the sanidines in appearance, composition and inclusions suggests that the ignimbrite was derived from the contiguous porphyry which followed it into the pipe and displaced the greater portion of the original pipe-filling. Unfortunately, the ignimbrite/Warramunga contact was not found.

The ignimbrite near the Bernborough Mine, about six miles north

of the Tennant Creek One-mile area, consists of various shaped fragments of euhedral and corroded crystals of quartz and microcline, set in a matrix of minute granular quartz and devitrified brown-stained shards of volcanic glass. This matrix comprises about 40 percent of the rock by volume. The shards of volcanic glass are the most significant component and, being oriented identify the rock positively as an ignimbrite. Many of the shards have characteristic conchoidal faces and some have a marginal zone of inward growing acicular crystals.

No plagioclase was found in the rock and very little mafic material, except for a few chloritized biotite flakes and a few grains of magnetite.

The shards commonly show a well marked parallel orientation and are deflected around the larger fragments enclosed in the matrix - a eutaxitic texture.

The outcrop was not examined in detail, but the published map, (Ivanac, 1954) suggests that the mass is a large pipe-filling rather than a flow. However, it is not certain whether the whole mass is one homogeneous body, or whether some later intrusions of prophyry are included in it.

Other Igneous Rocks possibly related to the granites and porphyries.

A number of igneous rocks of uncertain affinities are known from the vicinity of the Last Hope Mine, about 30 miles north-west of Tennant Creek. At the mine itself, Ivanac (1954, p.143) records lavas or tuffs within the transition zone from the Warramunga beds to the Ashburton Sandstone. Some three miles east of this mine, several bodies of igneous rock occupy areas of up to half a mile by a quarter of a mile, but are so deeply weathered and iron-stained that their characteristics and relationship with the surrounding sediments could not be established. Residual mineral grains and textures suggest that they may have been medium-grained acid or intermediate rocks, possibly related to the porphyries.

Similar rocks also occur within the Ashburton Sandstone, about 30 miles north of Tennant Creek township.

Diorites, Dolerites and Altered Basic Rocks

At 2,546,200 north, 186,000 east, in the Mary Lane area, an elongated mass of saussuritized and uralitized hornblende diorite intrudes the Warramunga sediments. This has been traced for about 2000 feet in an east-south-easterly direction, and appears to have a maximum width of about 50 feet. It is now largely composed of hornblende altered to actinolite and of plagioclase broken down to albite, zoisite, and sericite. Epidote, sphene, and apatite are subordinate constituents.

In the Golden Forty area, a small outcrop of a similar rock, composed largely of tremolite fibres and irregular rounded grains of iron oxide, has been shown spectroscopically to contain about 0.2 percent of copper and zinc.

At 2,543,000 north, 186,200 east, about one and a quarter miles north-west of the Caroline Mine, a small body of serpentine six feet wide is exposed in an irregular excavation about nine feet in diameter and

five feet deep. The mass consists of soft greenish material containing lenses and bands of serpentine, up to six inches in width. The mass trends roughly east-west and is flanked to the north and south by strongly sheared sediments with vertical cleavage striking at 085°. The origin of this serpentine is not known.

In the vicinity of 2,550,000 north, 191,500 east, a fine-grained dolerite dyke cuts across the Station Hill granite complex, and has been traced for more than a mile in an east-south-easterly direction. A similar rock type has also been encountered in No. 10A drill hole in the Cabbage Gum Basin.

Lamprophyres

The Warramunga sediments are also intruded by a number of fine- to medium-grained intermediate and basic rocks, tentatively grouped as lamprophyres. These usually occur as irregular bodies not more than 200 feet by 200 feet in extent, and are generally deeply weathered. An exceptionally large member of this group occurs in the vicinity of 2,542,000 north, 191,000 east, where it has been traced intermittently for more than half a mile with an average width of 100 to 150 feet, apparently following a major fault or shear zone. Others occur as flat-lying sheets, up to 20 feet thick, again presumably following joints or shear zones. At the Caroline Mine, at least one such sheet has been shown to cut across the quartz-hematite lodes. At the southern flank of the Aerodrome porphyry, one of these lamprophyres occurs within a few feet of the porphyry, but the contact relationships are obscured by shearing.

The petrology has not been investigated in detail, but the lamprophyres appear to include amphibolitic and pyroxenitic as well as biotite-rich types. The outcrops are commonly marked by a strong development of travertine, which may be regarded as almost diagnostic of this group.

The lamprophyre dykes and sills cut the ironstone reefs and the Rising Sun Formation, and thus are Upper Proterozoic or younger.

IRONSTONES, JASPERS AND QUARTZ VEINS

Ironstones

The general term ironstone is retained for the quartz-hematite and quartz-magnetite bodies. As a rule, the iron oxide is hematite at the surface and magnetite below the water table, but some ironstones still carry significant amounts of magnetite even in the oxidized zone. The ironstones range from a few inches to more than forty feet in width and up to several hundred yards in length.

All the known occurrences lie within the Warramunga Group, and are localized by both structural and lithological controls. Structurally, intense deformation and proximity to porphyry intrusions are favourable features, and lithologically the typical shale-greywacke succession, and especially the vicinity of the hematite shale, appears to be more favourable than either the shale-siltstone succession in the northern part of the area or the arenaceous facies in the south-east.

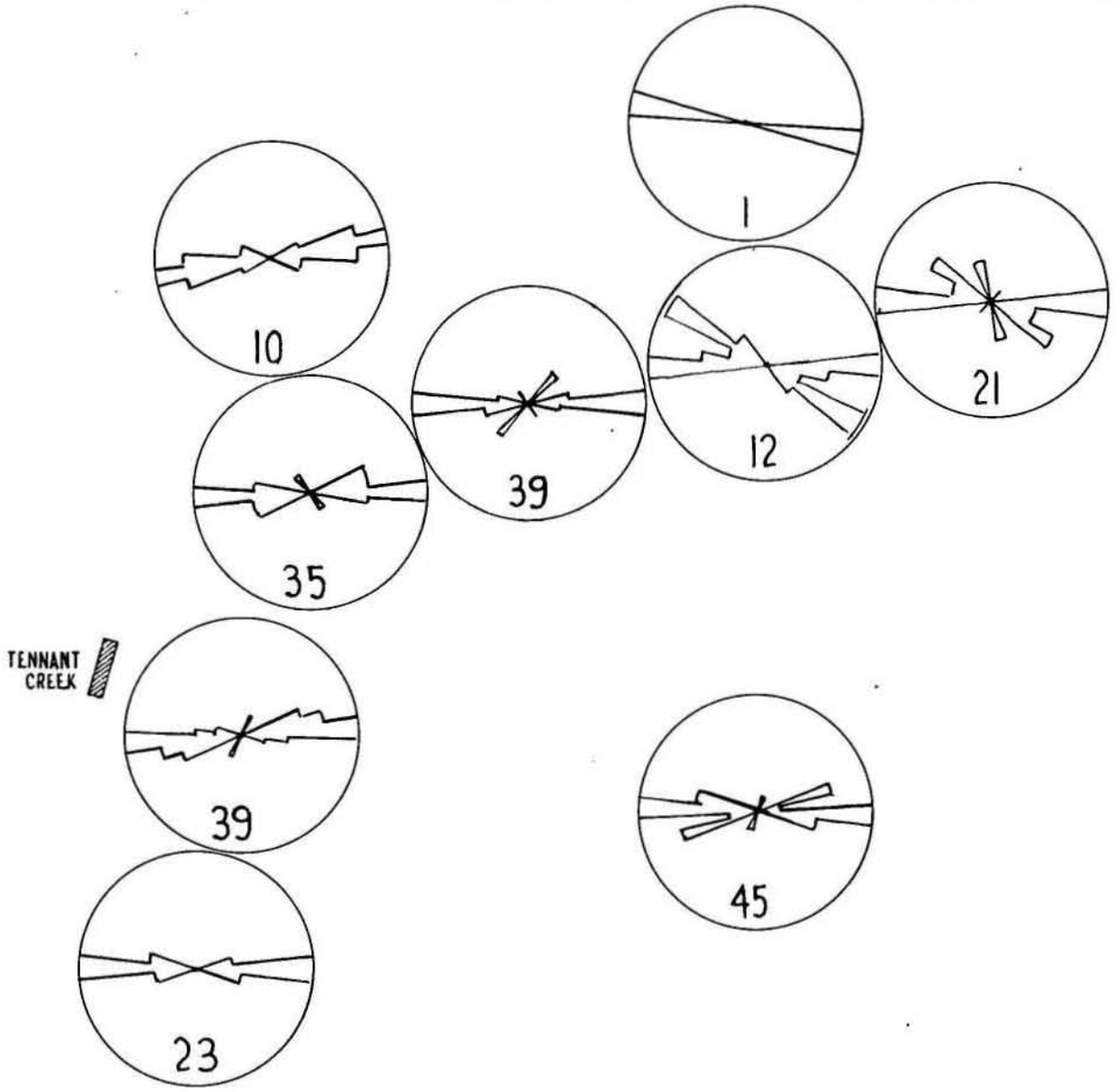
Most of the ironstones are tabular or lenticular bodies but some are irregular and one (at 2,540,000 north, 200,600 east) was found to be an inverted saddle reef. Another, about one mile north-west of the Momsahib Mine, is concordant with the surrounding sedimentary rocks, and has been traced through several gentle folds parallel to the bedding. This body is associated with a tabular transgressive ironstone in a major shear zone which may have acted as a feeder for the bedded deposit.

The most of the ironstones are elongated east - west, parallel to the regional strike of the bedding and cleavage and the accompanying set of strike faults and shears (Fig. 8). However, minor bodies striking about 070° are widespread, generally in association with a set of shear zones with that trend; strikes of 130°, parallel to the Quartz Hill/Rocky Range fault system, become important in the vicinity of the Lone Star Mine and in parts of the Honeymoon Ranges. A minor set of ironstones striking 040° is best developed in the vicinity of the Government Battery and in the Peko/Golden Forty area. The Peko orebody itself, which has the shape of a steeply plunging pipe, is exceptional and will be discussed in detail in a later section.

The ironstones can be sub-divided into three main groups according to their mode of occurrence.

1. Most occupy faults or shear zones, and many of them are localized at the intersections of these zones with favourable beds, such as the hematite shale. Occurrences of this type are thought to include most of the larger known bodies on the field, and they are obviously favoured by conditions in which the bedding and shearing of the sediments tend towards parallelism, i.e. in areas of steep dips. It does not follow however, that they are necessarily best developed in the largest shear zones. Good examples of ironstone bodies situated on major shear zones are provided among others by those at the Gigantic, New Hope, and Mary Lane Mines; but some of the largest bodies in the area, as at Eldorado and Mount Samuel, are associated with shears of only local significance. A pattern of right-hand echelon repetition tends to be developed under these

Fig. 8



Strike frequencies of ironstone from selected areas of the Tennant Creek 1-Mile Sheet

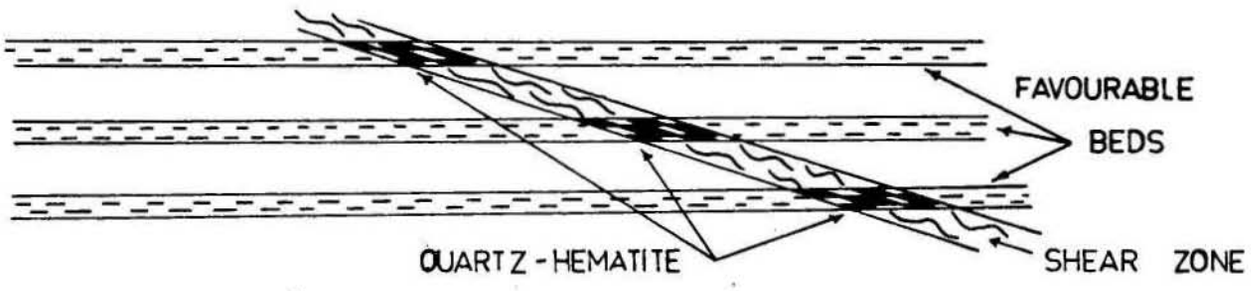
Note: Figures refer to numbers of observations incorporated in individual diagrams. Areas shown in Fig. 12.

Bureau of Mineral Resources, Geology and Geophysics. To accompany Record No. 1964/79

E53/A14/38

PLAN

Fig. 9



Diagrammatic relationship of ironstones to shear zones and favourable beds

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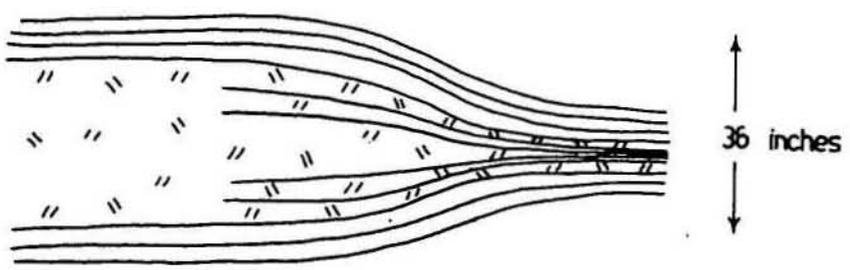
SECTION

Fig. 10



Relationship of small ironstone lode to bedding of Warramunga sediments, East Peko area

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E53/A14/40

circumstances, as many of the shears responsible for this type of intersection strike east-south-east, compared to a general east-west strike for the bedding (Fig. 9).

2. Ironstones of the second group, some approaching jasper in composition, are replacements of unsheared or only slightly sheared favourable beds, of which the hematite shale is again the outstanding example. The lodes at Metallic Hill and the Golden Mile are of this type.

3. The third group is developed at the margins of some of the larger porphyry intrusions, especially at concordant contacts. These lodes also tend to be jaspery and conform closely to the bedding of the host rocks. The best examples of this type are the ironstones near the Jubilee Mine.

There are transitions between the various groups, but the major divisions are quite clearly defined.

Differential replacement of very thin laminae of the country rock is comparitively rare. A good example occurs at 2,543,100 north, 193,800 east, where certain laminae of a minor drag-fold have been selectively replaced. This ironstone passes along the strike, into a massive quartz-hematite body occupying a shear zone.

The quartz-hematite bodies have not only replaced the pre-existing sediments volume for volume, but have also pushed them apart bodily as is well shown by a small exposure at 2,527,100 north, 205,300 east, where the banding of the sediments can be traced into and around a small quartz-hematite lens (Fig. 10).

Many of the quartz-hematite bodies are themselves sheared or faulted by major movements that affected the area after they were emplaced. Almost all mines have encountered such faults in their workings, the largest having displacements of a hundred feet or more, and a number of others became apparent during the regional mapping, e.g. near the Ace High, Kathleen, and Plain Jane Mines.

The proportion of quartz to iron oxides (hematite and/or magnetite) varies widely, even within a single ironstone, and many of the lodes are themselves cut by younger quartz veins free from iron oxides. In general, the long narrow bodies, which follow the bedding closely, tend to carry less quartz than the more lenticular bodies associated with shear zones. The two types are well contrasted in the Queen of Sheba Mine, about 20 miles north of Tennant Creek township, where the quartz-rich phase appears to be the younger of the two.

Mineragraphic evidence indicates that the hematite of these lodes is derived from magnetite, but the degree of oxidation varies considerably, and some magnetite is preserved even at the surface. Many grains of iron oxide show the crystal form of magnetite and are attracted to a hand magnet, but give a hematite streak.

Theoretically, magnetite can be oxidized to hematite either by hydrothermal or by supergene solutions. In this area, the evidence of

magnetometer surveys, deep drilling, and mine development all indicates a very abrupt increase in the hematite content of the ironstone above water level, showing that supergene solutions have been responsible for at least a large proportion of the hematite. On the other hand, the presence of bladed hematite intergrown with quartz, talc, and chlorite in many of the ironstones indicates that hydrothermal effects have also played a part. The relative importance of the two factors thus have to be evaluated for each occurrence.

Relative proportions of Iron in Lodes and in Country Rock. A very rough estimate indicates that ironstone lodes and lenses occupy areas of the order of 10,000 to 50,000 square feet per square mile in various parts of the Tennant Creek field. This is equivalent to about 0.04 to 0.20 percent of the country rock by volume or 0.08 to 0.40 per cent by weight. If the disseminated iron oxides contained in some of the major shear zones are included, this figure might have to be increased by a factor of two or three, but would even then be no more than 0.2 to 1.0 percent by weight.

On the other hand, a number of specimens of Warramunga rocks from the Eldorado, West Peko, and Lone Star areas were found to contain from about 0.5 percent iron oxides in sandstones, more than 1.0 percent in shales, and, as much as 20 percent in some of the hematite shale bands. The total quantity of iron oxide present in the country rocks is therefore likely to be comparable to or even in excess of that occurring in the defined lodes and heavily impregnated shear zones. Therefore much of the iron in the reefs could have been derived by lateral secretion from the adjacent sediments. Or it could have been derived from sediments caught up in the igneous complexes.

Relation of Ironstone Bodies to Hematite Shale Beds. The close association of many ironstone bodies with the hematite shale marker horizon has already been referred to. Apart from the extreme examples in which the hematite shale has itself been replaced to give jaspery ironstone lenses, there is a very marked concentration of ironstone bodies in the immediate vicinity of the hematite shale in several areas. The outstanding example is provided by the Mount Samuel/Outlaw/Enterprise/Eldorado line, but good examples also occur in the vicinity of the Gibbet, Wheal Doria, Burnt Shirt, Lone Star, Memsahib, and Mammoth Mines, and, outside the limits of the One-mile area, at the Northern Star Mine.

This persistent association could be due either to the fact that the hematite shale and the immediately adjoining beds, being originally rich in iron, provided the source of the iron which was concentrated into these ironstones, or that, by reason of their composition or physical characteristics, these beds were especially favourable for replacement from bearing iron and silica solutions.

In order to gain some further information on these relationships, concentrates of iron oxides from three ironstone lodes and three specimens of hematite shale were spectrochemically analysed by A.D.Haldane

of the Bureau of Mineral Resources Laboratory. All the specimens were collected from surface outcrops, so that the effects of surface leaching should be comparable. The samples of iron oxide from the hematite shale specimens were obtained by concentration on a superpanner. Specimen 4545 contained only hematite pseudomorphs after magnetite octahedra; specimen 97935 contained only crenulated layers of hematite; whereas specimen 196410 contained both octahedra and layers. Of the ironstone samples, specimens 52 A and 52 B were taken from the Mount Samuel Lode, and specimen 149419 was taken from the Skipper Hill Lode. The latter lode contained drusy cavities lined with high-temperature bi-pyramidal quartz and micaceous hematite.

As can be seen from the attached table, the magnetite octahedra and the hematite layers in the hematite shale contain the same trace elements, but these differ markedly from those of the ironstone lodes. The Hematite shale contains Cr, Mn, V, Ba, and Ag, whereas the ironstone lodes contain Bi, W, Ge, and Mo. The bismuth and tungsten content of the lodes is especially significant, as they are regarded as typical ephithermal elements and no trace of them was found in the hematite shale.

Spectrochemical Analyses

Spec. 52 A Ironstone, Mount Samuel.
52 B Ironstone, Mount Samuel.
149419 Ironstone, Skipper Hill.
4545 Hematite Shale with magnetite octahedra.
97935 Hematite Shale with hematite layers.
196410 Hematite Shale with both octahedra and layers.

Fe, Al, Si and Ti were present in all samples.

