COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT No. 101

Geological and Geochemical Survey of the Captains Flat Area, New South Wales

BY

W. OLDERSHAW

Issued under the Authority of the Hon. David Fairbairn
Minister for National Development
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SUMMARY

In 1961, the zinc-lead-copper orebodies then being worked at Captains Flat by Lake George Mines Pty Ltd were almost exhausted. The New South Wales Geochemical Survey and the Bureau of Mineral Resources were requested to undertake a search for new orebodies near the mine. The New South Wales Geological Survey mapped the area south of Captains Flat to Jerangle, and their map and report will appear separately. The Bureau of Mineral Resources mapped the area north of Captains Flat to Hoskinstown, and carried out a geochemical survey over the area from Hoskinstown to Jerangle. The results are given in this Report.

The worked-out orebodies were localized on the overturned, contorted western limb of a north-plunging synclinorium in Silurian shale, siltstone, and volcanics. The synclinorium extends 12 miles north and 6 miles south of the mine, and is 1 1/2 miles wide. It lies in a graben bounded by the Narongo Fault to the west and the Ballallaba Fault to the east. East and west of the graben are horsts of tightly folded Ordovician greywacke and shale intruded by granite.

A geochemical survey was carried out over the Silurian synclinorium and its outliers to the south. Five thousand soil samples were collected at intervals of 600 feet from the 'B' horizon of the residual soils. The numerous erosion gullies and creek of the trellised drainage pattern of the area were used as a natural grid for sampling. One hundred and ten geochemical anomalies were found, 93 of which overlie the Copper Creek Shale. Twenty of these anomalies had previously been found, tested, and abandoned by Lake George Mines Pty Ltd.

The sulphide mineralization in the Captains Flat area is mainly confined to three shale beds - the Ordovician Bullongong Shale Member of the Foxlow Beds, the Silurian Copper Creek Shale, and the Silurian Keatings Shale Member of the Kohinoor Volcanics. The Bullongong Shale Member and the Copper Creek Shale contain disseminated sulphides, but the major orebodies are in the Keatings Shale Member. The Keatings, Central, and Elliots orebodies occur where the north-trending Main Lode Shear is intersected within the Keatings Shale Member by a series of shears trending 020^{o} - the Narongo Shears. Small sulphide masses, with associated geochemical anomalies, occur where the Copper Creek Shale is sheared or folded. There appears to be a strong structural and stratigraphical control of the sulphide mineralization, and it is possible that the sulphide masses were formed by 'lateral accretion' of disseminated syngenetic sulphides which became mobilized in areas of structural disturbance.

Further work is recommended on the Vanderbilt and Bollard prospects and on three of the new geochemical anomalies.

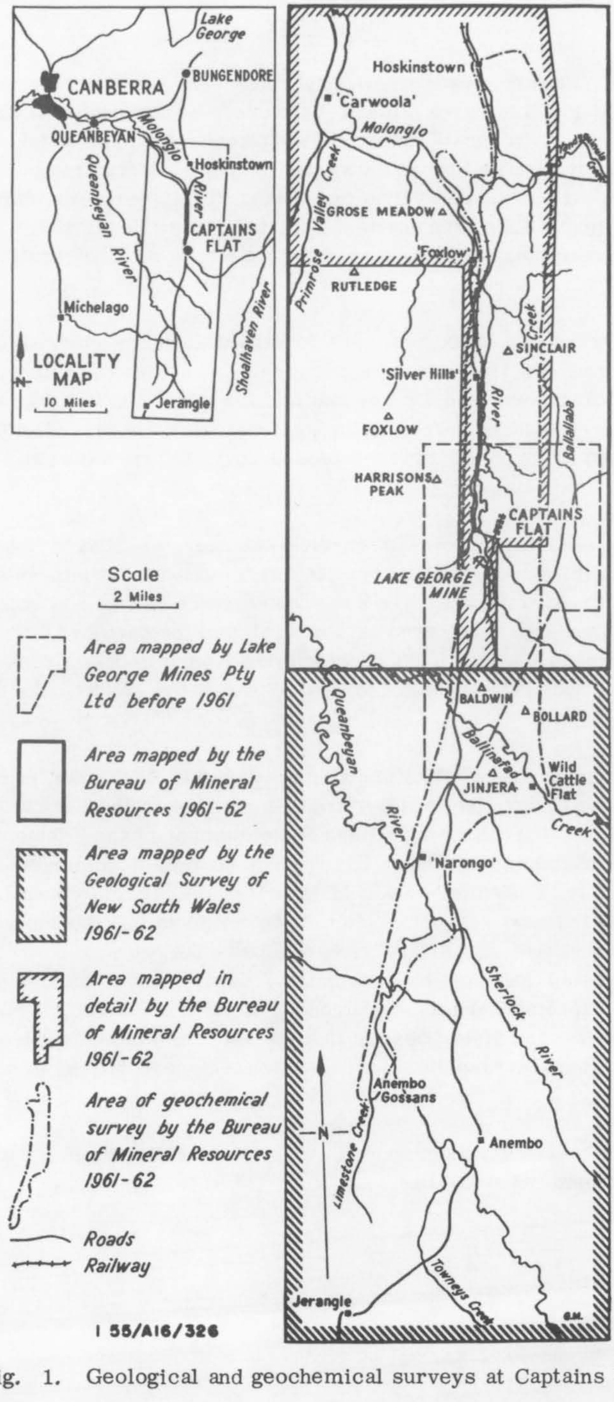

Fig. 1. Geological and geochemical surveys at Captains Flat

INTRODUCTION

Mineralization was discovered at Captains Flat, 35 miles south-east of Canberra, in 1874, and mining began in 1882 (Glasson, 1957). The separate orebodies were mined by different companies until 1928, when mining virtually ceased. Lake George Mines Pty Ltd took over the leases in 1937 and amalgamated the separate mines into one operation. Before the mine closed in March 1962, a total of 3,946,650 tons of ore averaging 6.24 percent Pb, 10.70 percent Zn, 18.57 percent Fe, 0.63 percent Cu, 1.63 oz Ag, and 1.11 dwt Au, had been mined.

In 1961 the Bureau of Mineral Resources and the Geological Survey of New South Wales were requested by Lake George Mines Pty Ltd to undertake a geological survey of the Captains Flat Synclinorium with the object of finding new orebodies. An area 34 miles long and 8 miles wide trending 182°* and centred on Captains Flat was mapped (see Fig. 1). The Bureau of Mineral Resources mapped the northern part of the area, from Hoskinstown to a line 3 miles south of Captains Flat, and the Geological Survey of New South Wales mapped the remainder of the area as far south as Jerangle. The Bureau subsequently undertook a geochemical survey of the whole synclinorium.

This Report is based on the results of the surveys by the Bureau of Mineral Resources, and on information provided by Lake George Mines Pty Ltd. The detailed geology of the Lake George mine and its environs is described in reports by the Mine Staff (1953) and Glasson (1957). The mineragraphy of the orebodies has been described by Edwards (1943) and Edwards & Baker (1953). The search for new orebodies has been described by Debnam (1957), Glasson & Paine (1959), and Paine (1961).

Physiography

The Captains Flat area is part of the Southern Highlands of New South Wales, and lies on the western slopes of the Great Dividing Range. In general it is an area of rugged relief except for the alluvial flats in the northern part of the Molonglo Valley. The Ordovician horsts to the east and west of the Molonglo Valley comprise rugged, deeply dissected, bush-covered country, whereas the Captains Flat Synclinorium consists of low undulating country with mature valleys.

North of Captains Flat the relief is about 1600 feet - from 2400 feet above sea level at Carwoola homestead to 4003 feet on Foxlow Mountain. South of Captains Flat, in the area mapped by the Geological Survey of New South Wales, the terrain is higher and more rugged - ranging from 3000 feet above sea level at Narongo homestead to 4839 feet on Tumanong Mountain.

The area mapped by both field parties comprises the upper parts of the Molonglo and Queanbeyan river systems. The drainage is structurally controlled. It is influenced in different places and to various degrees by the north-trending Narongo, Lake George, and Callallaba Faults; north-trending bedding and cleavage; and north-west trending faults.

Geological Mapping

Field mapping by Bureau personnel occupied 18 man-months. Those who took part were W. Oldershaw (Party Leader), G.R. Pearson, E.G. Wilson, C.M. Gregory, D.O.

* All compass bearings refer to true north.

Zimmerman, and C.D. Branch. E.K. Carter and D.A. White supervised the mapping and also took part in the field work. In the Silurian synclinorium outcrops were mapped on a scale of 700 feet to the inch (photo-scale), but the Ordovician horsts and the granites were mapped only on a reconnaissance basis (see Fig 2). The geological map of the area to the south of Lake George mine is based on the detailed maps of the geologists of Lake George Mines Pty Ltd. and on reconnaissance surveys by the Bureau of Mineral Resources.

Geochemical Survey

The search for mineral deposits included reconnaissance geochemical sampling of the residual soils in the Captains Flat Synclinorium and on outliers of Silurian strata to the south. The trellised drainage pattern of the area was used as a natural grid pattern for sampling, and soil samples were collected at 200-yard intervals with a 3-inch auger from the 'B' horizon of the residual soils along the valley bottoms. Water samples were collected from springs and seepages wherever the water was discoloured or acid, or contained sulphate, or had an unusual taste. Salt encrustations were collected, and gossans were sampled.

The geochemical survey began in May 1961, and 5000 samples were collected. The samples were analysed in the laboratory of the Bureau of Mineral Resources by S. Baker, E.J. Howard, N. Le Roux, and J.R. Beevers.

STRATIGRAPHY

Introduction

The following description of the lithology and distribution of the sediments and intrusives is a brief account of regional characteristics compiled from observations made during the survey and from mine records. More detailed description of rock types and underground workings can be found in the 'Geology of Australian Ore Deposits' (1953, pp. 910-920), Edwards & Baker (1954), and Glasson (1957).

Ordovician

Foxlow Beds

The oldest rocks in the Captains Flat area are the Foxlow Beds, a 4000-foot sequence of greywacke and shale (Fig 5). The Foxlow Beds crop out in two areas: The Rocky Peak Horst (Fig. 3), where they form a long narrow strip along the contact of the Rocky Peak Granite; and the Harrisons Peak Horst, where they crop out in a north-plunging anticlinorium. The lower part is a sequence of alternating greywacke and shale. The beds of greywacke range from 1 to 6 feet thick, and they decrease both in number and thickness upwards. They are dark grey and consist of rounded and subrounded grains of quartz, feldspar, and fragments of shale and siltstone 0.5 to 2mm across set in a fine-grained matrix of chlorite, biotite, sericite, quartz, and iron oxide. The interbedded shales range from dark to light grey and are well cleaved. The middle part of the Foxlow Beds consists of alternating shale and siltstone with a few thin beds of greywacke. The upper part is mainly shale, with a few thin beds of siltstone. The shales range from dark to light grey and from red to yellow, and some are well cleaved. The beds are mostly from 20 to 100 feet thick, but some are as thin as an eighth of an inch. There is some slight metamorphism: many of the quartz grains in the greywacke show

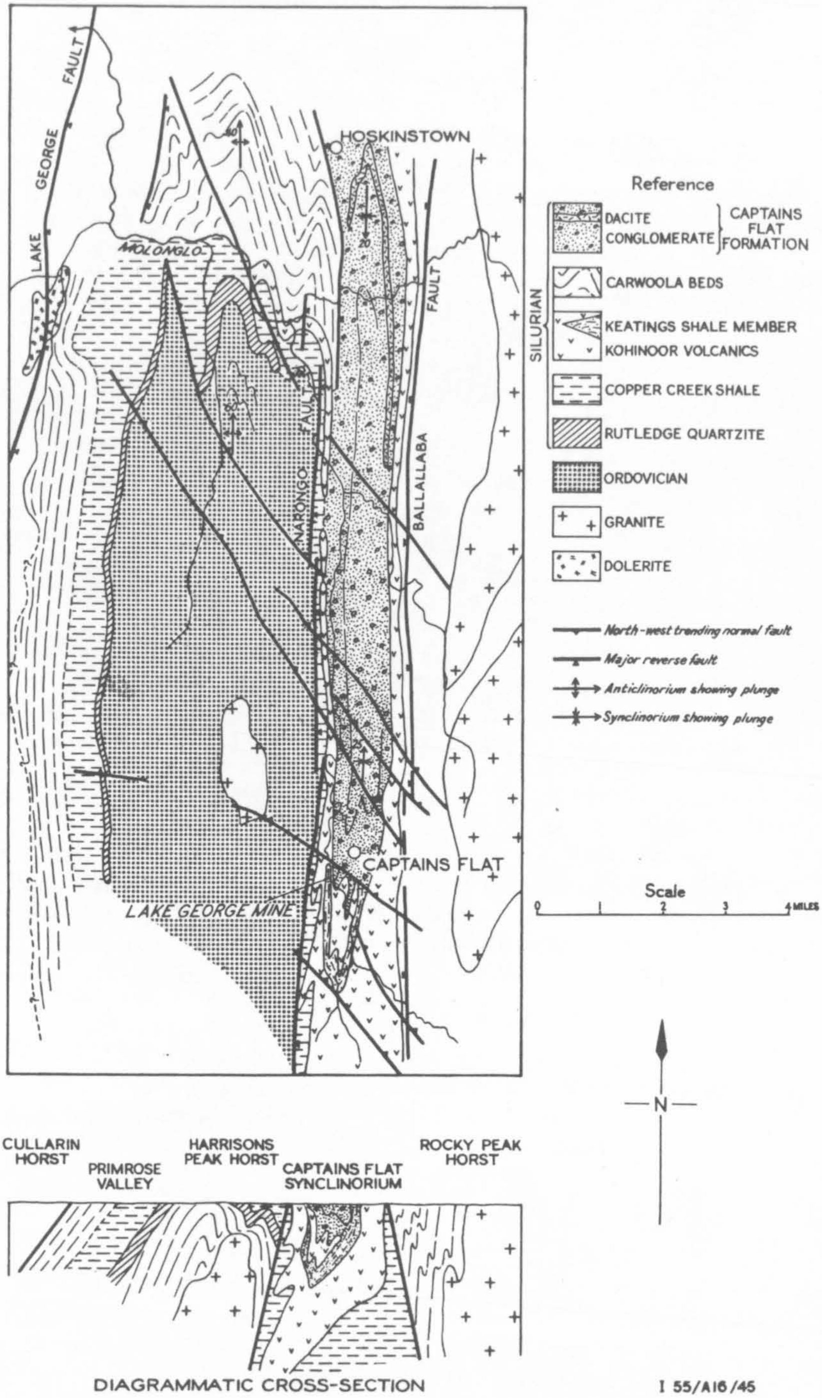

Fig. 2. General geology of Captains Flat area

marginal intergrowth with the groundmass, and some of the shale beds are extensively sericitized.

The upper part of the Foxlow Beds contains a distinctive and extensive marker bed - the Bullongong Shale Member. The member is 200 feet thick and consists of graphitic black shale with disseminated pyrite and chalcopyrite. In places it is highly contorted, sheared, and silicified. Graptolites found in unsheared parts of the shale have been identified by A. A. Öpik as *Mesograptus multidens*, *Nemagraptus tricornis*, *Dicranograptus glingani*, *Climacograptus bicornis*, *Leptograptus* sp., and *Dicellograptus* sp. These date the shale as Upper Ordovician, Zones 10 to 12 (Gisbornian). It appears to be the local representative of the Acton Shale in Canberra (Öpik, 1958), though it is slightly older. A similar graptolitic black shale is widely distributed in New South Wales. It consists of quartz dust and carbonaceous material, and is thought to be a widespread dust deposit; Joplin (1945) ascribed it to volcanic dust, but later authors (see Öpik, 1958) see little evidence of widespread vulcanicity. The Bullongong Member is well exposed at Captains Flat Railway Station.

Thin beds of fine-grained white quartzite, from 1 to 3 feet thick, occur in the Upper Ordovician on the Cullarin Horst in the north-western part of the area.

Silurian

Rutledge Quartzite

The Rutledge Quartzite, with a maximum thickness of 300 feet, consists of beds of white quartzite and conglomeratic quartzite, 2 to 6 feet thick, interbedded with thin siltstone. The conglomeratic quartzite contains rounded cobbles, up to 6 inches across, of white quartzite, silicified black slate, and silicified grey slate which were probably derived locally from the Upper Ordovician. The quartzite is composed of poorly sorted rounded grains of quartz set in a sparse fine-grained silicified matrix. Many of the quartz grains have sutured margins and irregular outlines, which suggests that they have been partly resorbed and metamorphosed. Very few bedded planes, and no current or graded bedding, were noted. The quartzite has been tightly folded, extensively sheared, and invaded by veins of white quartz from 2 to 6 inches wide. Some of the cobbles in the conglomerate have been elongated parallel to the minor folds. In places the quartzite contains disseminated cubes and irregular masses of pyrite up to a quarter of an inch across.

During the folding of the Captains Flat Synclinorium the Rutledge Quartzite was broken up into numerous sheared lenses, ranging from 150 to 1500 feet long and from 3 to 300 feet thick, which crop out along both limbs of the synclinorium and round the nose of the north-plunging anticline on Harrisons Peak Horst (Fig. 2). The quartzite crops out as narrow rocky ridges and forms a useful marker bed. The best exposure is near the Grose Meadow Trig.

Copper Creek Shale

The Copper Creek Shale is a sequence of thin-bedded grey shale, black shale, argillaceous siltstone, and thin beds of tuff from 200 to 300 feet thick. The shales contain thin lenses, small pods, and disseminated crystals of pyrite and chalcopyrite. Small lenses of limestone, less than 100 feet thick and 500 feet long, occur near the middle of the formation. A. A. Öpik has identified the following fossils from the limestone: *Hercophyllum shearsbyi*, *Entelophyllum yassensis*, *Atrypa* sp., bryozoa, gastropods, and crinoid ossicles.

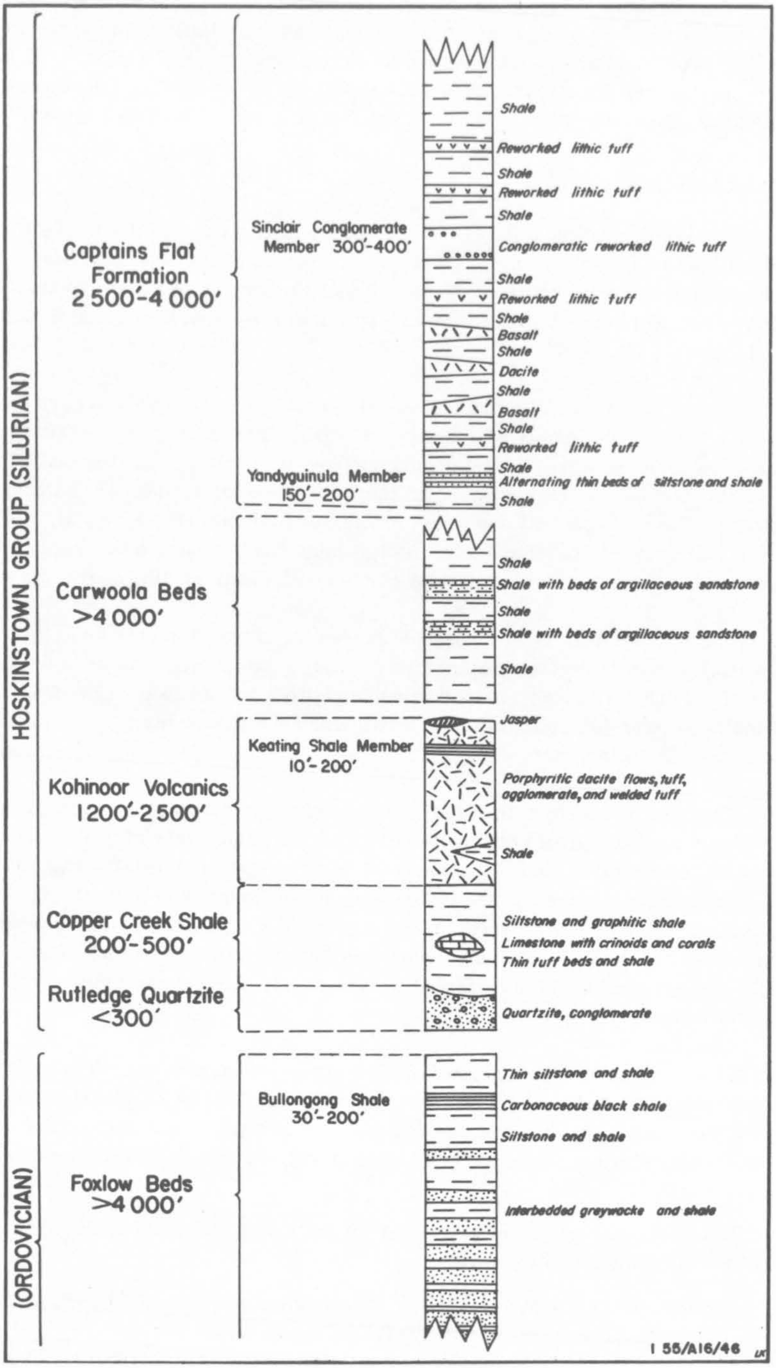

Fig. 3. Stratigraphic succession

The Copper Creek Shale rests conformably on the Rutledge Quartzite. It is an incompetent formation and was contorted and sheared into lenses during the folding of the Captains Flat Synclinorium. It crops out as a series of lenses along both limbs of the synclinorium and in two small anticlines south-west of the mine. The best exposures are in Copper Creek at Captains Flat and in a road cutting near Captains Flat Railway Station.

