N R O Barnard

BASE METAL OCCURRENCES WITHIN LOWER CAMBRIAN SEDIMENTS OF THE NORTHERN FLINDERS RANGES

Report of Investigations 37

Geological Survey of South Australia

DEPARTMENT OF MINES
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA

BASE METAL OCCURRENCES WITHIN LOWER CAMBRIAN SEDIMENTS OF THE NORTHERN FLINDERS RANGES

by
R. K. Johns
Supervising Geologist

Report of Investigations 37

Issued under the authority of
THE HON. D. A. DUNSTAN, M.P.
Minister of Development and Mines

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Geological Survey Office,
Department of Mines,
Adelaide, S.A. 5000.

9th June, 1972.

The Hon. the Minister of Development and Mines,

Mr. D. A. Dunstan, M.P.

I submit herewith for publication, a report by R. K. Johns, describing exploration for base metals in the Lower Cambrian formations of the Flinders Ranges. This report describes the results of activities by a number of mining companies during the years 1965 to 1969.

Because the work involved was carried out under conditions prevailing for Special Mining Leases, the results were held as confidential within the Department of Mines. As the leases concerned expired, the relevant reports became available on "open file", but the information generally was still not readily accessible to the public.

The present report is based on these company reports, and brings together a mass of information on mines and mineral prospects, including results of various geophysical, geochemical and drilling investigations which would be of vital interest to any future exploration work in the region.

The Flinders Ranges have been for many years, noted for mining activities, principally for copper. The disadvantages of remoteness and lack of transport facilities in those days combined with low metal prices, spelled failure to many early mining ventures. Under present day conditions, it is to be hoped that viable mining operations may yet result in the Flinders Ranges, from the present world wide interest in base metals.

G. F. WHITTEN, Acting Government Geologist

14th June, 1972.

Approved,

D. A. DUNSTAN, Minister of Development and Mines

Frontispiece

Sliding Rock copper mine, looking north across Sliding Rock Creek to bluff of Pound Quartzite.

Neg. 1845

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BASE METAL OCCURRENCES WITHIN LOWER CAMBRIAN SEDIMENTS OF THE NORTHERN FLINDERS RANGES, SOUTH AUSTRALIA*

INTRODUCTION

Significant concentrations of lead and zinc with minor copper and silver have been proved to be widely distributed within Lower Cambrian strata in the northern Flinders Ranges, the adjoining Torrens Sunkland and the Stuart Shelf. This report recounts the mining activity of the past and recent investigations which led to the recognition of this environment as a locus of geochemically important base metal mineralization. It summarizes the results of subsequent exploration activity by mining companies between 1965 and 1969 during the tenure of special mining leases in the northern Flinders Ranges. Fig. 1 shows the distribution of Lower Cambrian sediments, sites of previous mining operations and location of the now-surrendered special mining leases (S.M.L.).

GEOLOGICAL ENVIRONMENT

The base of the Lower Cambrian throughout the Adelaide Geosyncline and adjoining Stuart Shelf is marked either by a sedimentary hiatus or a local unconformity with the underlying upper Proterozoic (Marinoan) sediments.

In the northern Flinders Ranges the new cycle of sedimentation commences with the Parachilna Formation. There is an abrupt transition from the even grained resistant Pound Quartzite of the upper Proterozoic to the basal Cambrian Parachilna Formation, a weakly consolidated, easily eroded, argillaceous sandstone typified by occurrence of tubular worm borrows (*Scolithus*). Lenticular pebble beds, white, grey or green shales and siltstones with sandstones are common, while thin algal and oolitic limestones and ferruginous or manganiferous dolomitic siltstones are present in some sections. The environment of deposition is interpreted as fluctuating between sub-littoral and shallow shelf conditions prior to a more general transgression represented by carbonate rocks. The Parachilna Formation ranges up to over 1,500 feet in thickness but is seldom more than 200 feet thick. With increasing carbonate content these sediments pass upwards abruptly, or through transitional passage beds, into a thick sequence of dolomite and limestone, the Ajax Limestone (or equivalent Wilkawillina Limestone), which covered the site of the Adelaide Geosyncline and adjoining shelf areas (Andamooka Limestone, Kulpara Limestone, etc.) as an extensive sheet outlining the shallow transgressive Cambrian sea.

The Ajax Limestone is generally dolomitic, sandy or oolitic with sedimentary breccias near the base. These are succeeded by massive archaeocyathan limestones, commonly of high chemical purity, several thousand feet in thickness. These are in turn overlain by a barren sequence of red-brown siltstones, shales and sandstones (Billy Creek Formation, etc.).

*Manuscript received 4th November, 1968.

FLINDERS RANGES AREA

On a regional scale anomalously high lead, zinc and lesser copper contents characterize the beds near the base of the Lower Cambrian in many parts of the Flinders Ranges. There is evidence that within a narrow stratigraphic interval copper mineralization is associated chiefly with sandstone and shale in the Parachilna Formation and in the overlying limestones, while lead and zinc occur in an environment of sedimentary breccias, limestones and dolomites, usually in association with manganese.

Mining took place at a number of centres principally during the period from 1870 to 1900. Production from near-surface secondary enrichments of oxidized copper ores was sporadic and generally not very profitable, the ore being handpicked and transported to smelters in the region. Copper mines of this type include the Red Range, Ajax, Copper King, Sliding Rock, Mount Bayley, Angepena, Balcanoona, Moro, Mount Chambers, Mount Arden and Kanyaka mines.

The Sliding Rock copper mine from which recorded ore production amounts to 1,748 tons was investigated by Dickinson (1944). This was the major copper producer and the gross value of copper raised is estimated at £100,000. Next in importance with regard to copper output appear to be the Mount Bayley, Kanyaka, Ajax and Copper King mines.

Lead sulphides carrying silver were recovered at the Ediacara, Wirrealpa, Flinders, Fountain Head, Mount Lyall and Mount Chambers mines.

Only a few disjointed records of this period are available so that production from the various mines and the grade of ore mined and marketed are either unknown or the figures are far from complete. Sketchy details, mostly culled from Inspectors' of Mines reports and lacking plans, have been recorded by Brown (1908). Since that time many of the mines have been reported in publications of the Geological Survey of South Australia but few underground openings are now accessible.

Silver-lead producers of some importance were the Ediacara and the Wirreapla mines. Slugs and boulders of galena have been found at the surface at a number of other localities, but the output from these was generally small.

Following a detailed study of the Ediacara Basin and a programme of diamond drilling by the Department of Mines, Nixon (1963) concluded that the (principally) lead mineralization found there was of the Mississippi Valley type with many similarities to the southeast Missouri lead field—its occurrence in dolomites; the conformable attitude, with the mineralization being confined to a narrow stratigraphic thickness; its association with sedimentary breccias; and the absence of gangue minerals and the type of alteration commonly associated with epigenetic mineralization. Concentrations of lead, chiefly as galena, were proven to be restricted to near-basal carbonate rocks which comprise the Ajax Limestone. He considered the deposition of ore minerals was comtemporaneous with sedimentation and that they were recrystallized and mobilized after lithification of the enclosing sediments.

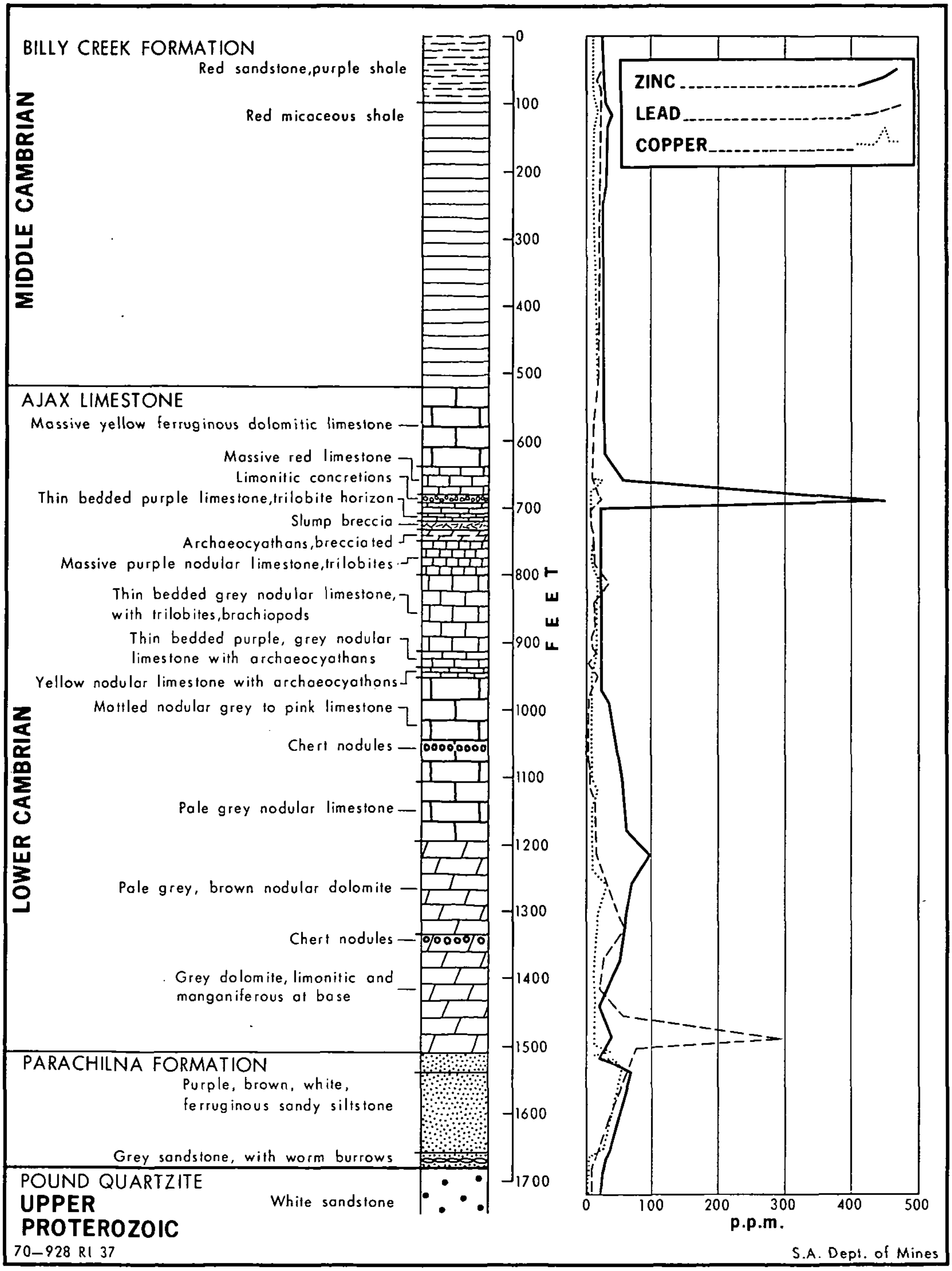


Fig. 2—Mount Scott, geochemical section.

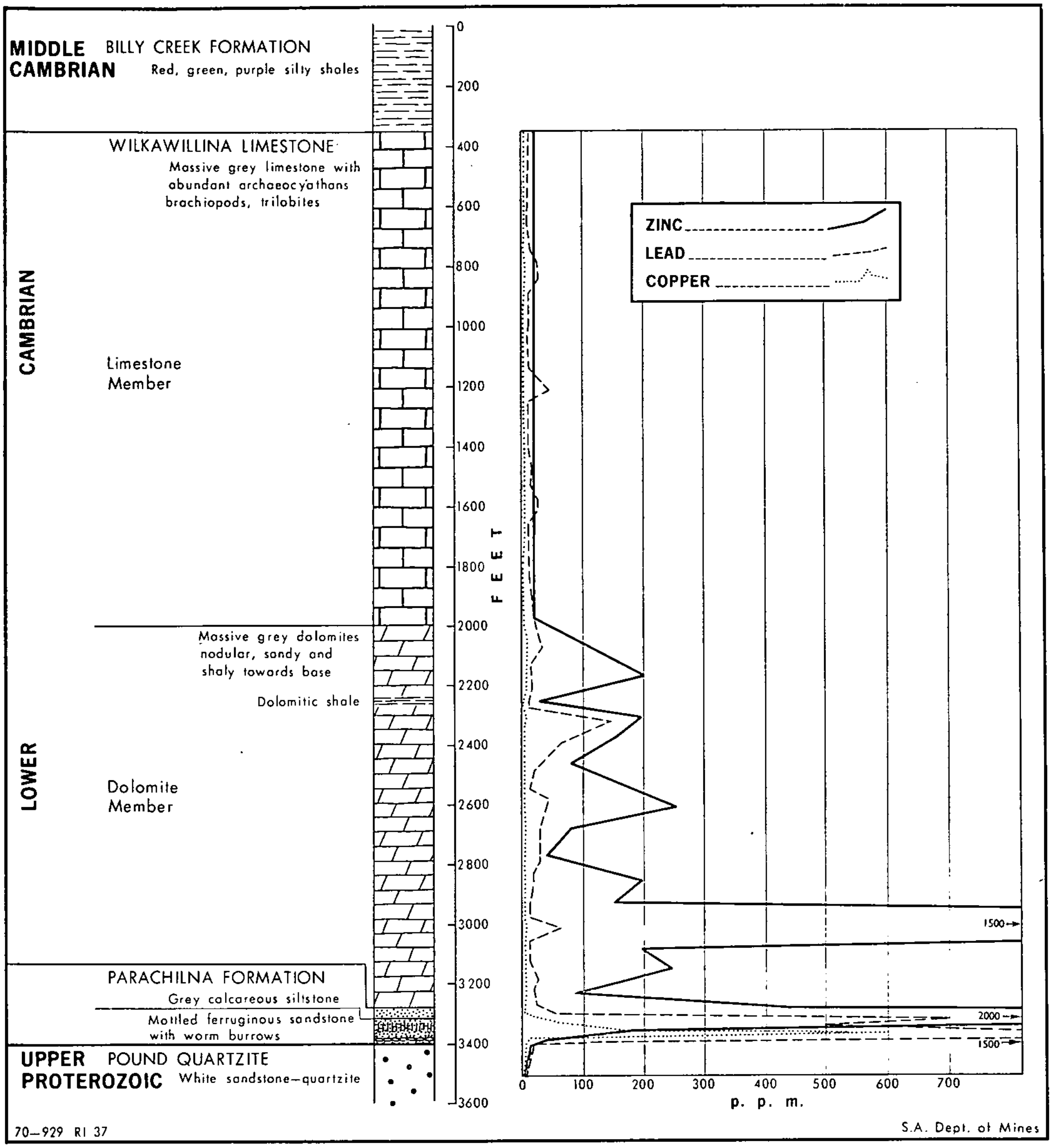


Fig. 3—Brachina Gorge, geochemical section.

Subsequently, an extended programme of sampling undertaken by Thomson (1962 and 1965) disclosed that there are above normal concentrations of base metals at this stratigraphic level elsewhere within the Adelaide Geosyncline and bordering shelves. The extensive enrichment of base metals within the Lower Cambrian was attributed to either a sedimentary exhalative process contemporaneous with sedimentation or later telethermal mineralization related to an Ordovician orogeny. The importance of basement fault-shear lineaments in providing channel ways for mineralizing solutions or gases and as controls in localizing base metal deposition were stressed. In Figs. 2 and 3 the distinct base-metal enrichment at several localities at the base of the Cambrian sequence is evident. There is also a marked association of manganese, iron, cobalt, nickel and barium at this stratigraphic level.

Exploration activity by mining companies since 1965 has further demonstrated that base metal mineralization is widespread within Lower Cambrian strata and several significant discoveries have been made. Geochemical surveys undertaken by Anaconda Australia Inc. resulted in the discovery of zinc and associated lead deposits at Puttapa which are being now developed by Electrolytic Zinc Co. of Australasia Ltd. In the Third Plain and Reaphook Hill localities Kennecott Explorations (Australia) Pty. Ltd. have outlined areas of anomalous zinc in a similar environment while the same company has investigated copper, lead and zinc occurrences in a number of other areas. Investigations at Ediacara have been extended by Conzinc Rio Australia Exploration Pty. Ltd., while similar sulphide mineralization has been recognized along the front of the Flinders Ranges between Mernmerna and Parachilna and in the Andamooka area by Mines Exploration Pty. Ltd. Following expiry of Special Mining Leases company reports have been placed on open file but details of operations on current leases are still held as confidential.

Ediacara mineral field

During the period from 1888 to 1913 an estimated 24,000 tons of silver-bearing high grade lead ore and a few hundred tons of secondary copper carbonate ore were mined from shallow pits and underground workings chiefly from Greenwood's and Southern workings along the western and southern margins of the Ediacara Basin. Ore from Greenwood's workings was reported to average 31.5 per cent lead and 8.7 oz of silver per ton. Zinc Corporation Ltd. carried out extensive sampling in 1938 and in 1946 and 1947 the Department of Mines undertook a limited programme of diamond drilling based on a study of the field by Broadhurst (1947).