	Ironstone Lodes			Hematite Shale		
	52 A	52 B	149419	4545	97935	196410
K	3	2	3	5	4	3
Ca	4	4	5	4	4	4
Sr	0	0	2	1	1	0
Ba	0	0	0	3	0	0
Ag	0	0	0	3	0	0
Cu	6	7	6	7	6	5
Pb	2	2	2	3	4	2
Sn	3	4	1	3	1	2
Bi	3	5	0	0	0	0
In	2	0	2	0	2	1
Cr	0	0	0	5	3	4
V	0	1	3	2	2	3
Mn	0	0	0	2	7	2
Co	0	1	0	1	1	1
Ni	1	2	2	2	3	2
W	4	1	3	0	0	0
Mo	5	5	4	2	1	2
Ge	1	1	0	0	0	0

Distinctive Elements :

Bi, W, Ge, Mo. Cr, Mn, V, (Ba, Ag).

The numbers indicate the relative proportions of the given elements in the six samples, but are not comparable between the elements.

These results therefore indicate important differences between the iron oxides in the hematite shale and those in the ironstone lodes. The iron oxides in the hematite shale are most probably syngenetic, and the magnetite octahedra in this rock were apparently formed by redistribution of the primary iron oxides in the shale during a period of mild metamorphism. On the other hand, the iron oxides in the ironstone lodes are probably epigenetic and must have been introduced into the Warramunga rocks, possibly by solutions emanating from the porphyry intrusions. If they had been merely redistributed on a large scale by solutions percolating through the country rock and picking up iron already present in these rocks, it would be necessary to assume that these solutions carried sufficient bismuth, tungsten, and other trace elements to account for the present occurrences of these elements in the lodes, and this is regarded as unlikely.

Jasper Beds and Breccias

The jasper beds and breccias are replacement bodies, similar in many ways to the ironstones, but composed mainly or entirely of cryptocrystalline silica, generally coloured red by minor amounts of iron oxides. Many are closely associated with the 'jaspery' types of ironstone described in an earlier section, and they are best developed in the vicinity of the Aerodrome, near the Jubilee Mine, at East Peko, at Metallic Hill, and at the Golden Mile. With the exception of the two last-named localities, they generally occur within a few hundred feet of one or other of the larger porphyry bodies. Their dimensions are comparable with those of the ironstones, and many of them contain minor coatings of hematite on joint planes. These jaspers, therefore, are formed by silicification of favourable beds and shear zones in the Warramunga rocks by solutions emanating from the porphyries, and the ironstone bodies by similar replacements by more iron-rich solutions, generally at greater distances from the porphyry contacts. Inclusions of jasper fragments in quartz-hematite lodes indicate that the jaspers were the earlier formed of the two.

The jasper breccias consist essentially of angular fragments of jasper re-cemented by white vein quartz. This shows that the emplacement of these jaspers was followed by a second phase of deformation, which resulted in the shattering of some of them, and by a second period of silica introduction, this time as vein quartz.

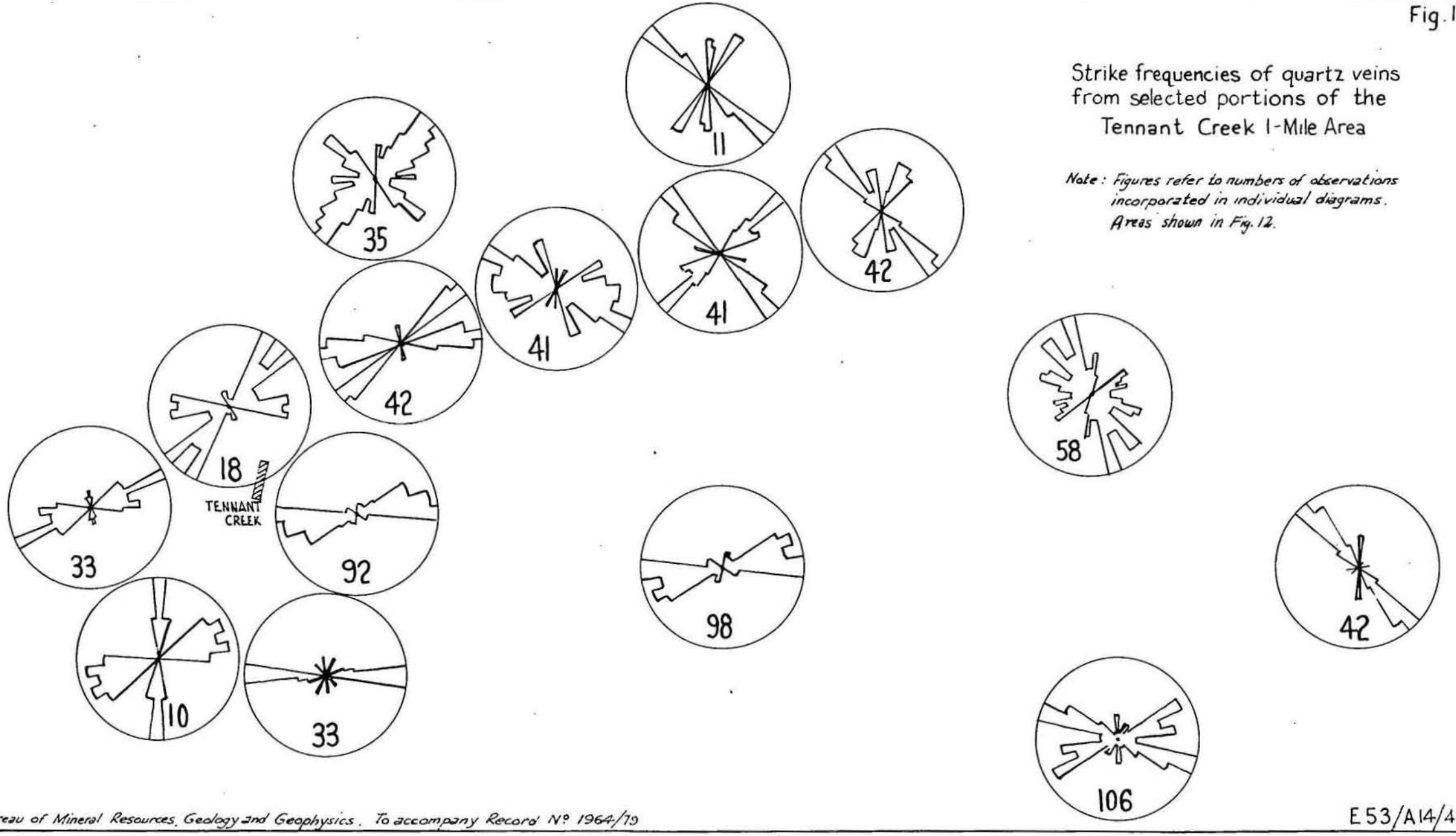
Quartz Veins

Quartz veins with only subordinate amounts of iron oxides occur in all rocks older than the Helen Springs Volcanics, including the ironstone lodes, the jasper bodies, the porphyry and adamellite intrusions, the Ashburton Sandstone, and the Rising Sun Formation. The veins are

Fig. 11

Strike frequencies of quartz veins from selected portions of the Tennant Creek 1-Mile Area

Note: Figures refer to numbers of observations incorporated in individual diagrams. Areas shown in Fig. 12.



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most probably of several different ages, but except in the case of veins cutting the Rising Sun Formation, it is not possible to distinguish the various groups.

The veins range in size from mere stringers, a fraction of an inch in width, to massive bodies up to thirty or forty feet wide and intermittently traceable for many miles, as in the Quartz Hill/Rocky Range fault zone. Most of the larger veins have been emplaced in shear zones, and something of their distribution has already been said in the section on shearing.

Taking the One-mile area as a whole, north-westerly trends, parallel to the Quartz Hill/Rocky Range fault zone, and north-easterly trends, parallel to the conjugate set of shears, account for the majority of the larger veins (Fig. 11). However, there is an important set striking at 090° in the central portion of the area, as for example in the Honeymoon Ranges and in the vicinity of Eldorado and the Government Battery. Minor sets striking at 340° and 020° can also be found in some areas.

A number of quartz veins in the Mount Rugged and Gibbet areas contain minor amounts of tourmaline, but generally they are singularly free from associated minerals.

The only locality within the One-mile area where gold has been found associated with quartz veins is at the Pup Prospect, about half a mile south of the Pinnacles Mine. At this prospect, a series of small auriferous quartz veins occurs in the marginal portion of a small porphyry stock and in the adjoining Warramunga rocks, but the total production from this locality only amounts to 40 ounces.

GOLD DEPOSITS

The workable gold deposits of the Tennant Creek field occur in a variety of structural and lithological environments, ranging from massive quartz-hematite and quartz-magnetite lodes to brecciated zones in sediments, generally mudstones, which may carry only minor amounts of iron oxides. Only two gold occurrences, at the Pup Mine and in the Last Hope area, 30 miles north-west of Tennant Creek township, are associated with quartz veins free from significant amounts of iron oxides.

Most of the individual mines and prospects of the field have been described in detail by Ivanac (1954) and these descriptions will not be duplicated here. Since the completion of Ivanac's survey, only two important new discoveries of gold have been made on the field. These are in the Orlando/One-Oh-One area, mentioned in an earlier section, and at Ivanhoe in the north-western portion of the One-mile area. Orlando Mines (a subsidiary of Peko-Wallsend Co. Ltd) started production late in 1962 at a rate of 100 tons per day.

The Orlando orebody was originally indicated by five diamond drill hole intersections, obtained by Peko Mines N.L., which gave assays of up to 26 dwt of gold over inclined widths of up to 22 feet. The

published reserves at the end of June 1963 amounted to 230,000 tons of ore averaging 1.2% copper and 11.7 dwt of gold per ton. Because of the exceptional depth of oxidation of this lode - more than 500 feet - there is so far little information on the composition of the primary ore, and it is possible that this prospect should be classed with the sulphide orebodies rather than the gold deposits.

The Ivanhoe occurrence is dominantly a copper orebody and is described more fully in a subsequent section.

Possibility of Secondary Enrichment

It seems likely that all the gold deposits of the Tennant Creek field were originally associated with some sulphides, for pyrite and minor chalcopyrite have been encountered in practically all mines where development or drilling have been carried out below water level.

As there is little/in the oxidized portions of these mines, copper material must have been redistributed by supergene solutions and it is at least possible that the gold may also have undergone some redistribution and secondary enrichment. This possibility is strengthened by the fact that some of the richest shoots at several mines, e.g., Enterprise, Whippet, and Nobles Nob, appear to lie at depths between 120 and 250 feet, and that this distribution cannot always be accounted for by structural and lithological factors. It is also supported by the reported occurrence of flaky gold and occasional nuggets within the oxidized zone of several mines, but not below it (Ivanac, 1954, p.54).

For this reason, it appears that the factors responsible for the distribution of gold in relatively shallow workings may be controls of enrichment rather than of original deposition; this applies especially to the ore-shoots in the brecciated sediments immediately adjoining some ironstone bodies and in shear zones and pug seams intersecting the ironstones themselves.

For the same reason, testing of new prospects on this field should always be taken to a depth of at least 200 to 250 feet in order to intersect such a zone of enrichment if it exists.

Relationship of Gold Occurrences to Hematite Shale

If the distribution of gold mines in the Tennant Creek One-mile area is examined statistically, a number of general trends become apparent. The most obvious is the marked concentration of highly productive mines in or close to the hematite shale horizon:

	Total	Within 1000 feet of nearest hematite shale outcrop	Per cent
Area of Warramunga Group rocks exposed in Tennant Creek One-mile area	Approx. 100 sq. miles	Approx. 10 sq. miles	10%
Number of ironstone bodies mapped in present survey	700	130	18%

N	Total	Within 1000 feet of nearest hematite shale outcrop	Per cent
Number of mines with total production of :			
1 to 100 ozs.	26	8	30%
100 to 1000 ozs.	27	11	41%
1000 to 10,000 ozs.	11	7	64%
Over 10,000 ozs.	4	3	75%

By contrast, ironstones developed in major shear zones, such as the Mary Lane, Mary Ann, Gigantic, and New Hope, have rarely been large producers, although the complex gold - sulphide shoots of Orlando and Ivanhoe may prove to be exceptions to this rule.

Ironstones along the margins of concordant porphyry intrusions, as to the west of the Jubilee Mine and to the south-west of the New Hope Mine, have produced little gold to date.

SULPHIDE DEPOSITS

With the emergence of Peko as the largest mine on the field, interest in exploration for copper is now equalling or surpassing that for gold. Since none of the other mines have so far exposed any massive sulphide ore, it is difficult to generalize on the factors responsible for the localization of such ore. However, a greater variety of environments appears to be represented, with major shear zones as the most important single control.

At Peko, massive sulphides, essentially pyrite, pyrrhotite, and chalcopyrite, replace the central portion of a quartz-magnetite pipe (Edwards, 1955). This quartz-magnetite differs in shape from the typical tabular bodies on the field and J. Elliston (1960) has suggested that it is due to the replacement of an original slump conglomerate, similar to that mapped as a 'pebble bed' from the vicinity of the Caroline Mine. However, the type pebble bed has a fine-grained impervious matrix, and does not appear intrinsically favourable for replacement. An alternative controlling influence on the Peko orebody could be the intersection of a steeply dipping north-east-trending shear zone with a zone of favourable beds or a shear zone sub-parallel to the bedding, which here trends roughly east - west. The sedimentary rocks adjoining the orebody are reported by Elliston to show only moderate disturbance, but the presence of chlorite schist on the 980-foot level suggests fairly intense shearing. The presence of two sets of linear structures is strongly suggested by the pattern of the aeromagnetic contours and the air photographs of this area, and it seems likely that the north-east-trending set represents an extension and possible branching of the major shear zone delineated by diamond drilling in the Cabbage Gum Basin (Hays, 1958; Crohn, 1961).

Low-grade lead and zinc sulphide mineralization is recorded

from the footwall sediments of the Peko copper orebody (Edwards, 1955), but little is so far known about its extent and relationship to structural or lithological controls.

At the time of writing (1963) the ore reserves at Peko are reported to amount to 645,000 tons of proved ore, averaging 5.3 percent copper, and 136,000 tons of indicated ore, averaging 3.2 percent copper.

At Orlando, 9.1 percent copper has been recorded between 348 and 353 feet inclined depth in Peko diamond drill hole No. 3 (Chem. Engng Min. Review, November 1958), and further evidence for the formerly widespread occurrence of sulphides has been provided by development work to a depth of more than 600 feet. However, owing to the quite abnormal depth of oxidation, the original distribution of sulphide minerals at this mine has not yet been fully determined. At the time of writing, 230,000 tons of ore, averaging 1.2 percent copper and 11.7 dwt of gold per ton, have been proved.

At Ivanhoe, some ten miles north-west of Tennant Creek township, another promising copper - gold orebody has recently been located by Peko Mines N.L. This is situated near the projected intersection of the Mary Lane/Mary Ann shear zone with a north-east-trending quartz-filled shear, and is reported to have proved reserves to date of 240,000 tons of ore, averaging 5 percent copper and 4 dwt of gold per ton.

At several other mines and prospects, disseminated sulphides have been recorded from diamond drill holes in sheared or brecciated sediments, associated with varying amounts of quartz and hematite or magnetite. The most important of these occurrences are as follows :

Northern Star : 4.05 percent copper as chalcopyrite between 967 and 977 feet in a vertical diamond drill hole put down by Peko Mines N.L. (Chem. Engng Min. Review, June 1957).

Wheal Doria : Disseminated sulphides with hematite and magnetite in chloritic slate between 157 and 170 feet in hole No.4, and between 167 and 183 feet in hole No.4 A, both vertical (A.G.G.S.N.A. Report, N.T., NO.41).

Eldorado No.3 Anomaly : Five assays averaging 0.48 percent copper in sheared rocks with quartz and magnetite between 413 and 452 feet vertical depth in hole No.2 (A.G.G.S.N.A. Report, N.T., No.41).

Peko No.2 Anomaly (East Peko) : Specks of sulphides in slate and dense magnetite between 264 and 280 feet vertical depth in hole No.5 (A.G.G.S.N.A. Report, N.T., No.41).

Nobles Nob : Minor amounts of pyrite and chalcopyrite in quartz-hematite and brecciated sediments between 268 and 278 feet and between 321 and 331 feet inclined depth in hole No.2, Bureau of Mineral Resources (Ivanac, 1954).

Golden Forty area : Average assay of 1.5 percent copper over 41 feet of chlorite schist in diamond drill hole put down by National Lead Co. of U.S.A. (personal communication, R.D. Ellett, quoted by McMillan & Debnam, 1961).

Some encouraging values have also been obtained in recent drilling at the Lone Star, Cat's Whiskers, and Golden Forty North prospects - the latter also known as the Golden Kangaroo. These are described more fully in subsequent sections.

In addition, secondary copper minerals have been worked in sheared and brecciated sediments at the Pinnacles and Shamrock Mines but none of the workings encountered primary ore. A diamond drilling programme at the Pinnacles was recently undertaken by the Mines Branch, N.T. Administration, but this failed to find any downward extension of the lode exposed in the old workings.

At the Aerodrome, a few specks of sulphide (pyrite and chalcopyrite) were found in massive quartz-feldspar porphyry. At several other localities, notably about three quarters of a mile south of the Pinnacles Mine, and to the east of the New Hope Mine, the weathered porphyry contains cavities partly filled with limonite, which are regarded, at least in part, as box-works due to the leaching of sulphide minerals.

On the other hand, the boxworks are similar in shape and size to the feldspar phenocrysts in the porphyries. They are partly filled with clay minerals and contain limonite networks which resemble the cleavage patterns of the feldspars (Plate VIII b). Thus the boxworks could be weathered out feldspars. The anomalously high concentrations of copper in some of the boxworks could be due to the adsorption, by the clay minerals, of copper from groundwater percolating through the porphyry.

In the Pinnacles area, spectrographic analyses of limonite from two porphyry specimens confirmed the presence of above-background amounts of copper (of the order of 150 parts per million), but a diamond drill hole put down to an inclined depth of 300 feet in this area by the Mines Branch, N.T. Administration, failed to locate any sulphides.

In the New Hope area, eight porphyry specimens showing structures which had been tentatively identified as boxworks only contained 10 to 30 parts per million copper. These results are regarded as inconclusive, as too little is known at present about the leaching processes to which these rocks have been subjected, and some further work is thought to be warranted in order to determine whether a systematic geochemical testing programme is capable of delineating areas which may warrant more detailed examination by geophysical resistivity of self-potential methods and by diamond drilling.

If the presence of significant amounts of copper in the porphyries could be confirmed, this would support the suggestion that the copper now occurring in the ironstones and Warramunga sediments was also derived from the porphyries in the first instance. This raises the question of the relationship of the gold and sulphide-bearing solutions to those responsible for the emplacement of the ironstones. At Peko, mineragraphic evidence indicates that the emplacement of the ironstone was essentially complete before the introduction of the gold and sulphides (Edwards, 1955).

In areas of disseminated magnetite - sulphide occurrences, as at Wheal Doria and Eldorado No. 3 Anomaly, relationship are not so clear-cut, but it appears improbable that solutions should be capable of simultaneously depositing significant quantities of iron oxides and sulphides.

If the two phases of activity were distinct, it follows that the present occurrence of gold and sulphides in close association with ironstone is not necessarily universal, being due only to the fact that the same channels generally tended to control the flow of both sets of solutions. Numerous ironstones are known which do not carry gold or sulphides, and recent exploration has revealed gold and sulphide deposits which are not closely associated with ironstone. The Orlando prospect appears to be an example of such a deposit, and the intersection of 41 feet of chlorite schist, carrying an average of 1.5 percent copper with only minor amounts of iron oxides, in a diamond drill hole at the Golden Forty Mine (McMillan & Debnam, 1961), is another.