Kohinoor Volcanics

The Kohinoor Volcanics comprise 2500 feet of strongly foliated dacite agglomerates and tuffs interbedded with flows of dacite, rhyolite, and andesite, and a few beds of shale. Individual flows and beds range from 30 to 100 feet thick and can rarely be traced for more than a mile. The Kohinoor Volcanics near the mine have been described in detail by Lyon (1949) and Glasson (1957).

Agglomerate is the most abundant rock type in the Kohinoor Volcanics. It contains 12-inch bombs, commonly with chilled margins, of pale grey fine-grained porphyritic dacite set in a matrix of dark grey well-foliated porphyritic dacite. The degree of flattening or elongation of the bombs varies according to the intensity of shearing. On Mount Baldwin the bombs are rounded and ellipsoidal and are only slightly flattened (Pl. 2, fig. 1), but in the road cutting half a mile north of the Lake George mine the bombs are markedly flattened and elongated parallel to the pronounced vertical north-south shearing (Pl. 2, fig. 2).

The crystal tuff is composed of broken crystals of quartz and oligoclase with a little interstitial fine-grained granular quartz and plagioclase. Some of the tuffs contain fragments of black shale and fine-grained volcanics up to 2 inches long. One unusual medium-grained granular quartz-feldspar tuff near Ballinafad Creek contains rounded ovoids of white vein quartz up to half an inch across.

The dacite and rhyolite flows are hard blue-grey fine-grained rocks with a well-marked foliation. They generally contain small embayed phenocrysts of quartz, some of which are bipyramidal, orthoclase, and oligoclase, set in a fine-grained foliated matrix of granular quartz and plagioclase studded with flakes and felted masses of sericite and chlorite. In places the matrix has a trachytic texture, but it generally consists of minute intergrowths of quartz and feldspar which have probably been formed by devitrification. The feldspar crystals are generally fresh, but along shear-zones they are highly altered and masses of sericite and chlorite have developed.

The Kohinoor Volcanics contain a few minor lenses of shale. The most important, the Keatings Shale Member, is 20 to 40 feet thick. It is a sheared silicified brown shale near the top of the formation, and has been traced for a mile south of the mine. The orebodies at the mine occur where mineralized shears trending 020° intersect this sheared and contorted shale.

Disseminated pyrite cubes occur in the marginal zones of the shales in contact with, and within, the Kohinoor Volcanics.

Lenses of red jasper, with a maximum thickness of 40 feet, occur along the contact of the Kohinoor Volcanics and the overlying Captains Flat Formation. They also occur along the contact of the Keatings Shale Member with the underlying volcanics. The jasper may be a primary deposit at the base of each major shale sequence, or it may have been formed by silicification of the shales underlain by volcanics.

The Kohinoor Volcanics rest conformably on the Copper Creek Shale (Fig. 3). They acted as a competent bed during the folding of the Captains Flat Synclinorium. They crop out along both limbs of the synclinorium and extend for 15 miles from Mount Baldwin northwards to Hoskinstown (Fig. 3). Outliers occur as far south as Jerangle, 20 miles from Captains Flat, but the upper section of the Kohinoor Volcanics above the Keatings Shale Member appears to be restricted to the keel of the synclinorium and crops out only around Vanderbilt Hill and the Molonglo Dam.

The foliation in the Kohinoor Volcanics resemble a primary flow or bedding foliation. It is commonly vertical and trends northwards parallel to the axial plane of the synclinorium, even in the keel of the synclinorium where it might be expected to curve around the keel or follow the plunge of the synclinorium. The variation in the degree of flattening of the bombs (Pl. 2) shows that the foliation varies in intensity from place to place, and it is possibly an axial plane foliation or shear.

Carwoola Beds

The Carwoola Beds crop out over an area of 10 square miles around Carwoola Trig., 2 miles west of Hoskinstown, and extend southwards along Primrose Valley. Good exposures occur around Carwoola Trig., where the beds appear to rest directly and conformably on the Kohinoor Volcanics.

The Carwoola Beds consist of over 4000 feet of well-cleaved brown shale, grey siltstone, and rhythmically bedded argillaceous brown sandstone. No volcanics are present. The argillaceous sandstones occur in rhythmically interbedded groups, separated by 300 to 500 feet of shale (Fig. 3). Within each group of sandstones, the beds of sandstone increase in thickness from 2 inches at the bottom of the group to 3 feet in the middle and decrease to 2 inches at the top. Graded bedding was found in the sandstones.

Captains Flat Formation

The Captains Flat Formation, forming the core of the Captains Flat Synclinorium, was formerly referred to as the Captains Flat Beds (Glasson, 1957; Paine, 1961). It is well exposed on Town Hill at Captains Flat, and consists of 2500 to 4000 feet of well-cleaved dark grey shale, reworked lithic tuff, acid crystal tuff, dacite flows, and basalt flows (see Fig. 5).

The Yandyguinula Member, near the bottom of the formation, is a 200-foot sequence of alternating beds of grey siltstone and shale, ranging from one eighth of an inch to 4 inches thick. The thicker beds of siltstone contain worm tubes. The member is well exposed along the eastern limb and round the southern keel of the Captains Flat Synclinorium.

The beds of reworked lithic tuff are dark grey coarse-grained rocks consisting of fragments of shale, siltstone, sandstone, fine-grained volcanics, and rounded grains of quartz and feldspar set in a fine-grained matrix of shale, quartz and sericite. Some of the thinner and finer-grained beds show graded bedding. Derived crinoid ossicles and brachiopods have been found in the fragments of shale and in the matrix.

The middle of the formation contains beds of light grey crystal tuff composed of fragments of quartz and plagioclase set in a matrix of minute grains of quartz, plagioclase, sericite, epidote, and calcite. Some of the tuffs, which consist largely of broken and angular crystals with a subordinate matrix, probably represent air-fall tuffs, but others, which are composed of rounded crystals set in an abundant matrix containing crinoid ossicles, are probably reworked crystal tuffs.

Dacitic flows and tuffs occur in the middle of the Captains Flat Formation and crop out in the northern keel of the synclinorium (Fig. 2). Basalt flows also occur in the middle of the formation and crop out in both the northern and southern keels of the synclinorium. A few of the basalt flows have vesicular tops, but none of them are spilitic or show pillow structure. The basalt consists of small euhedral crystals of poorly twinned plagioclase, actinolite, biotite, minute flakes of sericite and biotite, needles of actinolite and grains of epidote. The small aggregates of calcite are probably vesicular infillings.

The Sinclair Conglomerate Member, near the top of the formation, comprises a sequence of interbedded shale and reworked lithic tuff up to 400 feet thick (Fig. 3). Some of the beds of reworked lithic tuff contain rounded boulders, up to about 18 inches across, of white quartzite, dark grey slate, black slate, white dacite, and granite. No current bedding or flute casts were noted. This distinctive unit has been traced for 8 miles along the western limb of the synclinorium and round the northern keel to the eastern limb, but it has not been found in the southern keel.

The Captains Flat Formation rests conformably on the Carwoola Beds north of Hoskinstown, but in the Captains Flat Synclinorium it overlaps them and rests directly on the underlying Kohinoor Volcanics. The Captains Flat Formation contains indigenous and derived Silurian brachiopods, corals, and crinoids. A. A. Öpik has identified the following forms: Favosites gothlandicus, Alveolites, Rugosa, Bryozoa, Lingula, and Rhynchonellids.

Permian(?)

The coarse river gravels around the foot of Mount Bollard in the upper part of the Molonglo Valley are about 3200 feet above sea level. The gravels consist of rounded and subrounded cobbles of quartz and quartzite, up to 6 inches across, set in a sandy matrix.

A similar gravel, probably of the same age, caps the low hills along the southern side of Yandyguinula Creek, a tributary of the Molonglo. The gravel contains a few angular blocks of white quartz up to 4 feet across, and the upper part of the gravel has been silicified to form a hard compact layer of 'billy'. The gravels occur about 100 feet above the present flood-plain of the Yandyguinula and Molonglo and may be high-level terrace gravels. They are similar to the Fyshwick gravels in the Australian Capital Territory, which have been interpreted as Permian glacials by Öpik (1958).

Quaternary

The Molonglo flood-plain is covered with gravel, sand, and silt, laid down during the last phase of aggradation. The alluvium was contaminated by lead and zinc and copper-bearing tailings swept down from Lake George mine during a flood in 1942.

IGNEOUS INTRUSIONS

Rocky Peak Granite

The Rocky Peak Granite, on the eastern margin of the Captains Flat area, crops out over an area of at least 50 square miles along the crest of the Great Dividing Range (Fig. 2). It was not mapped in detail.

The main rock type is coarse-grained biotite-oligoclase-microcline granite with feldspar crystals up to half an inch across. Towards the western contact, the proportion of microcline decreases, and the rock grades into a medium-grained granodiorite. In the marginal zone the granodiorite has a well-marked foliation, and the xenoliths, biotite flakes, and hornblende crystals have a vertical orientation parallel to the contact.

Numerous small pods of medium-grained hornblende diorite, grading into amphibolite composed of interlocking crystals of plagioclase and actinolite, crop out along the western margin of the granite. They may represent a contaminated marginal phase of the granite.

Harrisons Peak Granite

The Harrisons Peak Granite crops out over an oval area of 2 square miles, 2 miles north-west of Lake George mine. It is generally a homogeneous non-foliated medium-grained grey granite with phenocrysts of feldspar from one-eighth to one quarter of an inch across. There are no veins of pegmatite, aplite, greisen, or quartz in the granite.

Amphibolite

Most of the amphibolite occurs along the western margin of the Rocky Peak Granite, but one small mass crops out in the Captains Flat Formation on the banks of Ballallaba Creek. It is a concordant lenticular intrusion, 2700 feet long from north to south and 300 feet wide. It is a medium-grained granular greenish rock, pegmatitic in places, with crystals of hornblende up to a quarter of an inch long. The overlying soils contain up to 160 ppm of Cu (eight times background), and a specimen of the amphibolite was found to contain 200 ppm. Further sampling showed that the anomaly is restricted to a small area, with maximum Cu values of 200 ppm.

Dolerite

Several dykes and one large lens of dolerite occur in the area. The dykes cut the Kohinoor Volcanics near Captains Flat. Most of them trend north parallel to the foliation. One of the dykes near the Foxlow gold mine contains disseminated pyrite.

One of the dolerite dykes near the Lake George mine has a north-westerly trend parallel to the Molonglo Fault. This dyke was intersected in the mine workings, where it was found to be displaced by the shear-plane along the lode channel, and to be partly mineralized (Glasson, 1957, p.35).

A north-trending lens of dolerite, grading into gabbro in places, crops out over an area, 2 miles long and a quarter of a mile wide, in Primrose Valley. It occurs along the Lake George Fault and has been cut by numerous shear-zones.

The dolerite has an ophitic texture and consists of plagioclase laths intergrown with subhedral crystals of augite. The plagioclase has been saussuritized, and the augite is rimmed and veined by actinolite. Skeletal crystals of ilmenite and granular epidote are abundant.

STRUCTURE

The Captains Flat area consists of a north-trending synclinorium of Silurian strata in a narrow graben bounded to the east and west by horsts of contorted Ordovician metasediments invaded by granite (see Figs 2 and 4).

The major structural elements - faults, shear-zones, fold axes, and cleavage - all have a northerly trend. The area was folded along north-south axes at the end of the Ordovician - the Benambran Orogeny - and again at the end of the Silurian - the Bowning Orogeny. During this later and more intense period of deformation, the area was broken up by north-south reverse faults and by later north-westerly faults.

Benambran Folding

The Ordovician strata in the Rocky Peak and Harrisons Peak Horsts contain few marker horizons, and their detailed structure is uncertain.

The evidence for Benambran folding includes (a) the slight difference in trend between the fold axes in the Ordovician strata and those in the Silurian strata in the northern part of the Harrisons Peak Horst; (b) the period of non-deposition, or erosion, in Lower Silurian times; and (c) the presence of cobbles of Ordovician slate and quartzite in the conglomerate at the base of the Wenlockian strata.

There are a few marker horizons in the Upper Ordovician strata in the northern part of the Harrisons Peak Horst. The Bullongong Shale Member and several greywacke beds can be traced for about a mile, and some of the structure can be deciphered. The fold axes plunge at 60° towards 010° and the cleavage trends 010°; whereas the fold axes in the overlying Silurian to the north plunge at 40° towards 360° and the cleavage trends 360° (Fig. 4).

Bowning Orogeny

At the end of the Silurian period, the folded Ordovician and the overlying Silurian strata were folded around north-south axes and were faulted into horsts and graben.

The major structure in the area is the Captains Flat Synclinorium, which is 20 miles long and 2 miles wide. It plunges gently to the north, but there are a few minor reversals in plunge and changes in trend. Near Lake George mine, the synclinorium plunges at about 25° towards 010°; north of the mine it is sub-horizontal and trends 360°; south of Hoskinstown it plunges 20° towards 180°; and north of Hoskinstown reverses again to 20° towards 340°.

The Rocky Peak Horst

The Rocky Peak Horst consists of isoclinally folded Ordovician micaceous siltstone and shale which have been invaded by a large mass of granite. The bedding, cleavage, and fold axes trend north parallel to the contact of the Rocky Peak Granite, which forms the core of the horst. There are two sets of isoclinal folds (see Fig. 4): one set plunges north at 60° and the other south at 40°. In places an early cleavage foliation, probably Benambran, has been isoclinally folded. Crinkle jointing (herringbone or chevron structures) with north-westerly 'S' planes parallel to the north-west faults occurs in places.