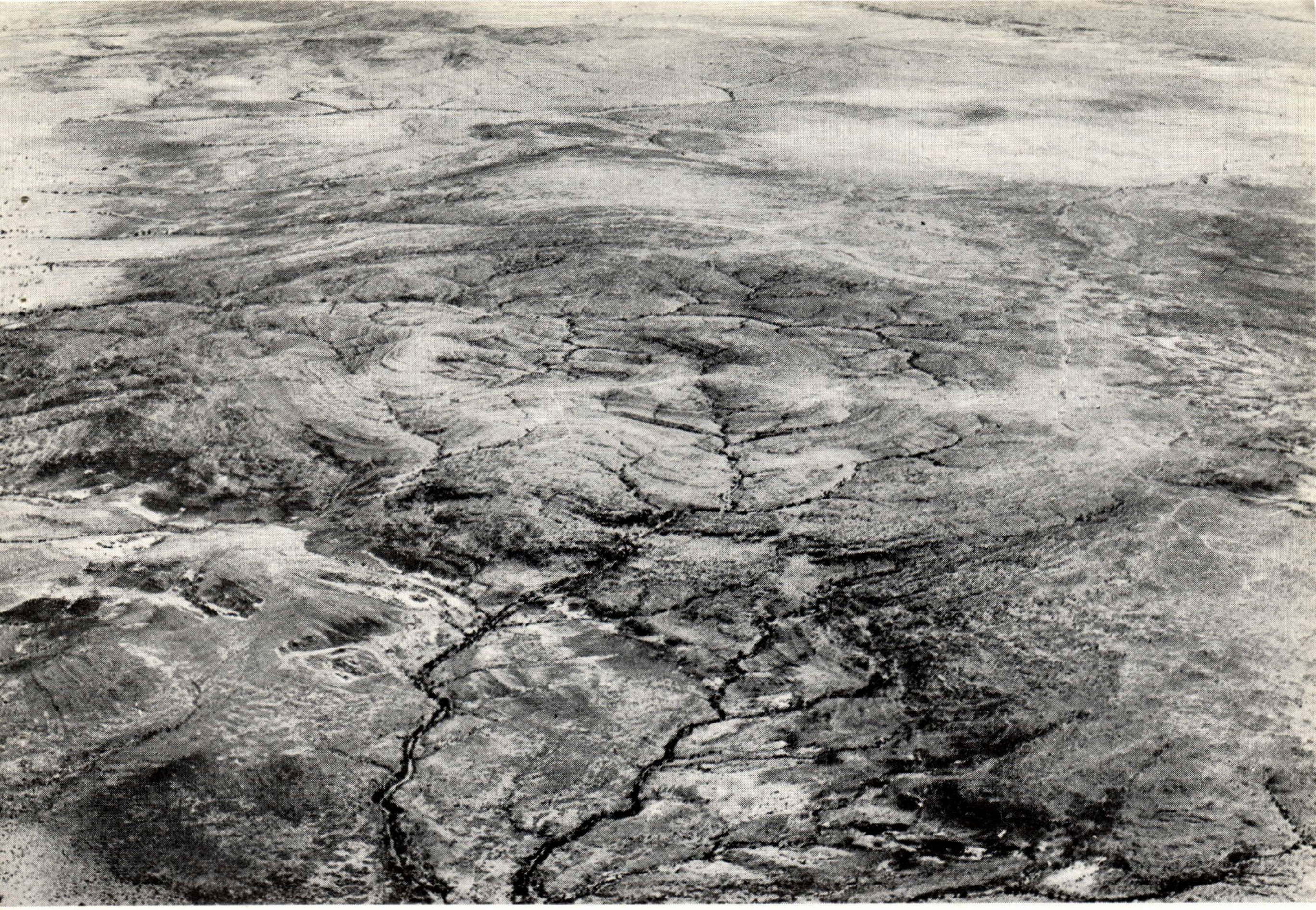
Interest in the locality was revived in 1961 when Nixon (1963, 1964 and 1967) supervised an extended diamond drilling programme to outline limits of disseminated lead and local copper mineralization. The drilling of a further 11 diamond drill holes was undertaken by Conzinc Rio Australia Exploration Pty. Ltd. during the tenure of S.M.L. 77 and S.M.L. 144 in 1965 and 1966 (McQueen, 1967).

The geological structure and disposition of the various units is depicted on the plans and sections (Figs. 4 and 5). The upper Proterozoic Pound Quartzite, almost 1,000 feet in thickness, that delimits the shallow closed synclinal basin, is overlain by the Parachilna Formation which comprises about 50 feet of gritty sandstones, greenish shales and dolomites and includes a 10 feet thick *Scolithus*—bearing bed. The succeeding Ajax Limestone, 1,000 feet thick, has been subdivided into several units. The lowermost sandy cross-bedded dolomite ranges from 50 to 450 feet in thickness and contains a well-bedded unit in which breccia layers are developed, manganese is common and primary lead mineralization occurs. Laminated algal dolomite, averaging 120 feet in thickness, is composed of buff and grey dolomites in which breccias are common, including a persistent outcropping siliceous manganiferous and iron-stained breccia near the base of the unit. Manganese staining is common throughout and the unit is the host to primary lead mineralization. The uppermost unit includes massive dolomite up to 450 feet in thickness in the centre of the basin; archaeocyathans are common, minor breccias occur and only minor mineralization is evident.

Difficulty was experienced in identification of some units in drill cores which had been defined from outcrop mapping, particularly with regard to cross-bedded sandy and laminated algal dolomites which sometimes have similar lithologies. To what extent facies changes affected identification of these stratigraphic units has not been determined.

Galena, the main "ore" mineral, occurs in individual crystals of varying size scattered throughout the dolomites; as small lenses along bedding planes; as vein fillings; or as the main constituent of the matrix of sedimentary (slump) breccias. The sulphide is generally encrusted by cerussite or anglesite and in the abandoned workings the principal minerals are galena and cerussite. Copper occurs as carbonates but useful concentrations are known only in a local area in the northern section of the basin and at Black Eagle workings, from whence there has been small production of ore, hand-picked to 20 per cent copper. Patches of "gossan" located in both the southeastern and southwestern parts of the field comprise thin, conformable, iron and manganese-stained siliceous breccias which contain insignificant copper and lead contents. Several masses of psilomelane and ironstone (limonite and hematite) have been opened up by pits and shafts to provide ironstone flux for local smelting of lead ores but these deposits are superficial. Drilling down-dip from the outcrop of the gossans has revealed minor lead and copper mineralization only in diamond drill hole 10.

Nixon (*op cit.*) concluded that the mineralization is stratiform and confined to a relatively narrow sequence in two zones relatively richer in metals, described as being 50 feet apart and between 100 and 200 feet above the base of the Cambrian. Deposition of ore minerals was considered to be contemporaneous with sedimentation, localization being influenced by sedimentary and structural features and ore minerals being mobilized and recrystallized after lithification of the sediments. The drilling of 35 diamond drill holes, by the Department of Mines, indicated some 17.5 million tons of "ore" over a thickness of 52 feet and having an average grade of 1.13 per cent lead. For a grade averaging 0.9 per cent lead with an average thickness of 58 feet the inferred reserves were estimated at 31.8 million tons (Nixon, 1967). It is apparent that mineralization is not restricted to any particular stratum and that lead and copper minerals are enclosed in various lithologies, namely, a shaley facies of the Parachilna Formation and sandy cross-bedded dolomites and laminated algal dolomites of the Ajax Limestone. Drilling has intersected mineralized rock in several zones, as outlined in Figs. 4 and 5 in plan and in the cross-sections, marginal to the fault which defines the western limits of the basin from the surface to depths ranging to 900 feet. Mineralization is richest, though of low grade, on the northwestern flank, trending to lower grade and pinching out to the south.



Ediacara mineral field. Aerial view looking north across gently folded Ajax Limestone. *Neg.* 12944

The drilling of 11 holes by Conzinc Rio Australia Exploration Pty. Ltd. failed to extend the limits of previously indicated mineralization. A revision of indicated tonnages based on an interpretation by McQueen (1967) of distribution of mineralization in the various units is as follows:

1. Body in laminated algal dolomite—12 million tons average 0.84 per cent lead.

2. Body in sandy cross-bedded dolomite—17 million tons average 1.23 per cent lead (with an enriched zone included in 2, of 1.2 million tons averaging 2.24 per cent lead).

It was concluded that the "density of the drilling and knowledge of mineralization in the . . . structure indicate that an economical deposit of base metals is unlikely to occur therein" and the lease expired on 31st March, 1967. It remains to be determined whether the down-faulted sector to the west of the Ediacara structure is underlain by Cambrian sediments and whether or not these are mineralized.

Table 1 shows the most significant diamond drill intersections at Ediacara with their average metal contents:

TABLE 1

AVERAGE METAL CONTENTS IN DIAMOND DRILL HOLE INTERSECTIONS AT EDIACARA

Bore No.	Interval (feet)	Thickness (feet)	Pb per cent	Cu per cent	Zn per cent	Ag oz	Ag dwt
2	105–108	3	0.97	0.02	0.01	0	8
3	6–12	6	1.43	12.4	0.28	7	7
5	115–141	26	0.91	0.01	0.005	3	19
	176–190	14	1.02	0.07	0.01	1	0
6	0–100	100	1.56	0.01	0.01	0	14
7	135–190	55	0.29	0.65	0.03	0	6
	190–290	100	1.32	0.18	0.06	0	3
10	187–247	60	0.97	0.15	0.08	0	12
13	52–100	48	0.83	0.005	0.01	0	4
14	20–115	95	1.26	0.004	0.007	0	17
15	80–180	100	1.04	n.d.	n.d.	n.d.	
17	100–110	10	1.07	n.d.	n.d.	n.d.	
	160–170	10	1.03	n.d.	n.d.	n.d.	
18	15–30	15	0.98	1.81	n.d.	n.d.	
19	21–34	13	0.20	2.78	n.d.	n.d.	
20	20–22	2	0.94	0.58	0.37	n.d.	
23	0–70	70	0.88	0.01	0.02	0	7
32	270–345	75	0.91	0.03	0.07	1	16
33A	310–380	70	1.03	0.004	0.005	0	10
34	450–510	60	0.91	0.005	0.02	0	4
	560–590	30	1.07	0.03	0.009	0	17
35	30–80	50	1.23	0.007	0.03	0	2
39	512–542	30	0.83	0.04	0.07	0	14
41	690–760	70	0.72	n.d.	n.d.	0	3
47	140–149	9	n.d.	0.38	n.d.	n.d.	

n.d.—not determined

Puttapa zinc prospect

Special Mining Lease 113 was granted to Anaconda Australia Inc. on the 16th May, 1966, to undertake a programme of geochemical sampling on a reconnaissance basis of selected areas where the Ajax Limestone occurred. Stream sediment samples taken on a density ranging from 5 to 10 per square mile were screened in the field and the minus 80 mesh fraction were submitted for determination of Cu, Pb and Zn contents after cold extraction with hydrochloric acid. These showed concentrations generally in the range of 2 to 10 p.p.m. Several areas showed anomalous (plus 40 p.p.m. and up to 450 p.p.m.) copper contents; mostly these were adjacent to old copper mines—Mucatoona, Nuccaleena, Red Range and Mount Bayley and also at the Angepena goldfield and near Patawarta Gap. Significant lead (40 p.p.m. to 400 p.p.m.) and zinc (100 p.p.m. to 1,300 p.p.m.) anomalies were located in the Puttapa locality in the vicinity of the Ajax copper mine, less than two miles east of the Leigh Creek-Port Augusta railway. Follow-up rock sampling and detailed mapping outlined outcrops of willemite (Zn_2SiO_4) with associated hedyphane ($PbCl.Pb_4(AsO_4)_3$), vanadinite ($PbCl.Pb_4(VO_4)_3$), finnemanite ($Pb_5Cl.(AsO_3)_3$) and coronadite (lead manganate) with manganese and iron oxides. Subsequently S.M.L. 113 (expired 6th December, 1966) and S.M.L. 136 were granted to include the prospect and the area was finally surrendered on 31st March, 1967. This report summarizes the results of work undertaken by Anaconda Australia Inc. at the Puttapa zinc deposit based on the report of Whitehead (1967).

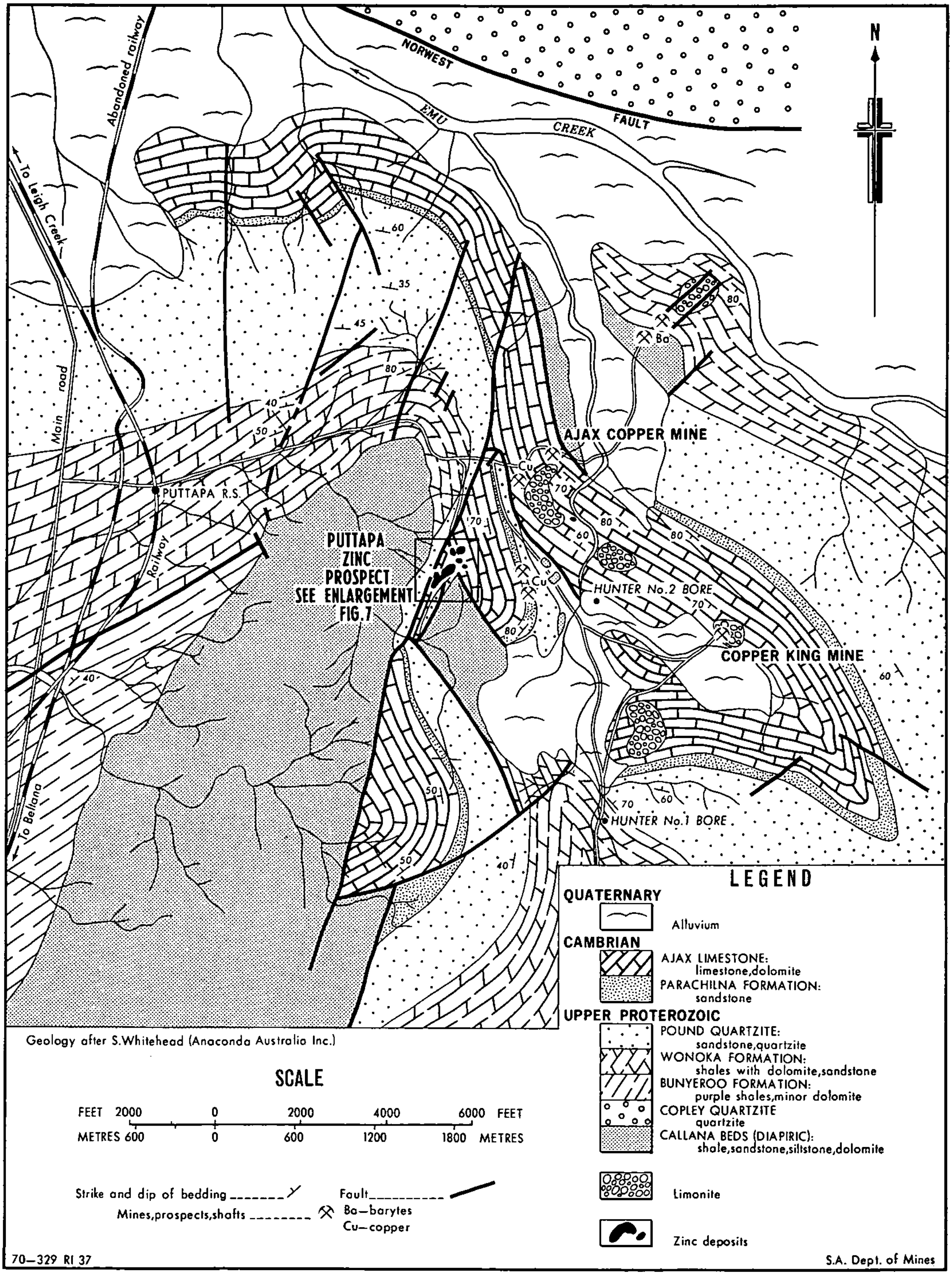


Fig. 6—Puttapa zinc prospect, regional geological plan.

At the prospect, zinc and lead minerals occur as weathered residuals and replacement deposits in a complex fault zone within an area of 1,000 feet by 400 feet. Fig. 6 shows the disposition of the various units of the upper Proterozoic and the overlying Lower Cambrian formations, the strata being contorted and often truncated by faults in an area marginal to the major Norwest fault. Locally, the Cambrian and older sediments have been intruded by masses of diapiric breccia containing blocks of finely banded shale and siltstone with halite casts, dolomite and quartzite, derived from the underlying Callanna Beds. The Lower Cambrian succession consists of kaolinitic sandstones of the Parachilna Formation, approximately 200 feet in thickness, and the overlying Ajax Limestone, 2,500 feet thick, which contains abundant well-preserved archaeocyathans.

Bold outcrops of white zinc silicate containing up to 52 per cent zinc (average 40 per cent zinc) with lead chloro-arsenates and chloro-vanadates (containing up to 46 per cent lead) and associated with manganese and ochreous iron oxides have been mapped in detail by Whitehead (*op cit.*), over an area of 1,000 feet by 400 feet (Fig. 7). Willemite occurs in radiating, prismatic or spherulitic aggregates, mammilated colloform bands and structureless masses. Laterally, these bodies pass abruptly into red recrystallized manganiferous dolomite which contains paper thin mineralized films along joints and fractures, the red dolomite being a recrystallized variety of the normal grey coloured Ajax Limestone. Whitehead (1967) describes the mineralization as follows:

> "No boxwork, pseudomorphous replacement or other indication of sulphides has been detected and the general appearance of the deposit strongly suggests that the zinc and lead have migrated in groundwater solutions. . . . The main concentration of zinc at the surface occurs in an extensively faulted area where massive Ajax Limestone . . . is closely associated with areas of diapiric breccia, but most of the zinc-bearing outcrops are separated from diapiric material by zones of fractured . . . quartzite.
>
> Results of geochemical stream sediment sampling in the surrounding area show lead and zinc anomalies in many creeks draining Ajax Limestone up to two miles north and one mile south of the (main) zinc mineralization. Analyses range up to 760 p.p.m. for zinc and 217 p.p.m. for lead. In contrast, the values for lead and zinc in sediments from streams draining Pound Quartzite, Wonoka shales and dolomites, and areas of diapir away from the limestone are generally low and rarely more than 7 p.p.m." (Whitehead, *op. cit.*)

Systematic chip sampling of the red dolomitic limestone showed contents of zinc up to 2,000 p.p.m., with lead generally in the range 80 to 170 p.p.m., in an area half a mile in length at the eastern margin of the deposit, and also to the south and at the southwestern end. Samples taken from a distance of a quarter of a mile from willemite outcrops average 2,520 p.p.m. lead. The only zoning apparent is in a progressive increase in zinc and lead contents as the willemite outcrops are approached.

Arsenic content which ranges up to 180 p.p.m. in the red dolomitic limestone on the eastern side of the deposit is greatly concentrated (400 to 4,000 p.p.m.) near the willemite outcrop; lead arsenates have since been identified.

Immediately south and west of the Ajax copper mine the Ajax Limestone is veneered by limonitic scree, and several small outcrops of almost pure willemite have been located approximately a half a mile east of the main zinc deposit.