The secondary copper minerals at the Shamrock and Pinnacles Mines, and the Eureka prospect, near the Iris Mine, may also be derived from such bodies. In general, shear zones not carrying significant amounts of iron oxides are likely to be soft structures, whose outcrops are easily obscured, and which will thus escape attention unless copper concentrations at the surface give obvious indications of mineralization. Geochemical and geophysical methods, such as resistivity and self-potential surveys, may be of value in detecting and tracing such shear zones carrying sulphides at depth.

The known copper deposits of the Tennant Creek Field thus appear to be developed in a greater variety of environmental conditions than the gold occurrences.

Copper occurs in some of the ironstone bodies close to the hematite shale, e.g., North Star, Lone Star and Cat's Whiskers, and in a shear zone close to the hematite shale at the Eureka Mine. However, the hematite shale has not been found near Peko - the most important copper mine. The hematite-gold-copper orebody at Peko is thought to be related to the intersection of major shear zones; and this is thought to be the case at the Ivanhoe prospect also.

Four other copper lodes, Golden Forty, Golden Forty North, Pinnacles, and Shamrock, are also associated with shear zones, but not with defined ironstone bodies, although in at least one of them, Golden Forty, the mineralization is concentrated in a magnetite-chlorite-talc schist which carries sufficient magnetite to give rise to quite strong magnetic anomalies. These prospects are also situated at some distance from any known outcrops of hematite shale. The Orlando Mine is also tentatively included in this group.

MINERALS OTHER THAN COPPER AND GOLD

Apart from copper, gold, and by-product silver, the only mineral of value on the Tennant Creek field is bismuth. At the Jubilee Mine,

several hundred tons of material containing between one and two percent bismuth are believed to be available, and a small plant has recently been set up by a local syndicate to recover this metal, which occurs mainly as the oxide and carbonate. Bismuth has been recorded from the Peko, Noble's Nob, Enterprise, Lone Star, Joker, and many other mines, but in most of these the distribution of bismuth minerals was very irregular and the average grade was very low. A major programme of sampling existing tailings dumps for their bismuth content has recently been proposed as a joint undertaking by the Bureau of Mineral Resources, the Australian Mineral Development Laboratories, the Mines Branch of the Northern Territory Administration, and the major operating companies on the field.

The total quantity of iron present in the known ironstone bodies of the field is estimated to be some tens of millions of tons, but owing to the isolation of the field, the scattered distribution of the ironstones, and the variation in grade, this is not likely to be an economic source of iron ore in the foreseeable future.

MAGNETIC ANOMALIES

On the aerial magnetic map of the Tennant Creek One-mile area, a pattern of regional anomalies with east-south-easterly trends is combined with local anomalies due to individual ironstone bodies. These east-south-easterly trends, striking at about 105°, are inclined at acute angles both to the regional trend of the bedding and to the most prominent faults of the area, such as the Quartz Hill/Rocky Range fault zone, but they appear to be parallel to a slightly less obvious system of shears, of which the Mary Lane/Mary Ann zone, with its probable extensions through the Ivanhoe prospect to the west and the Lone Star Mine to the east, is the most prominent example.

A second set of anomalies, striking at about 30°, and probably also related to faults or shear zones, is present in several areas, notably in the vicinity of the Peko and Golden Forty Mines.

It is possible, though highly conjectural, that this pattern reflects major structural features in a pre-Warramunga basement. This possibility is supported by a gravity traverse carried out by the Bureau of Mineral Resources along the Stuart Highway in 1960, which indicated that there is a close agreement between regional gravity and magnetic profiles, and that at least some of the gravity anomalies might be ascribed to bodies situated at depths of more than 5000 feet below the present surface (J. Ashley, Bureau of Mineral Resources, Darwin, personal communication). However, considerable additional work would be required to establish this conclusively.

Areas of low magnetic relief, as at White Hill, Station Hill, the Aerodrome, and between Peko and Eldorado, correspond to areas where igneous rocks cropcut at the surface or are believed to underlie it at relatively shallow depth.

A very sharp break in the pattern is apparent at the line of the Quartz Hill/Rocky Range fault zone. To the north-east of this line,

magnetic relief is very low, although outcrops of Warramunga sediments, complete with ironstones, etc., persist, especially in the New Moon and Golden Mile areas. However, folding in this area is more open and shearing less severe than in the area west of the fault zone, so that conditions are less favourable for the development of large ironstone bodies, as pointed out in a previous section. It is probably significant that the only pronounced anomaly in this eastern area is associated with the Gigantic group of ironstones, which are emplaced in a major shear zone.

Of the anomalies due to individual ironstones, only the larger ones, such as the Peko, Golden Forty, and Eldorado No.1, are obvious on the aerial map, and some of these, such as Golden Forty, have been divided into several smaller anomalies by ground surveys.

Ground magnetic surveys by A.G.G.S.N.A., the Bureau of Mineral Resources, and private companies have now covered a very large proportion of the areas on the field where potential gold or base metal lodes might be expected, and more than fifty separate anomalies are now known. Of these, many are related to outcropping ironstone bodies, but others show no relationship to any outcropping features.

There are at present no reliable criteria for distinguishing anomalies due to non-outcropping gold or copper-bearing quartz-magnetite lodes from those due to barren ironstones. The only orebody which is adequately exposed in the primary zone (Peko) is not typical of the ironstone bodies of the field in that it has a pipe-like rather than a tabular shape. Disregarding the question of whether this is due to tectonic factors, such as the intersection of two shear zones, or to the shape of the original sedimentary unit now replaced by the ore body, it may be that the shape of the original quartz-magnetite body was an essential factor in determining its subsequent replacement by the gold - sulphide mineral association. In this case, prospecting on this field would be reduced to the search for similar steeply pitching pipe-like bodies. However, it is more likely that the shape of the ironstone body was not a critical factor, in which case the chances of finding significant gold - sulphide mineralization in any quartz-magnetite body are about the same as those of finding payable shoots of copper or gold in the corresponding quartz-hematite surface outcrops after allowing for leaching and secondary enrichment, and the average size of ore-shoots at depth would be expected to be of the same order as those on the surface.

Within the area of the One-mile sheet, about 700 lenses of ironstone were encountered, of which 68 or about ten percent have been recorded as producing some gold. Of these, four percent produced less than 100 oz., four percent between 100 and 1,000 oz., 1.6 percent between 1,000 and 10,000 oz., and only four, i.e. 0.5 percent have produced more than 10,000 oz. Only one mine, Peko, has been a significant copper producer. For exploration at depth to be warranted, other criteria than the mere presence of a magnetic anomaly must therefore be satisfied. Criteria which could be used are: large size of the postulated ironstone body responsible for

the anomaly, favourable geochemical indications, or proximity to known productive lodes.

On purely empirical grounds, anomalies situated in the vicinity of intersecting regional magnetic trends, as shown by the aerial magnetic map, appear to be favourable targets. Peko, Orlando, and Ivanhoe all conform to this pattern, and similar conditions appear to be present in the Golden Forty, Red Bluff, Skipper, and New Hope areas.

GEOCHEMICAL SURVEYS

A geochemical prospecting campaign for copper was carried out by a Bureau of Mineral Resources party under J. McMillan in 1957 (McMillan & Debnam, 1961). Essentially this consisted of the analysis of numerous surface and near-surface samples, both of soil and of bed-rock, for trace amounts of copper. A concentration of 10 parts per million of copper in sediments and 30 parts per million in ironstones was regarded as background for the area, and concentrations of more than twice background were thought to indicate the presence of copper mineralization in the vicinity of the sample.

Such anomalously high concentrations could be due either to residual copper remaining in an originally mineralized rock after oxidation and partial leaching, or to copper derived from nearby mineralized formations by circulating ground waters. The search for the source of these copper concentrations would thus have to be guided by geological considerations.

The three main areas in which this geochemical survey indicated the presence of significant amounts of copper were Orlando, Cat's Whiskers, and Golden Forty North (Golden Kangaroo), all of which have already been referred to in the section on sulphide deposits. Some high copper values were also encountered near the Queen of Sheba Mine, but two diamond drill holes put down in this area by Consolidated Gold Mining Areas N.L. in 1960 gave disappointing results.

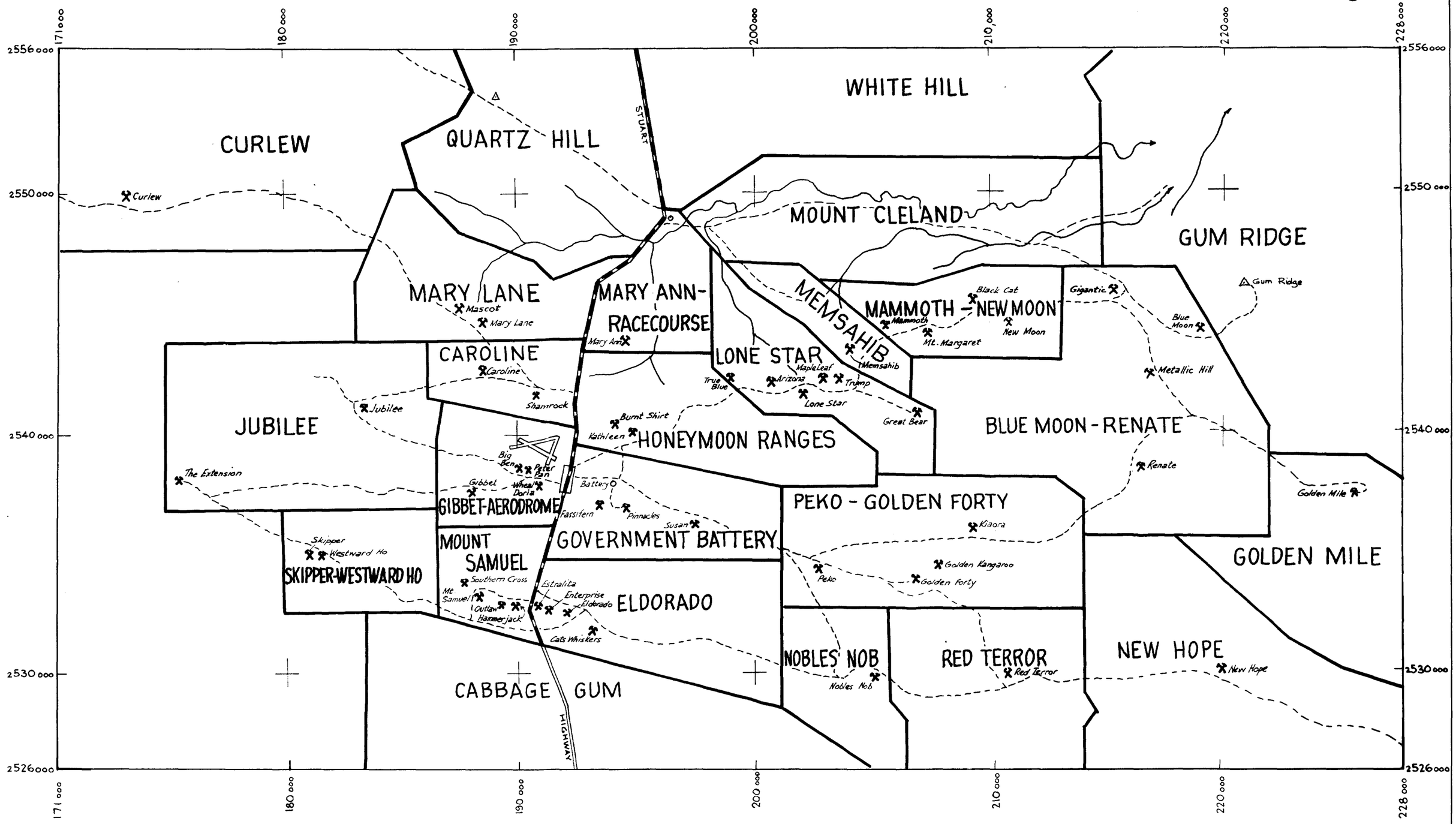
More recently, the Bureau has carried out some further surveys, based on spectrographic analyses of samples obtained from depths of 20 to 40 feet by the use of a power auger, and several areas of abnormal copper concentrations have been outlined by this work (P.G. Dunn, Bureau of Mineral Resources, unpublished report, 1963).

At two of these localities - Mary Lane "B" and Golden Forty - diamond drilling programmes to follow up these favourable indications are about to be undertaken at the time of writing.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER PROSPECTING

Gold and copper orebodies occur at Tennant Creek in close association with tabular and pipe-like quartz-hematite and quartz-magnetite bodies and in major shear zones cutting through rocks of the Warramunga Group. Among mines associated with the ironstones, the major gold producers appear to be restricted to the vicinity of the hematite shale marker bed (Eldorado, Noble's Nob, Lone Star, Whippet, Northern Star, etc), but the major copper producers appear to be at the intersections of major

Fig. 12



Subdivisions of Tennant Creek 1-Mile Area used in regional geological descriptions

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shear zones (Peko, Ivanhoe). To date only one major producing mine has worked an ore-shoot emplaced in a major shear zone away from defined ironstone bodies (Orlando), but there are a number of prospects in comparable settings (Golden Forty, Golden Forty North, Pinnacles, Shamrock, Mary Lane), and some of these still require testing.

For future exploration, the drilling of magnetic anomalies, especially anomalies situated at the intersections of major structural features, will undoubtedly remain one of the major programmes for some years to come. However, as the number of targets of this type is limited, it is expected that increasing attention will have to be given to deposits not associated with major ironstone bodies, such as disseminated mineralization in major shear zones. It is expected that geophysical methods, other than magnetic, and geochemical surveys will play increasingly important parts in those prospecting programmes.

A major semi-regional investigation, combining geological, geophysical and geochemical surveys, is planned by the Bureau during 1964 over an area known as the 'Aeromagnetic Ridge', north of Peko Mine, and it is hoped that the results of this investigation will lead to the development of more generally applicable prospecting procedures for the Tennant Creek Field.

DETAILED GEOLOGY OF INDIVIDUAL AREAS

For descriptive purposes, the area has been divided into twenty five sub-areas, based largely on continuity of outcrop and named after prominent mines or natural features. An attempt has been made to outline the outstanding characteristics of each sub-area, but in order to avoid unnecessary duplication, relationships which hold throughout the goldfield and which have already been referred to in the previous sections, will not be repeated. The order of discussion is based largely on convenience, so that areas with least specialized features are discussed before those with unusual relationships. The sub-division is shown on Fig. 12.

Honeymoon Ranges

The Honeymoon Ranges are a series of flat-topped hills rising up to 200 feet above the surrounding plains in the south-western part of the area.

The rocks are typical Warramunga shale and greywacke and rare grit, with dips averaging 60° to 70°. West of 197,000 east, the major structure is a west-pitching anticline with axis at about 2,541,000 north. East of 197,000 east, several other fold axes can be traced to the south of this main anticlinal structure, and the westerly pitches locally steepen to as much as 45°.

The hematite shale can be traced for about two miles on the southern limb and for over one mile on the northern limb of the main anticline, and a group of major north-south trending faults can be mapped by the displacement of this marker horizon. Other shear zones are dominantly sub-parallel to the strike of the bedding, but one major zone with a trend of about 110° has been traced with minor interruptions from 2,541,300 north,

196,300 east to 2,539,700 north, 201,000 east.

The area contains only minor occurrences of igneous rocks. Several dyke-like bodies of porphyry trend east in the vicinity of 2,541,500 north, 193,000 east. The largest of them covers an area of about 1000 by 200 feet. A very strongly sheared and weathered outcrop of porphyry also occurs about a quarter of a mile south of the Kathleen Mine, and a few smaller bodies have been noted in the eastern part of the area. A larger body is also thought to underlie much of the low-lying area south of the Kathleen Mine, but outcrops are very poor. Two small lamprophyres are known from the area, both apparently as flat-dipping sheets, not more than 20 feet thick.

Ironstones occur throughout the area, but the greatest concentration is found between 2,539,000 and 2,540,500 north and between 193,500 and 196,500 east, where two major east - west zones, about 1000 feet apart, each contain up to three sub-parallel ironstone lodes. Several lenses up to 200 by 20 feet occur in this group, and one at 2,540,300 north, 193,500 east is about 800 by 20 feet. The trends are dominantly east except near major transcurrent faults, as at the Ace High Mine. At 2,540,000 north, 200,500 east, an ironstone body with the shape of an inverted saddle reef was noted, apparently following the trend of a favourable bed.

In the southern foothills of the Honeymoon Ranges, a number of prominent jasper bars occur at 2,538,800 north, 195,000 east, and at 2,538,500 north, 196,100 east. They are probably associated with an extensive body of porphyry, as mentioned above, but this is only exposed at one point, about half-way between the two jasper localities.

Quartz veins are fairly uniformly scattered throughout the area, with trends of 080° to 090° and 030° to 040° about equally represented.

The only mines of any importance occur in the south-western part of the area, where the Burnt Shirt, Ace High and Kathleen Mines have recently been worked on a small scale. These are all in massive ironstone and have been worked for gold only; no sulphides have so far been encountered in any of the workings. The Burnt Shirt, with a total recorded production of 2340 oz. to June 1961, is the most important of this group. Recorded production of the Ace High is 100 oz. and of the Kathleen 1130 oz.

A magnetic anomaly of about 150 gammas has been located by the 1937 A.G.G.S.N.A. survey half-way between the Burnt Shirt and Ace High workings, and is interpreted by Daly (1957) as due to a magnetic body centred at a depth of at least 400 feet; the anomaly has not yet been tested.

Mary Ann/Racecourse Area

Bedrock is exposed over most of the southern part of this low-lying gently undulating area, which is regarded as a pediment into which the present creeks are incised to a depth varying from 2 to 20 feet. In the northern part of the area, outcrops are more intermittent amid extensive

deposits of bull-dust and alluvium.

The Warramunga sediments in the southern part of this area are generally similar to those of the Honeymoon Ranges, but there are considerable thicknesses of shale and fine-grained siltstone, free from any coarser-grained beds, to the north of the Mary Ann mine and close to the granite contact. These beds are the equivalents, at least in part, of the shale and siltstone at Mount Cleland, which will be described more fully in a later section. There are also a number of pebble-beds containing sub-angular fragments of greywacke and shale, indistinguishable in appearance from the normal Warramunga sediments, generally in a shaly matrix. These are regarded as deposits from small turbidity currents.

Dips are variable, with many minor fold axes trending east - west, commonly with gentle to moderate pitches either to the east or to the west. However, owing to the prevalence of incompetent beds in this part of the succession, these minor pitch changes do not necessarily reflect the major structural trends. In the vicinity of 2,543,500 north, 193,500 east minor folds pitching steeply down the limbs of the major structures indicate a second period of deformation under the action of differently oriented stresses.

Faulting and shearing are unevenly developed in the area. In the northern portion of the area, a system of major north-west-trending quartz reefs marks the position of part of the Quartz Hill/Rocky Range shear zone, which here consists of three main branches, up to half a mile apart. The Mary Ann mine itself is situated on another shear zone, and the line of quartz reefs and breccias passing about 100 yards north of this mine marks the course of another which trends about 100°, and has been followed intermittently for nearly one mile; it is thought to be part of an even larger structure extending to the vicinity of the Mary Lane mine in the west and the Lone Star mine in the east.