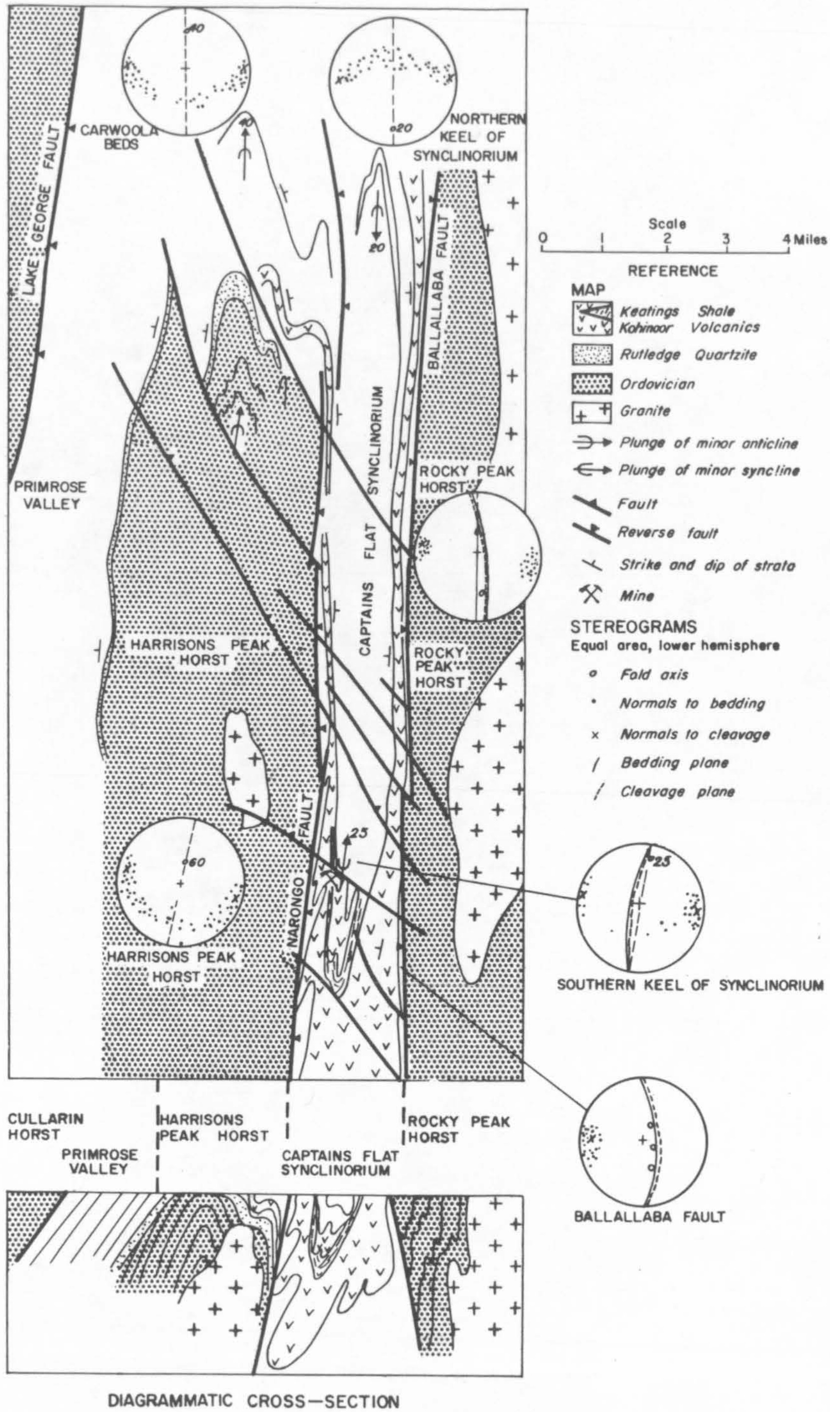

Fig. 4. Structure of the Captain's Flat area

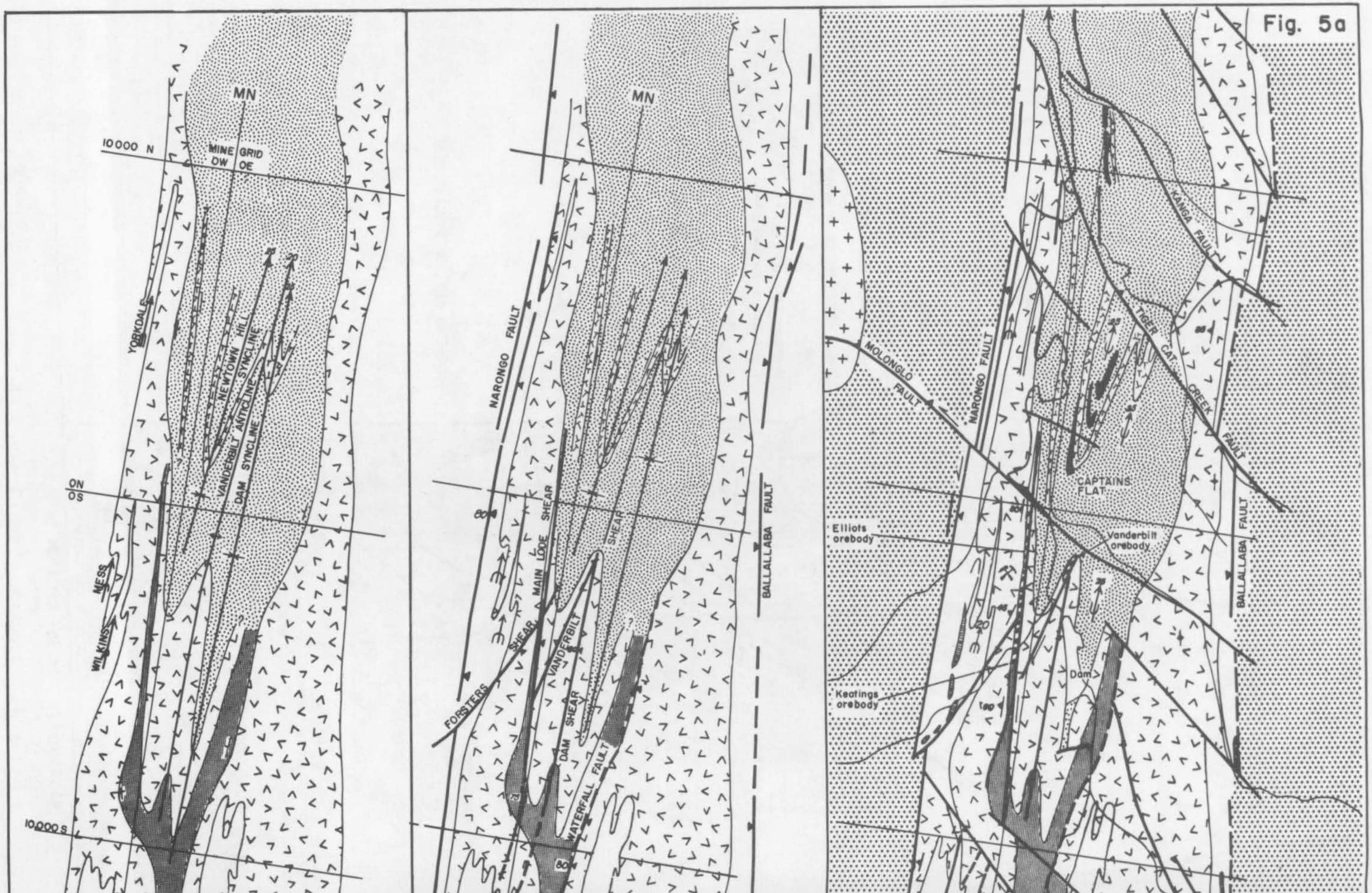

Fig. 5a
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MINE GRID
OW OE
10000 N
ON
OS
10000 S
YORKDALE
NEWTOWN HILL
SYNCLINE
VANDERBILT ANTICLINE
DAM SYNCLINE
MESS
WILKINS
HICKEY
Stage 1
Folding
NARONGO FAULT
MAIN LODE SHEAR
SHEAR
FORSTERS SHEAR
VANDERBILT SHEAR
DAM SHEAR
WATERFALL FAULT
BALLALLABA FAULT
Stage 2
Thrusting
MOLONGLO FAULT
NARONGO FAULT
KANGA FAULT
TIGER CAT CREEK FAULT
CAPTAINS FLAT
Elliots orebody
Vanderbilt orebody
Dam
Keatings orebody
BALLALLABA FAULT
GOLFCOURSE FAULT
Stage 3
Faulting
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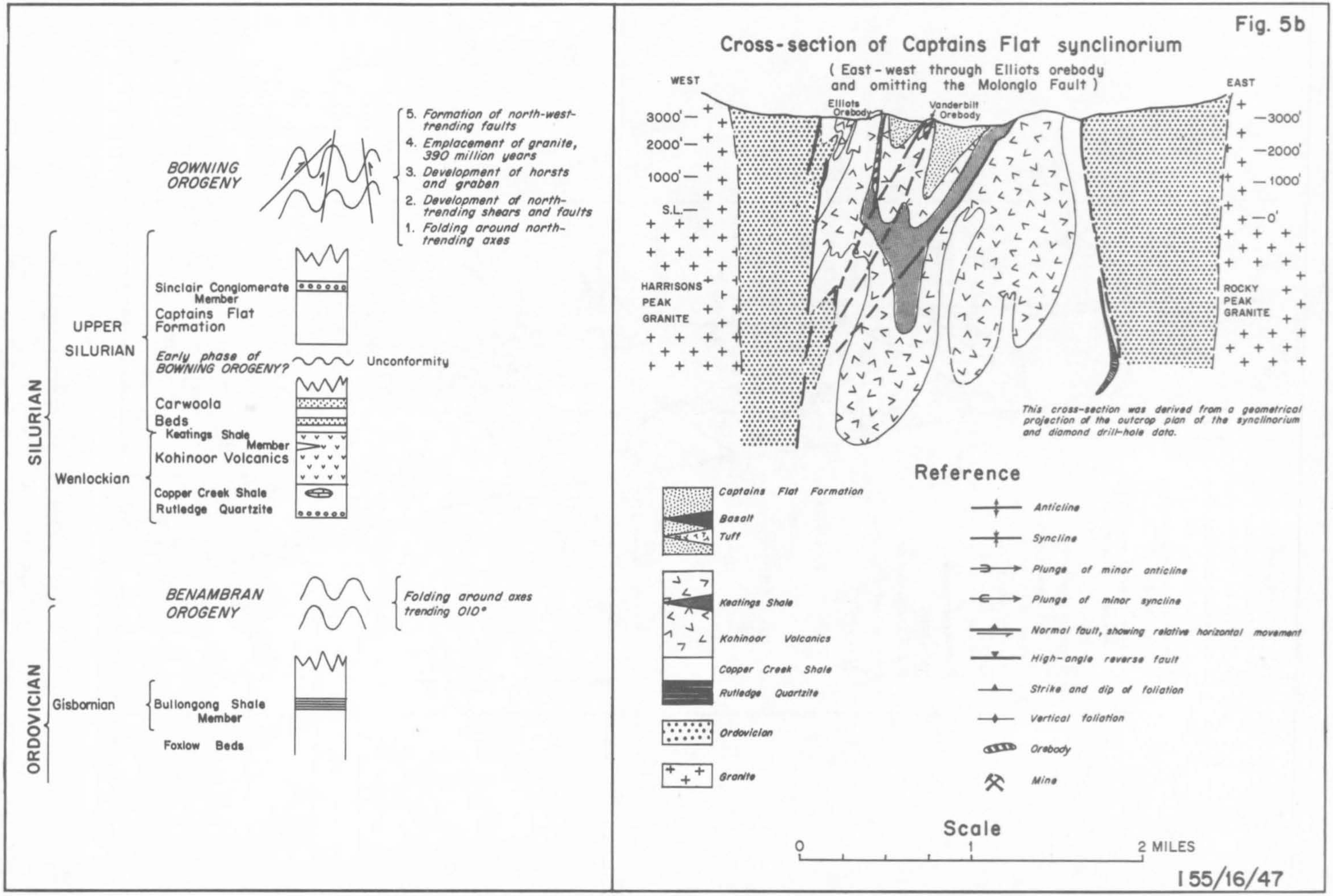


Fig. 5. Development of major structures and cross-section of Captains Flat synclinorium

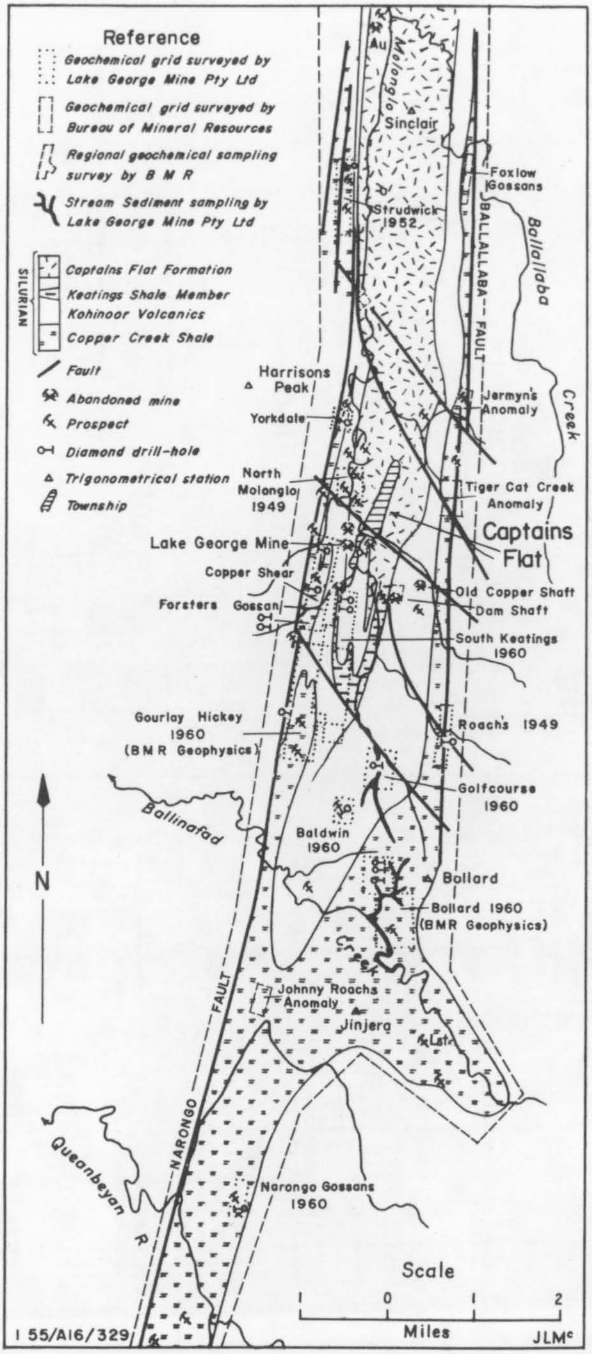


Fig. 6. The search for base-metal sulphide deposits in the Captain's Flat area

Harrisons Peak Horst

The northern part of the Harrisons Peak Horst consists of an anticlinorium of Ordovician greywacke and shale plunging at 60^{o} towards 010^{o}, overlain by folded Rutledge Quartzite, Kohinoor Volcanics, and Carwoola Beds plunging at 40^{o} towards 360^{o} (see Fig. 4). No refolding of the Benambran folds was found, but there is a slight difference in trend.

The Captains Flat Synclinorium

The synclinorium was folded twice, and owing to the different competencies of the different strata, it folded disharmonically.

The Kohinoor Volcanics and the Carwoola Beds were gently folded, and in places the Carwoola Beds were removed by erosion before the Captains Flat Formation was deposited. There was some differential slip along the Keatings Shale Member during the final folding. The strata above Keatings Shale were folded into a simple twin-keel structure, whereas the strata below were folded into one major asymmetric keel with numerous minor folds and dragfolds on both limbs (see Figs 5a and 5b).

The twin-keel structure consists of the contiguous Dam and Newtown Hill Synclines separated by the Vanderbilt Anticline (see Fig. 5a). North of the mine the strata have a northerly trend with minor reversals of plunge. The twin keels re-appear south of Hoskinstown, where they plunge south at 20^{o} towards 180^{o}. North of Hoskinstown they plunge north at 40^{o} towards 340^{o}.

The Kohinoor Volcanics below the Keatings Shale were folded and thickened into one major keel which, on the golf course 4 miles south of Captains Flat, plunges at 20^{o} towards 010^{o}. This syncline is flanked to the west by numerous smaller folds and dragfolds which plunge north at 20^{o} towards 010^{o} (see Hickey, Wilkins, and Yorkdale Anticlines on Fig. 5a). The Hickey Anticline contains a core of probable Ordovician black slate overlain by sheared remnants of the Rutledge Quartzite. The eastern limb of the synclinorium contains several minor folds which plunge north at about 20^{o}. The cores of these folds crop out on Bollard Mountain and contain Copper Creek Shale, Rutledge Quartzite, and probable Ordovician black slate.

During the later stages of the folding, the disharmonically folded sequence of incompetent shales and competent volcanics and quartzites was broken up by a series of north-south faults and shears which developed along the shale beds and the axial planes (Fig. 5b). The western limb was overturned to the east; the axial planes and the strata dip steeply towards the west at 70 to 80^{o}.

The first shear was possibly the Main Lode Shear within the Keatings Shale Member. The disharmonic folding of the overlying and underlying competent volcanics would cause extensive slipping and shearing along the shale bed between them. The east block has been displaced 120 feet north along this shear-zone.

Glasson (1957) regards the Waterfall Fault along the western margin of the east limb of the synclinorium as the most important fault in the area (Fig. 5a). This fault has little surface expression, except in the south, but it forms a zone of weakness which has been etched out by erosion. The whole of the western limb of this part of the synclinorium appears to have been thrust upwards and eastwards along this fault. Later overthrusting affected only the western limb, which over-rode the eastern limb. The eastern limb is relatively little sheared, and is not so plicated as the western limb; it does not appear to be a favourable locus for mineralization, except for the contorted quartzites of the Bollard area in the south.

The Dam Shear is a mineralized shear along the axial plane of the Vanderbilt Anticline. It is well exposed in the Molonglo at the foot of the dam wall, but to the south it is covered by tailings.

Forsters and Vanderbilt Shears are two prominent members of a series of shears, known as the Narongo Shears, which diverge eastwards from the Narongo Fault. Close to the fault they trend 040°, but farther east, near the Main Lode Shear, the trend changes to 020°. The Vanderbilt Shear extends to the Vanderbilt orebody and Forsters Shear follows Forsters Gully. These are only two of the numerous shears which diverge from the Narongo Fault. They form favourable loci for orebodies where they intersect the Main Lode Shear. The Narongo Shears dip to the west at 70° to 80°; they may be slightly convex to the east, and were probably formed in response to local overthrusting to the east.

Major Faults

The Captains Flat area was broken up into horsts and graben by major reverse faults trending north-south.

The Narongo Fault, which forms the western margin of the Captains Flat Synclinorium, has been traced for 37 miles from Jerangle to Hoskinstown. The fault consists of a zone, 50 to 200 feet wide, of parallel high-angle reverse faults which dip to the west at 70° to 80°. The outcrop of the fault zone is defined by breccias, some of which are mineralized, and quartz veins. The Harrisons Peak Horst was upthrown to the east along the Narongo Fault and tilted down to the north. The fold axes in the horst plunge steeply to the north, whereas the plunge of the folds in the synclinorium ranges from 20° south to 20° north (Fig. 4).

The Ballallaba Fault, which forms the eastern margin of the Captains Flat Synclinorium, has been traced for 16 miles. It is a high-angle reverse fault, and the Ordovician sediments to the east have been thrust up a few thousand feet against Silurian strata. The fault appears to have developed mainly within the Bullongong Shale Member of the Foxlow Beds, and is defined by zones of contorted slate, 20 to 100 feet wide, and veins of quartz.

These major faults were formed towards the end of the Bowning orogeny, when, after a period of intense folding, the rocks yielded to further stress by fracturing, and broke up into horsts and graben.

The movement along the major fault-zones appears to have been so intense that many of the older structures in the adjacent rocks were destroyed and a planar foliation was imposed parallel to the fault plane (see Ballallaba Fault-zone in Fig. 4). Close to the fault-zone the twice-folded Ordovician sediments cannot be distinguished from the once-folded Silurian sediments.

The North-westerly Faults

The final episode in the tectonic history of the Captains Flat Synclinorium was its disruption by north-westerly faults (e.g. the Molonglo, Golf Course, and Tiger Cat Creek

Faults, Fig. 5a). These faults offset the folding, the north-trending shears, and the orebodies. Some can be traced for up to 9 miles from the Rocky Peak Horst, across the Captains Flat Synclinorium, and across the Harrisons Peak Horst.

The Molonglo Fault cuts off the northern extensions of Elliots and Vanderbilt orebodies. Its north-block-down (over 1500 feet) and west (240 feet) movements have apparently carried the orebodies down beyond the limits of exploration and they have not yet been found in spite of extensive drilling. The fault extends westwards into the Harrisons Peak Granite.

The Golf Course Fault has a large but unmeasured north-block-down movement combined with a probable north-block-east movement. The fault obscures the closure of the Kohinoor Volcanics rounded the nose of the Hickey Anticline, and has displaced the axis of the anticline an unknown distance to the east. This makes it difficult to predict the position of the Hickey Anticline under the mine.

The three sets of crenulation cleavages, crinkle joints, or 'S' planes, were formed during the structural deformation associated with the faulting. Their late development is indicated by their deformation of intensely sheared and foliated volcanics and shales in different parts of the synclinorium. Two sets are vertical and trend 320° and 030°, and a third dips at 50° on a bearing of 160°. According to Rickard (1961) the 'S' planes are developed only in previously foliated rocks in response to local minor stresses. In the Captains Flat area they may be associated with local movements along the north-west-trending faults or with the regional forces associated with the faulting.

GEOLOGICAL HISTORY

The oldest rocks exposed in the Captains Flat area are the greywacke at the base of the Foxlow Beds. No current-bedding, flute casts, or fossils were found and the source of the greywackes is unknown. The Bullongong Shale Member has been dated as Gisbornian and extends over a wide area. The Upper Ordovician beds in the Cullarin Horst consist of thin quartzites which suggest a shallowing of the sea.

In the Captains Flat area there is a gap in the stratigraphical column between the Upper Ordovician and the Wenlockian. During this period, the Ordovician strata were folded around north-trending axes (Benambran orogeny) and various members of the Upper Ordovician were stripped off by erosion before the basal Silurian conglomerate - the Rutledge Quartzite - was laid down unconformably across the area (Fig. 5b). The Rutledge Quartzite contains rounded cobbles of quartzite and silicified shale derived from the underlying Ordovician.

The Rutledge Quartzite is succeeded by the Copper Creek Shale, which contains lenses of Wenlockian coral reef limestone. This was followed by a period of extensive volcanic activity which resulted in the deposition of nearly 3000 feet of dacite tuff, agglomerate, and lava - the Kohinoor Volcanics - in the area between Hoskinstown and Jerangle.

After the cessation of volcanic activity, the Carwoola Beds, a 4000-foot sequence of shale and argillaceous sandstone, were deposited. No current-bedding, flute casts, or fossils were found in the beds.

The area was folded slightly and somewhat eroded before the Captains Flat Formation was laid down. The formation rests on the Carwoola Beds at Hoskinstown and on the Kohinoor Volcanics at Captains Flat. This slight earth movement was followed by a renewal of volcanic activity, and both acid and basic flows and tuffs were deposited in the Captains Flat Formation. The formation was laid down in a shallow-water near-shore environment, for some of the reworked lithic tuffs contain beds of conglomerate with well-rounded cobbles of slate, quartzite, dacite, and granite. The presence of granite boulders is of interest because no pre-Bowning granites are known in the area.

After the deposition of the Captains Flat Formation, the area was subjected to its most intense period of deformation - the Bowning orogeny - and was folded around north-trending axes which in places trend slightly across the earlier Benambran axes. As folding continued, slippage occurred along incompetent strata, and the rocks parted along north-trending faults. During the final stages of the orogeny, movement took place along reverse faults dipping steeply to the east and west, and the area was broken up into graben and horsts trending north-south. The Harrisons Peak and the Rocky Peak Granites were probably emplaced during these final stages. The adjacent Tinderry, Boro, and Shannons Flat Granites have been dated as 390 million years old (Evernden & Richards, 1962). The final phase of movement was the disruption of the area along north-west-trending faults. One of these, the Molonglo Fault, cuts the Harrisons Peak Granite. Some basic intrusives were emplaced during the orogeny.

The copper-zinc-lead orebodies at Lake George mine were emplaced during the Bowning orogeny. The later gold-quartz mineralization appears to be associated with the last phases of the Bowning granites towards the end of the orogeny.