Minor copper mineralization has been disclosed in the locality, at the Ajax mine (where recorded ore production amounts to 134 tons) and in shallow pits a half a mile to the southwest. Sampling at the Copper King ochre deposit indicated that one near-surface section six feet in thickness contained 2.7 per cent copper while the weighted average of a number of samples was 0.7 per cent copper (Johns, 1956). Copper occurs principally as malachite, but cuprite has

Willemite outcrop, Puttapa zinc prospect. Mineralized Ajax Limestone in foreground; Mount Bayley Range in right background.

Neg. 18756

also been recorded, and during the period 1899 to 1908 recorded production of copper ore amounted to 122 tons with the average grade of hand-picked ore being 25 per cent copper.

The Puttapa prospect, because of the nature of the mineralization and the belief that the deposit represented but a thin residual "skin", held no further interest for the discoverers. Since title was gained by Electrolytic Zinc Co. of Australasia Ltd., drilling has been undertaken by that company to prove over one million tons of 40 per cent zinc ore associated with lead, and plans for exploitation have been announced.

Willochra area

On the 1st December, 1965, Kennecott Explorations (Australia) Pty. Ltd. was granted S.M.L. 94 to cover an area of 135 square miles in the Willochra area to the north of Quorn and extending towards Hawker. A programme of stream sediment sampling and reconnaissance rock chip sampling over the Parachilna Formation and the overlying Cambrian limestones was undertaken. Three areas were outlined which were considered (McNeil, 1966a) to warrant further exploration.

1. Mount Arden-Comstock area where sampling showed that there are anomalous zinc, lead and copper contents within Lower Cambrian strata over a strike length of 17 miles.
2. Radford Creek area where anomalous lead and zinc contents were disclosed at the same stratigraphic level.
3. Adjacent to the Kanyaka copper mine.

S.M.L. 94 was surrendered on 31st May, 1966 and three new leases within the limits of S.M.L. 94 were sought and granted to the company to further explore the area defined. These are discussed separately below.

Mount Arden—Comstock area

Minor copper (Mount Arden mine) and ironstone (Donnelly's or Comstock deposits) located within the Parachilna Formation, 15 miles north of Quorn, were exploited during the period between 1880 and 1900 (Brown, 1908; Jack, 1922; Armstrong, 1937 and Kingsbury, 1955).

At the Mount Arden mine numerous shallow shafts and pits have exposed small discontinuous thin veinlets, stains, irregular patches and bunches of malachite and azurite over an area of 1,500 by 300 feet. There is no defined lode and the copper carbonates occur patchily along the bedding and in fractures within kaolinitic siltstone, ferruginous jasperoidal shale and limonitic breccia. Selective mining resulted in the production of little more than 20 tons of hand-picked ore containing 14 to 20 per cent copper.

About two miles to the south in the Comstock area, a number of discontinuous ironstone pods outcrop in a zone traceable over a strike length of three miles around the keel of a tight synclinal structure. The ore comprises massive limonite with a little hematite, manganiferous in part, which results from surface enrichment of two beds of iron, and manganese-impregnated siltstones less than 250 feet in width that are interbedded with sandy shales, siltstones and sandstones. Exploratory adits driven below the main ore bodies prove that they do not persist in depth and that they are superficial secondary deposits. There are four main groups of workings from which 17,500 tons of ironstone were mined and shipped to Port Pirie for smelter flux during the 1890's. The northeastern workings 30 feet by 70 feet and 30 feet deep are based on a limonite mass 700 feet long and averaging 40 feet in width; reserves of 140,000 tons of 48.4 per cent iron ore remain (Whitten, 1963). The main or southeastern outcrop has been exposed in a quarry to a depth of 40 feet; reserves of 51.7 per cent iron ore approximate

100,000 tons. The northwestern ore body outcrops over a length of 400 feet and averages 16 feet in width; reserves are estimated at 16,000 tons. A number of pods of manganiferous limonite have been tested by an adit and pits in the southwestern sector of the area where reserves are estimated to be 63,000 tons. Total reserves of ironstone aggregate 350,000 tons with iron contents ranging from 48 to 58 per cent and contents of insolubles ranging to 16 per cent; selected pyrolusite samples contained up to 35 per cent manganese but these and the ironstone deposits are generally too small and of too low grade to be marketable.

Following discovery of significant concentrations of lead and zinc within the boundaries of S.M.L. 94 by Kennecott Explorations (Australia) Pty. Ltd. (McNeil, 1966a) the company sought and was granted on 1st June, 1966, S.M.L. 108 covering 18 square miles in the Mount Arden-Comstock locality to undertake further exploration. The results of geophysical and geochemical surveys, trenching and drilling undertaken up to 31st August, 1967, when the lease expired, have been detailed by McNeil (1966b and 1967a) and are summarized below.

The area studied is depicted in Fig. 8 which shows the Lower Cambrian and older sedimentary units disposed in two tight adjacent synclines. The Parachilna Formation, comprising 200 to 500 feet of thin-bedded argillaceous sandstone, siltstone, massive dolomite and dolomitic shale, forms subdued outcrops and is often mantled by scree derived from the underlying Pound Quartzite. The Wilkawillina Limestone is about 1,400 feet thick and includes well-bedded sandy, partly oolitic, pale grey limestone with interbedded siltstone at the base. It passes in to massive blue-grey limestone in the upper parts of the formation.

Stream sediment samples taken on a density of generally more than eight per square mile indicated that the Lower Cambrian formations were anomalous with respect to copper, lead and zinc contents over a strike length of about 17 miles. These showed zinc contents generally ranging from 20 to 60 p.p.m. and exceeding 150 p.p.m. in the Comstock area. More significant and more continuous concentrations were located in the eastern syncline along the flanks of Ragless Range over the Parachilna Formation and the Wilkawillina Limestone. Zinc contents of up to 1,740 p.p.m. were reported from the eastern syncline, while in the Comstock area anomalous base metal contents included zinc up to 1,000 p.p.m., lead to 410 p.p.m. and copper (which is more or less confined to the Mount Arden mine area) to 100 p.p.m. Follow-up rock chip sampling indicated that zinc mineralization ranging between 0.2 and 1.0 per cent zinc occurred over stratigraphic widths of 20 to 50 feet within the basal beds of the Wilkawillina Limestone and in the central part of the Parachilna Formation.

Self potential (nine lines over a length of 5.5 line miles) and induced polarization (three lines over 1.1 line miles) traverses were metered but geophysics proved to be of little assistance as no large or high intensity anomalies were defined.

To evaluate zinc mineralization associated with goethite and manganese wad along the western flank of Raglass Range, nine trenches were excavated using a bulldozer and these were channel sampled. A summary of results is shown in Table 2.

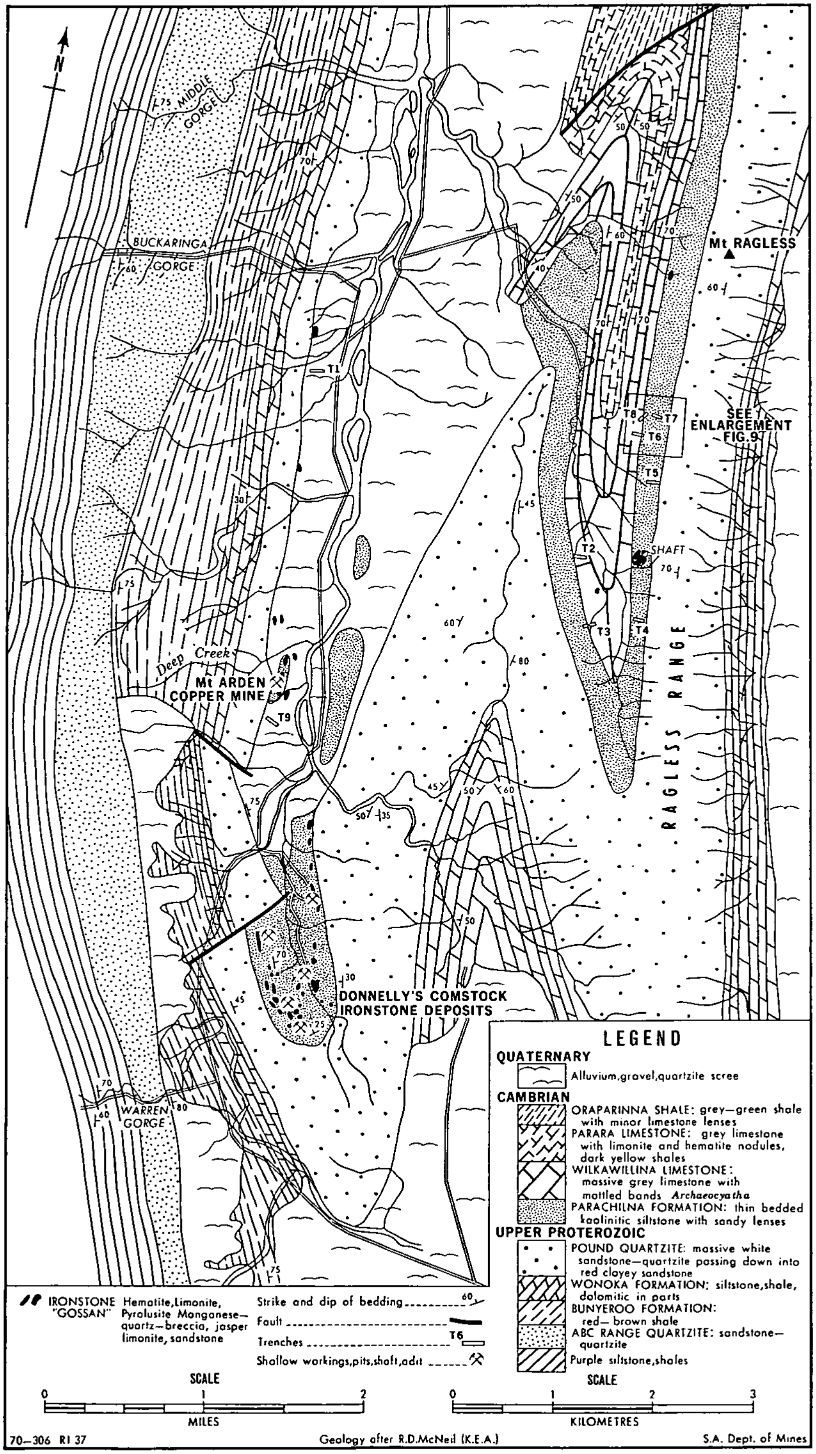


Fig. 8. Mount Arden—Comstock area, geological plan.

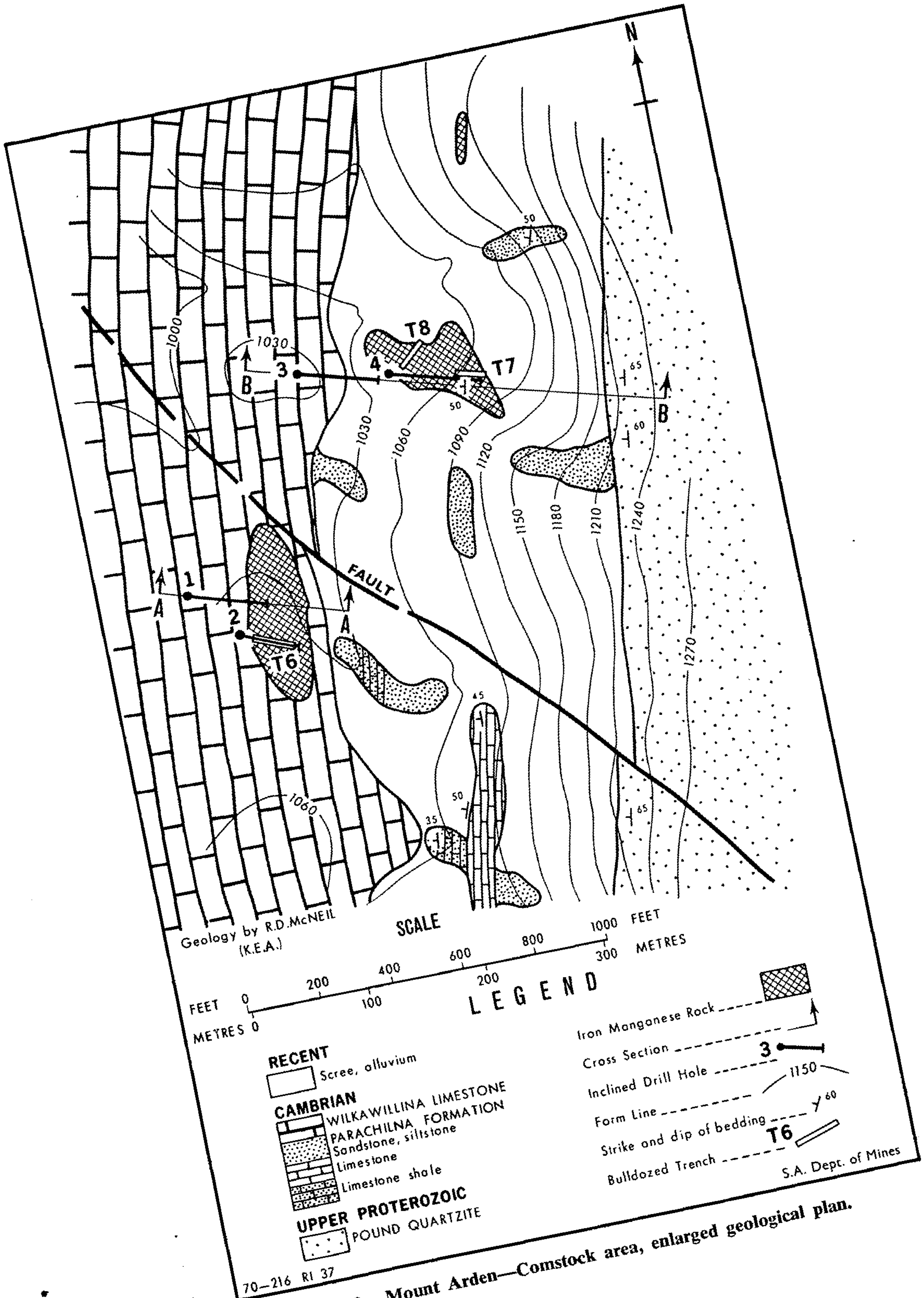


Fig. 9. Mount Arden—Comstock area, enlarged geological plan.

TABLE 2

METAL CONTENTS IN TRENCH SAMPLING ALONG WESTERN FLANK OF RAGLESS RANGE

Trench No.	Sample interval (feet)	Zn p.p.m.	Pb p.p.m.	Cu p.p.m.	Co p.p.m.	Ni p.p.m.	Mn p.p.m.
1	10	125	110	1,500	140	50	10,000
2	120	3,600	120	65	117	106	10,000
3	40	6,775	135	42	170	160	10,000
4	90	2,480	710	80	45	88	720
5	60	4,250	340	90	50	115	2,425
6	100	6,410	165	23	204	150	10,000
7	70	11,730	135	120	167	248	10,000
8	40	3,750	77	60	140	203	3,360
9 failed to penetrate overburden 13ft. thick—not sampled							

One sample 10ft. in width from trench 7 contained 3.55 per cent zinc.

The area in which the highest surface zinc values occur (see Figs. 9 and 10) was tested by four non-core drill holes, the footage totalling 1,485 feet. The best intersections are shown in Table 3.

TABLE 3

INTERSECTIONS OF DRILL HOLES SHOWING HIGHEST ZINC CONTENTS, WESTERN FLANK OF RAGLESS RANGE

Hole No.	Interval (feet)	Zn p.p.m.	Pb p.p.m.	Cu p.p.m.
1	260–270	3,650	—	—
2	0–200	2,260	—	—
3	100–130	3,800	—	—
4	137.5–150	10,050	150	50

The zinc mineral proved to be chalcophanite, (Mn, Zn) $O.2MnO_2.2H_2O$, which is invariably associated with goethite and manganiferous wad. No sulphide mineralization was detected. It was concluded that stratiform zinc mineralization as chalcophanite without significant copper or lead, is present in the Lower Cambrian sediments along a strike length of seven miles in the eastern syncline. It occurs associated with manganese in the basal part of the Wilkawillina Limestone and the central part of the Parachilna Formation. Mineralization was proven to extend down dip with relatively higher grades (up to 3.5 per cent zinc) at the surface resulting from surface enrichment of primary grades of between 0.2 and 1.0 per cent zinc. Copper occurs in the Parachilna Formation separately from, and to the west of, the zinc mineralization; it is less extensive and rarely exceeds 0.2 per cent copper. It was concluded that though the lease had not been exhaustively tested "all the evidence is against the occurrence of mineable grade zinc mineralization".