The northern part of the area is largely occupied by granitic rocks, which cropout intermittently over an area of about two by one miles, and are part of the Station Hill granite complex. Exposures generally are confined to the major creek beds, and the contact of this mass with the surrounding sediments is not well exposed. However, its north-eastern boundary is clearly faulted following one of the branches of the Quartz Hill/Rocky Range shear zone.

Contact metamorphism appears to have been slight, the main effect being a tendency to silicification of the sediments within about a quarter of a mile from the contact.

South of the main mass, a cluster of smaller bodies of igneous rocks, between 2,545,800 north, 194,000 east, and 2,546,500 north, 195,000 east, appears to be intermediate in petrological and structural characteristics between the granitic rocks and the typical porphyries, but exposures are too poor for detailed examination.

A number of normal porphyries have also been noted, especially

in the vicinity of 2,544,800 north, between 195,500 and 196,500 east. They are generally elongated parallel to the strike of the surrounding sediments and strongly sheared. Three occurrences of lamprophyre are also known, the largest occupying an area of about 300 by 50 feet, but all are too weathered for detailed petrological examination.

Only very minor ironstones are known from this area. Of these, the most interesting is that at 2,543,200 north, 193,800 east, where a massive ironstone lens passes along the strike into a zone in which individual laminae of the country rock have been selectively replaced by iron oxides.

Quartz veins are common, the two most prominent groups being those associated with the Quartz Hill/Rocky Range shear zone, and those following the west-north-west shear zone just north of the Mary Ann mine. However, there is also a very strong set striking 030° to 040° which shows its maximum development in the south-western part of the area.

The Mary Ann is the only mine which has been worked in this area. It is situated on an iron-impregnated shear zone trending 100°, and is recorded as having produced 180 oz. of gold.

Government Battery Area

The best exposures in this area are found in a line of flat-topped hills which extends for about two miles to the east-south-east of the Battery, and in a less regular group of hills between the Pinnacles, Pup and Southern Star mines, about one mile south-west of the Battery.

The Warramunga sediments of this area are generally similar to those of the Honeymoon Ranges, and show good graded bedding. Several fold axes have been mapped, trending roughly east. They pitch gently east in the western part of the area, and are nearly horizontal in the eastern part. In the northern part of the area, a few originally south-dipping beds are now overturned.

Shearing is not very pronounced. Most shears trend east, parallel to the regional strike of the bedding, and a minor set, as at the Pinnacles mine, trends 050° to 060°.

In the southern part of the area, a porphyry mass occupies an area of at least half a mile by a quarter of a mile. It is moderately sheared and rather strongly weathered, and its northern portion is cut by a network of quartz veins up to two feet wide. It also contains a number of inclusions of sheared Warramunga sediments, now represented by chlorite - magnetite schists. The quartz veins within the porphyry carry some gold and have been worked at the Pup mine. The porphyry itself contains numerous limonite-filled cavities, at least some of which are thought to be boxworks, due to the leaching of original sulphides. A diamond drill hole put down by the Mines Branch, N.T. Administration, to an inclined depth of 300 feet did not encounter any evidence of mineralization. It is more probable that these boxworks are weathered feldspars.

A lamprophyre was found about half a mile east of the Southern

Star mine.

At the Pinnacles mine, a rock consisting largely of chlorite and magnetite has been referred to as a basic dyke by Ivanac, but all the specimens obtained during the present survey could equally well be regarded as portions of a quartz-magnetite lode containing remnants of incompletely replaced chloritic Warramunga sediments.

Ironstones are distributed throughout this area, but the greatest concentration occurs at the Southern Star mine, where an area of approximately 2,000 by 500 feet contains about twenty separate lodes and lenses, the largest measuring about 400 by 15 feet. The strikes are generally east - west.

About two fifths of a mile south of the Pinnacles mine, three jasper lenses up to 100 by 15 feet trend north-east and lie in en-echelon formation. They locally grade into hematite-rich phases indistinguishable from typical ironstones, and are probably related to the porphyry mass outcropping at the nearby Pup mine. At the Pinnacles mine, silicification has also affected some bands of rock within and close to the mineralized shear zone, but these lack the red colour and very fine-grained texture of the typical jasper occurrences.

Quartz veins are very abundant throughout this area, and the majority trend east or east-north-east.

The main mines of the area are the Southern Star, with a recorded production of 120 oz. of gold, the Pinnacles, with a recorded production of 960 oz. of gold and an estimated 5 tons of copper in hand-picked ore, and the Susan, with a recorded production of 130 oz. to the end of 1961. The Susan is the only one which has been worked in recent years, and that only intermittently. In addition, some workings about 250 yards west of the Pinnacles are referred to by Ivanac as the Ajax mine, (recorded production 4 Oz.), although they are shown as the Western Chief on the A.G.G.S.N.A. 1937 plan. The Fassifern mine (recorded production 110 oz.) is believed, by interpolation from Ivanac's regional map, to be situated at 2,537,400 north, 193,900 east, and the International (recorded production 2 oz.) is situated a quarter of a mile south-east of the Susan.

Of these mines, the Pinnacles, Ajax, and International are situated on major shear zones associated with minor ironstones, while the remainder appear to be in massive ironstone. Copper mineralization is present at the Pinnacles Mine, as described in a previous section, and to a lesser extent at the Ajax Mine.

Only the immediate vicinity of the Pinnacles and Pup mines are covered by ground magnetic surveys. Daly (1954) interpreted the results at the Pinnacles as indicating the absence of any major anomalies, but at the Pup (referred to in his report as the Pinnacles Alluvial) he records a weak anomaly in a position roughly coincident with the porphyry contact.

A diamond drill programme to test the downward extension of the copper mineralization at the Pinnacles Mine was undertaken in 1962/1963

by the Mines Branch, Northern Territory Administration. In three of the shallower holes, intersections of 1.95 percent copper over 7 feet, 1.23 percent over 14 feet and 1.50 percent over 11 feet were obtained at vertical depths ranging from about 80 to 100 feet, but the results of deeper drilling, intended to test the mineralized zone at or below the water table, were disappointing.

Peko/Golden Forty Area

Deeply dissected ridges cropout in the eastern part of the area culminating in Mount Rugged; but outcrops in the western part, around the Peko Mine, are more limited.

The area contains a number of minor east - west fold axes, generally with westerly pitches of up to 30°, and a major anticline passes through 2,531,500 north, just to the south of the area.

Lithologically, the Warramunga sediments are similar to those described from other areas, e.g., the Honeymoon Ranges, except for a 50-foot succession of shale and greywacke at 2,534,400 north, 211,600 east, which contains scattered pebbles up to three inches in diameter, composed largely of sedimentary rock types similar to those of the Warramunga Group itself. The hematite shale has been found half a mile northeast of the Golden Forty Mine.

The intensity of shearing is greatest in the central part of the area, around the Golden Forty workings, where many shear zones are heavily impregnated with iron oxides. Trends of 080° and 100° are commonest. In addition, an east - west zone of about two miles by a quarter of a mile, passing through the Kia Ora Mine at the northern edge of the area, shows very well developed cleavage, which almost obliterates the bedding in both shales and greywackes. This must indicate intense local stresses, but is not accompanied by any marked increase in the number of defined shear zones.

Porphyry crops out prominently in the area between Peko and Golden Forty, and includes both sheared and massive phases. Some of the porphyries are associated with prominent jasper bars, but others have given rise to no discernible contact effects at all. At 2,535,000 north, 206,000 east, one of the porphyries is crowded with irregular xenoliths, from a few inches to about ten feet in diameter, but these have suffered no metamorphism except for slight induration.

A small altered diorite was found just west of the Great Eastern workings.

The ironstones are concentrated in three areas: Peko, East Peko, and Golden Forty. The Peko lode cropsout as two lenticular masses 200 feet long and 130 feet long striking east and south-east. The East Peko bodies are largely massive lenses, up to 200 by 40 feet, most commonly striking 070° and similar in general appearance to the outcrop at Peko itself. The Golden Forty ironstones, on the other hand, are mostly groups of small lenses associated with iron-impregnated shear zones. They

frequently show an echelon grouping and most commonly strike 090°.

Quartz veins are very prominently developed throughout the area, especially to the east of the Kia Ora Mine, where a number of blows up to 200 feet/have been observed. Two sets, striking 070° and 090°, are almost equally developed.

Peko is the only mine now operating. This orebody has been described at length by other workers, especially Edwards (1955), and its structural relationships have been discussed in a previous section. Its ore reserves are currently estimated at about 645,000 tons, equivalent to about four years' production at present rates (1963). Grade is estimated at 5 percent copper and 1 to 2 dwt. of gold per ton.

The Golden Forty, Great Eastern and several unnamed mines have all worked iron-impregnated shear zones containing lenses of massive quartz-hematite. Recorded production is 500 oz. for the Golden Forty and 280 oz. for the Great Eastern. The Golden Kangaroo (Golden Forty North), with a recorded production of 50 oz., is situated on a line of lenticular quartz and quartz-hematite bodies with vuggy and gossanous outcrops, between half and three quarters of a mile north of the Golden Forty. McMillan (1961) records that two diamond drill holes were put down on this prospect by the National Lead Co. of U.S.A. They were intended to test a combined geochemical and magnetic anomaly on this line, but they encountered neither sulphides nor magnetite. Some further testing in this area was carried out in 1962 by Australian Development, N.L., but no mineable orebodies were discovered.

About one mile south-east of Mount Rugged, the Tunnel Mine (recorded production 20 oz.) consists of two adits and irregular stopes in sheared and brecciated sediments associated with small quartz-hematite lenses. In the northern part of the area, the Kia Ora Mine has a recorded production of 520 oz. from a zone of brecciated sediments recemented by quartz and hematite. No massive ironstones are associated with this zone.

The area contains a large number of magnetic anomalies of the type normally associated with concealed quartz-magnetite bodies. These include the major anomaly at Peko itself.

At East Peko, a group of four anomalies has been tested by A.G.G.S.N.A. diamond drill hole No.5 and by several holes put down more recently by Peko Mines N.L. (Daly, 1957). The full results are not available, but were apparently not sufficiently encouraging to warrant further work on any of the bodies.

At Golden Forty, four anomalies are arranged in a roughly ring-shaped pattern. Two of these have been drilled by Kia Ora Gold Corporation and Australian Development N.L. (Daly, 1957), and a hole by the National Lead Co. of U.S.A. is reported to have intersected 41 feet of talc schist, averaging 1.5 percent copper (McMillan, 1961, quoting R. Ellett, personal communication).

The probable presence of extensive base metal mineralization in this area is also indicated by the occurrence of copper and lead geochemical anomalies (P.G. Dunn, Bureau of Mineral Resources, unpublished report, 1963), and some further work is proposed in this area by Australian Development N.L. at the time of writing.

Two magnetic anomalies of lesser intensity are known from the vicinity of the Great Eastern Mine. Some geophysical work, followed by wagon drilling, was recently carried out in this area by Australian Development N.L., but the results were disappointing.

Another very large anomaly is situated about one mile west of Peko. This was interpreted by Daly (1957) as due to a magnetic body of about 480 feet radius, centred at a depth of about 2140 feet; but a 2200-foot diamond drill hole put down in this area by the Bureau of Mineral Resources under an agreement with Peko Mines failed to interest either massive ironstone or gold or copper mineralization. It appears likely, on the evidence now available, that this anomaly is largely or entirely caused by magnetite disseminated through a considerable thickness of Warramunga sediments, rather than a discrete ironstone body.

Lone Star Area

This area consists of a group of well dissected ridges in its western portion, tailing away to more isolated outcrops to the east.

The Warramunga sediments show no features of special interest. Outcrops of hematite shale are known intermittently from the True Blue Mine at 2,541,800 north, 199,500 east, to the Great Bear Mine at 2,541,000 north, 206,300 east. Possibly more than one horizon may be present. The beds are fairly tightly folded with vertical dips at a number of localities. Pitches are variable, dominantly to the east at low angles.

Shearing is very pronounced, with a predominance of east-south-easterly trends in the western part of the area. In the eastern part, south-easterly trends are more marked, apparently associated with the proximity of the Quartz Hill/Rocky Range shear zone, which forms the north-east limit of the area.

Three or four small areas of basic igneous rocks (? lamprophyres) are indicated by patches of travertine at the surface.

The ironstones include massive lenses up to 300 by 50 feet, as at the Arizona Mine, and some strongly jasperoid types, as at the Trump Mine. At the True Blue Mine, a peculiar type of spotted lode consists of blebs of hematite, averaging half an inch in diameter, enclosed in quartz. At the Lone Star Mine, the ironstones are themselves extensively sheared, and at the Plain Jane Mine a north - south fault has displaced a portion of the lode by about 60 feet horizontally.

The dominant trend of the quartz-hematites is east - west, but two distinct minor sets, striking 060° and 120° are apparent in a number of localities.

Quartz veins are present throughout the area, but in the eastern portion they reach a maximum development in the Quartz Hill/Rocky

Range shear zone. Several lines of quartz reefs and quartz breccias with remnants of sediments in various stages of replacement by silica attain width of 20 to 30 feet and can be traced with minor interruptions for distances of at least one mile. They generally trend between 110° and 130° and are offset by minor north-east faults.

Among the mines of this area, the Lone Star with a recorded production of 5,560 oz. is the most important. The Trump and Maple Leaf were recently worked on a very small scale, but have no record of production. Others which have produced some gold in the past are the Arizona (22 oz.) Plain Jane (675 oz.) and Great Bear (180 oz.). In most of these mines, gold has been obtained both in massive ironstones and in brecciated iron-impregnated sediments on their flanks. Traces of secondary copper minerals are apparent in the ore from the lower levels of the Lone Star Mine.

A magnetic anomaly of about 300 gammas is located about 300 yards north-west of the Lone Star Mine. This was recently tested by two diamond drill holes put down under a subsidy agreement between the lease-holder and the Mines Branch, Northern Territory Administration. A third hole is in progress at the time of writing. As the quartz-hematite in the mine is reported to be cut off at depth by a thrust fault dipping gently to the north (Ivanac, 1954, p. 105), the body responsible for this anomaly may represent the displaced lower portion of the orebody in the mine itself.

Caroline Area

The eastern part of this area is an extension of the Honeymoon Ranges and has very closely spaced exposures, which gradually decrease in frequency to the west.

The sediments are typical of the Warramunga Group, except for a pebble bed at 2,542,000 north, 187,000 to 188,000 east, as previously described, but no hematite shale was found.

There are at least 15 fold axes in the area, mostly 200 to 300 yards apart. Pitches are predominantly to the west in the eastern part but the fold axes are roughly horizontal in the western part. The beds are strongly sheared at many localities, especially in a zone extending from 2,541,400 north, 187,000 east, to 2,542,400 north, 190,000 east. This zone, with an average trend of 070° is marked by a concentration of quartz reefs, breccias, lenses of sheared porphyry, jasper bars and minor quartz-hematite bodies. Another major line of weakness is marked by a zone of lamprophyre intrusions up to 150 feet wide, which extends from 2,542,000 north 191,000 east, to 2,542,800 north, 190,800 east, with an average trend of 340°.

There are several small porphyries emplaced along shear zones in the southern and western parts of the area. These comparatively small occurrences tend to be associated with relatively large jasper bars, and there are also a few jasper reefs and silicified sediments in areas where no porphyry is exposed at the surface, as at 2,540,000 north, 189,000 to

to 190,000 east. The northern extention of the Aerodrome porphyry, therefore, probably underlies much of the southern part of the area at relatively shallow depth.

Lamprophyres are well represented. In addition to those associated with the major shear zone already described, there are outcrops in the vicinity of the Caroline Mine and to the east of the Shamrock Mine. Several of those at the Caroline Mine are flat-lying sheets, and at least one of them intersects the main ironstone body at that mine.

Ironstones are sporadically distributed throughout the area, but are commonest and largest around the Caroline Mine, where several of them attain dimensions of about 15 by 100 feet. At 2,541,600 north, 189,500 to 190,300 east, several ironstone lenses cropout prominently on steepsided ridges, but terminate at shallow depths, generally above the level of the surrounding plains. East - west trends again predominate. Jasper bars and breccias commonly grade into less strongly silicified sediments, and are generally distinct from the quartz-hematite lodes. Quartz veins, except for a few associated with major shear zones, are not very prominent.

Among the mines of the area, only three have any recorded production. The Shamrock produced 20 oz. of gold and 6 tons of copper from a zone of sheared and brecciated sediments, converted in part to chlorite and sericite schists. The Caroline, which is still being worked intermittently, has produced 280 oz. from massive quartz-hematite lodes and associated sheared sediments, and the Great Northern has produced 450 oz. from an iron-impregnated shear zone in Warramunga sediments.

The only parts of this area covered by ground magnetometer surveys are the immediate vicinities of the Shamrock and Great Northern Mines. The area around the Shamrock gave no indication of the presence of any magnetic bodies at all, and that around the Great Northern indicated a number of small bodies at relatively shallow depths (Daly, 1957).

Gibbet/Aerodrome Area

This area consists of a central line of hills trending roughly east - west, flanked to the north and south by lower-lying ground with less continuous exposures.

The central part is largely occupied by normal sediments of the Warramunga Group. Hematite shale occurs at 2,537,200 north, 188,800 east, and at 2,537,900 north, 190,100 east. At both localities the rocks contain, in addition to the typical finely divided iron oxides, disseminated octahedral crystals, probably of martite (hematite pseudomorphs after magnetite), up to 0.01 inch in diameter.

Two or possibly three beds containing 'sand volcanoes' occur at 2,537,000 north, 189,300 east.

The most prominent structural features of the area are a group of tight west-pitching folds near the Wheal Doria Mine and an open dome-like structure centred about half a mile south-east of the Gibbet Mine.

In the vicinity of the Wheal Doria Mine, a strong set of shears trends 070°, and the alignment of ironstone lenses at the Gibbet Mine suggests that the shears extend into that area.

Almost the entire northern part of the area is occupied by a group of porphyry bodies, the largest of which is about one mile long and half a mile wide, elongated east - west. It has a very massive and relatively fresh central portion, surrounded by a more strongly sheared and weathered zone several hundred yards wide. It is intersected by major north-east trending quartz reefs and is rimmed to the south and south-west by a wide zone of silicification, including a number of well defined jasper bars.

South of this mass, a group of smaller porphyry bodies lies around 2,538,000 north, between 190,000 and 192,000 east. The most easterly member of the group occupies part of Town Hill, and some anomalous dips and pitches in the Warramunga sediments may be due to the effects of this intrusion. The body is strongly sheared throughout, and its contacts are also in part controlled by shearing. Xenoliths are abundant in some parts of the marginal zone, absent in others.

A small isolated porphyry has also been noted at 2,536,300 north, 190,000 east, in the southern part of the area.

A small body of lamprophyre, probably in the form of a flat-lying sheet, underlies the quartz-hematite at the Gibbet Mine, and a few specimens have also been found in spoil from a shallow shaft three quarters of a mile east-south-east of the mine.

The main ironstones are on the Wheal Doria/Big Ben line, and near the Gibbet Mine. They range up to forty feet in width and are associated with shears trending 070°; it is tentatively suggested that the major quartz-hematite and quartz-magnetite bodies are localized at the intersection of these shears with the hematite shale horizon.

The ironstones at the Gibbet Mine are cut off at about five feet below the surface, and adits driven underneath them have encountered either crush breccia or lamprophyre. They are thought to have been displaced by flat-lying faults, now marked by these breccia zones, along which the lamprophyres were subsequently intruded. Quartz veins, except for those associated with the major porphyry occurrences, are not very strongly developed. A group at 2,536,600 north, 189,500 east, contains minor amounts of dark green tourmaline.