The only post-Silurian deposits in the area are the silicified gravels along the terraces of the Molonglo and the alluvium on the floodplain. Some of the gravel resembles the Fyshwick Gravel in Canberra, which Öpik (1958) has identified as a Permian fluvioglacial deposit; if this is correct, most of the features of the present landscape date from the Permian.

GEOCHEMICAL SURVEY

Introduction

Between 1949 and 1960 the staff of Lake George Mines Pty Ltd carried out detailed geochemical surveys over several prospects which they had found (Fig. 6). Samples of soil, bedrock, and gossans were collected at intervals of 50 feet along north-south lines 200 feet apart. The anomalies with high zinc, lead, and copper were drilled, and some were found to be associated with narrow lodes of chalcopyrite, sphalerite, and galena.

In view of the successful use of geochemical surveys in the area, the Bureau of Mineral Resources made a reconnaissance geochemical survey over the whole of the Captains Flat Synclinorium and its southern outliers in an attempt to find new lead-zinc-copper orebodies.

Five thousand samples of soil, water, salt encrustations, and gossans were collected over an area extending for 27 miles from north to south and for 2 miles from east to west centred on Captains Flat. Owing to limitations of time and laboratory facilities the samples were analysed for zinc and copper only.

One hundred and ten anomalies were found, most of them associated with small gossans and mineralized shear-zones. Ninety three of the anomalies occurred on the Copper Creek Shale, but only four of them warrant further investigation.

Concentrations of zinc and copper in the residual soil could be due to the presence of fragments of metal-rich rock derived from an orebody or mineralized zone exposed nearby, or to the adsorption of zinc or copper from percolating groundwater by particles of clay in the soil.

The Captains Flat area has a highland temperate climate and an annual rainfall of 23 inches. The main springs and streams are perennial. A good cover of residual humid podsols supports extensive dry sclerophyll forest and savannah woodland. The rocks are being broken down by a combination of mechanical and chemical weathering. A permanent downward-percolating flow of groundwater attacks the bedrock, dissolving some of its constituents, percolating through the soils, and redepositing them in favourable horizons.

The water from the springs and seepages was tested for copper, zinc, sulphate, and acidity, and numerous salt encrustations were tested for copper and zinc. It was thought that the clay minerals in the soil would adsorb metals from percolating groundwater, especially where the flow is concentrated in the bottoms of depressions, gullies, and valleys, and soil samples were taken with a 3-inch post-hole auger from the 'B' horizon of the residual soils developed at such localities. The trellised drainage pattern on the Silurian strata was used as a natural grid pattern, and the soil samples were taken at every confluence and at intervals of 600 feet. Samples which contained anomalous values of copper or zinc were checked, and the sample area was re-sampled at closer intervals until the anomaly was delineated.

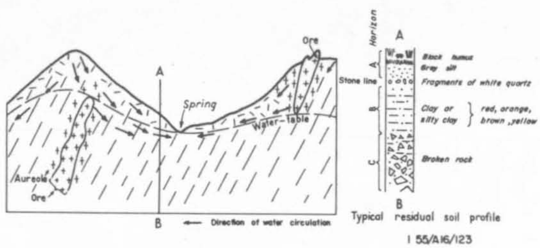


Fig. 7. Circulation of groundwater and possible contamination by mineralization

In the residual soil in the Captains Flat area the complete soil profile ranges from about 6 inches to over 6 feet thick. The 'A' horizon (Fig. 7) usually consists of leached grey silt. This is underlain by a 'stone line', a layer of fragments of white quartz which have sunk through the soil activated by burrowing organisms. In places the stone line was found to be compacted and resisted the augers or broke them. The 'B' horizon is the horizon of secondary enrichment in metals, colloids, clays etc., derived from the leaching of the 'A' horizon and adjacent rocks. Here, the minerals are broken down to red, orange, yellow, or brown clay with varying amounts of sand and silt.

In wet weather it was difficult to distinguish between the silts of the 'A' horizon and the residual clays of the 'B' horizon, and the extra water percolating through the subsoil diluted the springs. Salt encrustations were washed off by the rain, but they reappeared after the water percolating through the rocks had evaporated.

In 1959 the staff of Lake George Mines sampled the active sediments being transported by the streams on the golf course and on Bollard Mountain (Fig. 6) The sediment in the streams flowing off Bollard Mountain had a high metal content which can be traced back to the Bollard anomalies. No active stream sediments were sampled during the 1961 survey because the whole of the Molonglo valley was contaminated by tailings swept down the river in 1942, and the other streams are probably contaminated by the drainage from small mines, prospects, homesteads, eucalyptus stills, and rubbish dumps. Furthermore, the swampy areas are treated with copper sulphate to kill the fluke snail parasite.

DETERMINATION OF COPPER AND ZINC

Standard methods of colorimetric determination were used (Sandell, 1959). 500 mgm of the ground soil sample was digested in a crucible with 2 ml of concentrated sulphuric acid plus 0.5 ml of concentrated nitric acid, and heated until most of the acid had evaporated.

The residue and solution were transferred to a 50 ml measuring cylinder and made up to volume with distilled water. After mixing and settling of the residue, the copper and zinc were estimated colorimetrically by visual comparison with suitable standards. The copper was estimated with biquinoline in amyl alcohol and the zinc with dithizone in carbon tetrachloride.

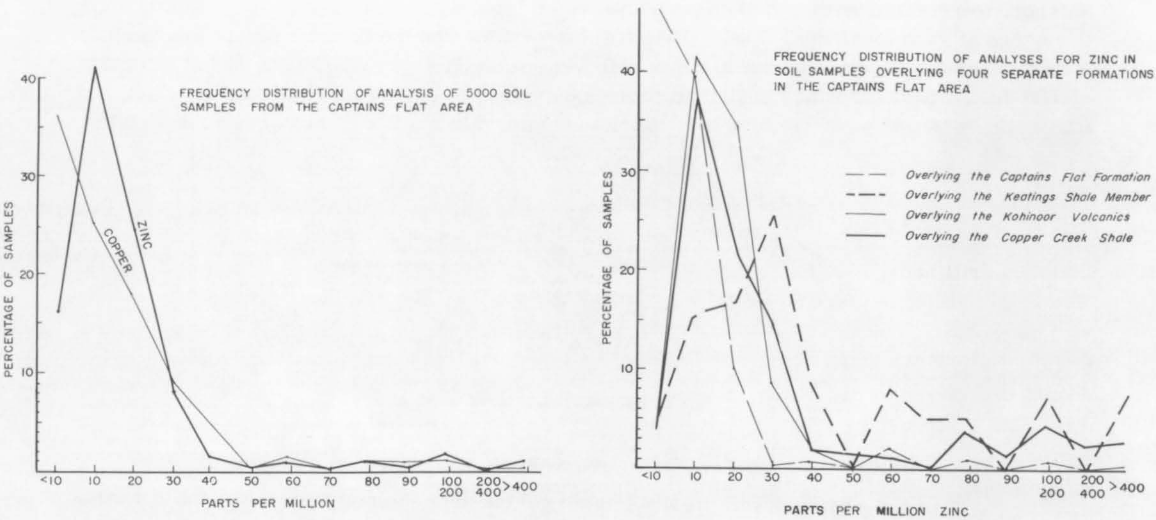


Fig. 8. Histograms of analyses

RESULTS

The results of the reconnaissance geochemical survey are shown on Plates 4 and 5. The major geochemical anomalies are discussed on pp. All prospects previously discovered by the staff of Lake George Mines were detected independently by the reconnaissance survey, and about 80 new anomalies were recorded. Where Bureau sample sites coincided with Lake George Mines sample sites, similar results were obtained.

Analysis of Results

The analyses of the 5000 samples were plotted on a histogram (Fig. 8) which shows that 94 percent of the samples contain less than 40 ppm Cu, and only 2 percent contain 100 ppm or more; 90 percent of the samples contain less than 40 ppm Zn, but nearly 6 percent contain 100 ppm or more. The regional background was taken as 0 to 30 ppm with a modal value of 10 ppm. Zinc is more abundant than copper and values of 100 ppm or over were regarded as significant. The regional background for zinc in water was found to be 0.02 ppm, and values over 0.2 were regarded as significant.

There is a significant variation in the analyses of the samples taken over the different formations. Only 1 percent of the samples over the Captains Flat Formation and the Kohinoor Volcanics contain 100 ppm Zn or more, compared with 11 percent over the Copper Creek Shale. The modal value of the samples over Keatings Shale Member is 30 ppm and 18 per cent of the samples contain more than 100 ppm Zn.

Correlation of Geochemical Anomalies with Adjacent Mineralization

The staff of Lake George Mines collected soil samples from around the gossan above Keatings orebody; the geochemical anomaly was found to extend for only 300 feet across the strike of the orebody and the highest value was 200 ppm Cu.

The mine staff found several anomalies over 'Keatings Extended'; the anomaly at 5500 feet South (mine grid, Fig. 6) covers an area of 400 by 500 feet with Cu valves up to 300 ppm. This anomaly was drilled by the mine, and the borehole (T55) intersected 5 feet of pyrite containing 1 percent Cu.

The mine staff made a detailed geochemical survey over an area showing traces of mineralization on Bollard Mountain and found anomalies extending over an area 4000 feet by 1500 feet with Cu valves up to 400 ppm. The 1961 reconnaissance survey delineated the same general area of mineralization and found anomalies with up to 5500 ppm Zn and 300 ppm Cu.

Lake George Mines tested the northern anomaly on Bollard by sinking four diamond drill holes into a lead anomaly (550 ppm Pb, 100 ppm Cu) at 5000 E, 22,000 S (Fig. 15). Drilling conditions were difficult, and core recovery was very poor. One hole was abandoned, and no core was recovered for the first 400 feet of the others. Values of 1.3 percent Pb over a minimum width of 6 feet were found in one hole, and 6 inches of massive sulphide with 9 percent Pb and 5.4 percent Zn in another.

The figures cited indicate that the size of the anomaly depends on both the size of the orebody and the degree of leaching. The latter is controlled by the rate of flow of the groundwater, acidity, oxidizing and reducing conditions, porosity, and permeability. The orebody at the Lake George mine occurs in impermeable silicified sheared shale enclosed in silicified sheared volcanics and the orebody is not greatly leached. The mineralized zones at Bollard occur in alternating graphitic black shale and porous sandstone. The low core recovery in the diamond drill-holes suggests that the host rocks are intensely shattered and permeable. The anomalies around the small mineralized zones are disproportionately large, owing to the intense leaching.

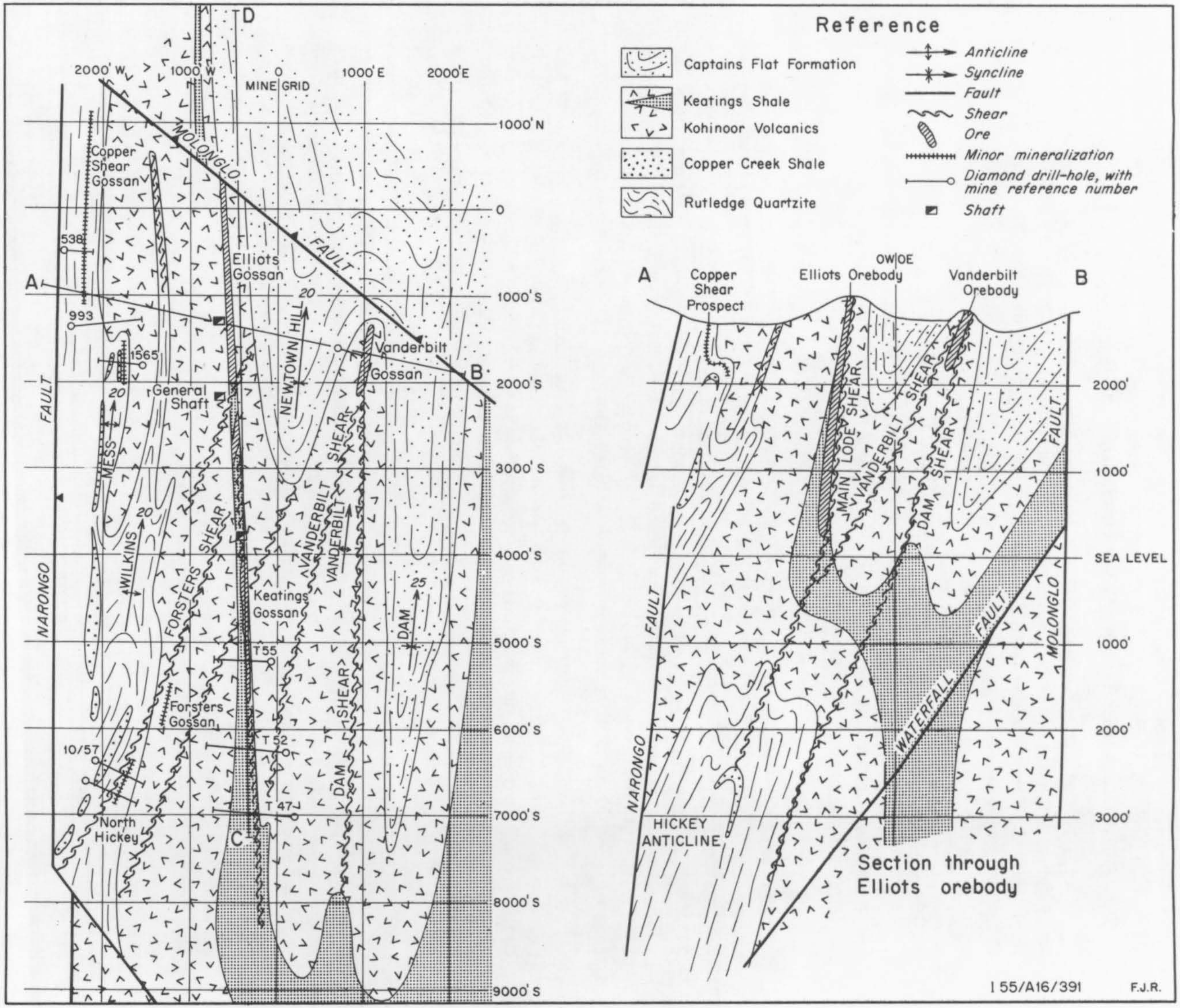


Fig. 9. Geology of Lake George mine area. Based on Lake George mine records and BMR mapping

MINERALIZATION

INTRODUCTION

The sulphide mineralization in the Captains Flat area occurs in the form of:

1. Large masses of sulphides, up to 40 feet thick and several hundred feet long, in the Keatings Shale Member of the Kohinoor Volcanics. They include the Keatings, Central, and Elliots orebodies.

2. Mineralized shear-zones in the Kohinoor Volcanics.

3. Small masses of sulphides, up to several feet thick, in the Copper Creek Shale and the Bullongong Shale Member of the Foxlow Beds.

4. Disseminated sulphides in the Copper Creek Shale and in the Bullongong Shale Member.

The Captains Flat orebodies are part of a north-trending zone of mineralization within a north-south belt of Silurian shale, volcanics, and limestone. Sulphide mineralization occurs along the belt at Cowra Creek, Jerangle, Anembo, Narongo, the Briars copper mine, Woodlands copper mine, Bungendore, Currawong and Breadalbane.

MINERALIZATION IN THE KOHINOOR VOLCANICS

The major orebodies at Captains Flat occur in the Keatings Shale Member of the Kohinoor Volcanics. They include the Keatings, Central, and Elliots orebodies and consist of thin north-south lenses of pyrite, sphalerite, galena, and chalcopyrite. The orebodies have been described by Glasson (1953, 1957), and the mineralogy by Edwards (1943) and Edwards & Baker (1953). The diagrams and cross-sections in Figures 9 and 10 are based on their work and on recent mapping by the Bureau of Mineral Resources. The cross-section of the synclinorium was drawn by a geochemical protection of the geological map. The upper part of the cross-section agrees well with available drill-hole information and with cross-sections of the mine workings.

Keatings, Central, and Elliots Orebodies

The ore consists of pyrite, sphalerite, galena, and chalcopyrite, with a little gold (1.1 dwt per ton), silver (1.63 oz per ton), antimony, and arsenic contained in tetrahedrite (Edwards, 1943).

The pyrite occurs as corroded and embayed euhedral crystals and appears to have been the first mineral to have been deposited (Edwards & Baker, 1953); but it is possible that the euhedral shape of the pyrite is due to its high force of crystallization (Stanton, 1960). The sphalerite has enclosed and embayed the pyrite. The galena and chalcopyrite occur as intergrowths in ramifying fracture fillings and veins.

In places, the ore is massive and homogeneous; in others, it has banded structure, with bands of pyrite alternating with other minerals, or shale.

The orebodies occur as flattened lenses which dip to the west at 80° and pitch to the north at 60 to 70° (see Fig. 10). The major orebodies trend 010°, but in places they are composed of small, contiguous, en-echelon lenses of ore trending 020° (Glasson, 1957). The orebodies developed along the intersections of the Narongo Shears with the Main Lode Shear. The Narongo Shears are an extensive series of shears, trending 020° and dipping westwards at 70 to 80°, which diverge from the Narongo Fault in the mine area. The Main Lode Shear lies within Keatings Shale Member and trends 010° and dips west at 80°. The footwalls of the orebodies are sharp, but the hangingwalls are more diffuse and traces of pyrite persist for a few hundred feet into the Kohinoor Volcanics.

The orebodies occur on the overturned western limb of the Captains Flat Synclinorium. During the folding of the synclinorium the Kohinoor Volcanics above the Keatings Shale Member folded disharmonically in relation to the volcanics below. Extensive differential slip occurred along the shale member and it was sheared out along the major limbs of the synclinorium. The Main Lode Shear may have been formed by this differential slip. The orebodies are restricted to the most highly stressed part of the shale bed near its northern limit. The bottoms of the successive orebodies increase in depth to the north, showing that the ore-bearing zone plunges to the north at about 20° parallel to the plunge of the synclinorium.

During an early stage of folding the synclinorium was disrupted along the Waterfall Fault, and the whole of the western limb was thrust upwards and to the east over the eastern limb. Thus the eastern limb, which is less mineralized, escaped the later stresses which plicated and sheared the western limb.

The western limb contains several minor folds overturned to the east, and plunging to the north at about 20°. The Mess Anticline contains a small lens of mineralization in its crest below the overlying Kohinoor Volcanics. The Hickey Anticline is a major anticline with a core of mineralized Copper Creek Shale which plunges to the north beneath the Keatings, Central, and Elliots orebodies (Fig. 9).

Later deformation caused thrusting and shearing along the axial planes of some of the minor folds on the western limb - e.g. the Dam Shear, Vanderbilt Shear, and the Narongo Shears.

<u>Vanderbilt Orebody</u>

The Vanderbilt orebody is a thin vertical lens of pyrite, galena, and chalcopyrite, with minor amounts of gold and silver. It occurs in highly sheared, foliated, and kaolinized Kohinoor Volcanics at the intersection of the Vanderbilt Shear (trending 020°) with the mineralized Dam Shear (trending 010°) along the axial plane of the Vanderbilt Anticline. The orebody plunges gently to the north but does not persist below 300 to 400 feet, and is cut off to the north by the Molonglo Fault. It has been worked out.

Unlike the other main orebodies, the Vanderbilt orebody does not occur in Keatings Shale. An orebody could have been formed where the mineralized shears intersect the overlying shale in the Captains Flat Formation, and the known orebody may be the bottom of a much larger orebody in the Captains Flat Formation. The major part of this postulated orebody may have been faulted down to the north of the Molonglo Fault. On the other hand, the orebody may be a small lens which developed where the Vanderbilt Shear intersects a large body of kaolin within the kaolinized Dam Shear, which acted as a sheared and stressed shale bed.

Vanderbilt Diamond-Drill-Hole

A gravity high on Vanderbilt Hill (Gibbons, 1962) was drilled in November 1961 (Fig. 12). The core contains traces of zinc at the target depth, but no extensive mineralization was found. The hole was continued for 80 feet beyond the target to 326 feet. The bottom 3 feet of core was found to contain small pods and stringers of pyrite which make up about 3 percent of the rock. The hole was probably entering the Vanderbilt Shear.