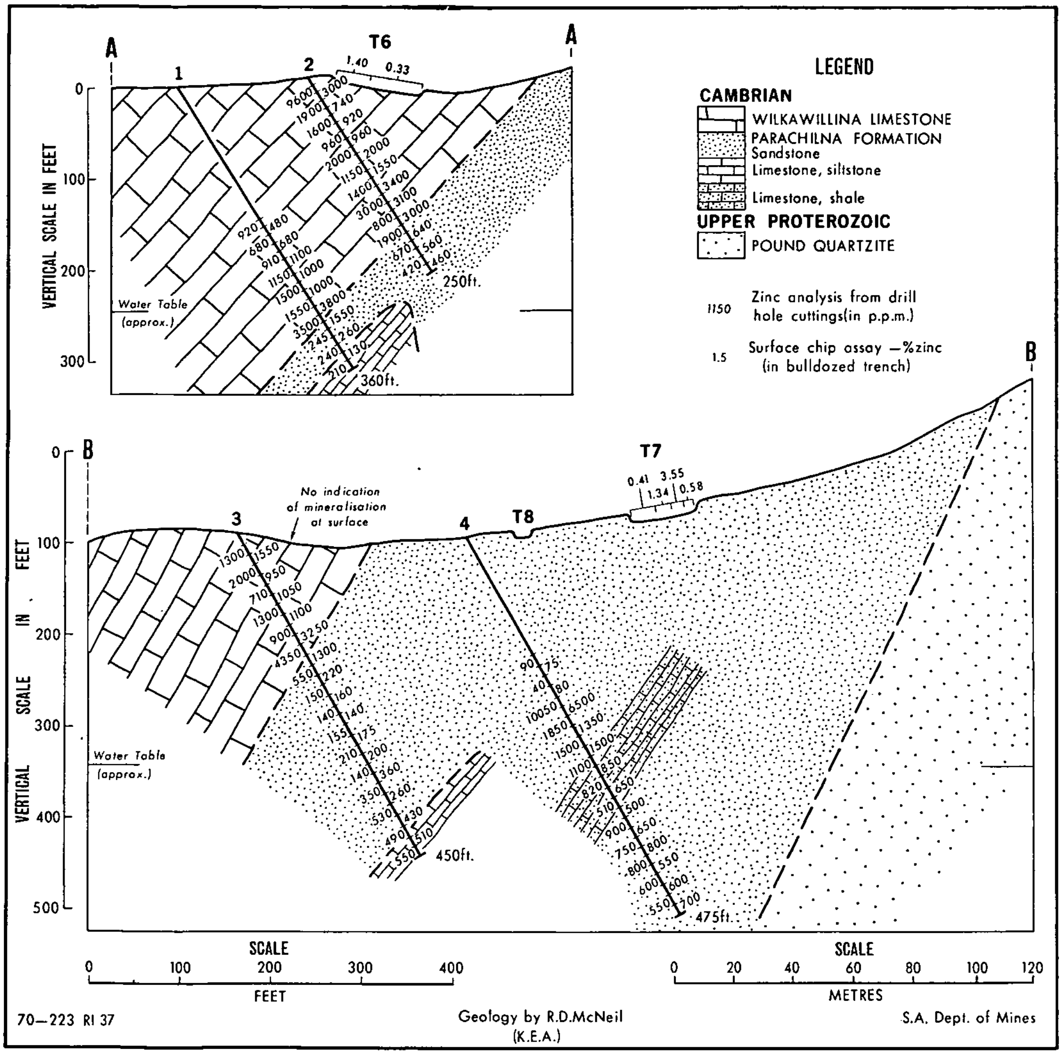


Fig 10. Mount Arden—Comstock area, geological cross sections through diamond drill holes.

Radford Creek area

At the turn of the century, three exploratory shafts were sunk 10 to 20 feet deep, to expose copper carbonates in a formation two to three feet wide adjacent to a shear zone separating Lower Cambrian limestones from shales of the Wonoka Formation near Radford Creek. A sample taken contained 4.5 per cent copper (Brown, 1908, p. 66). Several pits have also been sunk approximately one mile to the south in a pod of manganese adjacent to a fault zone.

Special Mining Lease 109, six square miles in area, within the limits of the former S.M.L. 94 was granted to Kennecott Explorations (Australia) Pty. Ltd. on 1st June, 1966 in order to undertake an extended programme of exploration. This included rock chip and soil sampling, geophysical surveys, trenching and drilling to investigate further the lead-zinc-copper mineralization which was located in this area during the course of a stream sediment geochemical programme (McNeil, 1966a, 1966c and 1967b).

The Lower Cambrian sequence within S.M.L. 109 includes 200 feet of thinly bedded argillaceous sandstones and siltstones with massive dolomite and dolomitic shale of the Parachilna Formation overlain by 1,400 feet of Wilkawillina Limestone (Fig. 11). These comprise a block having a strike length of less than two miles and margined on all but the western side by upper Proterozoic sediments faulted into juxtaposition. The Parachilna Formation is largely obscured by scree derived from the underlying quartzites.

Stream sediment samples taken by McNeil (1966a) showed contents of up to 1,000 p.p.m. lead, 700 p.p.m. zinc and 70 p.p.m. copper. Follow-up soil and rock chip sampling disclosed high coincident anomalies with respect to those metals, in association with iron and manganese oxides, within the Parachilna Formation and at the base of the Wilkawillina Limestone, traceable over a strike of almost one mile. Geophysical surveys yeilded inconclusive results; several small self potential anomalies were detected over eight lines comprising 2.5 line miles; induced polarization measurements taken along a line 0.3 mile in length showed small anomalies not coincident with known mineralization. Five trenches were cut using a bulldozer in the area of greatest metal concentration where soil samples contained up to 4,800 p.p.m. lead, 2,650 p.p.m. zinc and 390 p.p.m. copper, and rock chip samples showed up to 3.8 per cent lead, 1.15 per cent zinc and 0.13 per cent copper (Figs. 12, 13 and 14). Analyses of samples cut from the floors of the trenches are shown in Table 4.

TABLE 4

METAL CONTENTS IN TRENCH SAMPLING, RADFORD CREEK AREA

Trench No.	Sample interval (feet)	Zn p.p.m.	Pb p.p.m.	Cu p.p.m.	Co p.p.m.	Ni p.p.m.	Mn p.p.m.
1	33	1,410	135	70	102	78	10,000
2	88	1,820	97	40	140	104	10,000
3	144	6,210	800	90	220	130	10,000
4	120	3,380	4,630	745	60	64	10,000
5	200	330	760	140	16	15	55

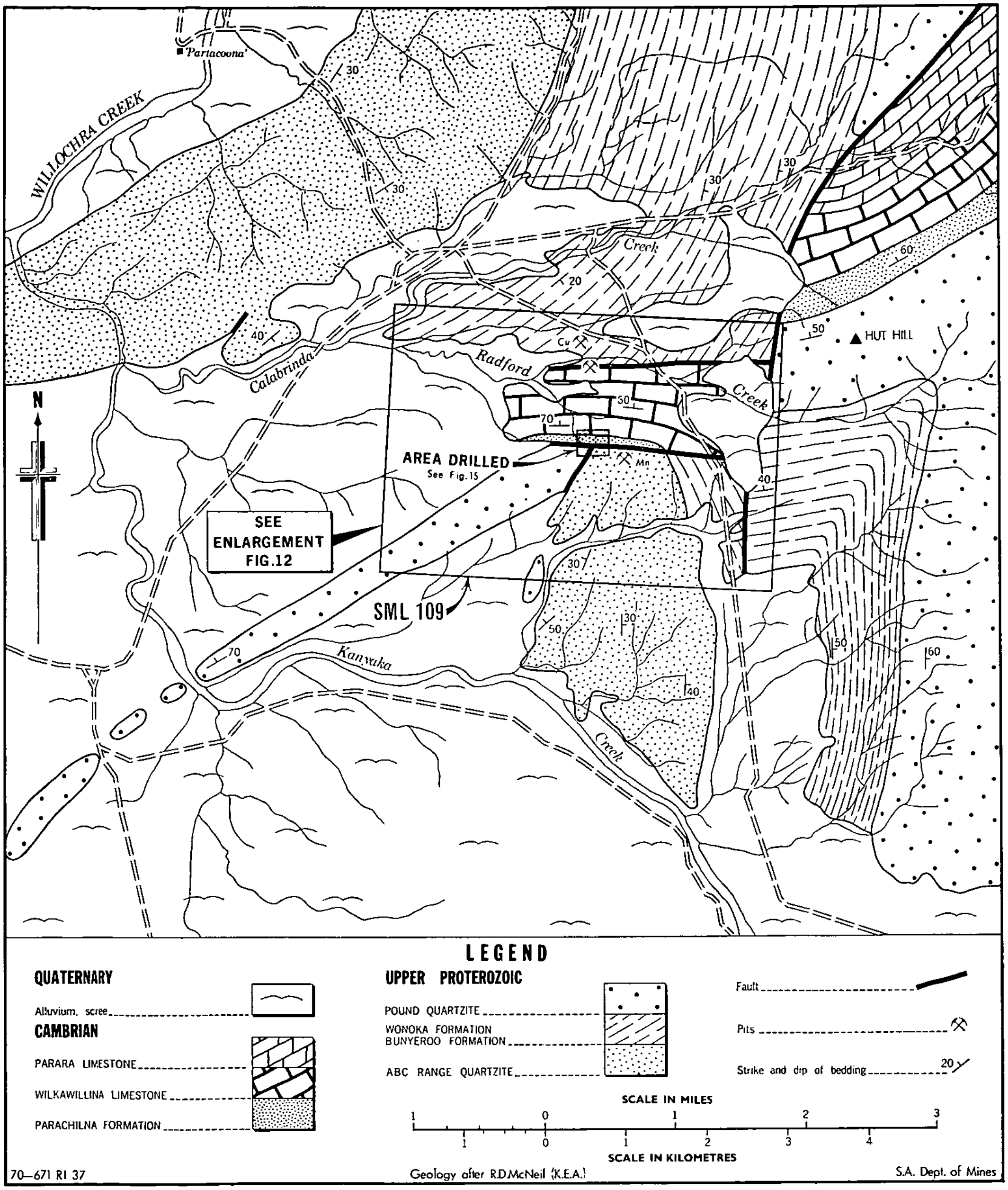


Fig. 11. Radford Creek area, geological plan.

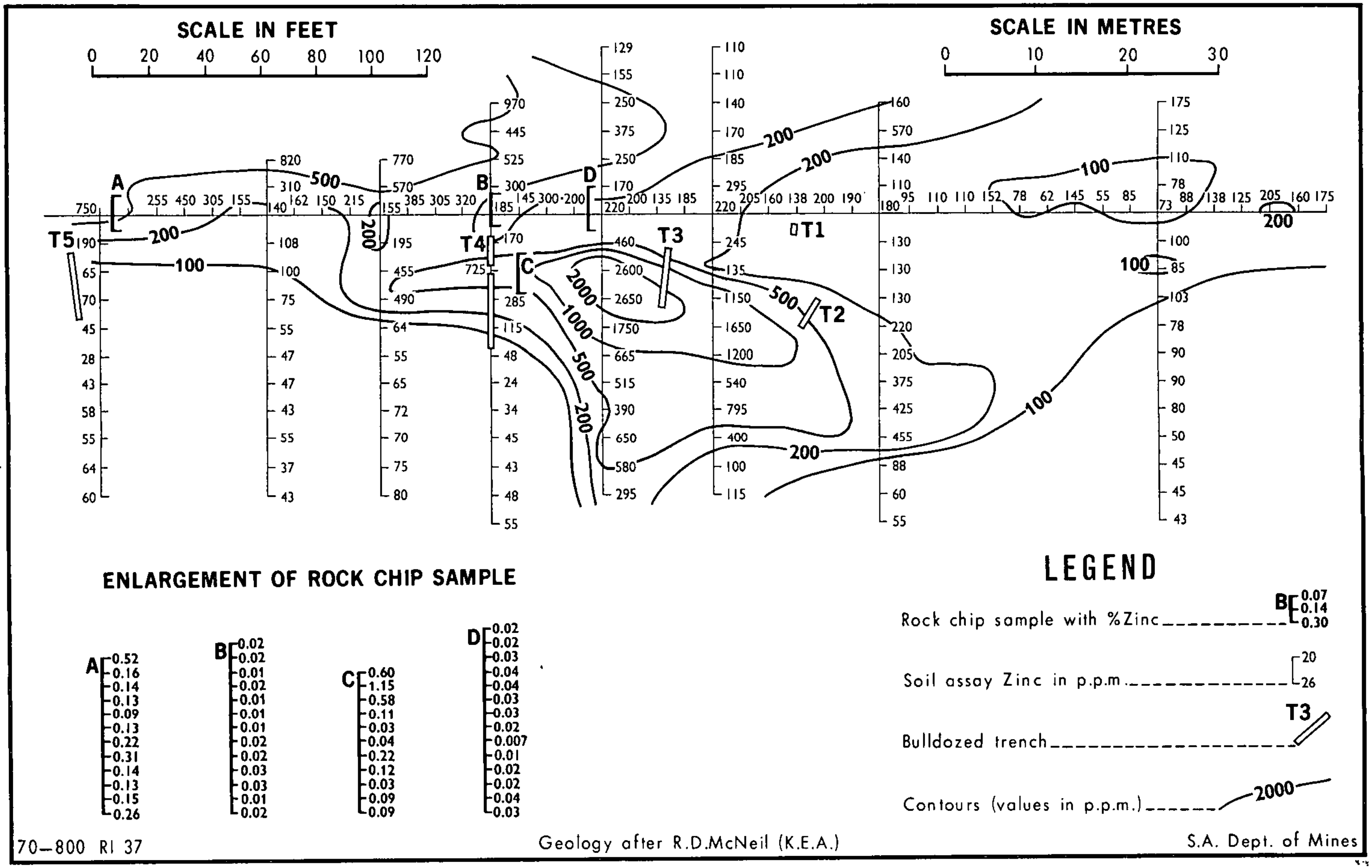


Fig. 12. Radford Creek area, contours of geochemical zinc values in soil.

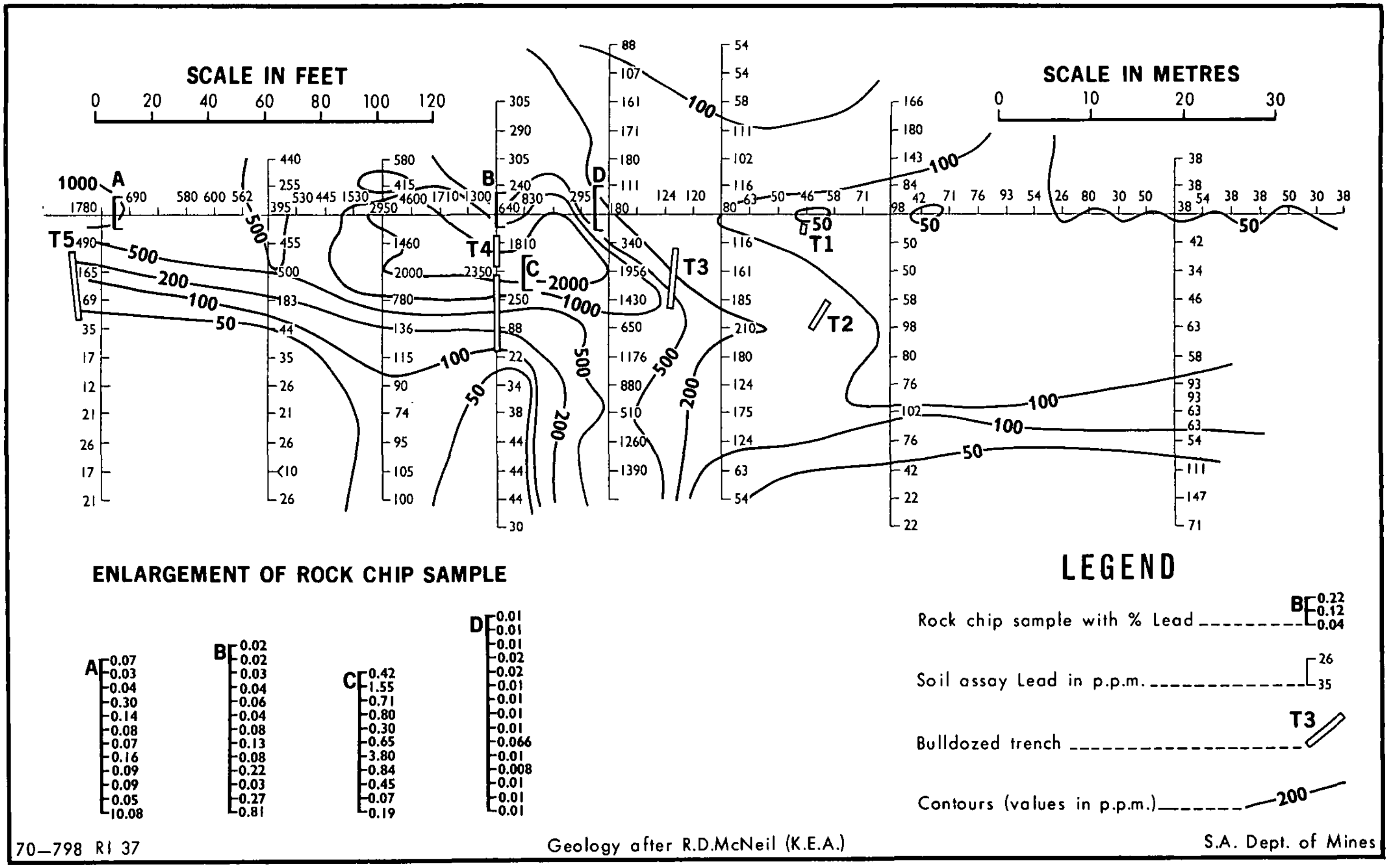


Fig. 13. Radford Creek area, contours of geochemical lead values in soil.