The mines are the Wheal Doria (recorded production 3,140 oz.), Peter Pan (95 oz.), Big Ben (7 oz.) and Gibbet (no record). Of these, the first three have mostly worked sheared and brecciated sediments impregnated with varying amounts of iron oxides, and locally with minor amounts of copper, bismuth, and manganese minerals. The shear zones strike about 070° and dip north at about 60°. Massive ironstone bodies also cropout on all these leases, but have apparently yielded very little gold. The Gibbet workings are in massive ironstone and in crush breccias intersecting them.

A relatively large part of the area has been covered by detailed magnetometer surveys. Four anomalies are recorded from the Wheal Doria/ Big Ben line, and a test of the strongest of these by two diamond drill holes (A.G.G.S.N.A. holes No.4 and 4 A), encountered disseminated hematite, magnetite, calcite, pyrite, and chalcopyrite in chloritic slate between 157 and 170 feet in hole No.4 and between 159 and 183 feet in hole No.4 A. However, only low gold and copper values were obtained.

In the southern part of the area, two very prominent anomalies are apparent on the aerial magnetic map. The more westerly of these (locally referred to as the West Gibbet) has been further investigated by ground magneto-meter surveys by Peko Mines N.L. Some diamond drilling has also been carried out in this area by Peko Mines, but the results are not available.

Eldorado Area

This area comprises a group of rather abrupt ridges extending from the Enterprise Mine to the Cat's Whiskers, and a number of gentler hillocks to the east and north-east (see Fig. 13).

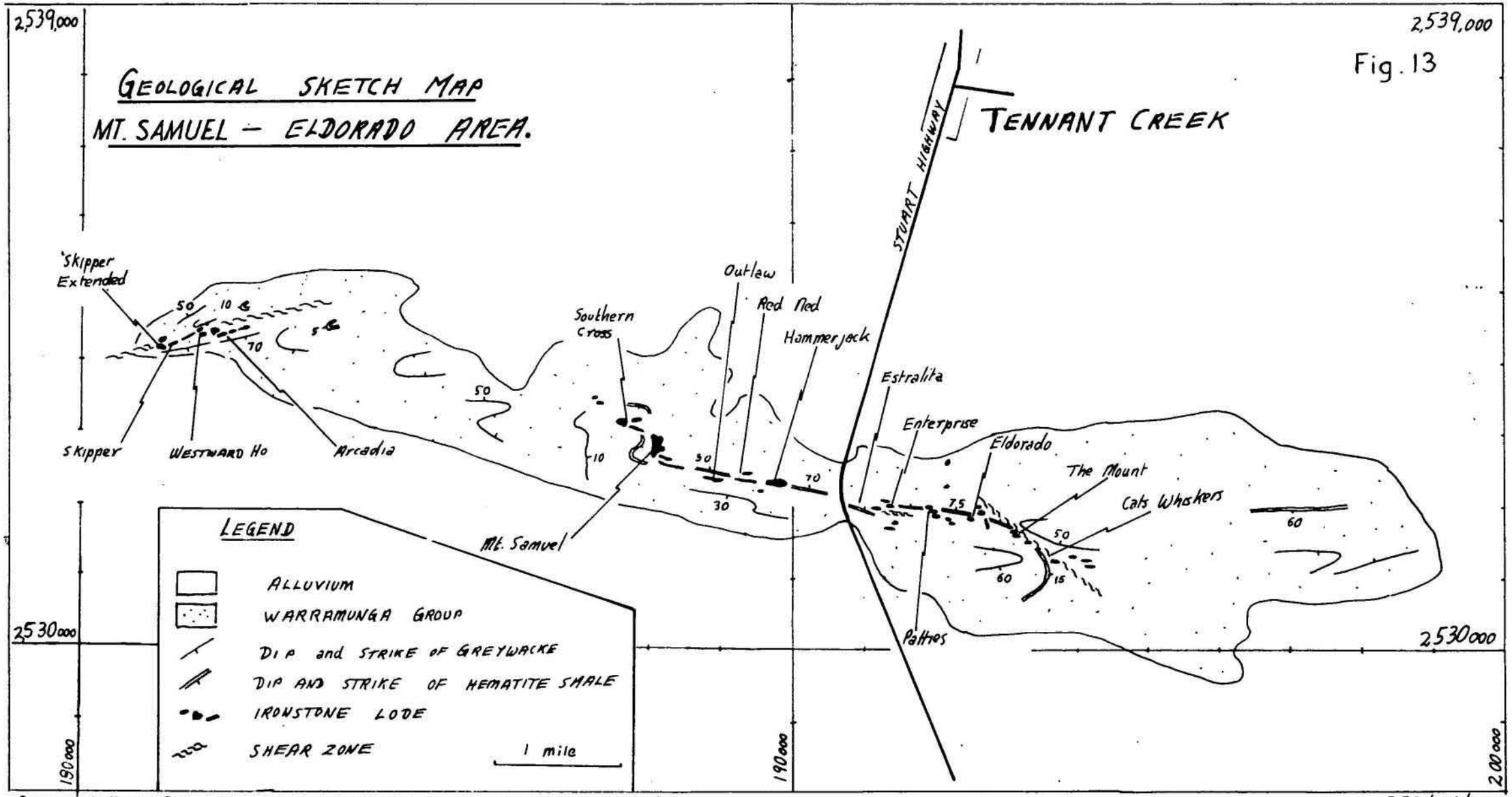
The Warramunga sediments show no unusual characteristics. The hematite shale is well developed and can be traced almost continuously from 2,532,000 north, 191,000 east to 2,531,000 north, 194,000 east, with minor occurrences about two miles north-east of the latter point. Two beds with 'sand volcanoes' occur stratigraphically just below the hematite shale.

Structurally, the main features are an open anticline just south of the Cat's Whiskers/Enterprise line of lodes, and a syncline just north of it. Pitches are to the east in the western part of the area and to the west in the eastern part, generally at angles of less than 15°. Shearing is not very prominently developed, except for a few localities near the Enterprise and Cat's Whiskers Mines, where the dominant sets trend 100° to 120°, and a few quartz breccias in the eastern part of the area, generally striking 340° to 360°.

A few small lenses of sheared porphyry were found about a quarter of a mile south-east of the Cat's Whiskers Mine.

Ironstones are very well developed, but are confined entirely to the western part of the area, where they occupy a belt extending from 2,532,000 north, 191,000 east to 2,531,200 north, 194,000 east. This belt, with an average width of some 500 feet, trends roughly east - west between the Enterprise and Eldorado Mines, and 120° between the Eldorado and Cat's Whiskers Mines. The individual ironstones range from massive lenses of 200 by 60 feet, as at the main shaft of the Eldorado Mine to bedded formations only a fraction of an inch wide. They all trend east - west, except for one irregular body about 200 yards south-east of the Eldorado Mine. The belt of ironstones coincides closely with the outcrop of the hematite shale, as pointed out in an earlier section, and also appears to coincide with the zone of steepest northerly dips in the area.

Quartz veins are more abundant in the eastern part, where two



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main sets strike 090° and 340° to 360°.

The mines are confined to the belt of ironstones extending from the Enterprise to the Cat's Whiskers Mine. From west to east, the main ones are the Enterprise (recorded production 6600 oz.), Patties (1570 oz.), Eldorado (106,000 oz.), The Mount (no recorded production), and Cat's Whiskers (100 oz.). At the Enterprise and Patties Mines most of the ore came from a zone of brecciated iron-impregnated sediments in the footwall (south side) of the massive ironstone lenses. At the Eldorado Mine, the bulk of the ore consisted of breccia zones in the ironstone itself. At The Mount, workings are largely in iron-impregnated sediments, and at the Cat's Whiskers in massive quartz-hematite and adjoining crush zones. At all mines, there were indications that much of the gold was secondary.

Both the Enterprise and Eldorado Mines have been worked recently, but only intermittently and on a small scale. At the Enterprise, a programme of exploration by long-hole drilling was recommended by Hayes (1961), but although some encouraging results were obtained, the mine has no significant ore reserves in sight at the time of writing.

At Eldorado, an exploration programme was recommended by Ryan (1958), but some of his suggestions still remain to be implemented, notably the testing of the lode beneath the Turner Fault below the 300-foot level.

Five major magnetic anomalies are known from the area north and east of the Eldorado Mine (Daly, 1957, Plate 3). Anomaly No.1, north of the mine, was tested by A.G.G.S.N.A. diamond drill hole No.1, which intersected massive ironstone from 223 feet to the bottom of the hole at 235 feet, but encountered only low gold and copper values. Ironstone has also been encountered in this vicinity by Eldorado drill hole S 3, 300-4 and 300-5. Anomaly No.2 may be due to the lower portion of the Eldorado orebody, and ironstone has been cut close to its calculated position by Eldorado diamond drill holes S 1 and S 2. Anomaly No.3 has been tested by A.G.G.S.N.A. hole No.2, which passed through sheared sediments with disseminated magnetite, chalcopyrite, and pyrite between 413 feet and the bottom of the hole at 452 feet, including a body of massive magnetite between 435 and 441 feet. Copper values over this 39-foot section averaged 0.42 percent, with a maximum of 0.88 percent for the bottom seven feet.

In the area occupied by No.4 anomaly (Cat's Whiskers), at least two diamond drill holes are known to have been drilled before 1960, but no record of these has been found. During 1962 and 1963, five further holes were drilled by Eldorado Tennant Creek Co. Ltd under an agreement with the Mines Branch, N.T. Administration, and a north-dipping ironstone body was found a little north of the position indicated by Daly. The first hole, vertical, intersected only low values in the oxidized zone of the body, but the next two holes, inclined to the south at angles of 60° and 75°, intersected mineralized zones averaging 2.5 percent copper over 31 feet inclined width and 3.6 percent copper over 12 feet inclined width respectively.

However, hole No.4, 100 feet to the east, obtained only trace amounts of copper and hole No.5, 100 feet to the west, obtained one intersection of three feet, assaying 2.6 percent copper, and one of six feet, assaying 2.55 percent copper. Gold values were very low throughout.

No.5 anomaly has not yet been drilled.

An anomaly about three miles east-south-east of the Eldorado Mine, locally known as the 'Bull-dust Anomaly', was tested by the National Lead Co. of U.S.A. by means of two diamond drill holes. According to McMillan & Debnam (1961), neither hole passed through ironstone or sulphide concentrations of any importance.

Mount Samuel Area

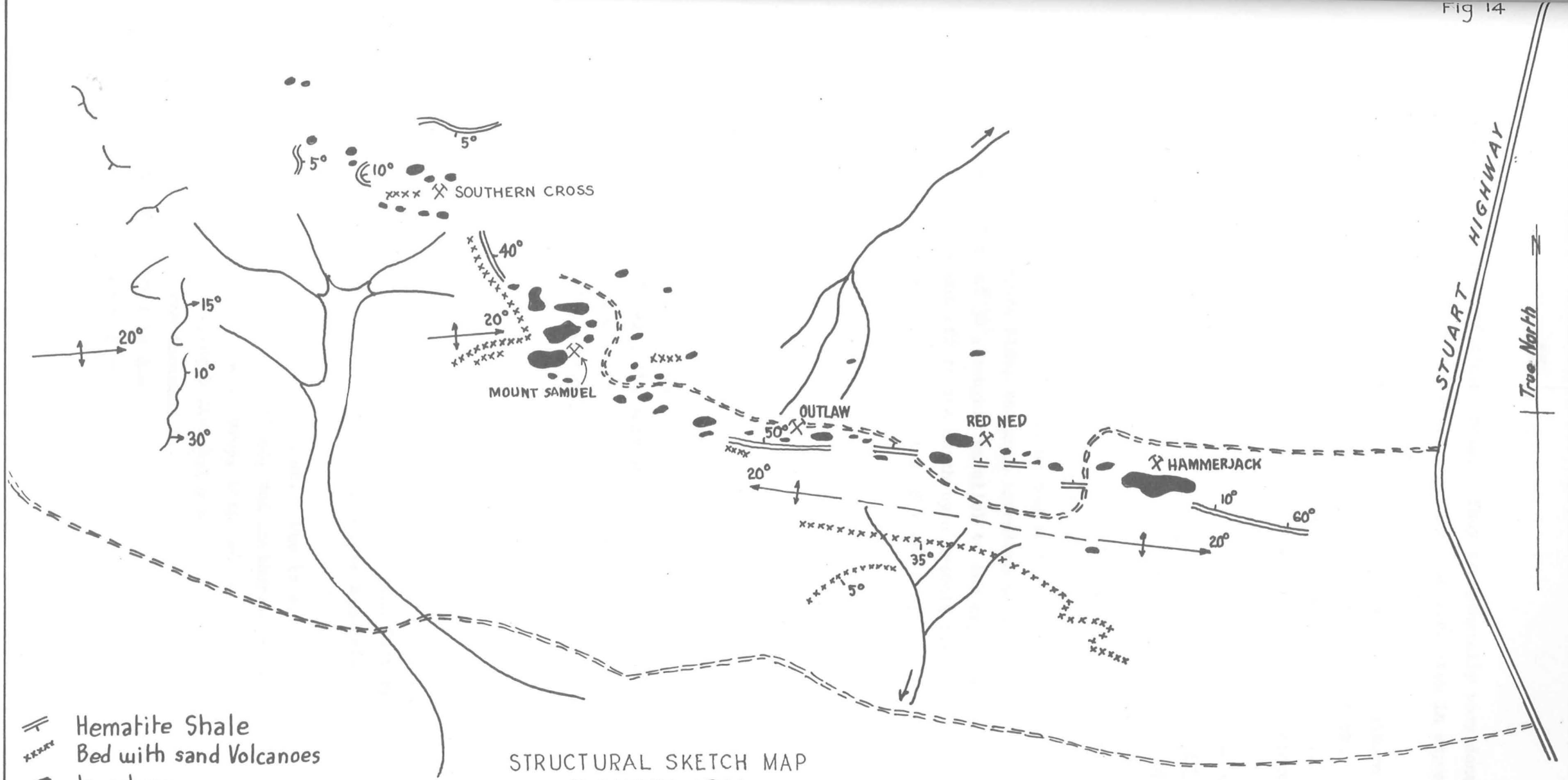
T The best exposures within this area are restricted to a group of ridges extending east-south-east from Mount Samuel to the Hammerjack Mine (Fig. 13).

The Warramunga sediments are very similar to those of the Eldorado area. The hematite shale can be traced intermittently for about a mile and a half, and at least two horizons with 'sand volcanoes' occur stratigraphically just below the hematite shale (Fig. 14). Structurally, the main features are two open east - west anticlinoria en echelon, one situated just south of the Red Ned/Hammerjack line of lode, and the other immediately west of Mount Samuel. A major syncline lies on the north flank of each. Dips throughout the area are gentle, generally less than 45°, except in the immediate vicinity of the Red Ned/Hammerjack line of lode, where steep northerly dips of up to 70° occur. Pitches are to the east at angles of 10° to 20° over most of the area, with a local reversal to 20° west half a mile south-east of Mount Samuel. One unexpected feature is that the hematite shale has been found only on the north flanks of the anticlinoria, although the beds with sand volcanoes occur on both flanks.

Shearing is not generally very obvious, but individual ironstone bodies are commonly surrounded by zones of brecciation up to ten feet wide. Some topographic features, such as the alignment of minor scarps and gullies, also suggest meridional faulting in this area. Cleavage is commonly well developed in the finer-grained sediments. It is roughly vertical and strikes 080° to 090°.

Owen (1942) records that porphyry was intersected at 60 feet in a bore at the south-west foot of Mount Samuel.

The ironstones are confined almost entirely to a belt about 500 feet wide, which trends 120° at the Southern Cross workings, swings to 135° at Mount Samuel, and continues at 100° between the Outlaw and Hammerjack Mines. The greater part of this belt coincides closely with the outcrop of hematite shale, and its eastern portion also coincides with the zone of steepest northerly dips in the area. This is similar to the relationships observed in the Eldorado area. Several of the individual lenses at Mt Samuel attain horizontal dimensions of the order of 200 by 500 feet, but as they are largely flat-lying sheets, their actual volumes



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are no greater than those of other areas. They are generally very dense and compact, and many of them are still strongly magnetic, even in exposed portions at the surface.

The main mines, from west to east (Fig. 14), are the Southern Cross (recorded production 300 oz.), Mount Samuel (4150 oz.), Outlaw (190 oz.), Red Ned (no recorded production), and Hammerjack (5500 oz.). Only the Outlaw has been worked recently. At all these mines, workings are partly in massive ironstone and partly in sheared and brecciated sediments close to the ironstones, but much of the richest ore appears to have been a porous granular or botryoidal limonitic material with ramifying solution pipes up to two inches in diameter. It is not possible to decide from the available evidence whether this material is the product of leaching of massive sulphides in situ, or is due to the re-precipitation of iron oxides transported by supergene solutions. However, analogy with other areas on the field would favour the latter origin.

At the Hammerjack Mine, the main ironstone bodies dip north at an average angle of about 30°, roughly parallel to the dip of the adjoining sediments, and are cut off to the north by a breccia zone, probably representing a major fault. No extension of these bodies to the north of this breccia zone is known.

At Mount Samuel, the ironstone bodies are up to 500 feet across, but they all bottom at depths of 70 to 90 feet. The underlying sediments, which are flat-lying, are slightly brecciated; so the base of the ironstones may be controlled either by a change in lithology or by a shear zone parallel to the bedding. Brecciated sediments also flank the ironstones to the north, and may indicate another faulted contact.

At the Red Ned and Outlaw Mines, the ironstone bodies dip north more steeply in conformity with the surrounding sediments. At the Southern Cross Mine, the dips of the sediments are predominantly to the south at low angles, but the ironstones are flat-lying bodies similar to those of Mount Samuel.

Throughout this and the adjoining Eldorado area, the major mines (Mount Samuel, Enterprise, Eldorado and possibly Hammerjack) are situated at points where the general ironstone-rich belt undergoes a change in direction. These changes in direction are probably reflections of pitch changes, which may be the underlying controlling factor.

Traces of chalcopyrite and secondary copper minerals have been found in several ironstones.

Three magnetic anomalies are known. One is situated vertically below the outcrop of the Red Ned ironstone, and another in a position down dip from the Outlaw ironstone outcrop; both are undoubtedly due to the extensions of the outcropping bodies below water level. The third anomaly is situated about one thousand feet north of the Outlaw workings, and according to Daly (1957) is due to a much more deeply buried body than either of the others. None of these anomalies has been tested.

Noble's Nob Area

This area contains a group of flat-topped ridges, with good outcrops in its central portion, which decrease in height towards the margin of the area.

Most of the area is occupied by Warramunga sediments of normal lithology. Minor occurrences of hematite shale were seen at Noble's Nob mine and half a mile south of the mine. Two, or possibly three, beds with 'sand volcanoes' have been traced intermittently for about a mile to the west of the mine, where they are repeatedly offset by minor faults.

Dips in the Warramunga sediments are generally to the south at angles of 60° to 80°, except near the northern margin of the area, where a few minor folds occur. A major anticlinal axis passes just north of the most northerly outcrops. Pitches are generally to the west at gentle or moderate angles.

In the south, the Rising Sun Formation cropsout intermittently over an area of about two miles by half a mile. These beds generally dip to the south, and are bounded on the south side by a group of major faults.

The dominant faults and shears, including those affecting the Rising Sun Formation, trend 070°, locally swinging to 050°, and are commonly marked by zones of silicification or irom-impregnation. A minor set strikes 330°.