The traces of zinc (750 ppm) found at the target depth suggest that the borehole passed through part of the mineralized halo around a small lens of sulphide.

Forsters Gossan

Forsters Gossan is a zone of small gossans, each up to 2 feet long, in sheared kaolinized Kohinoor Volcanics in Forsters Gully half a mile south of the General Shaft. The zone is about 4 feet wide, and has been traced for 600 yards along Forsters Shear. The gossans contain up to 80 ppm Cu and 200 ppm Zn, and the surrounding soil contains up to 180 ppm Cu and 250 ppm Zn.

Sample	Copper (ppm)	Zinc (ppm)
5303	60	50
6264 gossan	80	200
5309	15	60
6126	120	250
6129	180	30
4321	80	80

Dam Shaft

The Dam Shaft prospect on the eastern limb of the synclinorium is located at the intersection of a north-west fault and the Waterfall Fault along the western contact of the Kohinoor Volcanics (Fig. 6).

The spoil heap around the abandoned 150-foot shaft consists of red shale stained with malachite and azurite. The reconnaissance survey found values of up to 500 ppm Zn and 80 ppm Cu, but a detailed geochemical survey by Lake George Mines Pty Ltd revealed only a

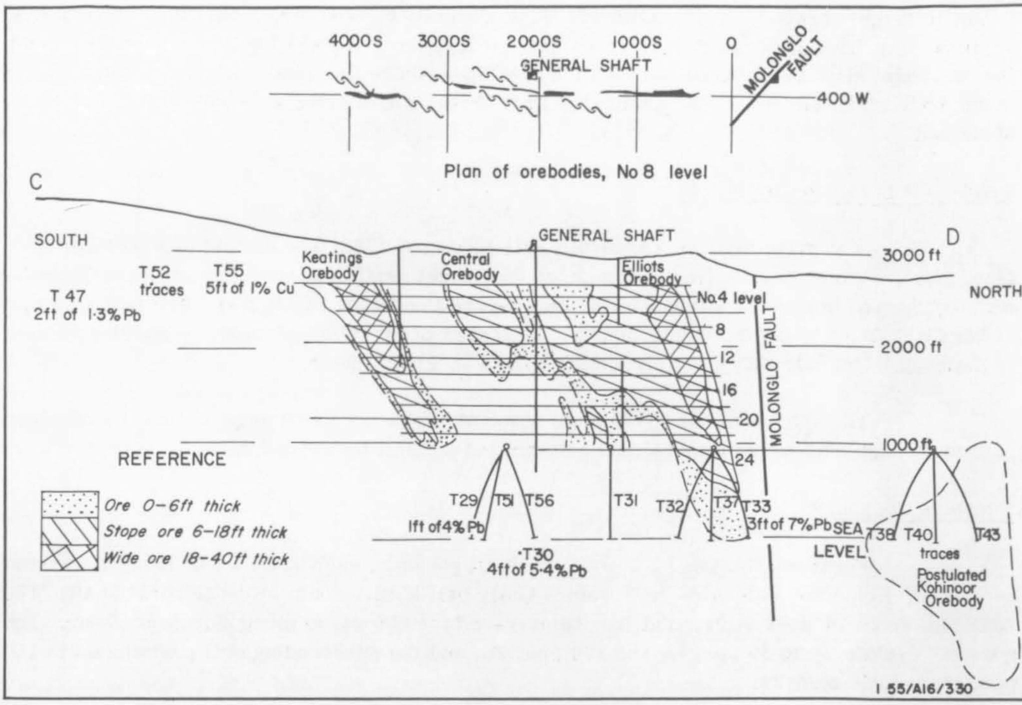
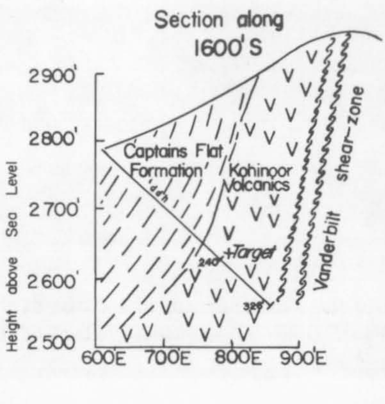


Fig. 10. Longitudinal section of orebodies, Lake George mine



Depth of Sample (ft)	Formation	Lithology	Number of Sample	Cu ppm	Zn ppm	Zinc profile
196	Captains Flat Formation	Red slate				
206		Red slate				
216	Shearing	Ironstone				
226		Sheared kaolinitic dacite	3955	10	30	
236	Fine-grained White Kohinoor Volcanics	4" qtz vein with 5% pyrite Sheared kaolinitic dacite	3954	10	500	
246		Disseminated pyrite	3953	20	750	Target
256		Sheared dacite	3952	30	30	
266		Disseminated pyrite	3951	20	300	
276		Disseminated pyrite	3950	10	150	
286		Sheared dacite	3949	10	30	
296		Sheared dacite	3948	10	20	
306		Sheared dacite	3947	10	20	
316		Sheared dacite	3946	10	30	
326		Dacite with 3% pyrite	3945	20	1200	

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Fig. 11. Vanderbilt diamond drill-hole

few areas with 100 ppm Cu. The prospect was abandoned as it appears to consist of minor mineralization along a shear zone in the Kohinoor Volcanics.

Old Copper Shaft

The sulphide ore in the spoil heap around the Old Copper Shaft, 1500 feet east of the Dam Shaft (Fig. 6), is similar to that from Elliots orebody. The shaft was sunk in a north-trending shear-zone in Kohinoor Volcanics.

No gossans are visible along the shear, and only one small geochemical anomaly was found, 1200 feet north of the shaft, where the deeply incised Jinero Creek crosses the shear.

The samples in the dump indicate that the shaft passed through a pod of rich mineralization along a shear-zone in the Kohinoor Volcanics. The absence of geochemical anomalies, except in Jinero Creek, suggests that the mineralization lies below the zone of leaching.

MINERALIZATION IN THE COPPER CREEK SHALE

The Copper Creek Shale, from Jerangle northwards to Bungendore and Breadalbane, contains pyrite, chalcopyrite, sphalerite, and galena, in the form of disseminated crystals, small pods and blebs from 1 to 2 inches long, veinlets, and thin layers up to a quarter of an inch thick. Bodies of sulphides up to 20 feet thick occur at Jerangle, Anembo, Narongo, Bollard Mountain, Captains Flat, Foxlow, and Woodlands. Copper-zinc anomalies, associated with small gossans a few feet across, occur along the outcrop of the Copper Creek Shale where it is cut by cross-faults or distorted by strike shearing (see Plates 4 and 5), and metal-rich springs, such as those in Tiger Cat Creek, emerge along some of the cross-faults.

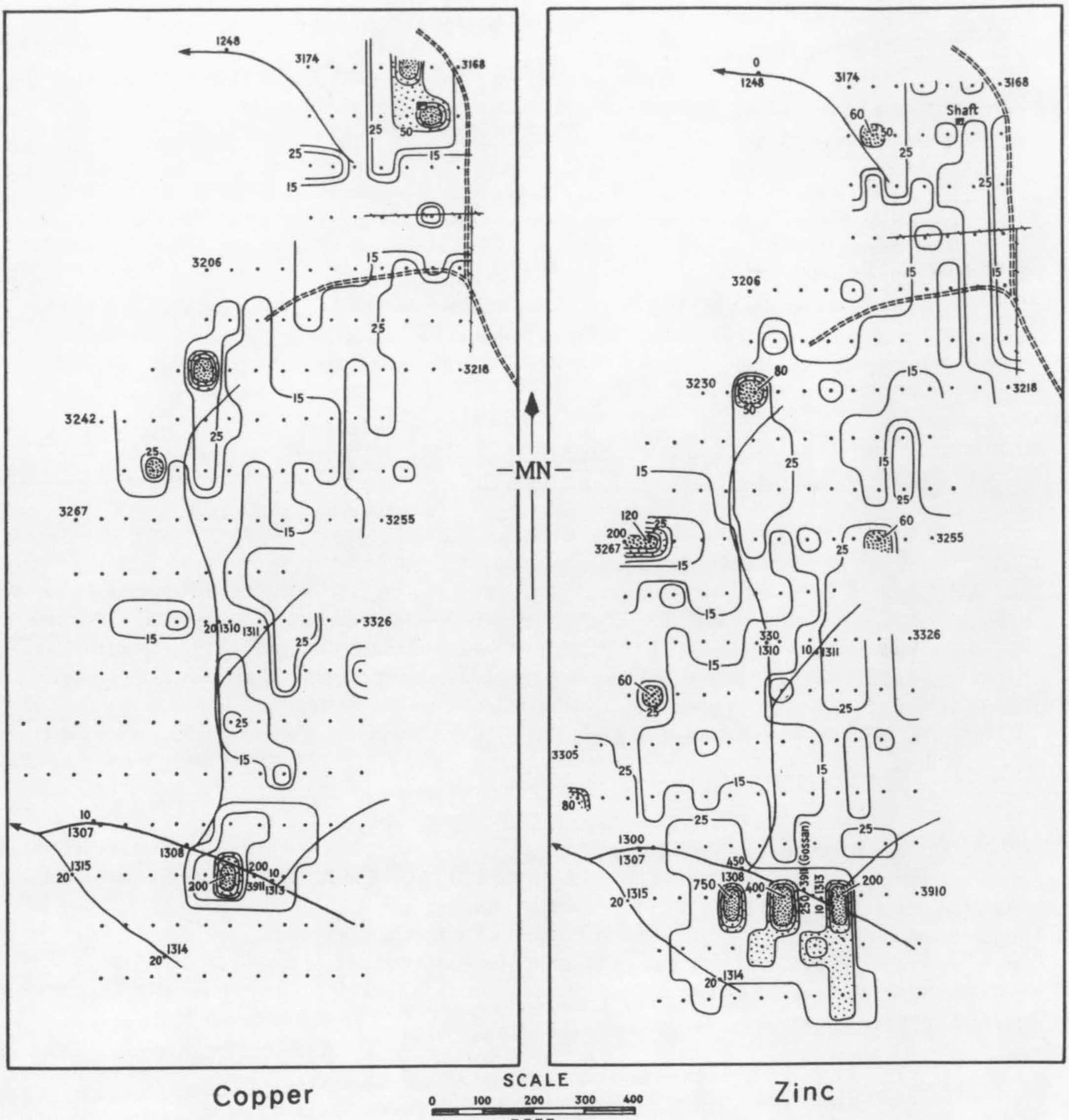
The Copper Shear Gossan

The Copper Shear Gossan (Fig. 9) is only about 2 feet wide, but it can be traced discontinuously for about 1000 feet along the strike. It occurs in sheared Copper Creek Shale, striking 010^{o}, intersected by Narongo Shears trending 020^{o}. A shallow drill hole (No. 538) drilled beneath the gossan intersected 12 feet of sulphides containing 1.4 percent Pb. The gossan crops out again near the Staff Mess on the eastern limb of the Mess Anticline, which plunges north at about 20^{o}. Two drill-holes in the crest of the anticline intersected 14 and 15 feet of mineralization:

D.D.H. 993: 15 ft containing 2.05% Pb, 3.4% Zn, 0.2% Cu.
D.D.H. 1565: 14 ft containing 1.5% Pb, 2.0% Zn, 0.1% Cu.

Other drill-holes showed that the lode thins out rapidly to the north and south and also on the limbs of the anticline. The mineralization occurs in the core of an anticline disrupted by the Narongo Shears, and thins out on the limbs of the fold.

The prospect was not sampled geochemically because of the widespread contamination by mine tailings and rubbish.



REFERENCE

Values in ppm — Fence. ====== Track. Contours at 15, 25, 50, 75, and 100ppm

10/1307 Reconnaissance samples (with results of over 10ppm). . . . Grid samples

Fig. 12. Jermyn geochemical anomalies

Jermyns Anomaly

The Jermyns anomaly was detected during the reconnaissance sampling and detailed sampling was subsequently carried out on a grid pattern (Figs 6, 12, 13 and Pl. 14), but the results were disappointing. The area overlies strongly sheared Copper Creek Shale between the Kohinoor Volcanics and the Ballallaba Fault. The highest anomalies occur where the north-west-trending Kanga Fault cuts the Ballallaba Fault.

The Tiger Cat Creek Anomaly

A few metal rich soil samples and a mineralized spring were found in Tiger Cat Creek during the reconnaissance survey, but detailed grid sampling failed to locate any extensive anomalies (Fig. 13). The area consists of sheared Copper Creek Shale trending northwards and containing small pods of gossans up to 2 feet long. A 2-foot lens of sheared Rutledge Quartzite crops out near the western margin of the area and contorted black slate crops out along the Ballallaba Fault 200 feet to the east. A mineralized spring containing 0.6 ppm Zn (30 times background for water) emerges along the Tiger Cat Creek Fault, which trends north-west across the area (Pl. 3).

The Foxlow Anomaly

The Foxlow anomaly consists of three small areas of over 80 ppm Cu around a mineralized spring on the eastern limb of the synclinorium (Fig. 14). The anomaly overlies sheared siltstone and shale, trending north-south, which probably belong to the Copper Creek Shale. The anomalies are bounded to the west by faulted lenses of Rutledge Quartzite, and to the east by the Ballallaba Fault, which is marked by a zone of contorted black slate. The Copper Creek Shale contains pods of gossan up to 30 inches long with 400 ppm Cu and 200 ppm Pb. The mineralized spring emerging from the centre of the anomaly contains 10 ppm Zn (500 times background for water), and another spring emerging 1200 feet to the south-east contains 0.5 ppm Zn.

A later and more detailed analysis of the water from the main spring after a dry period of two to three months showed the water to have not only a high zinc content, but also an abnormally high ratio of sulphate to chloride and a very low pH value.

Conductivity	1790 micro-ohms/cm
pH	2.9
Sulphate (SO_4)	940
Chloride (Cl)	25 "
Calcium (Ca)	18 "
Magnesium (Mg)	136 "
Sodium (Na)	173 "
Zinc (Zn)	13 "
Ratio SO_4/Cl	37.6

Analyst, S. Baker, BMR.