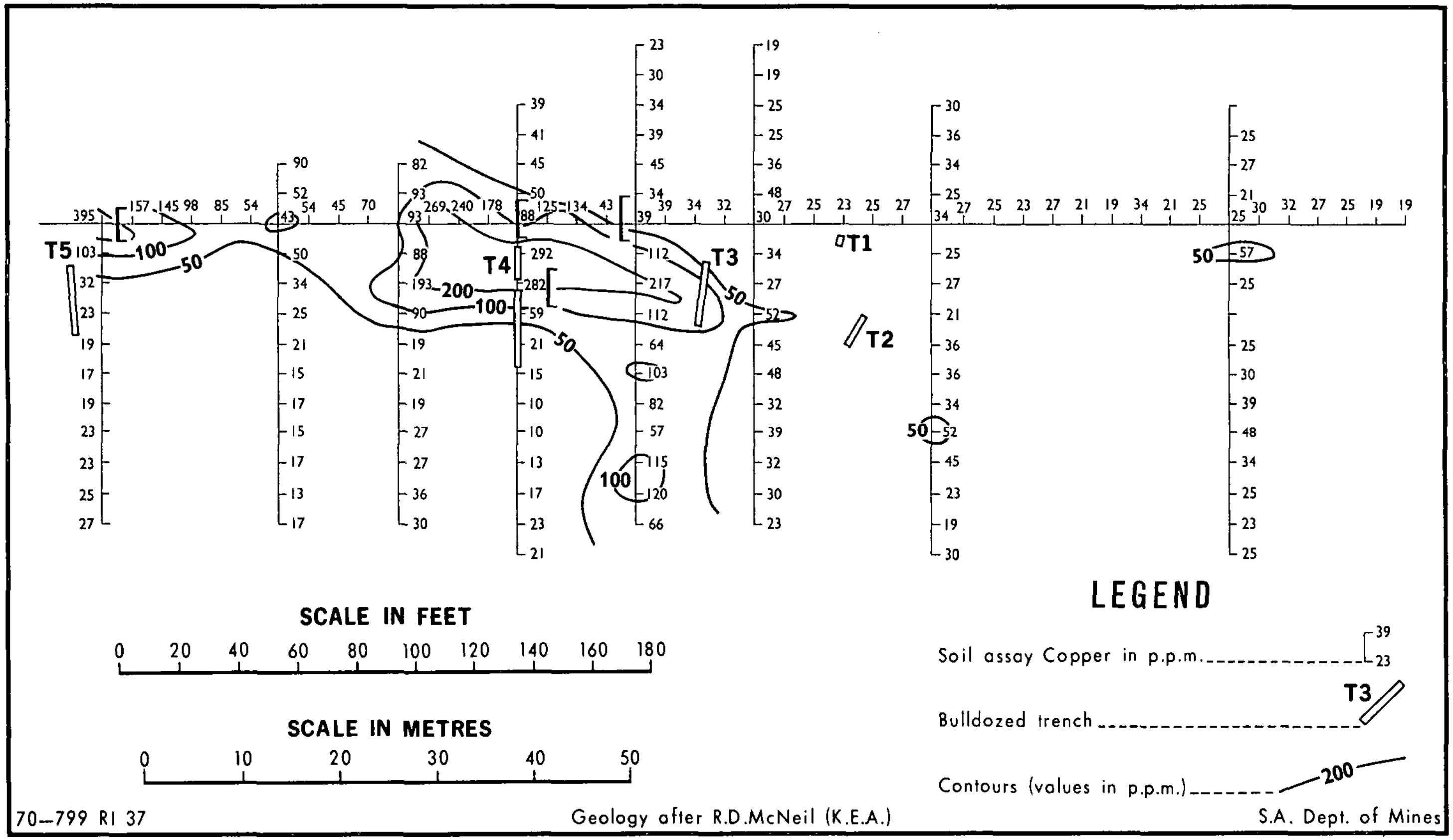


Fig. 14. Radford Creek area, contours of geochemical copper values in soil.

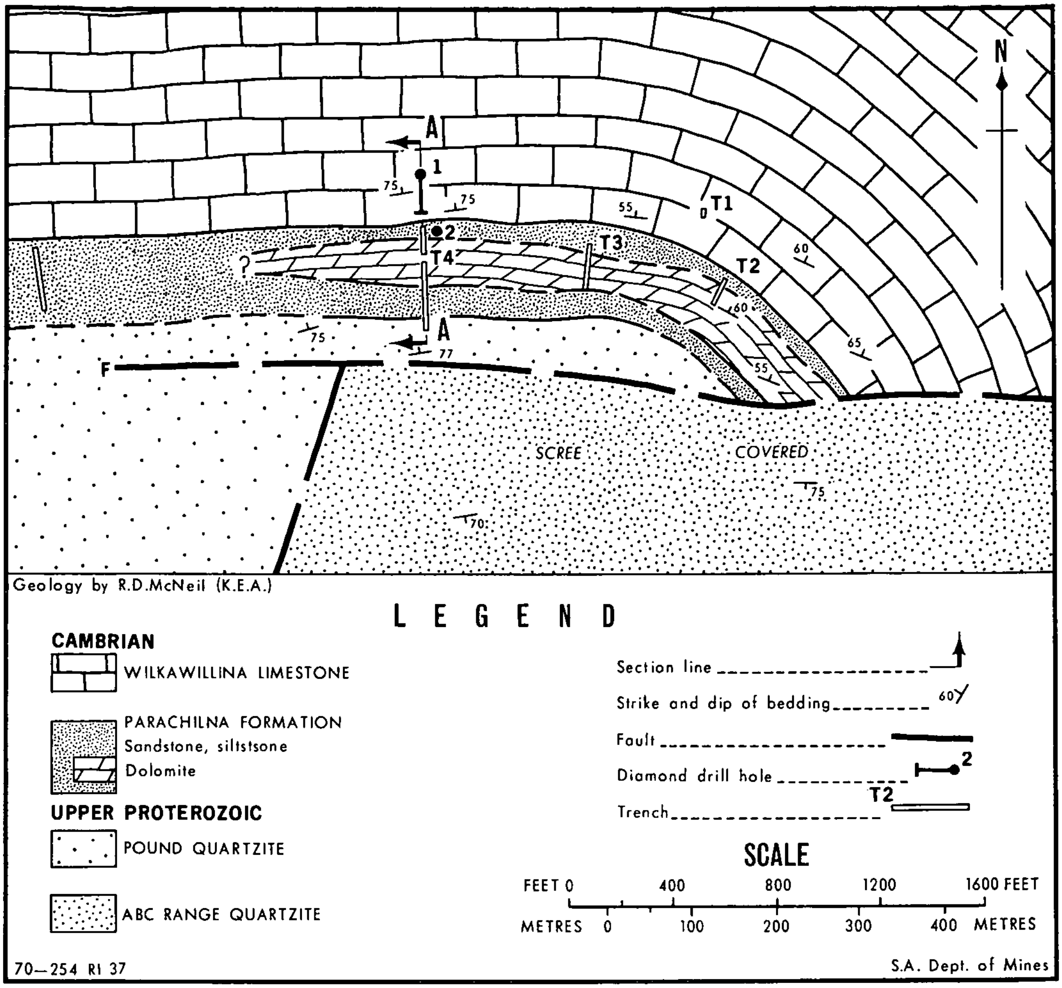


Fig. 15. Radford Creek area, geological sketch map showing diamond drill sites.

Two non-core rotary drill holes were sited to probe the deposits at depth (Figs. 15 and 16). Hole 1, inclined 59 degrees, was drilled to a depth of 315 feet and intersected low grade mineralization that averaged 0.12 per cent lead and 0.11 per cent zinc over the interval 185 to 315 feet; surface grades up-dip from the drill intersection were approximately 1 per cent lead and 1 per cent zinc. Hole 2, drilled vertical to 525 feet, intersected within the Parachilna Formation, ochreous limestone with minor sandstone and shale containing up to 0.34 per cent zinc and 0.30 per cent lead over a stratigraphic width of about 20 feet down-dip from the main area of surface mineralization.

The zinc mineral was determined by the Australian Mineral Development Laboratories as chalcophanite while cerussite was detected in the drill cuttings.

The westerly extension of the mineralized Lower Cambrian strata between the Radford Creek locality and Simmonston are obscured by Quaternary outward gravels. The lease was surrendered on 31st August, 1967.

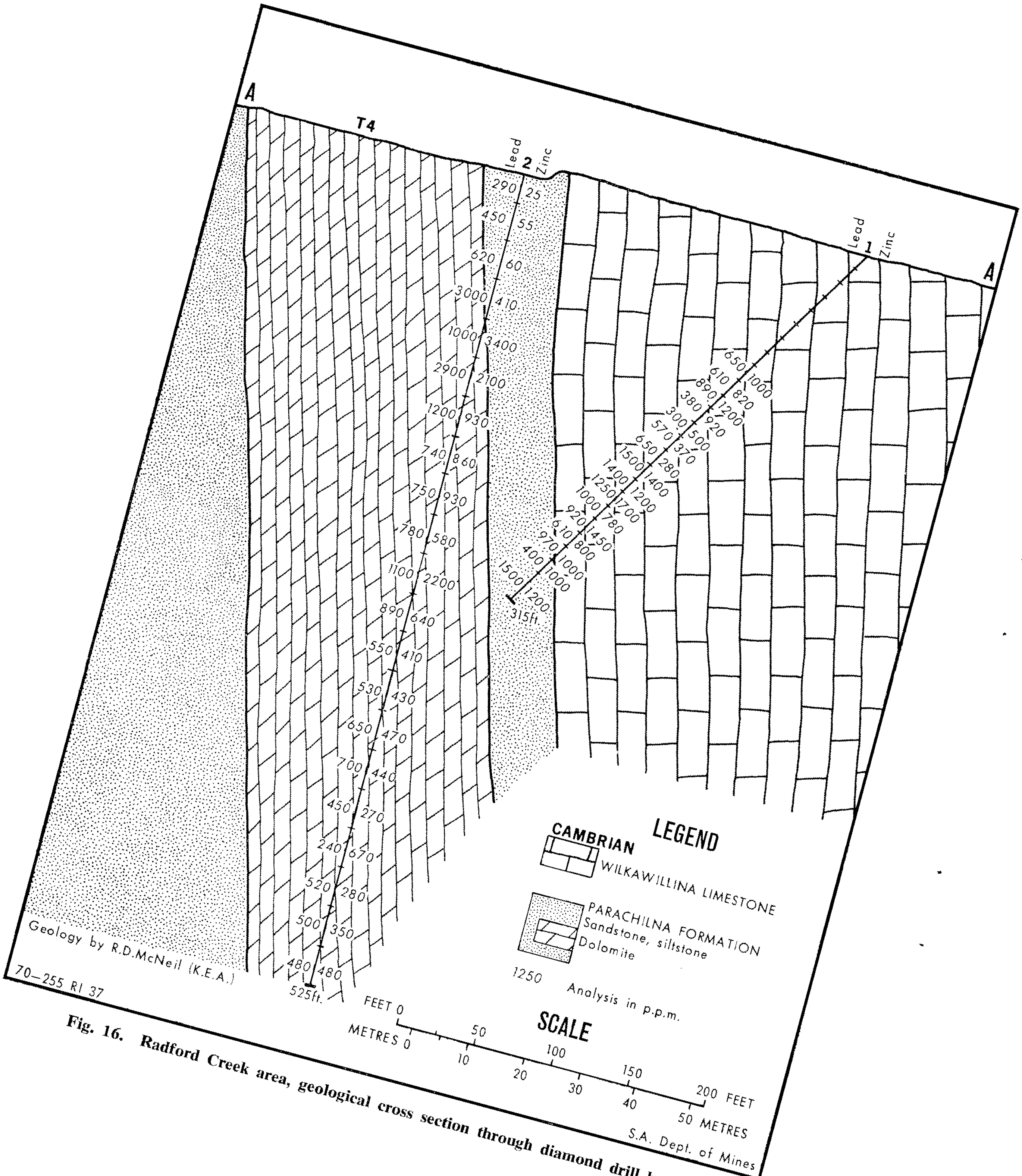


Fig. 16. Radford Creek area, geological cross section through diamond drill holes.

Kanyaka area

When Austin inspected the Kanyaka copper mine in 1863 (Brown, 1908, p. 65) several shafts had been sunk, the deepest being to 90 feet. These were connected by drives extending for about 240 feet on a well defined lode dipping at a low angle in apparent conformity with the enclosing Parachilna Formation sediments. Blue and green copper carbonates occupied a lode two to two and a half feet in thickness within slates and sandstone striking northwest-southeast. After a period of inactivity mining was resumed about 1899 when 200 tons of 10 per cent copper ore were recovered from workings which now included shafts and pits extending along strike a distance of over 1,000 feet and an open cut 50 by 12 feet and 25 feet deep. Subsequent recorded production totalled 165 tons with grades ranging from 7.5 to 16 per cent copper (Rev. Min. Ops. S. Aust., 1905, No. 3, p. 5; 1905, No. 4, p. 16; 1906, No. 5, p. 18; 1907, No. 6, p. 19; and 1916, No. 23, p. 7).

The mine area is covered by two to 12 feet of quartzite scree and all shafts except one at the western end have since collapsed and filled. Several shallow pits have also been sunk on a copper prospect several miles to the north of the Kanyaka mine.

In the Kanyaka syncline (Fig. 17) the Parachilna Formation varies from 200 to 400 feet in thickness and consists of thinly bedded white clayey sandstone, with worm burrows and interbedded white siltstone and limestone in the upper parts. The formation is limited in outcrop, being mostly veneered by quartzite scree derived from the underlying Pound Quartzite. The Wilkawillina Limestone, about 1,600 feet thick, is a massive blue-grey limestone containing occasional *Archaeocyatha* and chert pods; it is sandy, oolitic and buff-coloured near the base. The top of the unit is mottled and of dark colour and passes into the Parara Limestone which includes flaggy grey limestones with grey and olive-green siltstones. The uppermost Cambrian formation is the Oraparinna Shale (Milnes and Preiss, 1967).

Within S.M.L. 94 stream sediment samples and rock chip samples taken from a number of traverses showed several areas of anomalous base metal content. Isolated anomalous copper values occur but they are not related to any known or obvious mineralization; a stream sediment sample taken from immediately below the Kanyaka mine contained only 52 p.p.m. copper (McNeil, 1966a) suggesting that mineral dispersion trains are short.

Special Mining Lease 110, granted on 1st June, 1966, to Kennecott Explorations (Australia) Pty. Ltd. covers an area of 15 square miles. Here efforts were directed towards assessing the Kanyaka copper mine area, an area lacking manganese in surface outcrop in contrast to the Comstock and Radford Creek localities (McNeil, 1966d and 1967c).

Self potential geophysical traverses were metered (five lines, two line miles) which showed several small anomalies not correlated with known mineralization, while induced polarization of a single traverse 0.3 mile in length gave inconclusive results.

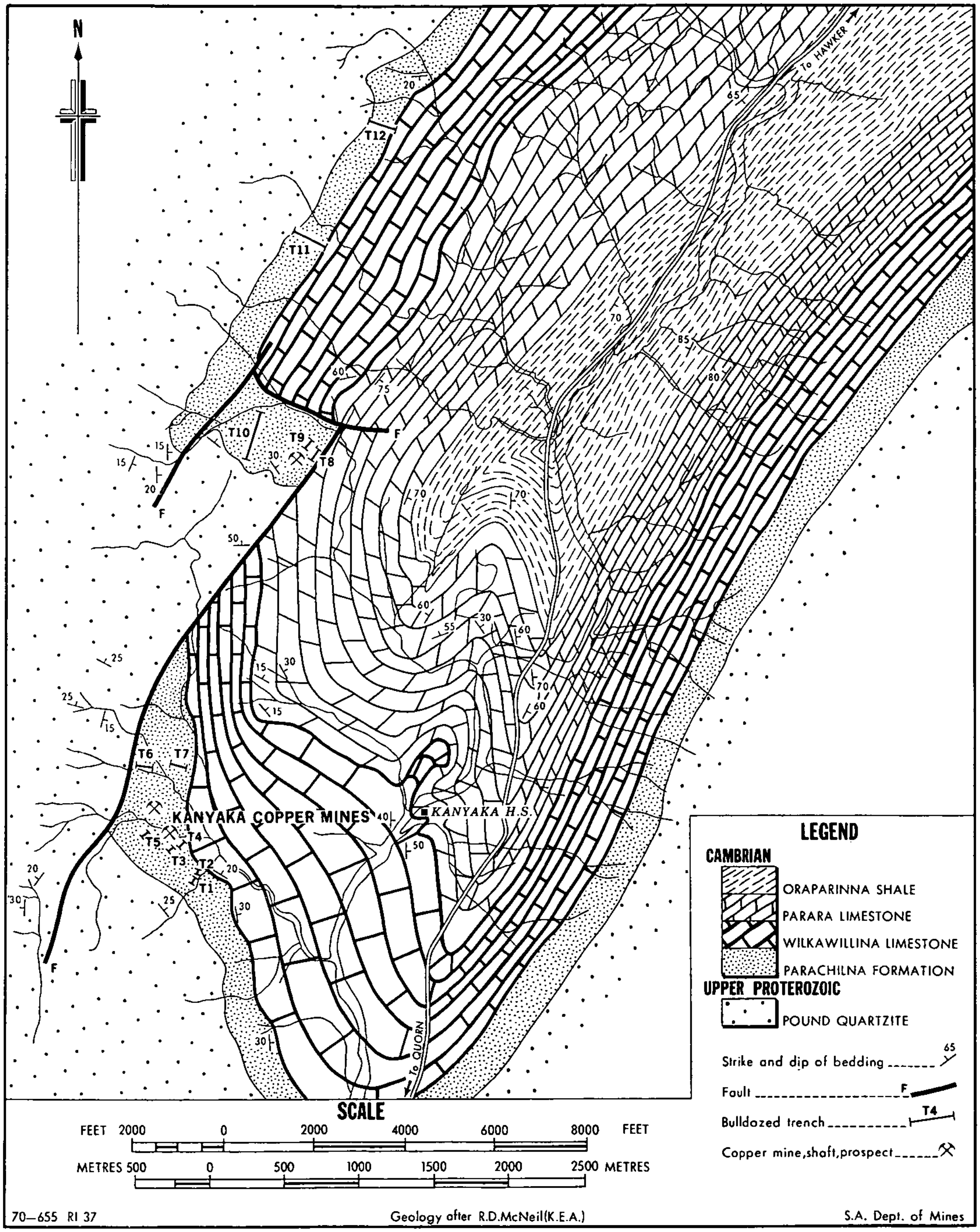


Fig. 17. Kanyaka area, geological plan.

From the mine dumps (Fig. 18) 57 samples, representing about 500 tons of mineralized rock rejected during mining operations, were taken for analysis and contained an average 1.43 per cent copper, 0.076 per cent lead and 0.56 per cent zinc. Five dump samples were scanned spectrographically (see Table 5) and it is noteworthy that in addition to copper, lead and zinc, there are significant concentrations of nickel, cobalt and the rare earths, scandium, lanthanum and yttrium.