Quartz-hematite lodes are best developed close to the Rising Sun and Noble's Nob Mines, and show the usual east - west elongation. Quartz veins are fairly widely distributed, and most commonly trend 100° to 120°.

The two main mines are Noble's Nob, with a recorded production of 630,000 oz. of gold to the end of June 1963, and Rising Sun, with a recorded production of 8000 oz.

At Noble's Nob, three massive quartz-hematite lenses crop out within a major east trending shear zone; the largest has a length of about 320 feet and a maximum width of 90 feet. The ore is largely localized in fractured zones within the ironstone and in the immediately adjoining Warramunga sediments, and is characterized by a high content of sericite and minor amounts of bismuth and copper minerals, the latter increasing markedly in depth. However, gold is only rarely visible to the naked eye, and the orebody has assay boundaries. The orebody has been traced to a depth of just over 300 feet, and reserves at June 1963 were reported as 75,000 tons, averaging 24.9 dwt. of gold per ton.

At the Rising Sun, a zone of brecciated sediments with minor lenses of hematite has been mined over a length of 125 feet and to a maximum width of 50 feet, mostly by means of a large open cut. Other prospects in the area include the Archangel, Bee's Knees, and Weaber's Find, all of which are associated with small ironstone lenses. Most of these prospects have recently been re-examined by Australian Development N.L., but no details have been released.

A rather feeble magnetic anomaly occurs roughly in the position of the ironstone intersected in the Bureau of Mineral Resources diamond drill hole at Noble's Nob, and Daly (1957) also interprets the magnetic contours to the east of the mine as indicating the presence of a very large body at a depth of 1500 feet or more. This is more likely to be due to rock magnetism or disseminated magnetite than to a defined ironstone body, and no attempt has been made to test it.

Red Terror/Joker Area

Several groups of typical flat-topped, steep-sided ridges in the Warramunga sediments reach their maximum development close to the Red Terror Mine. In addition, an east - west group of more rounded ridges is developed on the Rising Sun Formation in the south.

The greater part of the Warramunga sediments are the usual greywacke, siltstone and shale. The hematite shale has been traced for about three quarters of a mile in the vicinity of 2,529,000 north, between 207,600 and 208,900 east, and several isolated beds of sand volcanoes have been found between this point and the Red Terror Mine. Immediately west of this mine, a pebble bed, about 15 feet thick, offset by a number of faults, has been traced for nearly a mile. It is very similar to the bed already described from the area north-east of Mount Rugged.

Minor slump structures are widespread, and a few specimens from various localities contain nodules and structures resembling worm-tubes. Pyrite casts up to an eighth of an inch in diameter occur in shale about a quarter of a mile north-west of the Red Terror Mine.

The main structural feature is a major east - west anticline at 2,531,300 north, pitching west at 10° to 20°. Faulting and shearing are widespread. Two very prominent sets of faults strike 330° and 030°, and a set of mineralized shears, including those worked at the Red Terror and Joker Mines, strikes 070°.

The Rising Sun Formation occupies an east trending belt with an average width of a quarter to half a mile, continuous with that in the southern portion of the Noble's Nob area. Its lithology and main structural features have already been referred to in a previous section.

A large prophyry body, three miles by half a mile, elongated east - west crops out to the south and south-west of the Red Terror Mine. As in most other porphyries on the field, most of these outcrops are deeply weathered. On the northern flank of this porphyry mass, a few beds of graded greywacke show a superficial resemblance to the porphyry in hand-specimen, and some of the quartz grains in them show lobate outlines, reminiscent of those in the porphyry itself. These rocks have undoubtedly undergone some solution and recrystallization under the action of solutions from the nearby igneous intrusion, and the process has been described as 'porphyritization' by some other investigators (Ivanac, 1954, p. 27). Under the microscope, however, these rocks are invariably found to contain fragments of pre-existing fine-grained sediments, which distinguish them from the porphyry itself.

At its south-eastern margin, the porphyry is surrounded by a strong zone of silicification, including a number of prominent jasper bars, and is intersected by several quartz reefs with north-north-westerly trends. To the south and south-west, the porphyry is overlain by the Rising Sun Formation, and the contact relationships have been fully described in a previous section.

A smaller porphyry occupying an area of about 200 yards square occurs about a mile west-north-west of the Red Terror Mine. This porphyry has highly irregular boundaries and encloses numerous xenoliths of Warramunga sediments.

At 2,528,500 north, 211,500 east, a group of lamprophyres crops out close to the Red Terror porphyry, but is separated from it by a major shear zone.

Ironstones are not very well represented. Within the area half a mile north and north-west of the Red Terror Mine, a few have been tested by shallow workings, but no production is recorded from any of them. Quartz veins, on the other hand, are strongly developed, with a general predominance of north - south trends.

The only two mines with any recorded production are the Joker (760 oz.) and the Red Terror (1300 oz.). Both of these have worked steeply dipping iron-impregnated shear zones, trending 070°. In recent years, only the latter has been worked, intermittently.

The areas surrounding the Red Terror and Joker Mines have been covered by ground magnetometer surveys, but no major magnetic anomalies have been located.

Skipper/Westward Ho Area

This area is essentially a westerly extension of the Mount Samuel area but the folding of the Warramunga sediments is rather tighter. There are two major anticlinoria en echelon, each with a reversal of pitch, giving rise to partially closed dome-like structures. The close association between ironstone bodies and the hematite shale horizon can again be observed, and the range in size and attitudes of the ironstones in the two areas is roughly comparable. However, the individual ironstones in the Skipper area follow the intersections of shear zones and bedding and reach their maximum development in areas where the shearing is sub-parallel to the bedding, i.e., in areas of relatively steep dips along the southern limbs of the asymmetric anticlinoria. A small body of greissic granite cropsout about 200 yards north-west of the Skipper Extended Mine.

The main mines are the Skipper, Skipper Extended (recorded production 4250 oz.), Arcadia, and Westward Ho (820 oz.), none of which have been worked for some years. A major magnetic anomaly has been located about 2000 feet west of the Skipper Mine, and is reported to have been tested by two diamond drill holes, but only very low-grade disseminated sulphide mineralization was intersected, the host rock

being a magnetite-chlorite schist (P.G. Dunn, Bureau of Mineral Resources, personal communication).

Jubilee Area

Most of the rock exposures are in the form of low gentle hills, but there are also a number of small, razor-back ridges of quartz, jasper and ironstone.

The Warramunga sediments consist of the usual interbedded shale, siltstone, and greywacke. Some rocks superficially resemble the hematite shale described from other parts of the One-mile Sheet, but closer examination suggests that they are secondarily enriched in iron by processes similar to those responsible for the formation of the massive ironstones, and their distribution is therefore of no stratigraphic significance.

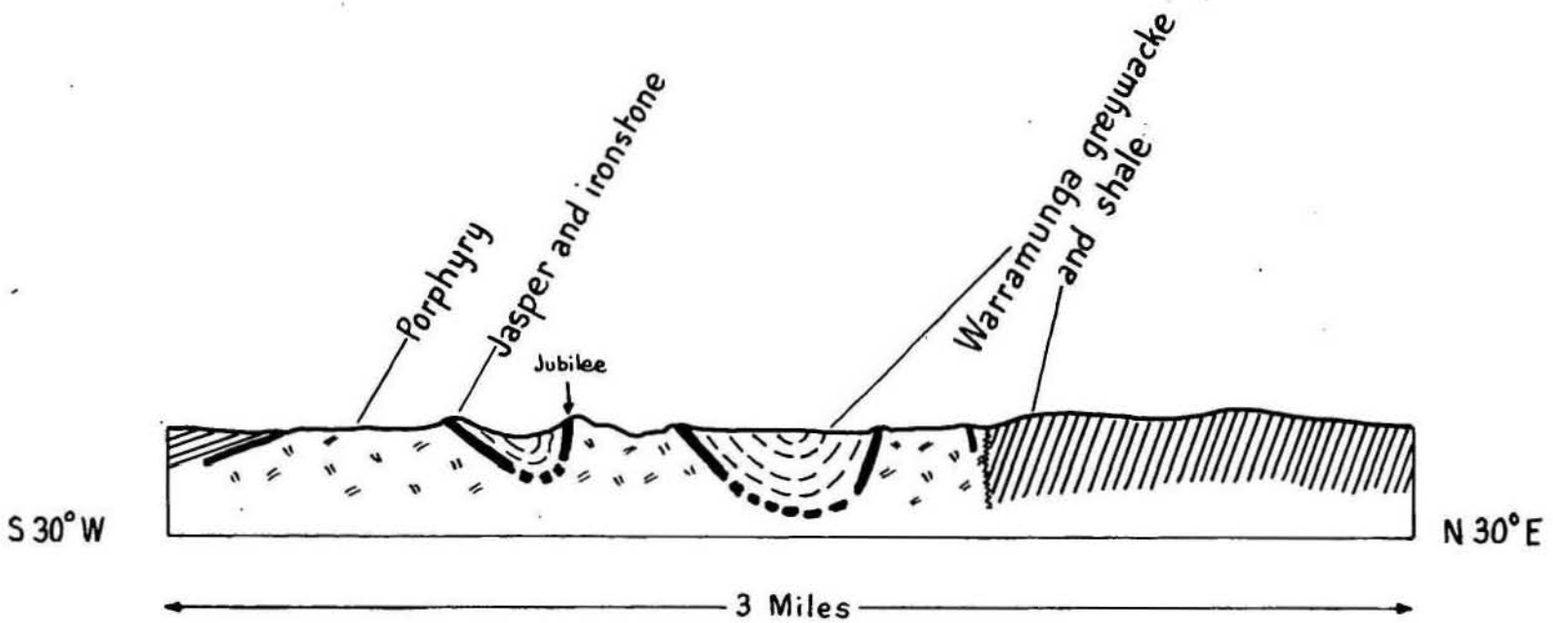
Structurally, the most prominent features are several large dome-like structures, up to two miles by one mile in extent, the cores of shich are occupied by bodies of Baveno-feldspar porphyry (Fig. 15). The dips on the flanks of these structures are commonly low to moderate, except near major shear zones. However, the northern contact of the most northerly of these porphyry masses is faulted, and the sediments north of this fault dip steeply towards it.

The porphyries themselves are somewhat coarser-grained than is typical for rocks of this group in other parts of the One-mile Sheet, and the presence of Baveno type microperthite phenocrysts in some of them indicates a relationship to the porphyritic phases of the Station Hill granite. Shearing is generally confined to the marginal portions of the masses, or may be altogether absent. No fine-grained border phases have been observed, but there is a general increase in the magnetite contents towards the margins at the intrusion, and minor lenses of porphyry occur within the sediments parallel to the contact of the larger masses.

Ironstones and jaspers are very prominently developed in this area, and are of two types. By far the more numerous occur in the sediments within about 200 feet of the contacts with the porphyry masses. They are conformable with the bedding of the sediments in which they occur, but they are lenticular, either pinching out along the strike with sharp boundaries, or passing into zones of only partly replaced sediments and thence into beds only slightly enriched in iron or silica or both. They are not confined to any definite stratigraphic horizons, and successive lenses may occur at different distances from the porphyry contact. Some occur at the contact itself, but this is not typical. The maximum thickness of individual lenses of this type is about 20 feet, but occasionally two or more lenses may overlap. The development of these lenses and the associated ferruginization and silicification are especially pronounced in areas where comparatively narrow tongues of sediments occur between two porphyry masses or as a re-entrant within one of the larger masses.

The exact mechanism responsible for the emplacement of these ironstone and jasper bodies is not known, but it is obviously related to

Fig. 15



Diagrammatic cross-section, about ¼ mile east of Jubilee Mine

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the intrusion of the porphyries and may be due to a wave or 'front' of iron-rich solutions.

The second type of ironstone and jasper lodes consists of the more usual tabular bodies associated with major shear zones. These are best developed in the northern part of the area and in the immediate vicinity of the Jubilee Mine itself. Their attitudes conform to those of the shears in which they occur, i.e. they commonly strike east - west and dip either to the north or to the south at angles between 70° and 90°.

Quartz veins are largely confined to the interior portions of some of the larger porphyry bodies, where they predominantly trend north to north-east and attain widths of up to 20 feet.

Only one example of a transgressive fault offsetting the porphyry contact and the near-by jasper bodies has been noted. This occurs three quarters of a mile south-east of the Jubilee Mine. The fault zone is occupied by a series of quartz veins up to 6 feet thick, and the apparent displacement on the fault is about 500 feet.

The only mine in the area is the Jubilee Mine. This was first worked for gold and yielded 620 ounces, but recently it has been worked for bismuth (carbonate) and the first parcel of 28 tons of ore yielded 500 lbs of bismuth of 99 percent purity. The gold and bismuth ore occurs in sheared and ferruginized sediments in an east-trending shear zone close to the southern contact of one of the larger porphyries.

An old mine dump of about 100 tons, with an estimated grade of between one and two percent bismuth, is still available for treatment, and an exploration programme to block out additional reserves of bismuth-rich material in the old mine workings has recently been proposed. From preliminary investigations, it appears that such a programme should be able to block out several hundred tons of one to two percent ore.

Mary Lane Area

The area consists of scattered mesas, mostly composed of Warramunga sediments, some razorback ridges of ironstone and quartz reefs, and some low-lying areas with good bedrock exposures in the creek beds, comparable to the pediplains of the adjoining Mary Ann area.

Lithologically, the Warramunga sediments show two main divisions - a dominantly shaly succession overlain by a greywacke-shale succession. The maximum thickness of the dominantly shaly succession is estimated at about 2100 feet, observed near the Stuart Highway. Several beds with shale fragments in a fine-grained matrix are regarded as deposits from turbidity currents. They reach a maximum thickness of about ten feet. North-east of the Hidden Mystery Mine, there is also a conglomerate bed, about one foot thick, which contains rounded quartzite pebbles up to two inches long.

The sediments within about three quarters of a mile of the Station Hill granite contact generally dip southerly, i.e. away from the contact, at angles of 35° to 80°. In the remainder of the area, almost vertical dips are common, but facings deduced from graded beds indicate

isoclinal folds. Minor drag folding occurs in the vicinity of some of the larger shear zones, e.g. at the Hidden Mystery Mine.

Within 1000 to 2000 feet of the granite contact, the Warramunga sediments are commonly extensive silicified, but no high-grade contact metamorphism was seen.

The dominant structural feature of the area is the Mary Lane shear, striking 105° to 110°, which has been traced for a total distance of six miles within this area, and continues as the Mary Ann shear to the east of the Highway. This appears to be one of the major structures of the Tennant Creek gold field, as it coincides with a marked linear feature on the serial magnetic map and is co-linear with a group of shears in the Red Bluff area, some three miles west of the limits of the Tennant Creek One-mile Sheet.

Two major and several minor porphyry dykes, which have petrological affinities with the Station Hill granite (just beyond the boundary of the Mary Lane area) trend roughly parallel with the granite contact at distances up to one mile from the main mass. The largest of these dykes has been traced for more than four miles.

At Grey's Bluff the trend of this contact diverges from the regional strike of the sediments and the porphyry lenses show a right hand en echelon arrangement.

A small diorite dyke intrudes the Warramunga sediments about one mile north-west of the Mary Lane Mine, and a few lamprophyre dykes, up to several feet thick, have been observed in sub-horizontal shear zones at the Hidden Mystery Mine.

Ironstones are practically confined to two parts of the area. One group occurs in the Grey's Bluff area, about one mile from the granite contact, where, however, they do not show any obvious alignment on major structures. The second group comprises the lodes occurring in or close to the main Mary Land shear zone. They are commonly associated with quartz reefs, jaspers, small bodies of sheared porphyry and zones of sheared, chloritized, silicified and iron-impregnated sediments, which may attain total widths of more than 200 feet. Gradations are commonly observed, especially the transition of sheared sediments into quarts reefs on the one hand and ironstones on the other.

The arrangement of the individual ironstone bodies within the shear zone is en echelon, and the size of the individual bodies ranges up to 15 by 50 feet in the vicinity of the Hidden Mystery Mine, and up to 30 by 180 feet in the vicinity of the Mary Lane Mine. Many of them are shown by costeans and shallow shafts, however, to bottom at shallow depths.

The quartz reefs of this area are also divisible into two main groups. One of these, trending at about 100° to 110°, comprises the reefs and breccias developed in the Mary Lane shear zone and in the several smaller sub-parallel zones between this and the granite contact. Some of these reefs attain widths of up to 100 feet and can be traced along the strike for several hundred yards. The second group, with dominantly

meridional trends, occur closer to the granite contact and occupy transcurrent faults, some of which have displaced the contact itself.

The only mines in the area are the Mary Lane (recorded production 2 oz.), Hidden Mystery (11 oz.), Eyes of Youth (no recorded production), and Mascot (22 oz.). All of these are situated on the main Mary Lane shear and have worked material ranging from massive ironstone to sheared iron-impregnated sediments. Traces of secondary copper minerals have been found in a small costean east of the Mary Lane shaft and in a minor shear zone to the south of this shaft, but there is no record that any primary copper mineralization was found in the existing workings, which are believed to be about 100 feet deep. A diamond drill hole, inclined at 60° to the north, is reported by a local prospector to have been drilled to a depth of 200 feet from a point 40 feet south of the shaft, but apparently failed to intersect the shear zone.

Two rather poorly defined magnetic anomalies occur in the vicinity of the Mascot Mine, but Daly (1957, p. 29) gave his opinion that these were not of the type produced by a discrete quartz-magnetite body of the usual type for the Tennant Creek field.

A geophysical survey by means of I.P. reconnaissance traverses over part of the area was recently carried out by Australian Development N.L., and three localities were subsequently further investigated by the Bureau of Mineral Resources by means of geochemical surveys. As a result of this work, several areas of above-background copper concentrations have been delineated, and diamond drilling to test some of them is about to be undertaken at the time of writing.

Curlew Area

This area comprises the extreme north-western portion of the Tennant Creek One-mile sheet and consists of a few prominent mesas in the eastern portion, a few razorback ridges due to the presence of resistant quartz and jasper lodes, and a number of low, gentle, dome-shaped rises which merge almost imperceptibly into the surrounding bulldust plains.

The Warramunga sediments in the northern part of the area are dominantly shale and slate belonging to the lower sub-division of the group, while the interbedded shale and greywacke of the upper sub-division predominate in the southern part.

The structure, as far as can be reconstructed from the rather limited outcrops, suggests that the north-eastern portion of the area is occupied by part of the dome surrounding the Station Hill granite complex, while the north-western portion contains a similar but rather smaller dome, the axis of which is occupied by the porphyry intrusion centred about two miles north of the Curlew Mine. In the south-east, closely spaced east - west fold axes are the dominant features.

The shale and slate of the lower sub-division are extensively silicified, probably by the Station Hill granite and the porphyry.

The granite does not cropout within this area, although it may underlie parts of it at relatively shallow depth, but the porphyry north

of the Curlew Mine occupies an area of about three by one miles, elongated east - west. It is petrologically similar to the porphyries near the Jubilee Mine, and like them appears to be related to the Station Hill granite.

The only ironstones which cropout are two lenses up to ten feet thick at the Curlew Mine, and a few jaspery types in the south-east. None of these can be shown to be localized on major structural features. Quartz reefs, on the other hand, are strongly developed, and fall into a number of well defined sets. The most prominent of these comprises the system of north-east-trending veins and breccias which extend from 2,549,000 north, 178,500 east, to the vicinity of Quartz Hill, a distance of about six miles. This group of veins, many of which are arranged in an en echelon pattern, is thought to mark the position of a major shear zone of the complementary set to the main Quartz Hill/Rocky Range zone. However, the amount and direction of displacement on this shear are not known. A second set, largely confined to the interior of the porphyry, trends north-south, and may, at least in part, fill transcurrent faults which have off-set the porphyry contact. Finally, there are also a number of scattered veins trending east - west and south-east - north-west.