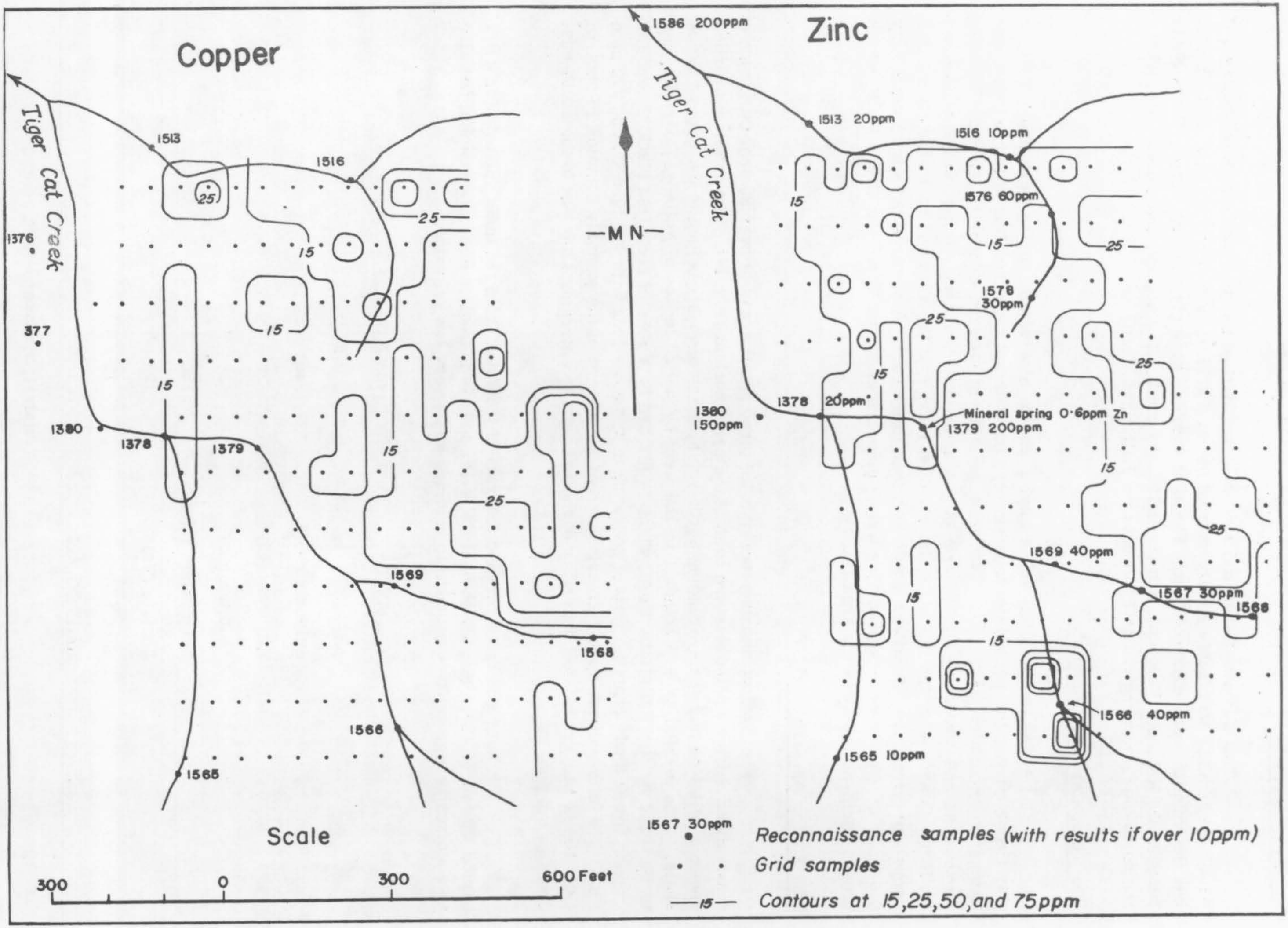


Fig. 13. Tiger Cat Creek geochemical anomalies

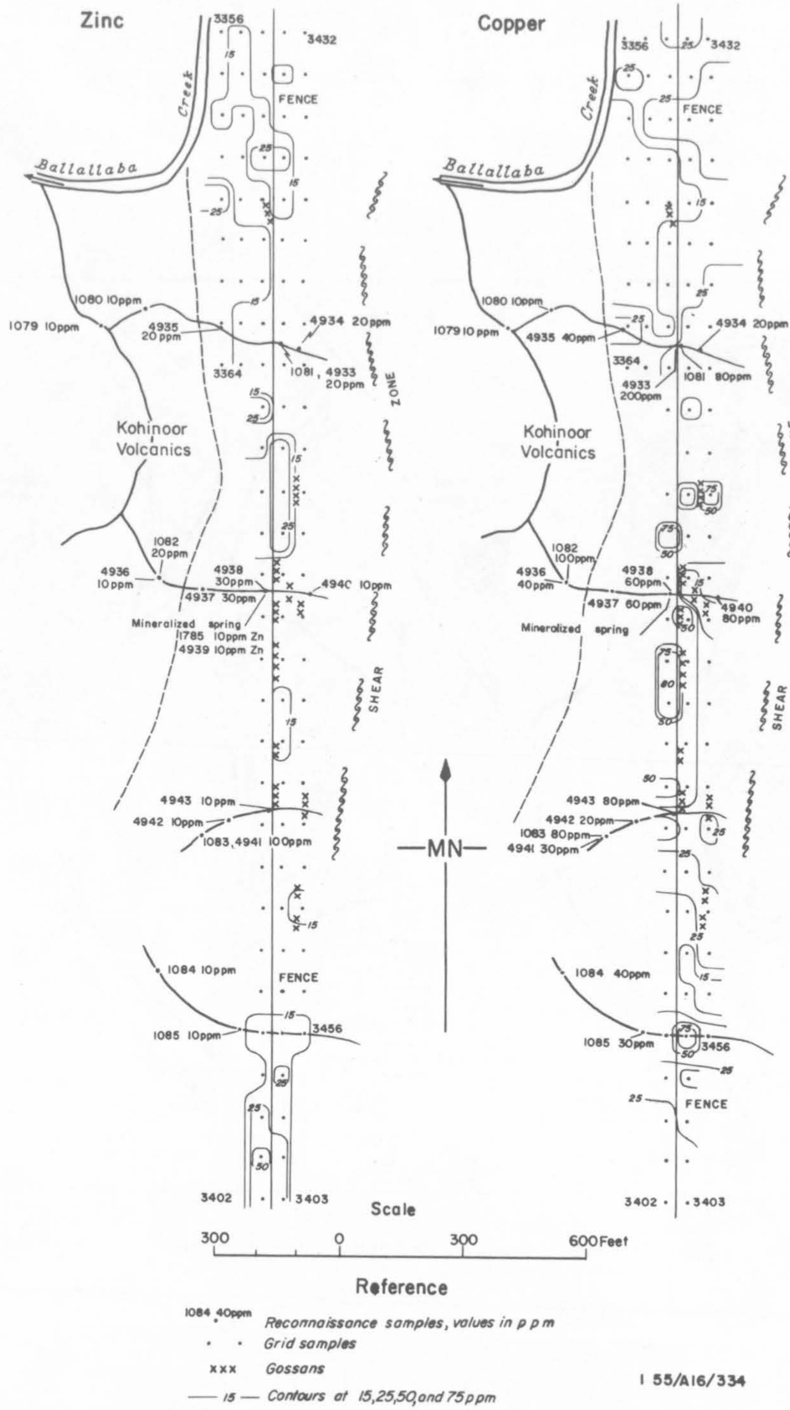


Fig. 14. Zinc and copper anomalies at Foxlow gossans

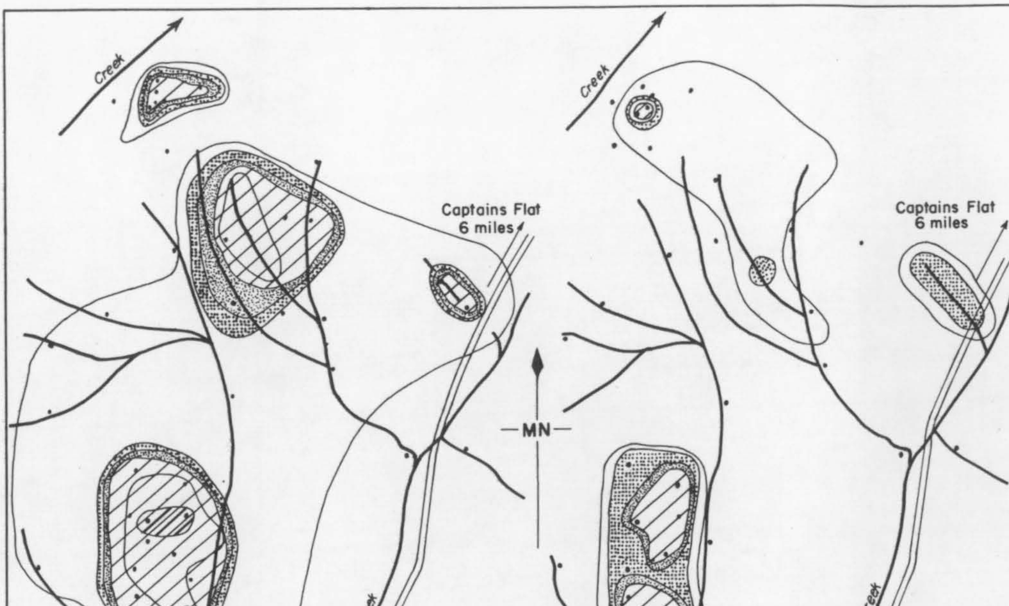
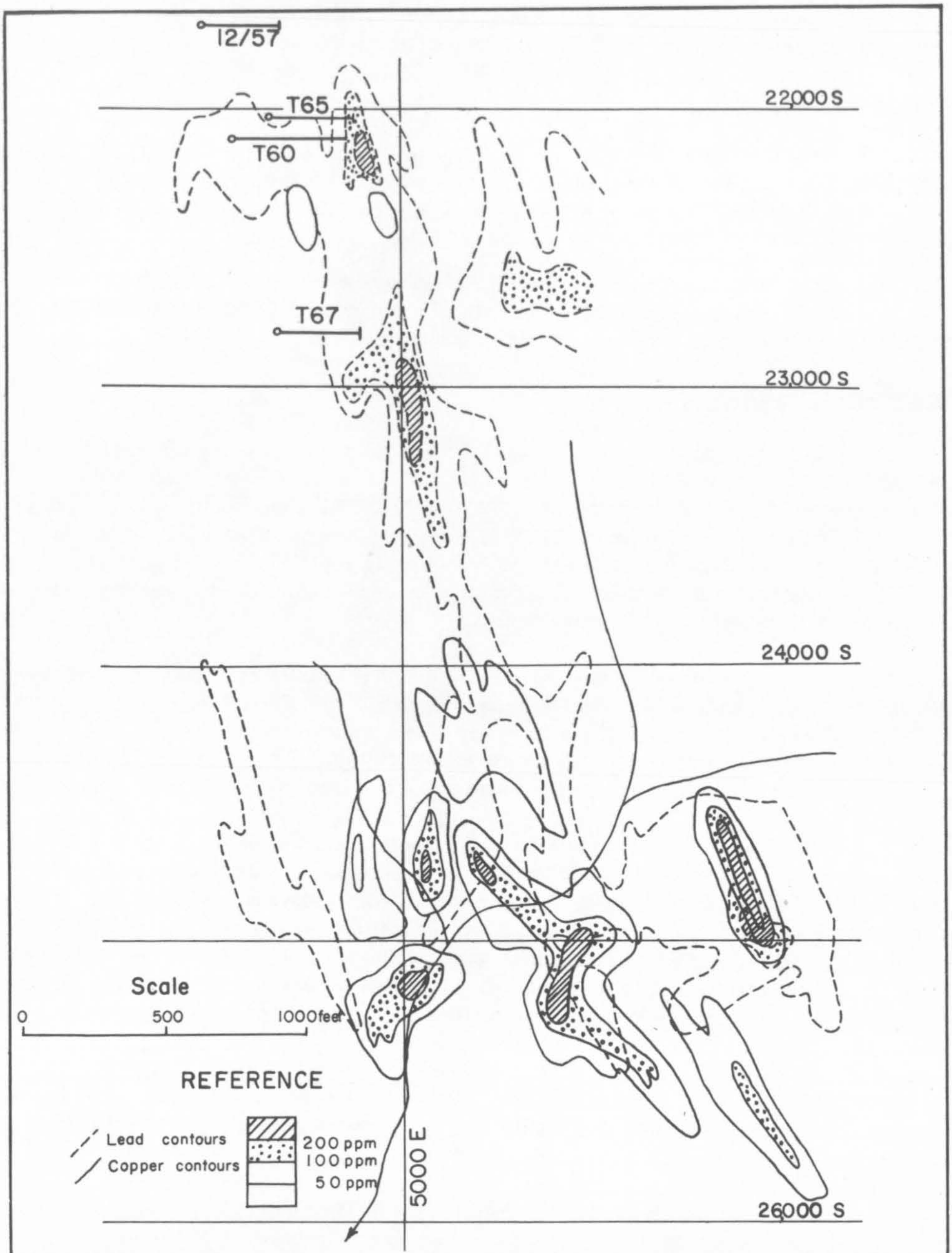


Fig. 15. Johnny Roach's zinc and copper anomalies



D. D.H. No	Target Mineralized sandstone at	Core Recovery	Depth Reached	Mineralization Intersected				
				Depth	Thickness	Lead %	Zinc %	Copper %
12/57	——	——	——	——	7'	1·54	1·62	——
T60	900'	No core for 400'	Abandoned at 581'	513'	6'	1·3	2·35	0·07
T65	800'	No core for 400'	Abandoned at 620'	415'	0·5'	8·9	5·4	0·65
T67	800'	No core	Abandoned at 440'	——	——	——	——	——

Fig. 16. Bollard prospect, geochemical anomalies and mineralization. Compiled from Lake George mine records

Although the geochemical anomalies are small, they surround a richly mineralized spring, and should be investigated by detailed geophysics.

Johnny Roach's Anomalies

The Johnny Roach's anomalies occur over sheared and contorted Copper Creek Shale to the south-west of the southern keel of the Captains Flat Synclinorium (see Fig. 6, Pl. 5). The sheared shale and siltstone trend northwards, and contain lenses of sheared and foliated quartzite contorted about fold axes, which plunge steeply to the north.

The major anomalies (Fig. 15) occur on a steep wooded hillside covered with scree composed of fragments of shale, mineralized shale, gossan, and foliated quartzite. This anomaly should be mapped in detail and geophysically surveyed.

The Bollard Anomalies

The Bollard anomalies (Fig. 16) were geochemically sampled and drilled by Lake George Mines Pty Ltd between 1956 and 1960 (Glasson & Paine, 1959; Paine, 1961). Electromagnetic surveys were made over the area by the Geophysical Branch of the Bureau of Mineral Resources in 1960 (Sedmik, 1965). Large geochemical anomalies were detected in the area by the Bureau's reconnaissance survey in 1961 (Pl. 5). The area was not resampled in detail, for the previous work was regarded as adequate, but further geological mapping and drilling appear to be warranted.

The geochemical anomalies overlie contorted metal-rich Copper Creek Shale, Rutledge Quartzite, and the Bullongong Shale Member of the Foxlow Beds. The strata are tightly folded about north-plunging axes, and are sheared along zones trending 350°, possibly axial plane shearing. The detailed structure and stratigraphy are not known. The shale and quartzite contain pods and stringers of gossan up to 3 feet long, which in places contain gold.

Only the smaller and more easily accessible lead anomalies at the northern end of the prospect have been tested. Four holes were drilled into a lead prospect at 5000 feet E, 22,000 feet S. Drilling conditions were very difficult, core recovery was poor, and the holes were abandoned before reaching the target of mineralized sandstone. One hole yielded no core at all and two holes yielded no core for the first 400 feet. The table in Figure 16 shows that some mineralization was intersected, but it is not known how much friable ore or interlayered ore and sediment were lost in the drilling; no analyses of the drilling sludge were made.

Three small anomalies were located by the Bureau of Mineral Resources electro-magnetic surveys, but they could not be correlated with any of the geochemical anomalies.

In view of the disappointing results of the drilling on the lead anomalies and the absence of large electromagnetic anomalies, the copper anomalies to the south were not drilled.

The large geochemical anomalies in the Bollard prospect may be due to extensive leaching of minor mineralization in permeable host rocks, but the prospect cannot be evaluated until the detailed geological structure is known.

Gourlay-Hickey Anomaly

Detailed geochemical and geophysical surveys were made over the Gourlay-Hickey area (Fig. 6), and a few promising anomalies were discovered (Sedmik, 1965). The area contains a tightly folded anticline of Copper Creek Shale, the Hickey Anticline, which plunges gently to the north beneath the Lake George mine. The core of the anticline consists of sheared Rutledge Quartzite, which is sheared along zones trending 010^{o}, and cross-faulted along faults striking 300^{o} and 320^{o}. The major electromagnetic anomaly occurs along the base of the volcanics on the western limb of the anticline and is associated with a small geochemical anomaly with 120 ppm Zn. The anomaly was drilled (Gourlay DDH No. 1), and a few inches of chalcopyrite in graphitic black shale were intersected.

Narongo Gossans

The Narongo Gossans occur in an outlier of Copper Creek Shale containing siltstone and limestone lenses, 8 miles south of Captains Flat (Fig. 6). The gossans consist of open siliceous limonitic boxworks. They were explored by shafts, costeans, and one drill-hole, but only a few traces of pyrite were found. The reconnaissance geochemical survey by the Bureau of Mineral Resources found anomalies with 80 ppm Cu, and the detailed geochemical survey by Lake George Mines Pty Ltd detected anomalies with 50 ppm Cu.

The area has not been mapped in detail and no geophysical surveys have been made as there appears to be little probability of extensive mineralization.

Anembo Gossans

Soil samples near the Anembo Gossans contain 1000 ppm Cu, and the gossan was found to contain from 800 to 400 ppm Cu. (Pl. 5).

The gossans are extensive, and one of them measures 300 feet by 150 feet. They were examined by early prospectors, and were mapped and drilled by the Electrolytic Zinc Co. of Australasia Ltd in 1950 (unpubl. Company Report). Some pyrite and sphalerite were intersected in three drill-holes, but not enough to warrant further exploration. The largest gossan is underlain by a limestone lens, and limestone crops out farther south near the other gossans. The gossans were not formed by the weathering of large orebodies, but are merely ferruginous precipitates from acid metal-bearing waters passing through the limestone.

Jerangle Gossan

In 1961 Lake George Mines Pty Ltd drilled a geochemical anomaly at Jerangle which is associated with a small limonitic gossan near a porous silicified limestone in sheared Copper Creek Shale. Core recovery was poor, and only a few traces of mineralization were recovered.

ORIGIN OF THE SULPHIDE MINERALIZATION IN THE CAPTAINS FLAT AREA

The sulphides may be syngenetic deposits laid down as (a) disseminated sulphides in the Copper Creek Shale and the Bullongong Shale Member, (b) minor masses of sulphides deposited with the Copper Creek Shale, and (c) large lenses of sulphides deposited with the Keatings Shale Member. Alternatively the sulphides may be epigenetic deposits formed by (a) replacement of favourable beds by hydrothermal solutions from granite, or (b) lateral secretion, or accretion, of disseminated syngenetic sulphides from the Copper Creek Shale, the Keatings Shale Member, or the Kohinoor Volcanics.

Richards (1962) dated several samples of galena from Keatings, Central, and Elliots orebodies. The ages range from 150 to 310 My and average 300 My - i.e., Middle Carboniferous. However, he states (p.881): 'if the large uncertainties in the model age are taken into account, the value obtained for Captains Flat of 300 My can be happily reconciled with either the Stanton (1960, 1961) model' (syngenetic precipitation of lenses of sulphide ore from sea water along with the surrounding sediments during the Silurian) 'or the earlier ideas (Browne, 1949) of correlation of mineralization with magmatic activity' (Carboniferous).

The strong stratigraphical control of the mineralization suggests that the sulphides are syngenetic. Stanton (1960, 1961) considers that vast quantities of metal halides and sulphur are introduced into the sea during periods of vulcanism and that there is a great increase in bacterial activity in those areas which could result in the deposition of large quantities of base metals in the sediments. The Silurian strata at Captains Flat include volcanics, limestone, and graphic shales, but the mineralization is not closely associated with the most extensive volcanics.

Many modern marine muds contain tracts of pyrite and base metals, but the formation of large lenses of sulphide ore, up to 20 feet thick, and with up to 6 percent lead and 10 percent zinc, is difficult to conceive, and no such lenses have yet been discovered in modern marine muds. However, the disseminated sulphides in the Copper Creek Shale are probably syngenetic in origin.

There is also a strong structural control of the sulphide mineralization in the Captains Flat area. The small lenses of sulphide in the Copper Creek Shale occur near folds, shears, and faults; and Keatings, Central, and Elliots orebodies occur at the intersection of the Narongo Shears with the attenuated Keatings Shale Member.

The main orebodies in the Keatings Shale Member and the small lenses of sulphide in the Copper Creek Shale could be epigenetic deposits formed by the replacement of a favourable bed by hydrothermal fluids moving along shears or faults.

Browne (1949) considers that the mineralization was due to replacement along shear-zones of favourable beds by hydrothermal emanations from Carboniferous granites, but recent determinations of the age of the granites by the K/Ar method by Evernden & Richards (1962) shows that they are Silurian-Devonian, with an average age of 390 My. Keatings, Central, and Elliots orebodies are only a mile from the Harrisons Peak and Rocky Peak Granites, but the granites appear to have been low-temperature intrusions which were poor in volatiles, and they contain no pegmatite veins or vugs, or any mineralization.

The sulphides at Captains Flat are part of a belt of sulphide lenses which occur at intervals along the belt of Silurian sediments extending for 70 miles from Cowra Creek, south of Jerangle, to Breadalbane, near Goulburn. The distribution of the sulphide deposits does not appear to be related to the granites, and large volumes of hydrothermal solutions would be required to permeate a belt of rocks 70 miles long.

The sulphide orebodies at Captains Flat and the small lenses of sulphides scattered through the Copper Creek Shale could have been formed by lateral accretion of syngenetic sulphides disseminated through the Silurian volcanics and shales. During the folding and faulting of the beds the disseminated sulphides may have migrated to areas of lower pressure, stress, or temperature - such as shears, faults, and the crests of anticlines. The mode of transport of the sulphides is uncertain, but there are several possibilities such as ionic migration through pore fluids, the movement of connate water, some form of gas fluxing, or hydrothermal solutions generated by the tectonic disturbance. If the orebodies were formed by lateral secretion the size of the orebodies would be proportional to the concentration of the disseminated sulphides and the intensity of tectonic disturbance.

The most probable source of the sulphides would appear to be the volcanic rocks, for it is known that large quantities of metal halides are evolved during volcanic eruptions (Fenner, 1933; Williams, 1962). However, little mineralization and few geochemical anomalies have been found in the Kohinoor Volcanics. No mineralization or geochemical anomalies have been found in the overlying Carwoola Beds, and there is little mineralization in the volcanics and shale of the Captains Flat Formation. The mineralization and the geochemical anomalies are restricted to the Copper Creek Shale and Keatings Shale Member (see Fig. 9); and these two shale beds are the most probable source of the sulphides.

Although the Keatings, Central, and Elliots orebodies occur in the Keatings Shale Member, the area of outcrop around Captains Flat is small and it could not be the source of the lenses of sulphide far beyond the outcrop. Lenses of sulphide occur at intervals in the Copper Creek Shale between Jerangle and Bungendore, and the Copper Creek Shale appears to be the major source of sulphides in the area.

Love (1957, p.37) records that some oil shales contain 8 percent of pyrite; if it is assumed that the Copper Creek Shale and the Keatings Shale Member originally contained merely 1 per cent of disseminated sulphides, it is estimated that these two beds would have contained about 500 million and 20 million tons respectively of sulphides.

Keatings, Central, and Elliots orebodies lie about 2000 feet above the Hickey Anticline (see Fig. 9). It is estimated that the core of this anticline contains over 6000 million tons of contorted Copper Creek shale. The shale may have contained disseminated sulphides, some of which possibly migrated upwards, because of tectonic disturbance, along the Narongo Shears and the Main Lode Shear into the highly stressed Keatings Shale Member to form Keatings, Central, and Elliots orebodies.

In the search for new sulphide orebodies in the Captains Flat area, the contorted and sheared Copper Creek Shale and lenses of sheared shale in the Kohinoor Volcanics appear to be the most promising environments.

POSSIBLE NEW OREBODIES IN THE CAPTAINS FLAT AREA

Repetitions of Keatings, Central, and Elliots Orebodies

The Keatings, Central, and Elliots orebodies were formed along the intersections of the Narongo Shears and the Main Lode Shear in the Keatings Shale Member. The orebodies plunge to the north at 60° to 70°, and increase in depth to the north parallel to the plunge of the Captains Flat Synclinorium (see Fig. 10).

It was thought that Elliots orebody would be repeated to the north of the Molonglo Fault, where the ore-bearing zone appears to have been downfaulted at least 2000 feet. However, exploratory boreholes drilled from the northern end of the No. 24 level intersected only traces of sulphides in a few feet of sheared shale. Geological mapping indicates that the Keatings Shale Member is sheared out to the north, and the favourable shale horizon may therefore be missing. Furthermore the Narongo Shears appear to flatten in depth and the length of intersection decreases.

There appears to be no possibility of any downward repetition of Elliots, Central, or Keatings orebodies because the ore-forming structures diverge with depth. The Keatings Shale Member bends away to the east round the keel of the Captains Flat Synclinorium (Fig. 9); the Main Lode Shear continues downwards into Kohinoor Volcanics; and the Narongo Shears bend away to the west as their dip decreases with depth.