TABLE 5

SPECTROGRAPHICALLY DETECTED METAL CONTENTS FROM DUMPS, KANYAKA COPPER MINE

	Sample No. 16360	Sample No. 19370	Sample No. 16380	Sample No. 16390	Sample No. 16400
Cu (p.p.m.)......	3,000	10,000	10,000	10,000	10,000
Pb (p.p.m.)	1,000	800	1,500	1,500	500
Zn (p.p.m.)	600	10,000	10,000	500	500
Co (p.p.m.)	60	2,000	2,000	15	80
Ni (p.p.m.)	150	1,200	1,200	25	250
Sn (p.p.m.)	2	2	2	2	1
Bi (p.p.m).	3	3	3	3	3
Cd (p.p.m.)	3	3	3	8	3
Ag (p.p.m.)	2.5	3.0	15.0	5.0	1.0
V (p.p.m.)........	200	200	200	200	15
B (p.p.m.)........	100	200	200	150	20
As (p.p.m.)	70	70	50	70	70
Cr (p.p.m.)	200	200	250	200	120
Mo (p.p.m).	4	4	2	1	1
Be (p.p.m.)	5	3	1	8	40
Ga (p.p.m.)	20	15	8	30	3
Ge (p.p.m.)	1	1	1	1	1
Mn (p.p.m.)	15	70	5	15	200
Li (p.p.m.)	250	200	100	200	50
Rb (p.p.m.)	100	80	80	100	30
P (p.p.m.)........	800	600	1,000	1,000	1,000
Ba (p.p.m.)	300	300	400	500	250
Sr (p.p.m.)	500	150	150	150	120
Sc (p.p.m.)	80	300	1	80	30
La (p.p.m.)	500	700	100	100	100
Y (p.p.m.)........	500	800	100	600	500

Ta, Nb, Os, Rh, Ir, Te, Tl, Sb, Au, W, Pd, In, Cs, Zr, Ce not detected.

Five trenches, cut by a bulldozer to depths of four to 10 feet within the mine area (Figs. 18 and 19) to expose bedrock under cover of quartzite scree, revealed traces of malachite and azurite in sandstones of the Parachilna Formation over a width of almost 180 feet and along the strike for a distance of at least 1,000 feet. Results of sampling (average of samples cut from both walls and floor) are shown in Table 6.

TABLE 6

METAL CONTENTS IN TRENCH SAMPLING, KANYAKA COPPER MINE

Pit No.	Sample interval (feet)	Cu p.p.m.	Pb p.p.m.	Zn p.p.m.	Co p.p.m.	Ni p.p.m.	Ag p.p.m.	Mn p.p.m.
1	29	113	163	42	7	14	0.5	—
2	52	114	837	56	5	—	—	—
3	35	125	64	243	48	—	—	—
4	100	1,255	820	970	59	52	—	23
5	80	2,768	800	337	21	31	—	154

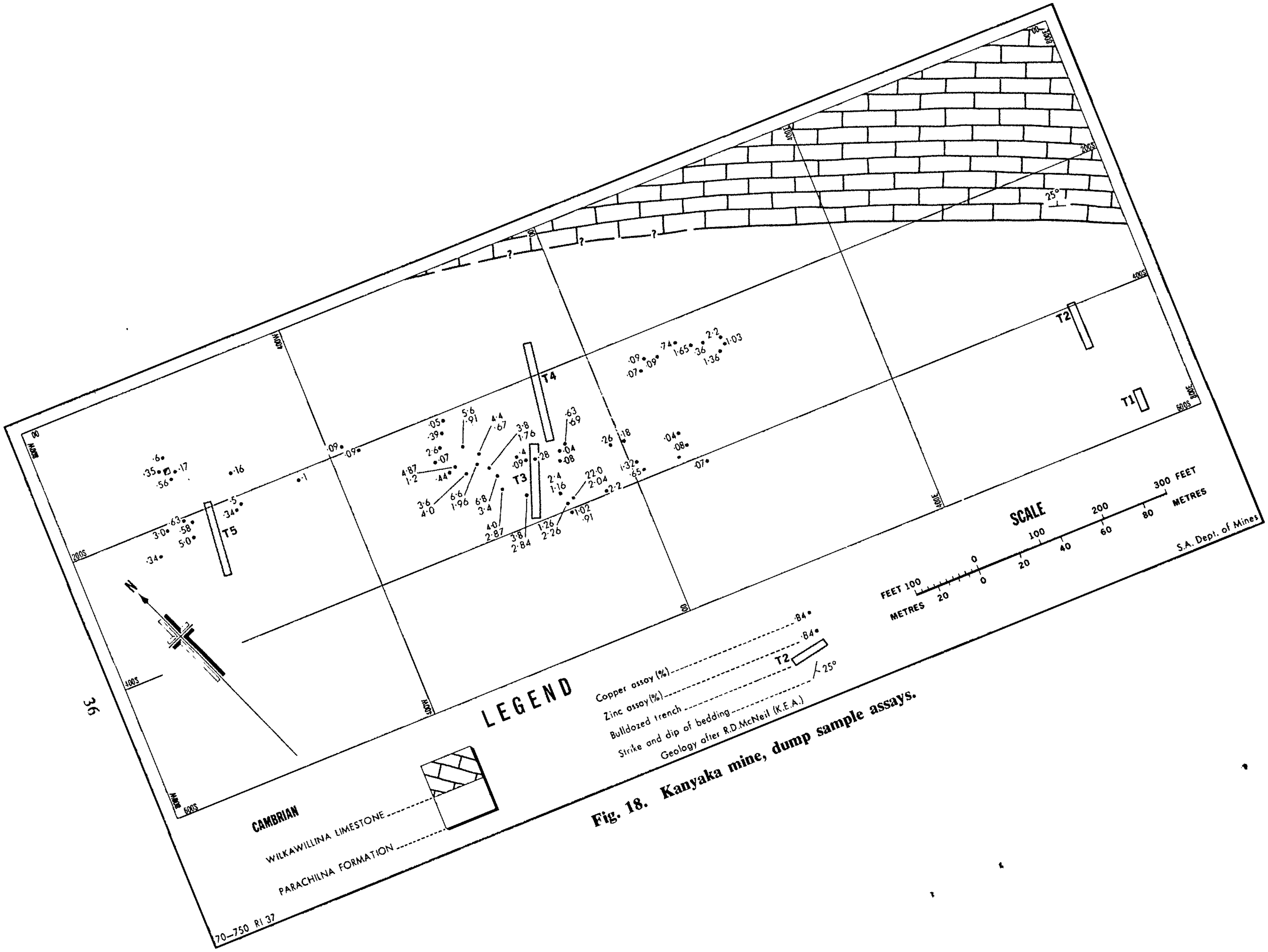


Fig. 18. Kanyaka mine, dump sample assays.

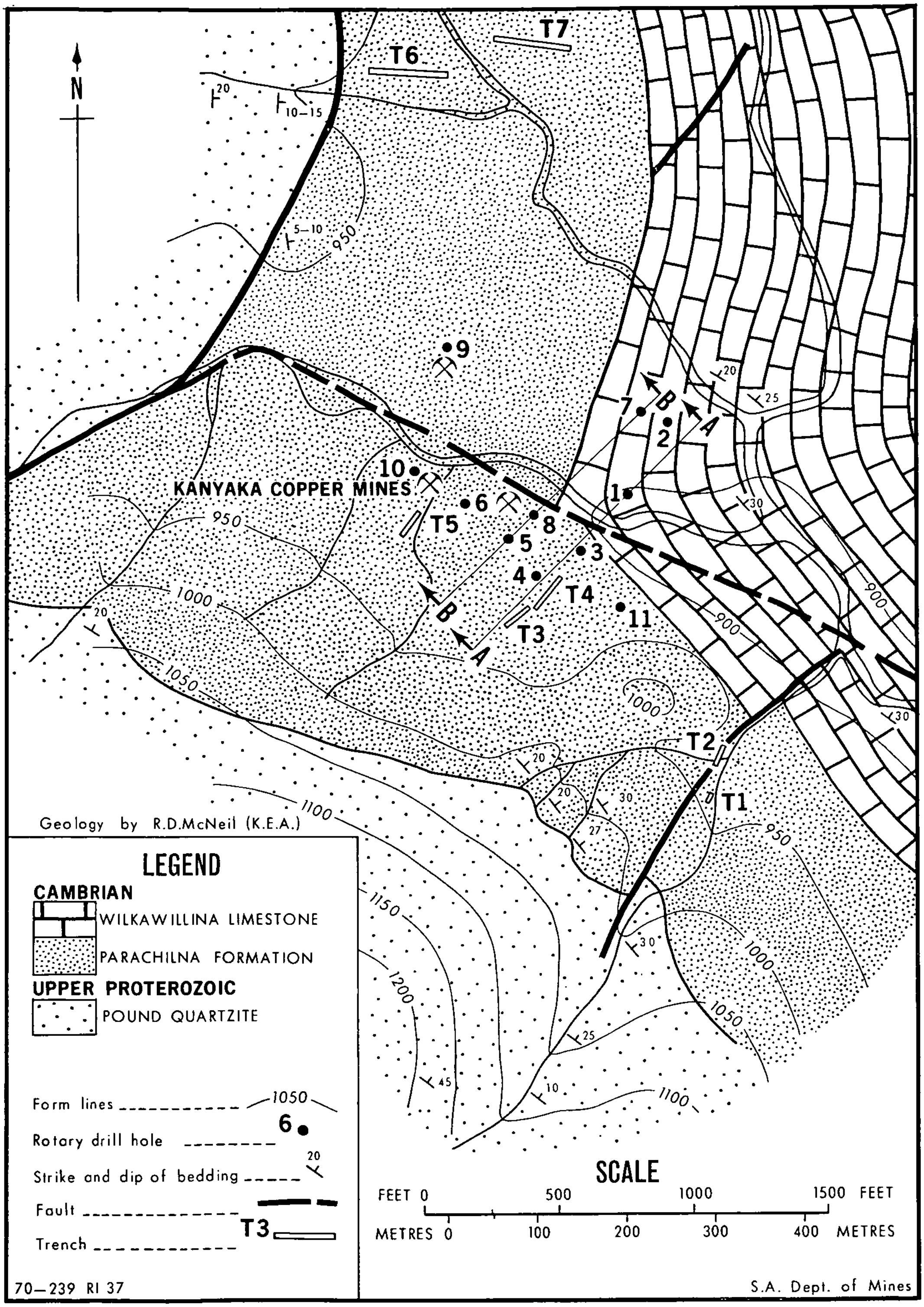


Fig. 19. Kanyaka mine, geological plan showing rotary drill sites.

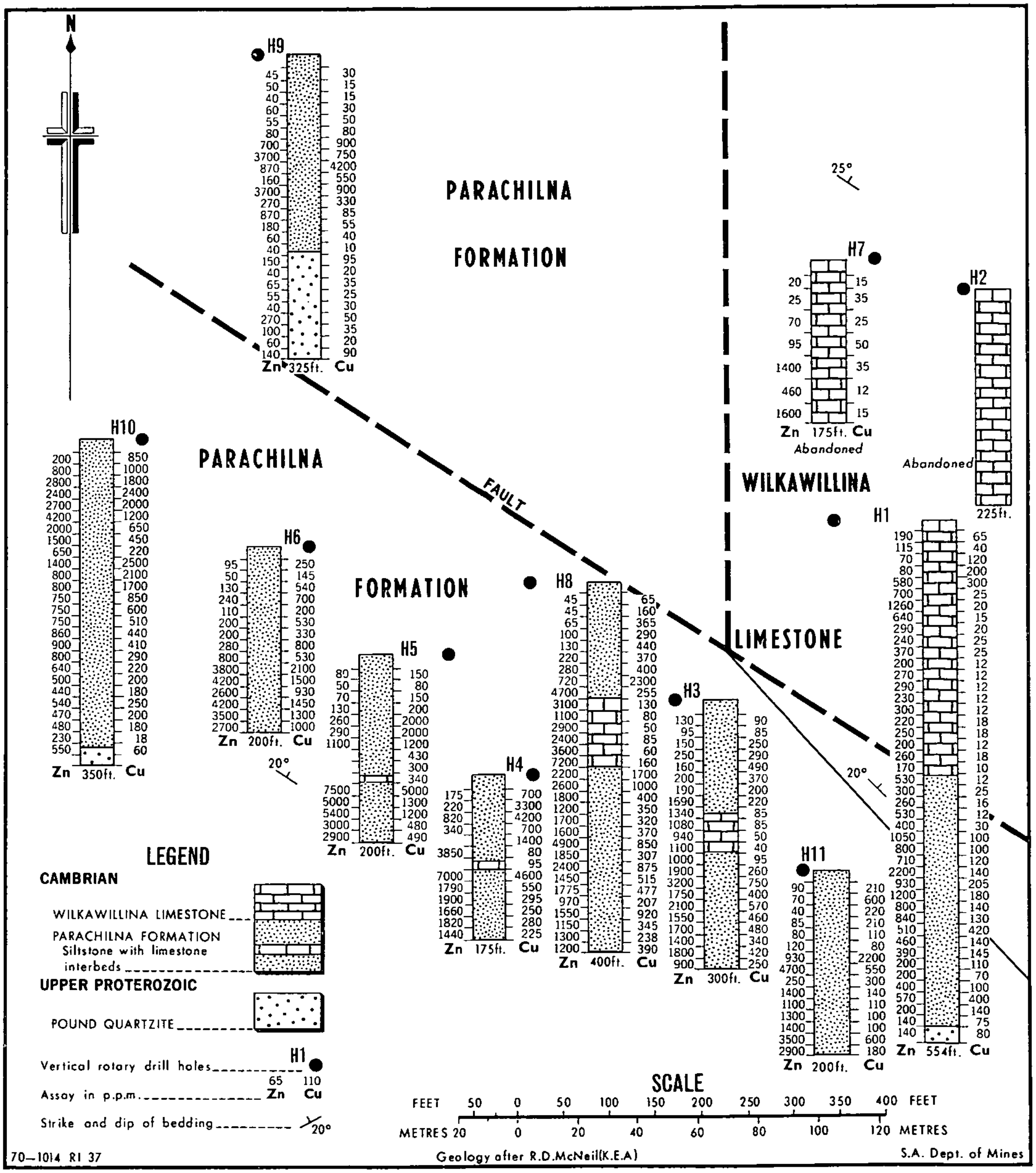


Fig. 20. Kanyaka mine, plan showing location of rotary drill holes and assays.

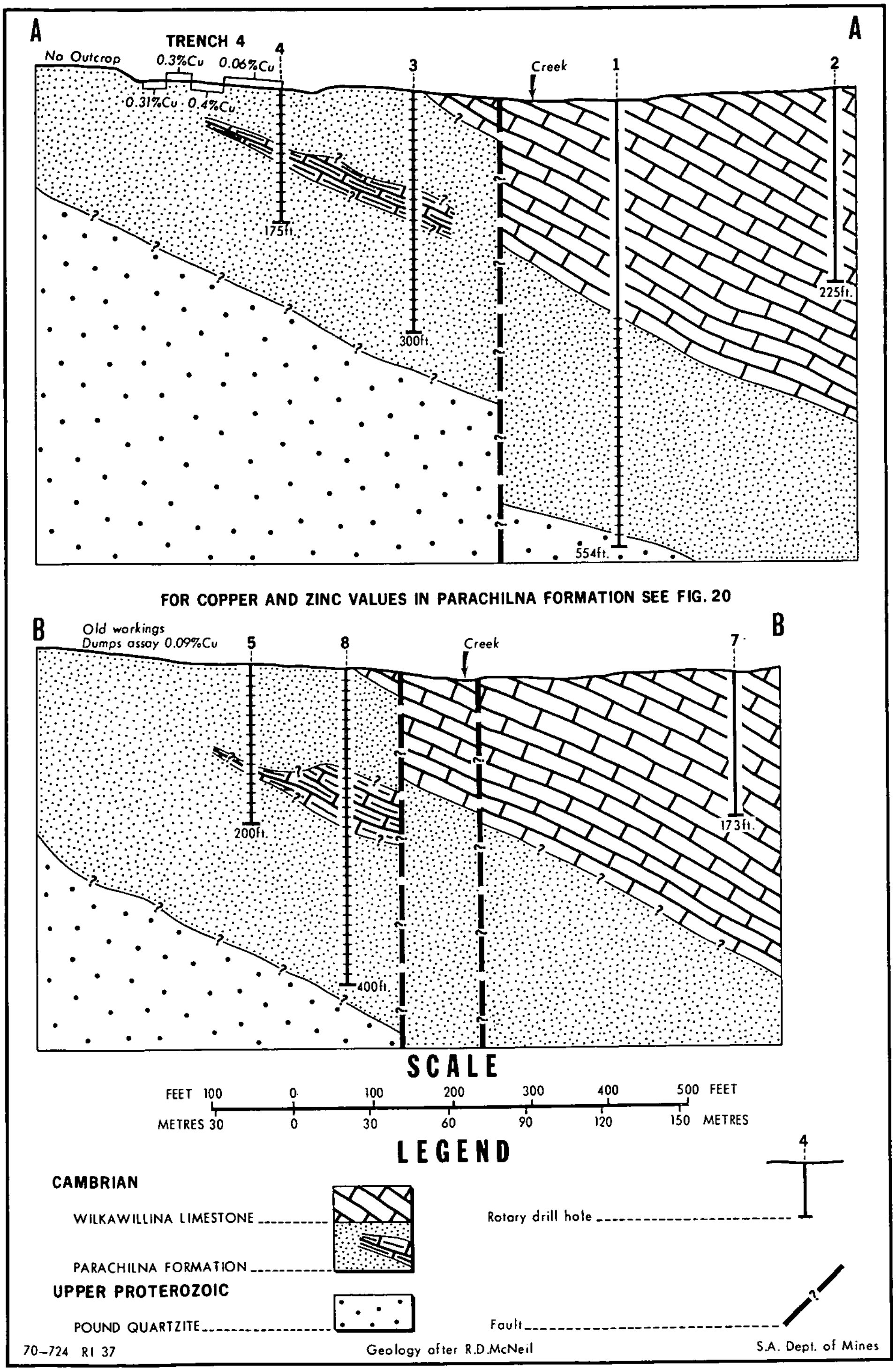


Fig. 21. Kanyaka mine, geological cross sections showing distribution of zinc and copper in Parachilna Formation.