Until 1963, the shallow pits and costeans at the Curlew Mine were the only workings in the area, and there is no recorded production from them. However, extensive diamond drilling by Peko Mines on a group of magnetic anomalies about two miles south-east of this mine has recently led to the decision to develop the Ivanhoe Mine, situated at 2,548,400 north, 176,800 east, on the basis of reported reserves of 240,000 tons of ore, averaging 5 percent copper and 4 dwt of gold per ton. There is as yet little information on the structural setting of this orebody, except that it lies at or very close to the intersection of the north-east shear zone with the westward extension of the Mary Lane shear.

Memsahib Area

The south-western portion of this area is an extension of the Honeymoon Ranges, while the northern and eastern portions contain less abundant outcrops, largely confined to creek beds and to ridges composed of resistant rock types, such as quartz reefs.

The Warramunga sediments fall into two main divisions, separated by a major north-west shear zone, and their distribution corresponds roughly to the topographic divisions. In the south-west they consist of alternating greywacke and shale with at least two horizons of hematite shale. In the east, shale predominates and there are a number of pebble beds up to five feet thick which contain abundant subangular to subrounded fragments of shale and sandstone up to three inches in diameter, and in at least one case subordinate pebbles of an igneous rock. Their best development is at 2,545,600 north, 202,000 east.

Structures are simple throughout the area. Strikes are dominantly north-west, parallel to the branches of the Quartz Hill/Rocky Range shear zone which bound the area, and to the shear which separates the two

south west, and those in the north contrasting lithologies. Dips in the south-west are dominantly to the / east-dip, but minor folds are common in both sections. Several of these minor folds pitch south-east at angles of up to 25°, and at 2,543,000 north, 203,000 east, a small closed dome shows that local pitch reversals also occur.

Two quartz-feldspar porphyry dykes cropout in the north-east, and a group of three or four lamprophyre dykes and sills, up to six feet thick cropout in the vicinity of 2,545,000 north, 201,500 east.

Ironstones are concentrated in two groups. In the southern part, the lodes show relations similar to those prevailing within the Honeymoon Ranges. Individual lodes, measuring up to 20 by 100 feet, are confined to the vicinity of the hematite shale horizons and generally trend parallel to the strike of the surrounding sediments. A second group of ironstones is associated with the shear zone, which extends practically across the whole of the area from north-west to south-east. Within and close to the shear zone, iron has concentrated to produce bodies ranging from massive quartz-hematite to disseminated zones of iron-impregnation in the sediments. Most of these are steeply dipping tabular bodies trending parallel to the strike of the shear zone, but a few are markedly irregular, and several have obviously replaced favourable beds of the Warramunga Group. The outstanding example of the last type occurs at 2,544,600 north, 203,600 east, where a replacement body of massive quartz-hematite, some six feet thick, can be traced across the exposed noses of several small pitching folds.

A jasper lens with a width of up to ten feet occurs in the south-east, and appears to represent a silicified section of hematite shale.

The quarts veins also fall into two main sets. North-westerly reefs occupy the two branches of the Quartz Hill/Rocky Range fault zone which form the north-east and south-west boundaries of the area, but in the remainder of the area, reefs of the complementary set, striking almost at right angles to them, are dominant.

The only mines are the Memsahib (recorded production 132 oz.), and the Iris (no recorded production).

Traces of secondary copper minerals are apparent in shallow pits and costeans on a small shear zone west of the Iris Mine, and this prospect, known as the Eureka, was recently tested by Australian Development N.L. by wagon drilling. The results are reported to have been disappointing.

Mammoth/New Moon Area

Topographically, the dominant features are clusters of flat-topped or gently sloping mesas, about 100 feet above the level of the surrounding plains, which gradually decrease in height and in frequency towards the eastern boundary of the area.

Interbedded Warramunga shale and greywacke is the dominant rock, and the hematite shale horizon cropsout almost continuously across the area from east to west. At the Three Keys Mine, three hematite shale

beds, each up to four feet thick, occur within 20 feet of each other, while the maximum thickness for a single bed - 12 feet - was observed about one mile further east.

Dips are predominantly to the south at moderate angles, generally less than 50°, although a few minor folds have been encountered. Pitches, where they could be observed, are generally easterly.

In the west, a zone of tightly folded strata striking north-west adjoins the quartz reefs which mark the eastern branch of the Quartz Hill/ Rocky Range shear zone. Other shear zones are mainly of limited extent and show no obvious preferred trends.

A small body of rounded aggregates of quartz crystals in a matrix of fine-grained quartz and sericite was found in a small shear zone about a quarter of a mile south of the Mammoth Mine. It may originally have been a quartz-feldspar porphyry which has undergone an unusual type of alteration and recrystallization, or an amygdaloidal acid hypabyssal or extrusive rock.

The ironstones comprise two main groups with different distribution and modes of occurrence. By far the most numerous are those occurring within the east - west belt, extending from the Mammoth to the New Moon Mines, which lies close to the hematite shale. The individual ironstone bodies of this belt appear to be localized at the intersection of minor steeply dipping shears with less steeply dipping favourable beds, many of which are the hematite shale beds themselves. They therefore trend predominantly east and are generally of limited vertical extent. All the mines of the area are associated with ironstones of this type.

The second group comprises less numerous but generally larger ironstone bodies in the northern part of the area. These are roughly aligned along a line stretching from 2,545,500 north, 204,000 east, to 2,545,800 north, 209,500 east, and are not associated with any distinctive sedimentary formation, nor are they necessarily elongated parallel to the strike of the surrounding sediments. Also, they are composed mainly of very coarsely crystalline hematite, intergrown with quartz, and, from the absence of extensive workings on them, they are apparently devoid of gold. Their general alignment indicates that they are controlled by some major linear feature, such as a shear zone, but no direct indication of such a feature could be seen.

Jasper lenses are distributed similarly to the ironstone of the first group, and appear to be similarly localized at the intersections of minor shears with the hematite shale horizon. Good examples of a gradation from silicified hematite shale to massive jasper can be observed near the Black Cat Mine.

Quartz veins again fall into the complementary north - east and north-west sets already described from the Memsahib area. The largest single vein is a prominent vein of the north-east set which starts a few hundred yards north of the Three Keys Mine. The main mines of the area are the Mammoth (recorded production 103 oz.), Three Keys (293 oz.), Little Wonder (27 oz.), Mount Margaret (no recorded production), Black Cat

(1023 oz.), Mauretania (210 oz.), Hopeful Star (170 oz.) and New Moon (no recorded production). They are all associated with ironstones or iron-impregnated shear zones situated within or close to the hematite shale horizon. The Black Cat and New Moon are reported to have been examined and wagon-drilled by Australian Development N.L. recently, but no encouraging results were obtained.

The immediate vicinity of the Mammoth, Black Cat and Hopeful Star Mines were also covered by ground magnetic surveys, but no major anomalies were discovered.

Mount Cleland Area

Topographically, the dominant features are the cluster of ridges culminating in Mount Cleland itself, but there are also good exposures of Warramunga sediments in the bed of Tennant Creek, in the extreme north-western portion of the area.

In the central and northern parts of the area, the dominant rock types are shale and siltstone of the lower division of the Warramunga Group. Dips are dominantly to the south at angles between 40° and 60°, but a few minor folds, generally with easterly pitches of 15° to 30°, have been noted. In the southern part of the area, the shale is overlain by interbedded shale and greywacke, part of the upper division of the Warramunga Group. Allowing for repetition by the minor folds, a minimum thickness of 2500 feet of shale and 500 feet of interbedded shale and greywacke is exposed. Much of the greywacke at the base of the shale-greywacke succession is noticeably lenticular. No hematite shale occurs in this area, but pebble beds are strongly developed in at least four localities. Several of them are six feet thick and contain pebbles and shale fragments up to three inches in diameter; but, owing to lack of continuity in the exposures, it is impossible to determine whether they belong to a single continuous horizon or form a series of lenses within a limited stratigraphic interval.

A few shear zones have been noted, generally trending east but do not appear to have more than local significance. A few quartz reefs are also present, and fall into two sets, one trending 360° to 030° and the other 120° to 130°.

Blue Moon/Renate Area

Relief is generally low, interrupted by isolated steep-sided hills which are generally composed of ironstone or jasper, as for instance at the Metallic Hill and Gigantic Mines. In the south, quartz reefs forming part of the Quartz Hill/Rocky Range shear zone cropout prominantly.

The Warramunga sediments are shale, siltstone and greywacke, and a few beds of hematite shale which cannot be correlated for lack of continuity of outcrops. At least two beds of hematite shale appear to be present at the Blue Moon Mine, separated by several hundred feet of greywacke. Dips rarely exceed 45°, but the directions of strike and pitch of the fold axes are very variable.

Minor faults, generally trending north to north-west, are

revealed by the displacement of the hematite shale beds, ironstones, and quartz reefs, especially in the areas one mile south-east of Metallic Hill and immediately south of the Renate Mine.

Major north-westerly shear zones, marked by the presence of en echelon ironstone bodies, pass through the Gigantic and Renate Mines. The sediments close to each shear zone dip more steeply and are more tightly folded than is normal for the area.

Small lenses of sheared and silicified porphyry occur close to some of the major quartz reefs in the southern part of the area. Most of the ironstone and jasper bodies are bedded, and generally occur close to the hematite shale, e.g. at the Blue Moon and Metallic Hill Mines. The main exceptions are the steeply dipping bodies associated with the shear zones at the Gigantic and Renate Mines.

The major quartz reefs occur in the south, where they form part of the Quartz Hill/Rocky Range shear zone. These reefs are mostly 30 feet, and in places 100 feet, wide. Some occur in groups with a left-hand en echelon pattern (looking along the shear zone; see fig. 9). A minor set of quartz reefs strikes east-north-east.

The mines in the area are the Blue Moon (recorded production 12,500 oz.), Gigantic (520 oz.), Metallic Hill (150 oz.) and Renate (13 Oz.). A shallow geophysical anomaly was found to the south-east of the Gigantic Mine (Ivanac, 1954, p.121), and a larger and more deep-seated anomaly north-west of the mine. Australian Development N.L. are reported to have tested the shallower anomaly by diamond drilling but results were disappointing. The deeper anomaly has not been tested to date.

The only work carried out in this area in recent years was at the Blue Moon, where a small repetition of the main shoot was discovered and worked in 1959.

New Hope Area

The area displays a variety of land forms. These include several clusters of hills with rounded outlines, as at 2,532,000 north, 218,000 east, and at 2,527,000 north, 224,000 east: this is due to the absence of the iron-enriched surface layer which is responsible for the development of the steep-sided mesas on Warramunga Group rocks in other parts of the field. The extreme north-east is dominated by the ridges formed by the major quartz reefs of the Rocky Range/Quartz Hill shear zone; most of the remainder of the area is of low relief, although outcrops are generally abundant.

The Warramunga sediments fall into three distinct units. A central belt, up to three miles wide, trending east-north-east, consists of shale, slate and greywacke, commonly strongly cleaved and sheared, so that the bedding is obliterated over large areas. Where they are recognisable, dips are dominantly to the south at steep angles. No major folds can be recognised, but minor folds, pitching in various directions, are not uncommon. The belt is also marked by numerous small porphyry intrusions and quartz veins trending east. Many of these quartz veins are thought

to occupy minor shear zones, and the entire belt is one of relatively intense deformation.

The hills in the vicinity of 2,527,000 north, 224,000 east are composed of sandstone which is more quartzitic and more massive than the normal Warramunga greywacke, and shows cross-bedding in units up to nine inches thick. Many of the beds are silicified and some are intersected by complex networks of diffuse anastomosing quartz veinlets, generally only a fraction of an inch in thickness. Major quartz reefs are rare and igneous rocks are altogether absent. The structure of these hills is part of a large, open north-pitching syncline, the greater part of which falls outside the limits of the area mapped. It is truncated to the north by an east-north-easterly shear zone which brings these rocks into juxtaposition with normal Warramunga shale and greywacke. On the eastern flank of the syncline, the sandstone succession is underlain by a series of shales including at least two pebble beds probably deposited from turbidity currents. Elsewhere on the field, such pebble beds have been found only in the upper part of the shale sequence which forms the lower unit of the Warramunga Group. If the pebble beds in this area are in the same stratigraphic position, the overlying quartzitic sandstone is the equivalent of the upper Warramunga greywacke - shale succession. The quartzitic sandstone also forms the prominent group of ridges in the vicinity of 2,528,000 north, 227,000 east. Here again, the major structures are open, gently pitching folds, in part truncated by east-north-east shears, but the direction and angle of pitch vary considerably. Many of the individual beds are up to four feet and some up to six feet thick, and show both cross-bedding and ripple marks.

The group of hills at 2,532,000 north, 218,000 east, in the north-west, is composed of rocks in some respects intermediate between quartzitic sandstone and the typical Warramunga greywacke - shale assemblage. They consist largely of silicified sandstone and shale: the silicification may be a surface effect of deep-seated origin; the almost entire absence of minor deformation, faulting, igneous intrusion, or quartz veins suggests that it may be a surface effect. The beds dip uniformly to the south, generally at angles between 40° and 60°, and their total thickness is estimated at 3000 feet.

The silicified beds probably extend eastward into the area between 2,530,000 north, 224,000 east, and 2,529,000 north, 227,000 east. Southerly dips again predominate, so that these beds must underlie the shale - greywacke succession to the south, unless they are separated from them by a series of non-outcropping shears.

The igneous rocks consist of a wide range of porphyries and granitic rocks, including sheared, massive, and pneumatolytically altered phases. West and south of the New Hope Mine, slightly to moderately sheared fine and medium-grained quartz-feldspar porphyries predominate; individual bodies occupy areas up to a quarter of a mile across.

In the area from one and a half to three miles east of the New

Hope Mine, porphyries and fine to medium-grained porphyritic granites are represented. Boundaries between the various phases can be mapped in a few places only, owing to poor exposure, and the individual units appear to range from a few chains to about half a mile across. Parts of the granite and porphyry, several hundred yards across, have been pneumatolytically altered; in some places tourmaline has developed.

Cavities, believed to represent boxworks due to the leaching of sulphide minerals, have been noted in some of the igneous rocks, but in the absence of significant copper concentrations in specimens tested from this area, as described in a previous section, the possible economic importance of these occurrences cannot be assessed without further investigation.

An isolated medium-grained porphyritic granite forms spectacular tors about one and a half miles north-east of the New Hope Mine, and some minor sheared and pneumatolytically altered porphyries cropout on the southern flank of the Rocky Range quartz reefs, between half a mile and two miles east-south-east of the Rocky Range Trig. Station.

The ironstone lodes fall into two groups. One comprises the numerous small bodies associated with the margins of porphyry intrusions south and west of the New Hope Mine. These invariably conform to the bedding of the sediments, faithfully following minor folds and puckers, and in places grade along the strike into typical jasper bodies. They may occur several feet away from the actual porphyry contacts. They are generally not more than four or five feet wide, and none of them has been recorded as being mineralized. Except for their smaller size, they are therefore comparable in every respect with the ironstones and jaspers of the Jubilee area. The other group comprises the ironstones of the New Hope and Plum areas, which are steeply dipping, transgressive bodies associated with a major west-north-west shear zone.

The quartz reefs also fall into two main groups. One consists of the reefs of the Rocky Range shear zone, which trends west-north-west in this area. These reefs are commonly 30 feet, and rarely 50 feet wide. In places, up to five sub-parallel reefs, spread over several hundred feet, may occur side by side, but in other parts of the shear zone the individual reefs are arranged in a left-hand echelon pattern.

The other group comprises the east-north-easterly set of reefs which reach their maximum development in the area of sheared porphyries and Warramunga sediments to the west and south of the New Hope Mine. Most are five feet wide and some are twenty feet wide, but few of them persist along the strike for more than a few hundred feet.

The only mines in this area are the New Hope (recorded production 88 oz.) and the Plum (no recorded production). The area around these mines has been covered by ground magnetometer surveys by the Bureau of Mineral Resources, and a number of small anomalies were located (Daly, 1959). However, diamond drilling by the National Lead Co. of U.S.A. (2 holes), and by New Merloo Gold Mines N.L. (1 hole), gave disappointing results.

On the aerial magnetic map of this area, the most striking feature is the contrast between the disturbed area to the west of grid line 223,000 east, and the featureless area to the east of this. This boundary coincides roughly with that between the porphyry intrusions flanked by minor concordant ironstone bodies to the west, and the porphyry-granite complexes without associated ironstones to the east. However, it does not correspond to any structural feature that can be recognised on the ground, and a number of structures, such as the fault which forms the northern boundary of the sandstone in the vicinity of 2,527,000 north, 224,000 east, appear to cross it without any disturbance or offsetting.

Golden Mile Area

This area consists of rounded hills composed dominantly of relatively massive sandstone, mesas of the typical Warramunga shale-greywacke, and ridges of reef quartz.

The sandstone occupies one area of approximately two and a half by one miles, elongated north - south, in the eastern part of the area, and several smaller areas to the west of this. It is lithologically similar to those of the New Hope area. The total exposed thickness of this sandstone succession is approximately 3000 feet. Dips are dominantly to the west and north-west at angles of 45° to 60°, and the main structural feature is a large open north-west-pitching syncline, centred at about 2,532,500 north, 228,000 east.

In the extreme south-east and also at 2,533,000 north, 225,000 east, the sandstone appears to be underlain by strongly sheared shale and greywacke with minor porphyry intrusions, closely comparable with the corresponding assemblages in the New Hope area. However, minor shear zones obscure the contact.

Near the base of the sandstone succession, two conglomerate beds, each up to ten feet thick, contain well-rounded pebbles of sandstone, shale, and reef quartz up to three inches in diameter. These beds have been traced intermittently for about a mile in the vicinity of 2,532,500 north, 228,000 east, and a similar but less extensive outcrop has been noted at 2,534,500 north, 224,300 east. If these outcrops can be correlated, as appears likely, an apparent displacement of about two miles, east block south, must have taken place on the north-west trending shear zone, now marked by a discontinuous line of major quartz reefs, which separates the two occurrences.

In the northern part of the area, normal Warramunga shale and greywacke occupy an east - west belt of about four miles by three quarters of a mile centred roughly on the Golden Mile mine. The beds exposed in this area comprise shale, greywacke, and hematite shale, two major horizons of hematite shale, each up to 12 feet thick, and two or three minor ones, have been found. These beds strike generally east-north-east and dip north at angles of 60° to 70°. Minor folds with a relatively constant west-south-westerly pitch of 20° to 40° are abundant. The observed dips indicate that these beds overlie the sandstone to the south, unless a major shear zone is present in the

intervening area of poor exposures.

A complex of quartz-feldspar porphyry and fine to medium-grained porphyritic granite, in part pneumatolytically altered, occupies an area of about half a square mile in the south. It is similar to some of the igneous complexes from the eastern portion of the New Hope area.

In the extreme south-eastern corner, a series of minor lamprophyre and quartz-feldspar porphyry bodies occurs near the junction of the main Rocky Range shear zone with two north-west-trending branches. The porphyries from this locality are moderately to strongly pneumatolytically altered and include a silicified and tourmalinized rock which is now composed entirely of quartz phenocrysts set in a quartz-tourmaline matrix.