The Main Lode Shear persists southwards from the orebodies, but Keatings orebody thins southwards to a few feet thick. The absence of major orebodies to the south of Keatings is due to several factors:

(i) The Keatings Shale Member thickens southwards, and is less stressed;

(ii) The steep westerly dip of the member reverses to a steep easterly dip as the shale trends round the keel of the Captains Flat Synclinorium. Thus the intersections of the Narongo Shears with the shale become shorter and less acute;

(iii) The Narongo Shears are less numerous southwards.

Thus, as the exploratory holes drilled by Lake George Mines Pty Ltd show (Fig. 10), Keatings Central, and Elliots orebodies do not persist downwards, and they are not repeated to the north or south.

Vanderbilt Orebody

Vanderbilt orebody is cut off to the north by the Molonglo Fault, and any possible extension to the north has been downfaulted. No attempt has been made to find a possible northern extension under the township owing to the small size of the known orebody and the 2000-foot throw of the Molonglo Fault.

Gravity surveys across the Newtown Hill Syncline (Sedmik, 1965) closely reflect the structure. Further traverses to the north would delineate the position and depth of the Vanderbilt Anticline to the north of the Molonglo Fault, and they might indicate the presence of mineralization along its crest.

The Vanderbilt orebody may be repeated at a depth of 2000 to 3000 feet below the known orebody. Keatings Shear intersects the mineralized Dam Shear in the contorted Keatings Shale Member in the core of the Vanderbilt Anticline. The thin contorted Shale Member in the core of the anticline would be a favourable locus for mineralization where intersected by mineralizing shears, for it contains minor mineralization where it crops out on the golf course.

This favourable environment for mineralization may persist to the north of the Molonglo Fault, but it would be downfaulted at least 2000 feet. The Narongo Shears, however, appear to be mainly developed on the overturned western limb of the Captains Flat Synclinorium, and may not persist at depth within the core of the synclinorium, or they may flatten out at depth, and not give such long intersections with favourable shale beds as at Elliots orebody.

Forsters Gossans

Gossans (Fig. 9) appear to have developed from lenses of sulphide, a few feet long, along Forsters Shear. Geophysical methods might assist in prospecting the area.

Old Copper Shaft

A spoil heap containing abundant pyrite surrounds the Old Copper Shaft (Fig. 6). No geochemical anomalies, gossans, or copper stains in the shear-zone have been recorded but geophysical surveys might be useful in prospecting the area.

Bollard Anomalies

The Bollard anomalies (Figs 6 and 16) are the largest and most extensive geochemical anomalies in the Captains Flat area, and some sulphide mineralization was intersected by the four exploratory boreholes drilled into the northern anomalies. The large geochemical anomalies may be due to intensive leaching of small lenses of sulphide scattered through permeable host-rocks, or they may be due to the leaching of a major orebody.

The prospect cannot be evaluated until the area has been mapped in detail, and the complicated structure deciphered. Then the geochemical and geophysical anomalies can be co-ordinated with the geological structure and the exploratory drilling.

Foxlow Gossans

The geochemical anomalies are neither big nor extensive, but the two mineralized springs show that the area contains sulphide mineralization, either as many small lenses a few feet long or as one medium-sized orebody a few hundred feet long. Geophysical surveys over the area may detect some anomalies.

Johnny Roach's Anomaly

The geochemical anomalies, the gossans, and the intense deformation make the prospect appear promising, but detailed geological mapping and geophysical surveying are required before the prospect can be evaluated.

ACKNOWLEDGMENTS

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APPENDIX

TABLE OF GEOCHEMICAL ANOMALIES

The anomalously high reconnaissance samples are tabulated first, e.g. 297s, 10 ppm Cu, 400 ppm Zn. Three or four check samples were taken around the reconnaissance samples and are tabulated thus: 4150, 30 ppm Cu, 60 ppm Zn. If the check samples contained low values of copper and zinc, the anomaly was abandoned. If the check samples contained high values, additional samples were taken until the anomaly was delineated. Sample numbers are shown on the geochemical maps (Pls 4 and 5).

The symbol 'g' has been used for samples of gossan, 's' for samples of salt encrustation, and 'w' for samples of water. The rest were samples of soil from the 'B' horizon of the residual soils.

Sample	Result (ppm) Copper	Result (ppm) Zinc	Geological Environment	Comment
297s	10	400	Sheared Copper Creek siltstones with some quartz veins and hematite stringers.	Minor mineralization in Copper Creek Shale.
4150	30	60		
4151	20	20		
4152	10	20		
4153	10	100		
311s		200	Alluvial flat.	Contamination from Molonglo River.
1390	0	10		
1082	100	20	Sheared gossans in Copper Creek Shale.	Foxlow gossans (see text).
1081	80	10		
1083	80	10		
1785w		10	Mineral spring.	
1126	160	20	Anomaly occurs over small mass of amphibolite.	Minor copper mineralization associated with a minor basic intrusion.
1394	100	20		
1398	50	20		
1400	70	30		
1723	200	30	Specimen of amphibolite.	
1307	-	1300	Sheared Copper Creek siltstones with small gossans.	Jermyn anomaly (see text).
1308	-	450		
1310	20	330		
1346	10	4000	Black shales in Captains Flat Formation.	Contamination by scraps of galvanized iron wire.
1559	-	10		
1560	-	10		
1561	-	10		
1562	-	10		
1563	-	10		
1379	-	200	Overlies sheared faulted Copper Creek Shale containing gossans.	Tiger Cat Creek gossans (see text).
1380	10	150		
1570w		0.6		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
1383	-	100	Over faulted Kohinoor Volcanics.	Possibly contaminated by scraps of galvanized iron wire.
1385	-	20		
1583	-	10		
1584	-	10		
1414	-	30	Overlies sheared gossanous grey shales & siltstones. May be Copper Creek Shale or Ordovician. Sediments strike 010°, and are cut by quartz veins striking 010° and 350°	Minor mineralization over sheared shale along Ballallaba Fault.
w	0.05	0.2		
s	-	400		
1415	-	100		
1416	-	100		
1836	-	-		
1837	30	20		
1838	20	20		
1839	20	10		
1842	40	80		
1451	60	1000	Occurs over sheared shales & siltstones striking 010° and containing pods of gossan near Ballallaba Fault. May be Copper Creek Shale or Ordovician. Quartz veins strike 010° and 350°.	Minor mineralization in shales near Ballallaba Fault.
w	0.05	2		
1453	20	20		
w	0.05	1.0		
1843	30	80		
1844	60	20		
1845	10	10		
1846	40	20		
1847	40	30		
1848	40	20		
1525	250	40	Overlies black slate in the Captains Flat Formation.	Contamination due to scrap metal.
3883	10	100		
3882	10	20		
3884	10	80		
1629	70	30	Overlies weathered Kohinoor Volcanics. Quartz vein nearby.	Minor mineralization in Kohinoor Volcanics.
1626	50	10		
3886	10	50		
3885	10	20		
3887	10	20		
1674	60	20	Overlies Copper Creek Shale & thin shale lens in Kohinoor Volcanics.	Minor mineralization in sheared volcanics and shales.
1677	60	20		
1664	60	10		
1665	30	10		
1909	-	200	Occurs in a shear-zone in Kohinoor Volcanics near an old shaft.	Minor mineralization along shear-zone.
6058	20	30		
6059	20	20		
6060	10	20		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
1957	30	500	Occurs over a fault in the Kohinoor Volcanics a few hundred yards north of the Dam Shaft.	Minor mineralization along a fault.
1956	20	120		
1952	40	20		
1953	30	400		
1981	80	30		
5003	10	20		
5004	20	30		
5005	20	30		
1991	80	30	Iron-stained shear-zone in Kohinoor Volcanics.	Minor mineralization along a major shear-zone.
4042	30	10		
4041	30	10		
2014	50	30	Overlies Narongo Fault (specimen of fault breccia 400 ppm Cu).	Minor mineralization along Narongo Fault.
2013	30	30		
1076	40	10		
1078	30			
2094	30	1500	Limonitic rubble over limestone in sheared Copper Creek Shale.	'Northern gossans' tested and abandoned by Lake George Mines. Minor mineralization along Narongo Fault.
2093	-	200		
3881	10	500		
3888	10	400		
2135	-	100	Faulted Kohinoor Volcanics.	Strudwick's anomaly. A small grid survey failed to find any more metal.
2133	-	70		
2261	-	200	Sheared Copper Creek Shale with small gossans. Surface limonite rubble resembles that developed over limestone.	Minor mineralization in sheared Copper Creek Shale.
4142	-	100		
4143	-	20		
4144	-	30		
4145s	40	1000		
4146	-	20		
4147	20	20		
4148	10	30		
2357w	-	1	Occurs over Narongo Shears carrying strong gossans.	Yorkdale prospect trial pits & shafts intersected some lead mineralization. Drilled by Lake George Mines but no significant mineralization was intersected.
2355	-	80		
4135		100		
4136	20	150		
4137	10	20		
4138	-	20		
4139	20	100		
4140	20	300		
4141	40	300		
2395	-	2000	Overlies sheared black and green Copper Creek Shale. White salt encrustations.	Minor mineralization close to Narongo Fault.
4130	-	20		
4131	20	30		
4132	10	20		
4133s	20	10		
4134s		100		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
2441	-	1000	Overlies contorted Bullongong Shale containing patches and vugs of gossan.	Minor mineralization associated with the Narongo Fault.
4124	60	20		
4125	40	20		
4126	200	20		
4127	60	60		
4128	80	20		
4129	30	20		
2654w		1	Overlies Narongo Fault.	Mineral spring emerging along Narongo Fault.
4156s	20	200		
4156		0.08		
2653	-	10		
2670	10	10		
2652	-	10		
2655	-	-		
2700w		5	Overlies Narongo Fault.	Mineral spring emerging along Narongo Fault.
2700	10	10		
2694	-	10		
2676	10	10		
2713	20	20		
3462	200	20	Close to contact between Copper Creek Shale and Kohinoor Volcanics.	Minor mineralization in sheared shale.
3963	10	100		
5185	20	150		
3964	20	20		
3965	40	30		
3471g	600	40	Overlies contorted Copper Creek shale in keel of Captains Flat Synclinorium.	Part of Johnny Roach's anomaly (see text).
3966	40	30		
3967	40	30		
3968	30	100		
3969	50	150		
3970	20	150		
3971	30	20		
3563	10	120	Contorted Copper Creek Shale in keel of synclinorium.	Minor mineralization.
5155	10	120		
5156	20	120		
5154	30	30		
3570	60	300	Sheared Copper Creek Shale in keel of synclinorium.	Minor mineralization.
5141	40	30		
5142	30	30		
5140	20	20		
3576	20	600	Sheared Copper Creek Shale.	Minor mineralization.
5143	40	30		
5144	40	30		
5145	40	30		

Sample	Result (ppm)		Geological Environment	Comment
	Copper	Zinc		
3582	1000	50	Gossanous Copper Creek Shale in keel of synclinorium.	Gossan.
5184g	600	100		
3583	10	-		
3587	20	10		
3586	20	120	Sheared gossanous Copper Creek Shale in keel of synclinorium.	Minor mineralization.
3582g	1000	50		
5148	80	120		
5149	30	80		
5150	40	20		
3601g	4000	1000	Gossanous Copper Creek Shale near lens of recrystallized limestone.	Minor mineralization.
5119g	400	30		
3631	-	10		
3639	40	10		
5269	30	-		
5270	60	-		
5271	-	-		
3636	120	-	Stained shear zone in Copper Creek Shale.	Minor mineralization.
5098	80	10		
5099	40	20		
5100	40	10		
3647	120	10	Contorted sheared Copper Creek Shale on Jinjera in keel of synclinorium	Minor mineralization.
5089	100	20		
5090	100	10		
5091	100	20		
5092	40	20		
5093	50	20		
5094	50	10		
3658	250	30	Contorted Copper Creek Shale in keel of synclinorium.	Minor mineralization.
3661	20	120		
3650w	-	0.2		
5081	30	20		
5082	20	20		
5083	30	20		
3683	30	120	Contorted Copper Creek Shale.	Minor mineralization.
5072	20	20		
5073	20	20		
5074	20	150		
3699	20	300	Contorted Copper Creek Shale.	Small shear-zone.
5169	30	30		
5170	30	20		
5168	20	20		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
3708	20	200	Contorted Copper Creek Shale.	Minor staining.
5171	10	20		
5172	20	20		
5173	10	10		
3719	20	120	Contorted Copper Creek Shale.	Small gossanous area.
5174	20	30		
5175	30	150		
5176	20	30		
3727	20	120	Contorted Copper Creek Shale.	
5181	20	20		
5182	10	10		
5183	10	20		
3743	30	120	Small lens of Kohinoor Volcanics in Copper Creek Shale	Trace of mineralization.
3988	-	10		
3989	20	20		
3990	10	10		
3946	60	300	Overlies western contact of a small lens of Kohinoor Volcanics in Copper Creek Shale.	Trace of mineralization.
3744	40	120		
3972	30	20		
3973	30	20		
3974	30	30		
3975	20	100		
3976	50	300		
3764	20	750	Contorted Copper Creek Shale and Rutledge Quartzite.	Southern part of Johnny Roach's anomaly (see text).
3760	30	500		
3754	20	200		
3789	10	120	Contorted Copper Creek Shale.	Trace of mineralization.
5023	10	30		
5024	30	10		
3819g	200	150	Contorted shale.	Small gossan. Part of Anembo gossans (see text).
5330	-	40		
5331	-	-		
3821	400	2000	Large gossan over Copper Creek. Shale with lens of limestone.	Main Anembo gossan. Drilled by Electrolytic Zinc Corp. in 1950. Traces of sulphides, but size of gossan is due to precipitation of limonite by limestone.
5359	1000	120		
5360	200	120		
5362	30	120		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
3822g	800	200	Sheared volcanics.	Small gossan.
5353	-	15		
5354	-	25		
3846	120	20	Contorted Copper Creek Shale.	Trace of mineralization.
5116	100	10		
5117	30	30		
5118	80	10		
3855	40	120	Contorted Copper Creek Shale.	
5113	20	20		
5114	10	20		
5115	30	10		
3858	80	40	Contorted Copper Creek Shale.	Trace of mineralization.
5102	500	100		
5103	40	20		
5104	60	10		
3869g	2000	5000	Contorted Copper Creek Shale in south-east keel of synclinorium.	Trace of mineralization. A continuation of 3926.
5066g	1600	750		
5067	40	10		
5068	40	10		
3926	80	20	Overlies thin vein of granite intruding shale.	Minor mineralization.
5059	200	10		
5060	60	20		
5061	120	10		
3939	20	80	Overlies Narongo Fault.	Trace of mineralization.
5028	10	20		
3943	10	100	Overlies Narongo Fault.	Trace of mineralization.
5065	20	20		
3958	20	100	Contorted Copper Creek Shale.	Trace of mineralization.
5085	40	100		
5084	40	20		
5086	30	10		
3980	300	500	Contorted Copper Creek Shale	Johnny Roach's anomaly (see text).
3984	600	30		
4016	80	120	Occurs over Ballallaba Fault and Copper Creek Shale.	Minor mineralization along Ballallaba Fault.
6061	20	20		
6062	30	30		
6063	10	30		
6064	150	300		
6065	10	20		
6066	150	300		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
4047	40	120	Lens of sheared shale in	Minor mineralization.
4046	40	20	Kohinoor Volcanics.	
4045	40	40		
4063	30	120	Occurs over contact between	Minor mineralization.
4117	-	50	Kohinoor Volcanics and Copper	
6067	30	30	Creek Shale.	
6068	30	300		
6069	10	30		
4083	10	120	Overlies sheared Kohinoor	Mineralized shear.
4088	10	60	Volcanics.	
6082	10	30		
6085	10	30		
4120	10	80	Overlies sheared Copper Creek	Part of Roach's prospect.
4119	10	60	Shale and Rutledge Quartzite.	Drilled 1949. Only traces of
6077	30	150		sulphides found.
6078	20	30		
6079	40	300		
6080	30	150		
6081	60	120		
4168	40	120	Copper Creek Shale near Narongo	Part of Copper Shear prospect.
6131	30	150	Fault.	Drill-holes intersected miner-
6132	60	150		alization (see text).
6133	60	150		
4171	100	30	Copper Creek Shale.	Part of Copper Shear prospect.
4170	20	120		
4172	60	30		
6139	160	30		
6134	100	30		
4180	10	400	Close to small infold of Copper	Part of Copper Shear prospect.
4181	20	30	Creek Shale in Kohinoor Vol-	
4179	10	10	canics.	
4187	80	120	Contact of Copper Creek Shale	Part of North Hickey prospect.
4188	160	400	and Kohinoor Volcanics.	
6144	240	500		
6145	60	300		
4189	60	100	Close to small infold of Copper	Close to Forsters gossan.
6147	60	200	Creek Shale in Kohinoor Vol-	
6146	30	10	canics.	
6148	40	150		

Sample	Result (ppm)		Geological Environment	Comment
	Copper	Zinc		
4199	30	750	Overlies keel of Keatings Shale Member.	Part of Keatings Extended prospect (see text).
4198	40	300		
6019	20	20		
6023	10	10		
6020	30	100		
6021	150	1500		
6022	10	20		
4224	100	20	Overlies sheared Kohinoor Volcanics.	Part of Gourlay Hickey prospect. Traces of mineralization found (see text).
6041	100	20		
6042	10	10		
4251	30	150	Occurs over sheared Kohinoor Volcanics close to Waterfall Fault.	Minor mineralization along fault zone.
4250	20	80		
6047	10	20		
6048	10	10		
6049	10	10		
4260	30	100	Occurs over contorted Copper Creek Shale in Hickeys Anticline.	Part of Gourlay Hickey prospect. Some electro-magnetic anomalies. One drill-hole and trenching gave disappointing results (see text).
4261	30	500		
4262	10	250		
6031	30	40		
6032	40	120		
6033	20	40		
6034	20	40		
6035	10	20		
4293	-	70	Overlies mineralized shear zone in Kohinoor Volcanics.	Trace of mineralization along the Dam Shear.
4292	-	60		
4947	40	150		
4948	40	200		
4949	30	20		
6000	10	20		
4301	80	30	Overlies Keatings Shale Member.	Forms northern part of Keatings Extended (see text).
4944	300	80		
4945	30	100		
4946	40	200		
4305	100	40	Overlies Keatings Shale.	Forms part of Keatings Extended. Drill-holes intersected sulphides (see text).
4304	60	40		
6001	60	20		
6002	100	10		
6003	100	30		
6004	120	100		
4311	80	20	Overlies Keatings Shale.	Forms part of Keatings Extended.
6017	150	10		
6018	50	20		