The drilling of 11 non-core rotary holes aggregating 3,112 feet (see Fig. 19 for location, Figs. 20 and 21 for results) outlined a zone of low grade zinc and copper mineralization in this same area. "The holes were closely spaced to allow correlations between hole sections and thus prove whether or not the mineralized zone is conformable with the sediments . . . and there is no doubt that the mineralized zone, as exposed on the surface and intersected in the boreholes, has a stratiform nature" (McNeil, 1967c). Copper contents ranged up to 0.5 per cent but generally there is only a trace of copper (less than 100 p.p.m.) Dolomitic limestones in the upper part of the Parachilna Formation contain up to 2.75 per cent zinc over a stratigraphic interval of about 10 feet. Though the water table is at a depth of 100 to 120 feet, oxidation effects persist to a depth in excess of 300 feet. From the surface to about 100 feet no zinc minerals were detected in the cores while copper occurred as azurite and malachite; in the interval 100 to 200 feet zinc occurred as chalcophanite while some secondary copper sulphides were present. Mineralogical examination by the Australian Mineral Development Laboratories (AMDEL) of samples taken from Hole 1 disclosed that primary sulphides occur below a depth of 375 feet and sphalerite, galena and pyrite were recognized in the interval 375 feet to 387 feet 6 inches.

In an attempt to establish continuity of mineralization at the surface, seven trenches (T6 to T12), having a total effective length of 2,880 feet, were cut to a depth of up to 10 feet, within the Parachilna Formation for about four miles north along strike from the Kanyaka mine. Table 7 shows the results of trench sampling; base metal contents are low throughout; manganese content exceeded 100 p.p.m. only in T8.

TABLE 7

METAL CONTENTS IN TRENCH SAMPLING, NORTH OF KANYAKA COPPER MINE

Trench No.	Sample interval (feet)	Cu p.p.m.	Pb p.p.m.	Zn p.p.m.
T6	150	20	20	20
T7	300	20	20	20
T8	90	140	80	250
T9	110	125	400	600
T10	210	125	880	250
T11	150	60	900	125
T12	10	100	120	1,100
	250	25	350	125

As it was "evident that the copper mineralization at Kanyaka represents a small, localized deposit" S.M.L. 110 was allowed to lapse on 31st October, 1967.

Reaphook Hill zinc prospect

Reconnaissance rock chip sampling by the Department of Mines near Reaphook Hill in 1963 had shown 350 p.p.m. copper and over 1 per cent zinc over an interval of 65 feet within the Wilkawillina Limestone. Though prospectors had previously gouged several small shallow pits in outcrops of manganiferous limonite in the locality, the significance of the prospect remained undetermined until Kennecott Explorations (Australia) Pty. Ltd. acquired S.M.L. 95 over an area of 57 square miles on 1st December, 1965 (McNeil, 1966e and 1966f). On expiration

Aerial view looking west to Reaphook Hill. Zinc-bearing Wilkawillina Limestone (dark outcrops) in foreground. Scholzite exposed in flooded trench in left foreground. *Neg.* 18758

of that lease two further leases, S.M.L. 137 (Emu Bore area of nine square miles) and S.M.L. 138 (Reaphook Hill area of 57 square miles), were granted on 1st December, 1966.

Stream sediment sampling undertaken by that company and analysis of the minus 20-mesh fraction indicated that copper contents were generally in the range 20 to 25 p.p.m. with several samples containing in excess of 45 p.p.m. Lead contents were generally less than 30 p.p.m. but samples taken from channels draining the Lower Cambrian rocks were anomalous and in excess of 100 p.p.m. Coincident with the lead anomalies, zinc values from the basal Cambrian sediments ranged up to 1,170 p.p.m. (McNeill, 1966e). Two areas were thus outlined, Emu Bore area where follow-up surface sampling and traversing discounted useful enrichment of zinc, and the Reaphook Hill prospect where subsequent activity was concentrated (McNeil, 1968).

The stratigraphy and structure of the area depicted in Fig. 22 were detailed by Loos, Milnes and Preiss (1967). The Parachilna Formation which ranges up to almost 100 feet in thickness is here characterized by gritty, poorly sorted argillaceous sandstone with conglomerate lenses containing well-rounded quartz pebbles up to one inch in diameter dispersed in a matrix of weakly consolidated sand and grit. The outcrop is poor and the formation is almost completely obscured by derived gravels. The basal beds of the Wilkawillina Limestone are brown to buff coloured, manganese-stained, sandy dolomites which are succeeded by massive brown, buff or blue-grey dolomitic limestone totalling 1,400 feet. The physiography of the area is dominated by ridges of white Pound Quartzite of which Reaphook Hill is the highest, rising to 1,271 feet above sea level. Over its outcrop length the Cambrian limestones tend to show an accordance of summit levels at about 300 feet above the surrounding plains, remnants of a now-dissected erosion surface.

The Cambrian and underlying strata lie in broad scale open folds but repetition of the stratigraphic units by faulting complicate the structure.

Reaphook Hill zinc prospect. Exploratory trench exposes scholzite deposit in Parachilna Formation in foreground; mineralized Wilkawillina Limestone outcrops at extreme right. Reaphook Hill in background. *Neg.* 18757

Zinc mineralization is associated with ferruginized and manganiferous limestone as chalcophanite, scholzite ($Ca,Zn_2(PO_4)_2 2H_2O$), and manganese wad in massive to irregularly banded goethitic and manganese-rich masses and as disseminations. Chip sampling revealed substantial zinc content within the basal 600 feet of the Wilkawillina Limestone over an area of approximately 4,000 by 2,000 feet (see Fig. 22). Chip samples showed isolated zinc contents of up to 20 per cent zinc while the best traverses were 60 feet containing 4.09 per cent zinc and 80 feet containing 3.56 per cent zinc over two different stratigraphic horizons. Except for the scholzite occurrence the zinc content is low in the Parachilna Formation. Here white prismatic needles of scholzite comprise three discrete masses which directly overlie sandstones and loosely consolidated gravels less than 60 feet stratigraphically above the top of the Pound Quartzite. These outcrops have a high iron and manganese content and contain 20 per cent zinc and 30 per cent P_2O_5.

Lead, copper and silver are present in trace amounts; cobalt and nickel are present in anomalous concentrations but the manganese content is high throughout the Wilkawillina Limestone. Galena occurs in calcite veins within the underlying Wonoka Formation and accounts for the high lead and zinc stream values in the Emu Bore locality. Selected minor metal contents of selected samples are shown in Table 8.

TABLE 8

METAL CONTENTS OF SELECTED SAMPLES, REAPHOOK HILL AREA

	Zn per cent	Cu p.p.m.	Pb p.p.m.	Ni p.p.m.	Co p.p.m.	Ag p.p.m.	Mn per cent
Goethitic and zinciferous wad	4.9	10	26	448	1,070	0.5	37.5
Scholzite	20.7	35	83	39	125	1.5	1.8

Three lines of self potential survey over 1.1 line miles and 0.8 line mile of induced polarization were metered, and the several small weak anomalies defined by these methods were attributed to pyrolusite.

Two non-core rotary holes (total 737 feet) and five diamond drill holes (aggregate 2,054 feet) were drilled without disclosing sulphides or mineralization below the base of oxidation; poor core recoveries were achieved.

Drilling disclosed low grade zinc contents within the basal 600 feet of the Wilkawillina Limestone (average 0.2 per cent zinc) with a zone up to 20 feet in width near the centre of the Parachilna Formation containing from 0.3 to 2.0 per cent zinc. The fault-bound block of limestone which contained the best surface grades showing 2 to 5 per cent zinc proved to be a "crust" ranging from 10 to 20 feet in thickness underlain by yellow-brown clays. The zinc and manganese have apparently been concentrated at the surface within the basal units of the Cambrian strata by weathering and erosional processes. The scholzite occurrence in the Parachilna Formation results from the surface enrichment of zinc and phosphorus derived from originally low grade mineralization within the Parachilna Formation (McNeil, 1968).

Faulting appears to have exerted some control on mineralization and localization of the manganese which has an affinity for zinc.

Representative surface chip samples and cores from diamond drill hole 4 were scanned spectrographically for a number of elements and this indicated that Zn, Co, Ni, Cd and Mn have been enriched within the top five to 30 feet of the limestone. Between 268 and 273 feet the samples contained 500 p.p.m. yttrium, 500 p.p.m. lanthanum and 1,000 p.p.m. cerium. The down-dip projection of the scholzite zone between 273 and 280 feet contained 0.25 per cent zinc. The locations of drill holes and results of drilling are shown in Figs. 22 and 23.

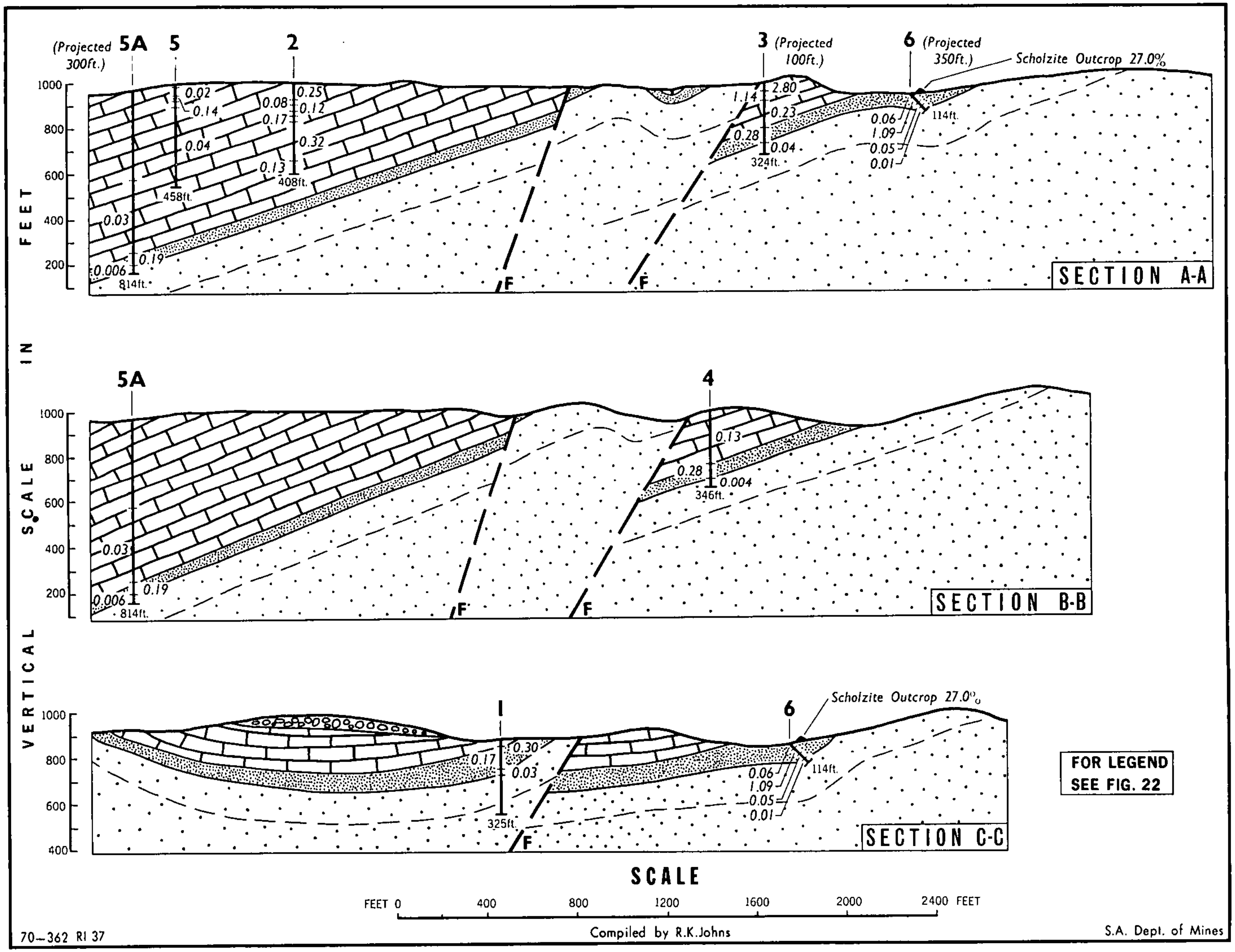


Fig 23. Reaphook Hill zinc prospect, geological cross sections through diamond drill holes.

It was concluded that small tonnages of 2 to 4 per cent secondary zinc mineralization, in association with manganese as wad or chalcophanite, occur at or near the surface of a faulted block of Wilkawillina Limestone. The prospect was considered incapable of sustaining a mining operation and the leases were surrendered on 18th April, 1968.

Third Plain zinc prospect and ajoining areas

Small outcrops of high grade zinc mineralization (willemite) were located during the course of a regional stream sediment sampling programme by Kennecott Explorations (Australia) Pty. Ltd. in the Third Plain Creek locality, and in order to evaluate the prospect, S.M.L. 143 covering an area of 30 square miles, was acquired by that company of 1st January, 1967 (Besley, 1967a).

In this region, Lower Cambrian sedimentation was influenced by tectonic activity adjacent to the Oraparinna and Wirrealpa Diapirs. This resulted in the reduced thickness or absence of the Parachilna and other formations. Immediately to the south in the Wilkawillina Gorge area, a much greater thickness of Lower Cambrian sediments accumulated in a graben as a consequence of contemporaneous subsidence related to the development of the Oraparinna Diapir. The easterly dipping strata have been subsequently dislocated by a number of sub-parallel transverse faults oriented northeast-southwest with lateral displacement generally less than 100 feet.

Regional reconnaissance sampling of stream sediments of the Cambrian tract along the eastern margin of the Flinders Ranges showed that about one mile south of Balcoracana Creek anomalous zinc contents were in excess of 400 p.p.m., whereas elsewhere in this region these were generally in the range of 30 to 50 p.p.m. Follow-up sampling disclosed a train of anomalous values in the creeks draining north from the Third Plain area and this led to the discovery of willemite in outcrop at the base of the massive grey to buff dolomitic limestone. The Parachilna Formation comprises kaolinitic sandy shale lenticles only a few feet in thickness or is locally absent.

The several lenticular outcrops of willemite are up to 40 feet wide and 150 feet long, and are separated and surrounded by an area of 1,000 by 400 feet of reddened hematitic dolomite containing from 0.1 to 1.0 per cent zinc (see Fig. 24). The mineralization and environment is analogous to that at Puttapa. Willemite containing up to 55 per cent zinc is mainly in the form of white radiating spherulitic aggregates or colloform bands, massive or as spherules in dolomite. Manganese oxides are intimately associated, lead is a minor constituent, but one example contained 3.5 per cent lead, while the arsenic content is high and exceeds 1 per cent in some samples.

Chip samples were taken along lines to define the surface grades and extent of mineralization. Spectographic analyses of selected samples are shown in Table 9.

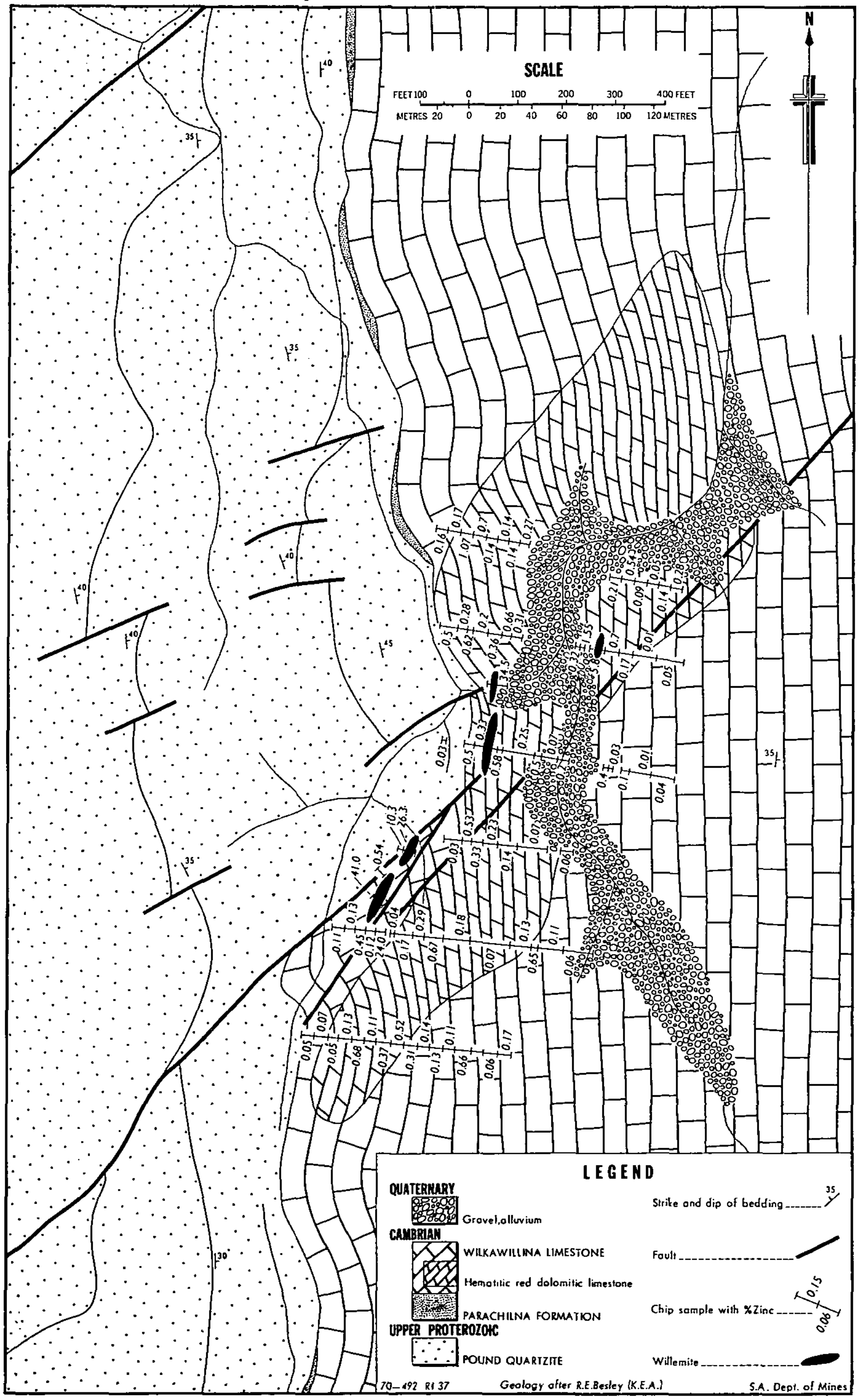


Fig. 24. Third Plain zinc prospect, geological plan.