Finally, two zones of small quartz porphyry outcrops extend east-north-east of 2,534,200 north, 224,200 east, and north-north-east of 2,532,000 north, 228,000 east. Each of these zones can be traced, with minor gaps, for more than half a mile, and has an average width of about 100 yards. They trend parallel to the strike of the adjoining sediments and each occurs stratigraphically just below the conglomerate horizons described above. They are therefore regarded as portions of a sill, displaced by the north-west trending shear zone.

Ironstone bodies are confined to the northern portion of the area, where they are closely associated with the hematite shale horizons. Nearly all strike east-north-east, parallel to the surrounding sediments, except in the north-west where both ironstones and sediments strike northerly and north-westerly. Widths are generally up to 20 feet and even up to 50 feet, with lengths of up to 200 feet. Generally, the smaller bodies follow the bedding of the sediments in great detail, including minor pitching folds. The larger bodies tend to have sheared margins but large shear zones are absent, and this, taken in conjunction with the relatively low average dip of the beds, indicates that none of the ironstones could be expected to have a large vertical extent. Jasper lenses show similar distribution and mode of occurrence, and some grade into ironstones along the strike.

The main quartz reefs of the area comprise two major north-west zones, which are regarded as branches of the Rocky Range shear zone. Within each zone, the individual reefs are up to 30 feet wide, and two or three parallel reefs occur side by side in some sections. The more easterly zone, as described previously, has an apparent displacement of about two miles, east block south. The displacement along the other shear zone cannot be determined.

At 2,532,100 north, 226,000 east, the highest portions of a small north - south ridge are capped by a succession of quartzite, quartz grit, and conglomerates with pebbles up to one inch in diameter. The attitude of the bedding could not be determined accurately, but is probably sub-horizontal, and the beds appear to rest on an eroded surface of porphyry and porphyritic granite. The total area of these outcrops is about five acres, and the exposed thickness of the beds is probably

only 30 to 50 feet, but they are regarded as being part of the Rising Sun Formation.

The only mines in this area are the Blue Bird (recorded production 51 oz.), Perseverance (192 oz.), and Golden Mile (96 oz.), all associated with the belt of hematite shale, ironstone, and jasper in the north.

Quartz Hill Area

This area comprises a group of low but very rugged ridges composed of granite cliffs and tors, together with a few razorback ridges of reef quartz. Bedrock exposures are almost continuous for several square miles south-east of Station Hill in the south-central portion of the area.

The Warramunga sediments are shale and slate belonging to the lower unit. They occur around the margins of the igneous complex, as in-faulted or in-folded septa within it, and as scattered xenoliths within some of the igneous rocks themselves. They are generally silicified, but not otherwise metamorphosed. The sediments on the flanks of the igneous complex invariably dip outwards, generally at angles between 40° and 70°. The shale septa within the complex are 100 feet wide in places and some are several miles long, generally elongated east-south-east, but the bedding of the shale within them is generally obliterated by shearing. The minor xenoliths vary widely in size, shape, attitude, and degree of recrystallization, ranging from almost unaltered inclusions with sharp boundaries to vague schlieren almost completely absorbed by the igneous rocks.

The main rock types recognised within the granite complex are a massive porphyritic granite which is strongly foliated in places, a medium-grained even-grained granite, and an aplite. The aplite occurs on the margins of the mass, and may be a marginal phase. The complex is cut by minor aplitic dykes, ranging up to twenty feet wide and striking in various directions, but no age relations have been established between the major phases except that the aplite is the youngest.

Dolerite dykes, up to 50 feet wide and several hundred yards long, with east-south-easterly trends, intrude the complex.

The Quartz Hill/Rocky Range fault zone cuts through the complex in a south-easterly direction and displaces its contact with the sediments. It is marked by a group of quartz reefs up to 50 feet wide, in part showing en echelon arrangement. A major south-west shear of the complementary set abuts against this zone just west of Quartz Hill, but does not cut the igneous complex. Other quartz veins trend north - south, as at Station Hill, and some east - west.

There is no mining in this area, but the quartz detritus from the flanks of Quartz Hill has been extensively quarried for use as road aggregate.

White Hill Area

This area is very similar to the Quartz Hill area, with the main outcrop area centred on White Hill itself.

Warramunga sediments occur around the southern margin of the igneous complex, as in-folded or in-faulted septa and as xenoliths. In addition, there are some outcrops of indurated slate and hornfels in the eastern part of the area, associated with a major north-west quartz-filled shear zone. The shear zone has not been traced into the igneous complex, but probably offsets it in the same sense as the Quartz Hill/ Rocky Range shear zone, to which it is parallel.

The main component of the igneous complex is a porphyritic granite, similar to the predominant rock at Station Hill. Minor aplitic and medium-grained phases are also present.

Although there is a gap of some four miles without any outcrops, it seems likely that the Quartz Hill and White Hill exposures are part of a single igneous complex, which would thus have a total area of approximately 15 by 8 miles, elongated east - west, with a possible extension to the Barkly Highway, some eight miles east of the Flynn Memorial.

Quartz reefs are strongly developed. Apart from those associated with the shear in the east, the majority are confined to the interior of the igneous complex. Of these, the group of reefs passing through White Hill itself is the most prominent. The trend of these reefs is meridional in the south, swinging to north-west in the north, and they probably occupy a fault or shear, which has slightly offset the southern boundary of the igneous complex. Other quartz veins within this complex strike at various angles from north through north-west to west-north-west.

Two small ironstone bodies have been noted a little more than a mile south of White Hill Trig. Station, but there are no mines in this area.

Gum Ridge Area

Warramunga sediments are exposed at only two localities. One is about one mile east of the Blue Moon Mine, where they are overlain by the Helen Springs Volcanics, and the other is about five miles east of White Hill, where they are directly overlain by Cambrian sediments. At both localities, they show normal lithological and structural features, but pass upwards into material not unlike the soil cover with abundant rock fragments which overlies much of the present-day area of Warramunga outcrops. At the northern locality this rubbly layer in turn passes upwards into the basal beds of the Cambrian formation.

The Helen Springs Volcanics cropout at the base of small scarps formed by the Cambrian beds, and in a creek bed at 2,548,500 north, 228,000 east. The volcanics consist of rhyolite, amygdaloidal basalt, tuff and agglomerate, and attain a maximum exposed thickness of about 50 feet. They are absent in the area due east of White Hill, where the Cambrian sediments rest directly on rocks of the Warramunga Group.

The greater portion of the area is occupied by Middle Cambrian Gum Ridge shale formation: chert and siliceous limestone with minor grit, sand and sedimentary breccia. These beds dip regionally eastward, to a

maximum of 20° but average less than 5°. As a result, the best exposures, including practically all the known fossil localities, are situated on a west-facing scarp which extends for approximately five miles in a north-south direction between Gum Ridge Trig. Station and the Pigeon Water Holes. Locally, however, minor basin structures are developed, with scarps facing in various directions. The maximum exposed thickness of the formation is about 40 feet.

Although the existing dips in the Cambrian sediments must be due to tectonic forces, no faulting has been noted within them and neither they nor the underlying Helen Springs Volcanics have been affected by igneous intrusions, quartz veins, or mineralization.

There is no record of any mining activity in this area.

Cabbage Gum Area

This area is devoid of outcrops except for a few small exposures of porphyritic adamellite in the vicinity of 2,527,500 north, 199,000 east, and one prominent east-north-east quartz vein at 2,576,000 north, 191,500 east. Nevertheless, a good deal is known about the geology, for it forms the northern portion of the Cabbage Gum Basin which has been investigated in some detail as a source of underground water supplies for Tennant Creek township.

Warramunga sediments underlying the north-eastern portion of the area are an extension of those croppingout in the Eldorado area, and show no unusual features; but, in the central part of the basin, just south of the limits of the Tennant Creek One-mile sheet, Warramunga sediments form a series of roof pendants and infaulted inliers within an igneous complex, and these rocks are intensely sheared and recrystallised.

The igneous complex itself appears to be very similar to that previously described from the White Hill and Quartz Hill areas. The three main constituents are a medium-grained adamellite with spheroidal feldspar phenocrysts, an augen gneiss composed of quartz-feldspar aggregates separated by biotite folia, and a medium-grained gneissic granite. In addition, there are minor occurrences of quartz-feldspar porphyry, aplite, and dolerite. These igneous rocks commonly show a very distinctive deep weathering profile of only slightly weathered rock, passing downwards into strongly weathered or completely decomposed material, and thence back to slightly weathered and finally to fresh rock. In places, the upper part of this profile is lacking, probably because it was eroded before the superficial sediments were laid down. The maximum thickness of decomposed material encountered in a drill hole was 110 feet, about 2⅛ miles south of the southern margin of the Tennant Creek One-mile sheet, and the thickness decreases towards the northern and eastern margins of the basin.

Quartz veins, apart from the large one already referred to, are generally less than 12 inches thick, and are concentrated in a north-easterly belt, which passes through 2,526,000 north, 196,000 east, and 2,530,000 north, 199,000 east. This belt, which coincides with the axis

of a gentle topographic depression and shows up as a strong linear feature on the air photographs is thought to mark the position of a major shear zone. On the photographs, it can be traced north-east for at least another three miles to the vicinity of Peko Mine, but it has no surface expression there.

Perhaps the most interesting feature of the area is the presence of an extensive series of superficial sediments - clay, siltstone, sandstone and grit ranging from unconsolidated to well cemented. The cementing material is siliceous or ferruginous or both. There are few well-defined beds, and none can be traced laterally for any distance. In parts, lateritization has produced complete profiles comprising ferruginous, mottled, and leached zones. Elsewhere, however, parts of the profile are lacking and at a few localities reworked laterite fragments appear to have been incorporated in some of the beds.

The base of the succession generally consists of a layer of reworked material derived from the immediately underlying bedrock. This takes the form of an impure sandstone in areas of granitic rocks, and of a conglomerate or sedimentary breccia in areas of Warramunga sediments.

At the top, these sediments generally pass into a layer of loosely to moderately consolidated rubble, which is regarded as an incipient soil horizon, related to the present land-surface. This, in turn, may be overlain by up to ten feet of unconsolidated wind-blown sand. The maximum thickness of these sediments within the Tennant Creek One-mile Sheet area is about 40 feet, but they attain thicknesses of more than 80 feet in the central and southern parts of the Cabbage Gum Basin.

The superficial sediments and the decomposed zone of the granitic rocks in places give good yields of potable water (Hays, 1958 a and b; Crohn, 1960; Bracewell, Crohn & Hays, 1962). A reticulated water supply, derived from this basin, has recently been constructed for Tennant Creek.

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No. 499. Specimens from Peko, Eldorado, Enterprise and other mines, Tennant Creek, N.T.

No. 462. Cores from Peko Mine, Tennant Creek, N.T.

No. 524. Specimens from Peko Mine, Tennant Creek, N.T.

No. 571. Specimens from Peko Mine, Tennant Creek, N.T.

No. 592. Specimens from Peko Mine, Tennant Creek, N.T.

No. 618. Specimens from Peko No.2 diamond drill hole, Tennant Creek, N.T.

No. 626. Specimens from Peko diamond drill holes, Tennant Creek, N.T.

No. 653. Specimens from Peko No.3 diamond drill hole, Tennant Creek, N.T.

No. 655. Examination of copper concentrate from Peko Mine, Tennant Creek, N.T.

No. 686. Tailings from Noble's Nob Mine, Tennant Creek, N.T.

No. 724. Pyrrhotite in Peko ore.

No. 738. Drill cores from Peko Mine, Tennant Creek, N.T.

No. 759. Flotation tailings from Peko Mine, Tennant Creek, N.T.

No. 786. Auriferous drill core from Tennant Creek, N.T.

No. 766. Ore from the deeper levels of the Peko Mine, Tennant Creek, N.T.

No. 814. Gold ore from Noble's Nob, Tennant Creek, N.T.

No. 815. Ore specimens from the Orlando gold prospect, Tennant Creek, N.T.

No. 844. Magnetite-hematite core samples from the Explorer 13 prospect, Peko Mines, Tennant Creek, N.T.

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No. 116. Ore from the Northern Star Mine, Tennant Creek, N.T.

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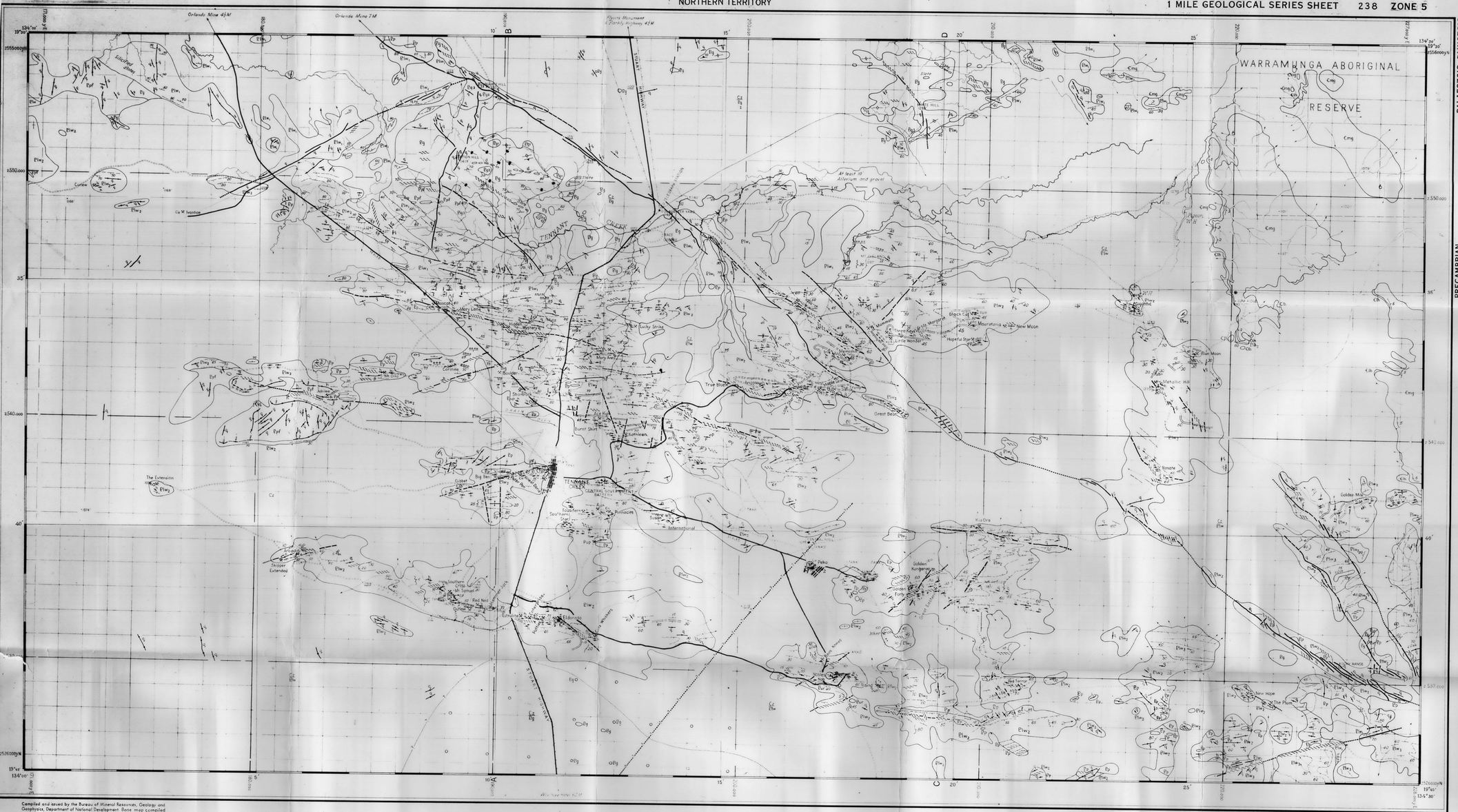
AUSTRALIA 1:63,360

TENNANT CREEK
NORTHERN TERRITORY

1 MILE GEOLOGICAL SERIES SHEET 238 ZONE 5

PRELIMINARY EDITION, 1964
SUBJECT TO AMENDMENT



Reference

		Cz	Alluvium, gravel, sand, silt, clay (bulldust)
PALAEOZOIC CAINOZOIC	CAMBRIAN MIDDLE	Gum Ridge Formation	Cmg	Calcareous sandstone, shale, chert
	CAMBRIAN LOWER	Helen Springs Volcanics	Clh	Lavas, pyroclasts
	UPPER	Rising Sun Conglomerate	Pur	Conglomerate, quartzite, sandstone, shale
PRECAMBRIAN PROTEROZOIC	UPPER & LOWER		q	Quartz
			l	Lamprophyre
			h	Quartz - hematite - magnetite
			j	Hematite jasper
			p	Porphyry
			qp	Quartz - boveno - porphyry
				Dolerite
			di	Diorite
				Serpentine
	LOWER		Pp	Quartz - feldspar - porphyry
			Ppf	Quartz - boveno feldspar-porphyry
			Pg3	Fine-grained granite
			Pg2	Foliated course-grained porphyritic granite
			Pg1	Course-grained granite
			Pg	Porphyritic granite (foliated in places)
		Warramunga Group	Plw2	Greywacke, shale, Hematite shale
			Plw1	Sandstone, Shale, Siltstone
				Pebble beds
				Pebble beds, Shale, stone greywacke

Compiled and issued by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Base map compiled by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force, complete vertical coverage at 1:80,000 scale, and the Bureau of Mineral Resources at 1:25,000 scale. Transverse Mercator Projection.

Geology, 1958-59, by: P.W. Crohn, W. Oldershaw, G.R. Ryan, K. Rochow
Compiled, 1963, by: P.W. Crohn, W. Oldershaw
Drawn by: D.E. Breetnall

INDEX TO ADJOINING SHEETS
Showing Magnetic Declination

TENNANT CREEK					ALROY
MARION REVE	MT WOODCOCK	WARRAMUNGA			
RED BLUFF	TENNANT CREEK	GOOSE RIVER			
	BOONS	GOOSE RIVER SOUTH			
BONNEY WELL					FREW RIVER

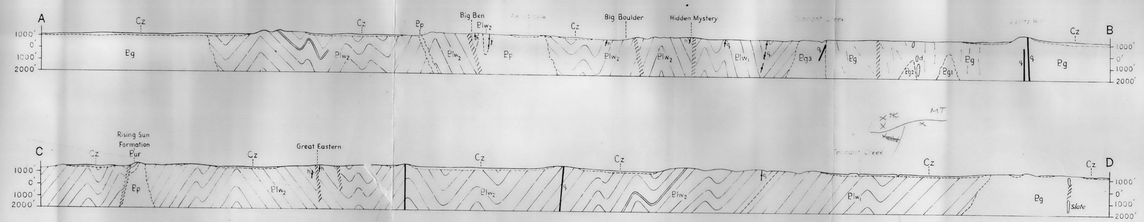
ANNUAL CHANGE 1°E

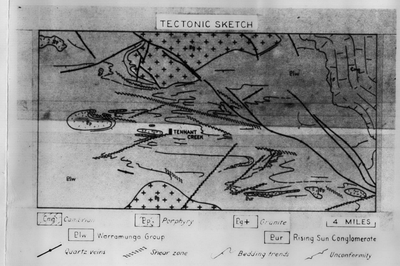
Scale
1 Mile to 1 Inch
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETRES

GEOLOGICAL RELIABILITY DIAGRAM

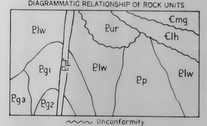
A Detailed mapping

Sections
Folding diagrammatic
Scale E = 1





DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



TENNANT CREEK
SHEET 238 ZONE 5