Sample	Result (ppm) Copper	Result (ppm) Zinc	Geological Environment	Comment
4320	20	100	Overlies gossanous sheared	Forsters gossan prospect (see
4321	80	80	Kohinoor Volcanics.	text).
4319	40	100		
6127	20	100		
6126	120	250		
6128	20	10		
6129	180	30		
6130	60	80		
4322	100	20	Overlies contorted Copper Creek	Part of North Hickey prospect.
4325	50	20	Shale between Rutledge Quartz	Drilled in 1955. 11 feet of 1%
6123	100	100	and Kohinoor Volcanics.	Pb and 3% Zn.
6124	40	10		
6125	40	10		
4519	-	100	Overlies contorted Copper	Forms northern part of Bollard
6052	10	10	Creek Shale and Rutledge	prospect. Drill-holes inter-
6053	10	20	Quartzite.	sected some mineralization (see
6054	10	40		text).
4524	60	750	Overlies contorted Copper Creek	Part of Bollard prospect.
6055	30	10	Shale.	
6056	40	10		
6057	40	10		
4541	30	120	Over Kohinoor Volcanics and	Part of Gourlay prospect.
4541w		5	Narongo Fault. Mineral spring.	Drilled 1961, traces of sulphides
6120	30	20		(see text).
6121	10	10		
6122	20	20		
4579	120	30	Over Narongo Fault.	Trace of mineralization.
4924	20	10		
4923	20	150		
4582	30	120	Near outlier of Kohinoor	Trace of mineralization.
4926	20	10	Volcanics.	
4927	20	10		
4928	20	10		
4668	20	300	Near outlier of Kohinoor	Trace of mineralization (goss-
4939	100	20	Volcanics in Copper Creek	an).
4931	70	20	Shale.	
4932	20	20		
4779	10	400	Contorted Copper Creek	Trace of mineralization.
6229	50	20	Shale.	
6230	10	30		
6231	10	10		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
4802	10	600	Contorted shales.	Minor mineralization 1/2 mile south of prospect pits.
4803	10	100		
4804	10	500		
6216	20	50		
6217	10	50		
6221	10	30		
6219	10	30		
4857	200	20	Contorted shale close to granite.	Trace of mineralization along strike from Narongo gossans, 3/4 mile to the north.
4861	30	100		
4859	30	120		
6239	30	150		
6237	10	100		
6236	30	120		
6235	10	20		
4887	80	10	Contorted shales near outlier of Kohinoor Volcanics.	Trace of mineralization 1/4 mile south of prospect pits.
6224	40	10		
6222	30	30		
6225	10	30		
4911	50	100	Inlier of Kohinoor Volcanics in Copper Creek Shale.	Minor mineralization.
6241	40	100		
6242	60	80		
6243	20	100		
5051	10	200	Contorted shale.	Trace of mineralization.
5050	-	-		
5049	10	10		
5219	-	5500	Contorted Copper Creek Shale.	Part of Bollard anomalies (see text).
6170	40	1000		
6175	100	1200		
6174	80	500		
5220	270	60	Contorted Copper Creek Shale.	Part of Bollard anomalies.
6170	40	1000		
5226	300	300	Contorted Copper Creek Shale.	Part of Bollard anomalies
5225	150	600		
5224	60	60		
5227	170	500		
5231	300	25	Contorted Copper Creek Shale.	Part of Bollard anomalies.
5230	150	500		
5279	120	75	Contorted Copper Creek Shale.	Part of Bollard anomalies.
6207	40	300		
6259	200	50		

Sample	Result (ppm) Copper	Zinc	Geological Environment	Comment
6093	10	150	Occurs over the Golf course	Forms northern golfcourse
6094	10	150	fault in Kohinoor Volcanics.	prospect. Drilled in 1960: only
6096	10	100		traces of sulphides found.
6153	60	1200	Contorted Copper Creek Shale.	Bollard anomalies.
6150	40	150		
6152	40	750		
6154	40	1200		
6194	600	500	Contact of Kohinoor Volcanics.	Trace of mineralization near
6195	150	10		abandoned prospect shaft.
6193	100	120		
6284	600	50		
6197g	700	40	Sheared Copper Creek Shale in	Small gossan in anticlinal crest.
4276	10	20	crest of Hickey Anticline.	
6279	700Pb	-		
4257	20	30		
6251	40	300	Contorted Copper Creek Shale.	Part of Bollard anomalies.
6211	10	150		
6252	80	30		
6250	30	300		
6259	200	50	Contorted Copper Creek Shale.	Part of Bollard anomalies.
5280	60	-		
5281	50	-		
5279	120	75		
6281	300	25	Contact between Copper Creek	Trace of mineralization.
6190	-	30	Shale and Kohinoor Volcanics.	
6197	15	60		

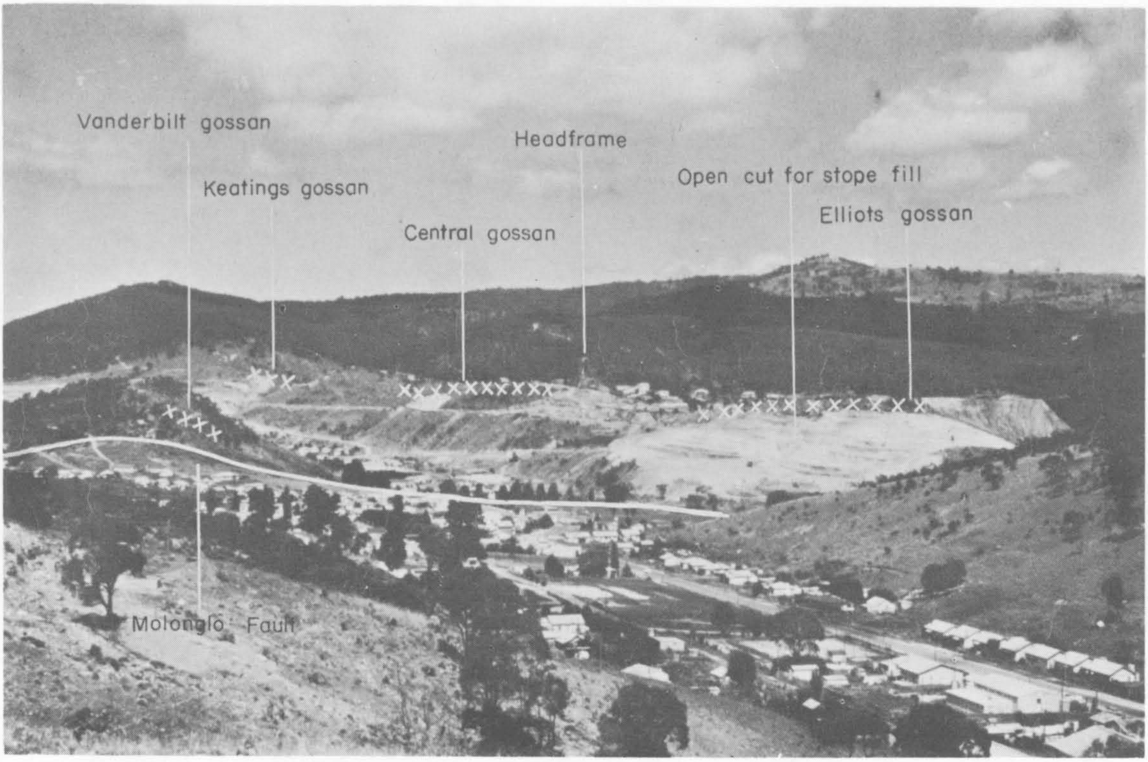
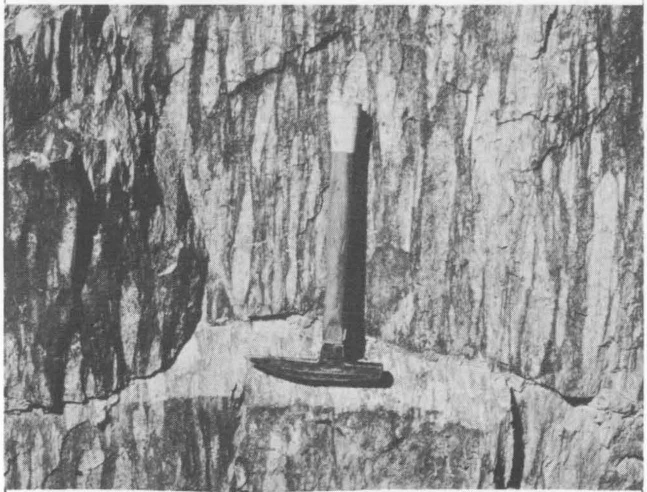


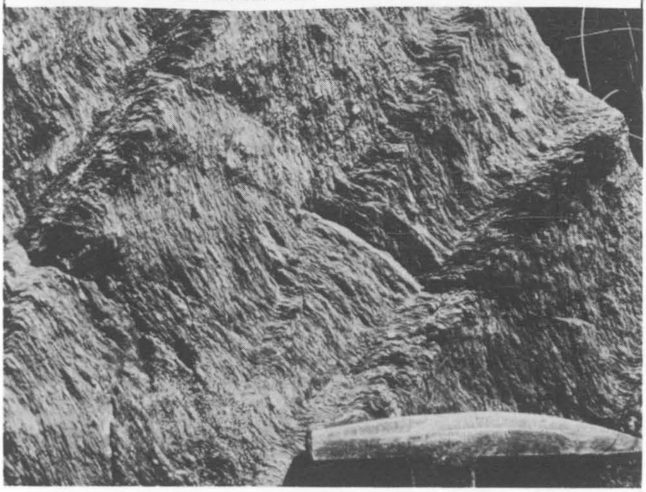
Plate 1. Captains Flat, 1961

Plate 2,

Kohinoor Volcanics, Baldwin Mountain. The rock consists of spindle shaped 'bombs' of fine-grained dacite set in a matrix of foliated porphyritic dacite (A. 9/5004).



Sheared Kohinoor Volcanics in road cutting half a mile north of Lake George mine (B. 9/5006).



Highly sheared Kohinoor Volcanics 1 1/2 miles south of Lake George mine (C. 9/5005).


CAPTAINS FLAT AREA
Scale
0 1 2 MILES
Geology, 1961-62, by W. Oldershaw, G.R. Pearson, E.G. Wilson, C.M. Gregory.
Compiled, 1962, by W. Oldershaw
Drawn by R.J. Pennington
Reference
CAINOZOIC
QUATERNARY
Alluvium
PALAEOZOIC
PERMIAN ?
Pg Gravel
SILURIAN - DEVONIAN
Harrisons Peak Granite
gbx Biotite granite
Rocky Peak Granite
gho Hornblende - biotite granite
a Amphibolite
SILURIAN
Captains Flat Formation
Suf Shale
Sinclair Conglomerate Member
Sufc Conglomeratic reworked lithic tuff
Suft Reworked lithic tuff
Sufb Basalt
Sufd Dacite
Yandyguinula Member
Sufy Alternating thin beds of siltstone and shale
Carwoola Beds
Suwa Shale
Suwb Alternating thin beds of shale and argillaceous sandstone
Kohinoor Volcanics
Smk Porphyritic dacite flows, tuff, agglomerate welded tuff
Keatings Shale Member
Smks Shale
Copper Creek Shale
Smc Siltstone, graphitic shale, shale limestone, minor tuff
Rutledge Quartzite
Smr Quartzite conglomerate
ORDOVICIAN
Undifferentiated
Os Siltstone, shale, greywacke
Bullongong Shale
Oub Siliceous black shale
Od Dacite
Geological boundary
Anticline
Syncline, showing plunge
Plunge of minor anticline
Plunge of minor syncline
Plunge of drag fold
Plunge of fold axis
Measured plunge of fold axis
Fault, showing relative horizontal movement
Fault breccia
Where location of boundaries, folds and faults is approximate, line is broken. Where concealed, boundaries and folds are dotted and faults shown by short dashes.
Strike and dip of strata
Prevailing strike and dip of strata
Strike, dip not determinable
Vertical strata
Horizontal strata
Generalized strike and dip of undulating strata
Trend of bedding
Graded bedding
Strike and dip of foliation
Prevailing strike and dip of foliation
Strike; dip not determinable
Vertical foliation
Strike and dip of cleavage
Prevailing strike and dip of cleavage
Vertical cleavage
Apparent dip of bedding on cleavage plane
Apparent dip of cleavage on bedding plane
Strike and dip of joints
Prevailing strike and dip of joints
Dyke or vein; d-dolerite, Fe-iron, j-jasper q-quartz.
Abandoned mine
Prospect
Quarry
Dump
Road
Vehicle track
Railway
Fence
Building
Trignometrical station
Scarp
Section
A B
Scale: V/H = 1
Copper Creek
MOLONGLO R.
Jinero Creek
ORE
Narongo Fault
Ballallaba Fault
QUEANBEYAN AND BUNGENDORE
HOSKINSTOWN
SPIRE
MOLONGLO
RIVER
LAKE
GROSE MEADOW
RUTLEDGE
THURLILLY
SINCLAIR
Silver Hills
Limestone
HARRISONS PEAK
CAPTAINS FLAT
LAKE GEORGE MINE
Elliott Gossan
Vanderbilt Gossan
Central Gossan
Keatings Gossan
Macrofossil
ROCKY PEAK
BRAIDWOOD
JERANGLE AND COOMA
Copper Creek
Kanga Fault
Tiger Cat Creek Fault
Jinero Cr
Yandyguinula Cr
Forbes Cr
Thurlilly Creek
Ballallaba Cr
Primrose Valley Cr
Foxlow Cr
Golfcourse Fault
Molonglo
NARONGO
BALLALLABA
FAULT
35°25′ 149°22′ 149°30′ 35°30′ 35°31′ 35°35′ 35°38′ 149°25′

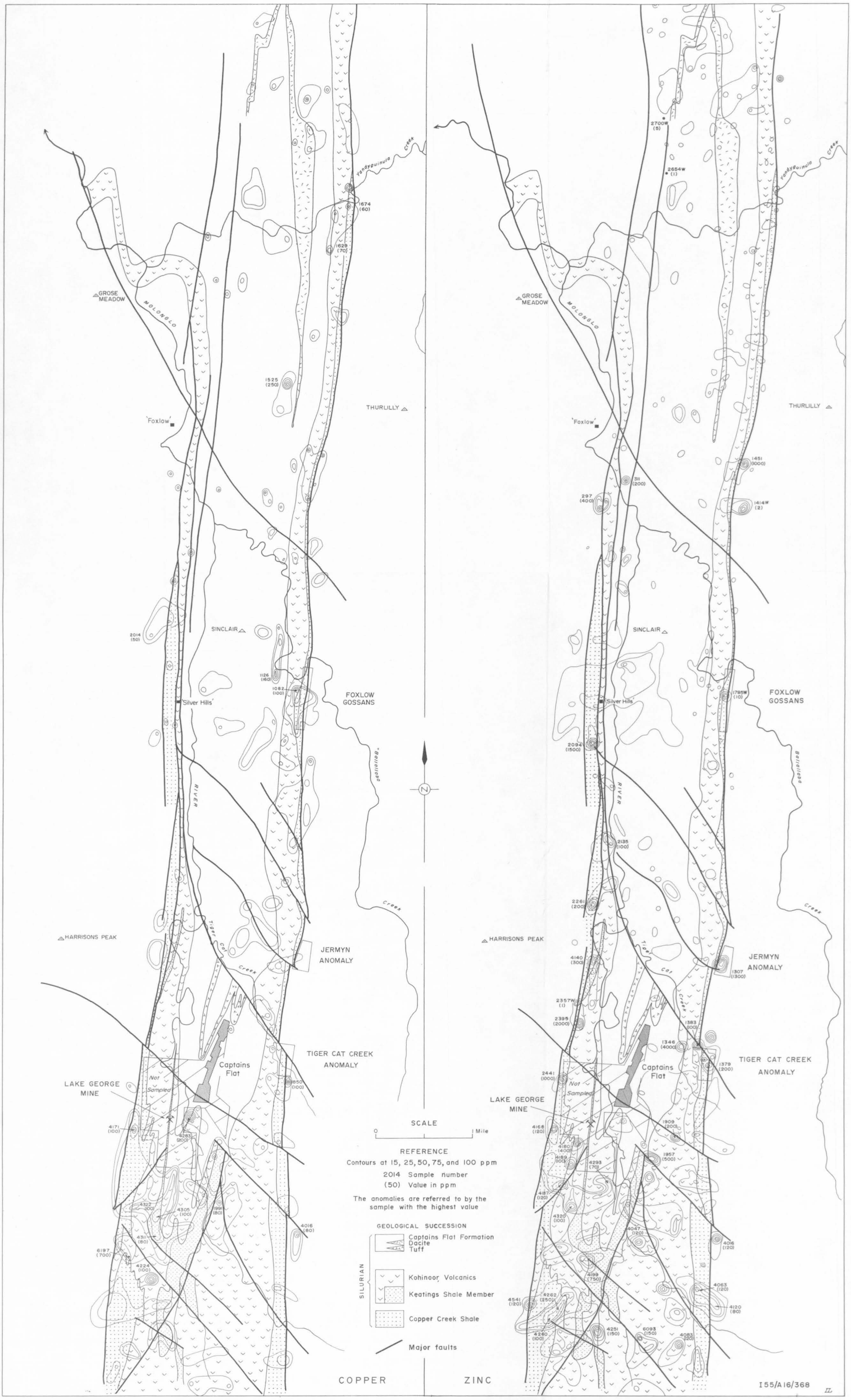


Plate 4 Geochemical contours (copper and zinc), northern part of Captains Flat area

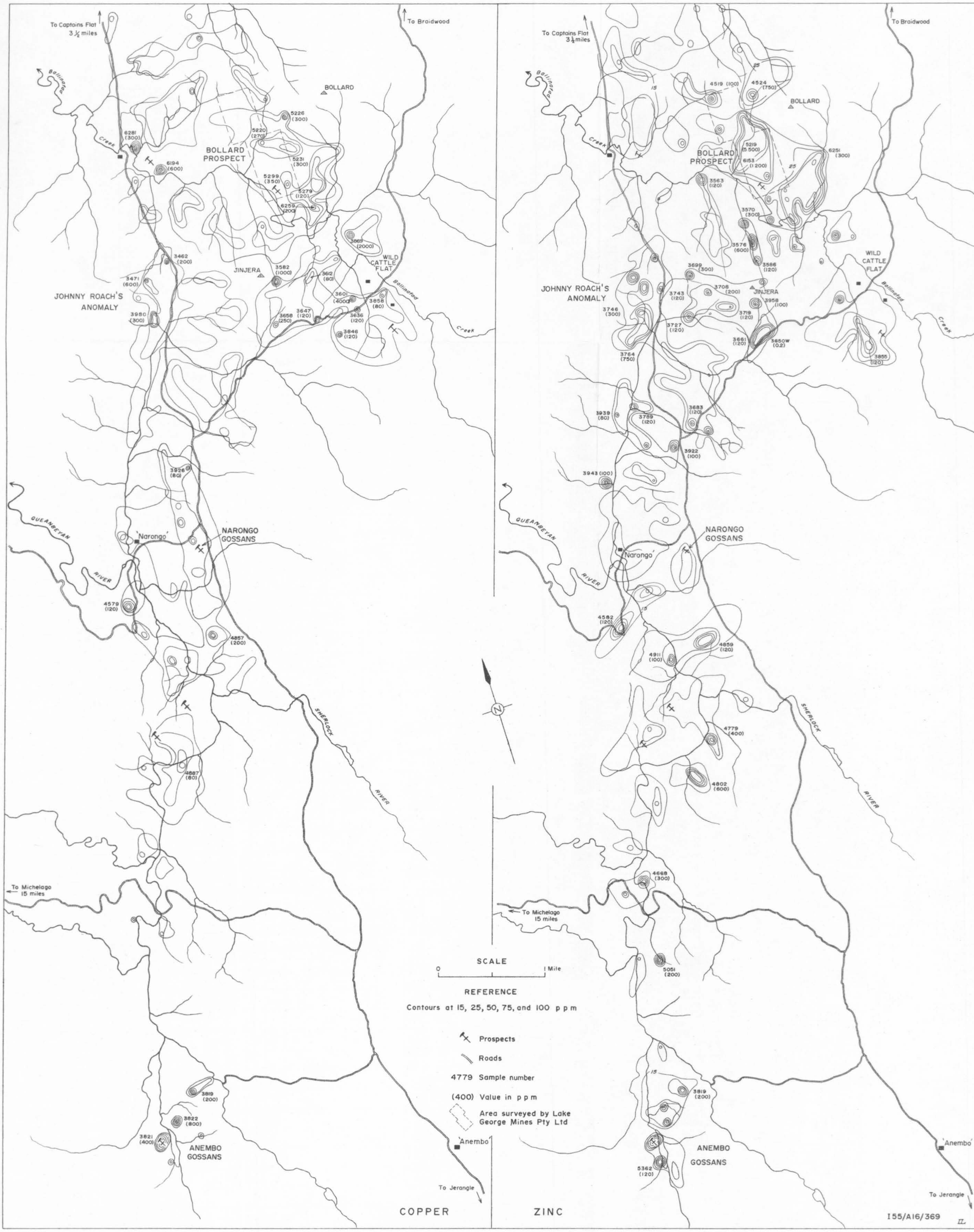


Plate 5 Geochemical contours (copper and zinc), southern part of Captains Flat area