TABLE 9

SPECTROGRAPHICALLY DETECTED METAL CONTENTS FROM SELECTED CHIP SAMPLES, THIRD PLAIN PROSPECT

	Sample Nos.						
	1	2	3	4	5	6	7
Zn (per cent)	0.9	55.5	2.3	41.5	0.2	16.0	52.5
Pb (per cent)......	3.5	0.3	0.05	0.55	0.05	0.1	0.2
Mn (p.p.m.)	10,000	250	10,000	5,000	25	3,000	50
As (p.p.m.)	6,000	5,000	120	10,000	50	150	200
Co (p.p.m.)	60	1	12	10	1	4	1
Ni (p.p.m.)	80	1	7	100	1	2	1
Cd (p.p.m.)	5	3	10	3	3	3	3
Cr (p.p.m.)	15	12	4	100	400	4	4
V (p.p.m.)	20	20	2	50	12	10	3
Mo (p.p.m.)	50	2	1	6	1	1	1
Ga (p.p.m.)	5	1	1	7	1	1	1
Ge (p.p.m.)	5	150	1	200	1	3	70
Ba (p.p.m.)	250	80	40	100	5	150	10
Sn (p.p.m.)	5	1	50	150	1	20	1
B (p.p.m.)	8	300	1	7	3	4	300
P (p.p.m.)	400	500	100	250	120	100	150
Sc (p.p.m.)	1	1	1	12	1	1	1

Besley (*op. cit.*) noted that "the relationship between this supergene surface outcrop of zinc mineralization and the primary mineralization is obscure" and concluded that, in this arid environment, open circulation of silica-laden ground waters, through fault zones and fractures, would facilitate the enrichment of zinc silicate possibly derived in turn from carbonate (smithsonite) and primary low grade sulphide (sphalerite).

No sub-surface exploration was undertaken, hence a reliable assessment of reserves is not currently available. The lease expired on 30th September, 1967 and a mineral claim has subsequently been pegged.

An area of 200 square miles was granted to Kennecott Exploration (Australia) Pty. Ltd. on 1st September, 1966 as S.M.L. 124 in order to undertake a programme of stream sediment sampling west from the Reaphook Hill locality and adjoining the Third Plain area to the south. The Cambrian strata are concealed along the northern and eastern flanks of the ridge which culminates in the Pound Quartzite of Mount Mantell. Lower Cambrian outcrops are restricted to the Wilkawillina Gorge area. Some 500 stream sediment samples were taken utilizing a helicopter, but no anomalous base metal contents were disclosed (Clema, 1966a and 1967a). Copper values were generally in the range 10 to 20 p.p.m., lead 10 to 20 p.p.m. and zinc 40 to 50 p.p.m. S.M.L. 124 was relinquished on 1st March, 1967.

Kennecott (Australia) Pty. Ltd. was granted S.M.L. 123 on 1st September, 1966. This covered an area of 600 square miles in the Wirrealpa-Mount Frome district which included the Wirrealpa lead mine (Ridgeway, 1949; Mansfield, 1953) and the Mount Chambers lead and copper mine. Stream sediment sampling was expedited by use of a helicopter; some 3,000 samples were taken and the minus 80 mesh fraction was analysed for copper, lead and zinc. Three anomalous areas were outlined, designated Wirrealpa, Mount Lyall and Mount Chambers, over which the regional stream sediment sampling revealed abnormal lead and zinc contents in streams draining Lower Cambrian Wilkawillina Limestone (Beasley, 1967b).

In the Wirrealpa Mount Lyall locality the Parachilna Formation and succeeding limestones occur in open fold structures which have been disrupted by normal faulting and associated diapiric intrusion. Galena and barite are present in small veins in the Wilkawillina Limestone at the Wirrealpa lead mine, and these have been mined to a depth of 195 feet from several shafts and underground workings and at the surface for a length of 280 feet. Recorded production exceeds 1,000 tons of ore. Numerous limonitic-manganese oxide pods, which are concentrated near the base of the carbonate sequence, proved to have low base metal contents. The highest values recorded in sediments from streams draining the Wilkawillina Limestone ranged up to 300 p.p.m. zinc and 160 p.p.m. lead. Follow-up rock chip sampling failed to reveal any significant mineralization.

In the Mount Chambers area shallow workings expose malachite-stained siltstones, and minor blebs of galena in limestone have been recorded. Chip sampling was undertaken to define a stratigraphic thickness of almost 3,000 feet where regional stream sediment sampling had revealed abnormal lead and zinc concentrations (Besley, 1967b). The highest metal contents proved to be 200 p.p.m. lead and 1,000 p.p.m. zinc over a length of 100 feet. A number of small manganese-iron oxide cappings scattered throughout this area also have low base metal contents with one isolated high of 200 p.p.m. lead and 2,500 p.p.m. zinc being located.

As it was considered that there was little likelihood of economic deposits of lead, zinc or copper being present in the region, the lease was relinquished on 31st May, 1967.

Moro area

Copper was discovered nine miles west-southwest of Wertaloona Homestead, in the Moro locality, in 1857. Numerous shallow pits comprising the Moro (Mooroo), Moorowie and Balcanoona mines and the Moro Central prospect were worked during the period between 1861 and 1865, and with desultory mining activity to 1908, for recovery of copper carbonates, but recorded production amounts to only 25 tons. The richest patches of ore were mined principally from deposits within the Parachilna Formation, where stratigraphic control on mineralization is evident (Fig. 25). The ore was hand picked to about 20 per cent grade as was then the practice. Malachite staining is prominent in the Pound Quartzite and in fault breccia adjacent to the boundary fault near the Moro ruins. It is also present one mile to the west and southwest, where copper mineralization is localized at the crest of a north pitching anticline, and around the flanks of this structure within the Parachilna Formation. The core of the anticline is occupied by massive dolomitic limestones, sandy limestones and dolomitic shales of the Wonoka Formation (Leeson, 1967). The overlying Pound Quartzite is composed of massive white sandstone (over 1,000 feet in thickness) which forms high hills flanked by valleys marking Parachilna Formation outcrop. The Parachilna Formation which outcrops poorly consists of about 100 feet of buff to white thinly-bedded silty sandstones with dolomite lenses. Contacts with the succeeding chocolate to buff-coloured massive Wilkawillina Limestone are generally obscured by masses of manganiferous ironstone and scree, particularly along the eastern limb of the anticline. The Cambrian limestone outcrops in low plateaux. The structure is dislocated by numerous cross-faults along the eastern limb and by several near-strike faults with which manganiferous ironstone "gossans" are associated.

During the tenure of S.M.L. 54 held in 1963 over an area of two and a half square miles by C.R.A. Exploration Pty. Ltd., chip sampling undertaken by

Aerial view looking south along Mount John Fault near Moro Homestead ruins. *Neg.* 21596

MacKenzie and MacNamara (1963) near the Balcanoona mine outlined an area of low grade copper mineralization, the principal mineral being malachite with some azurite and minor chalcocite. Extensive copper staining and veining in joints, fractures and narrow breccia zones within the Pound Quartzite showed up to 2.25 per cent copper in several chip sampled traverses over lengths of up to 15 feet. The mineralization which spans a stratigraphic interval of about 600 feet within the uppermost units of the formation is sporadically developed over an area measuring 2,400 feet in length by 400 feet average width. Patches of better grade ore, having an aggregate surface area of only 12,000 square feet and averaging 0.54 per cent copper, are separated by large areas of near-barren quartzite. Thin malachite stainings often with limonite and manganese oxides occur on the undersides of crags but seldom on the upper exposed surfaces. The outer detectable limits of this mineralization is indicated in Fig. 25.

It was considered that copper was derived from the overlying beds of the Parachilna Formation by accumulating in closely jointed and broken quartzite at the anticlinal crest under the control of a pre-existing water table whereas the tighter formations on the limbs were not mineralized. As the indicated tonnage of 890 tons per vertical foot of 0.54 per cent copper "ore" was too small to support a mining operation the lease was abandoned in December, 1963.

An area of four square miles in this same locality was granted on 1st August, 1965 to F. R. Hawkins (Copper) Pty. Ltd. as S.M.L. 89 but after drilling four shallow percussion drill holes with discouraging results, this lease and a surrounding area of 110 square miles (S.M.L. 91) were acquired on 1st September, 1965 by Kennecott Explorations (Australia) Pty. Ltd. to further explore the occurrence of base metal mineralization of an apparent stratiform nature (Brooks, 1966a; Clema, 1966b and Lennon, 1966). On expiry of those leases two further leases were granted to the same company on 1st September, 1966, both 45 square miles in area, S.M.L. 127 encompassing the Balcanoona mine locality (Brooks, 1966b; Lennon, 1967a and 1967b) and S.M.L. 128 (Ironstone Bore area) immediately adjoining the south (Clema, 1966c and 1967b; Brooks, 1967). Kennecott Explorations (Australia) Pty. Ltd. carried out a programme of stream sediment, rock chip and pit dump sampling, geological survey and diamond drilling, the results of which, up until the surrender of S.M.L. 128 on 9th May, 1967 and of S.M.L. 127 on 31st October, 1967 are detailed below.

Stream sediment sampling (500 samples), rock chip sampling (120 samples) and testing of old pit dumps in the vicinity of the Moro Central prospect showed copper contents ranging up to several per cent, several tenths of 1 per cent zinc, trace lead and cobalt in Lower Cambrian strata, and resulted in the discovery of cinnabar (containing up to 5 per cent mercury), associated with malachite, in a pit located 100 yards northerly from Moro ruins adjacent to the major fault bounding the Lake Frome plains.

The Moro Central prospect is located within the Parachilna Formation wherein sedimentary control of copper mineralization is apparent over a stratigraphic width of up to 50 feet about the nose and both flanks of the anticline intermittently over a strike length of at least two and a half miles. Sampling has shown that the overlying limestones are anomalously rich in lead and zinc and, to a lesser extent, copper, particularly in gossanous areas and adjacent to faults. Sampling undertaken by MacKenzie and MacNamara (1963) outlined limits of copper mineralization within the Pound Quartzite in the vicinity of the Balcanoona mine. Mineralization within the Parachilna Formation comprises irregular patches, veinlets and impregnations along joints of malachite, azurite and minor chalcocite. Samples taken from the dumps of the numerous shallow pits contained up to 4 per cent copper. The less broken siltstones and the dolomitic sequences within this formation contain only a few hundred parts per million copper at the most, while along the outcrop of the Parachilna Formation, in the complementary limb of the syncline to the northeast, there is no visible copper mineralization. An adit was chip sampled at 10 feet intervals over its length of 120 feet; from the portal to 70 feet the weathered rock averaged 0.76 per cent copper, 135 p.p.m. lead, 926 p.p.m. zinc and 290 p.p.m. cobalt while less weathered rock from 70 feet to 120 feet contained 320 p.p.m. copper, 40 p.p.m. lead, 88 p.p.m. zinc and 22 p.p.m. cobalt.

Manganese ores are associated with, and form part of, a secondary manganiferous ironstone formation which caps a mineralized zone along the faulted contact between Pound Quartzite and Wilkawillina Limestone on the eastern limb of the anticline. The gossan type manganiferous ironstones are secondary deposits resulting from concentration and replacement of the underlying belts similar in nature and form, and in a similar structural environment. This type of deposit occurs elsewhere in the Flinders Ranges at the same stratigraphic level at Mount Arden (Comstock), Radford Creek, Reaphook Hill, Bunyeroo, Parachilna, Ediacara, Eregunda, Bungoola, Narina, Copper King, etc. They are concentrated on areas of the Wilkawillina Limestone penetrated by faults and to some adjacent parts of the Parachilna Formation and the Pound Quartzite which have been affected by faulting. The surface cappings are locally up to eight feet thick and are composed of massive colloform, banded or brecciated ironstone (limonite and hematite) with earthy goethite and manganese oxide (psilomelane and wad).

The manganese content shows a considerable range from 0.2 to 44.5 per cent while the iron content in these extremes is 51.5 and 4.9 per cent respectively (Fairburn, 1967). The underlying limestones have proved to be favourable host rocks for cavity and joint filling and for replacement deposits. Relict bands of unreplaced massive limestone are discernible within some manganiferous ironstone masses. Malachite, azurite and cobalt wad are sometimes associated with the gossanous rock. Analyses of several grab samples are shown in Table 10.

TABLE 10

METAL CONTENTS OF GRAB SAMPLES, MORO AREA

Sample No.	Mn	Cu	Co
	per cent	per cent	per cent
1	23.4	3.2	0.11
2	20.4	0.03	0.12
3	21.4	6.3	0.98
4	34.4	0.07	0.29
5	7.8	6.5	0.50

Geophysics was undertaken including self-potential profiles over 12 lines aggregating 16,750 feet and induced polarization across the basal Cambrian section in the area of visible mineralization. Several small, rather ill-defined anomalies were defined.

Diamond drilling was undertaken (see Figs. 25 and 26) to test for presence of stratiform base metal deposits with the following results:

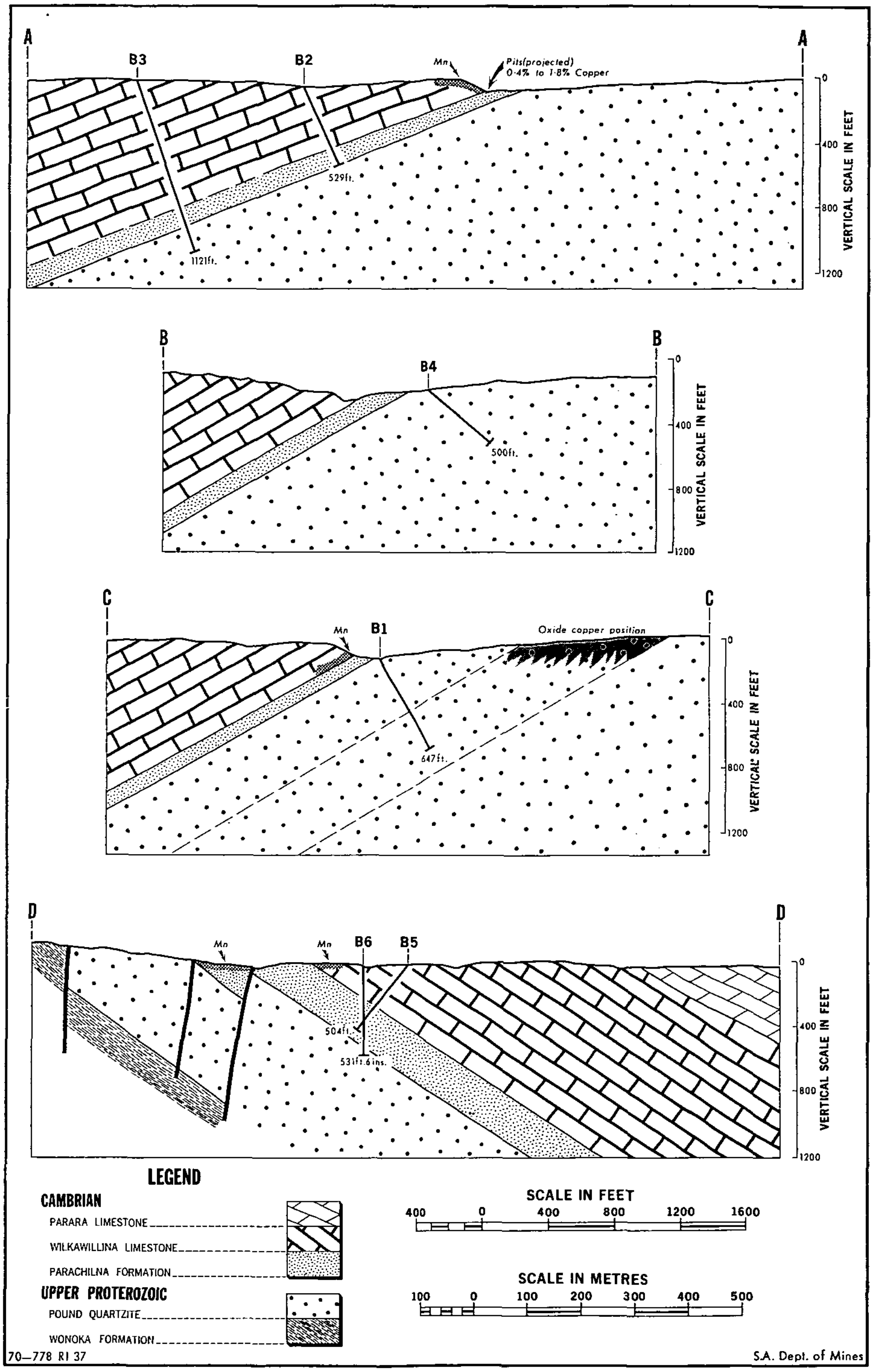


Fig 26. Moro area, geological cross sections through diamond drill holes.

B1 to test for continuity of grade and possible secondary copper enrichment in the zone of copper carbonate occurrence within the Pound Quartzite. Drilling to 647 feet penetrated purple sandstone under white quartzite with sporadic grains of pyrite. Almost full core recovery was achieved but no copper minerals were detected.

B2 where the target zone comprised the down-dip extension of the lower part of the Wilkawillina Limestone, which commonly contains 0.1 to 0.4 per cent zinc and 0.1 per cent lead at the surface, and the Parachilna Formation just west of the zone where pit dump samples contain up to 2 per cent copper and 400 p.p.m. yttrium. The hole, 529 feet in length, penetrated Pound Quartzite and disclosed minor pyrite. The core was weathered throughout; poor core recovery was achieved in the zone of interest.

B3 designed to intersect the same zone as in B2 well below the zone of weathering, was drilled to 1,121 feet. Core recovery was poor and sludge samples from the Parachilna Formation showed copper contents generally in the range 12 to 25 p.p.m., lead 40 to 150 p.p.m. and zinc 30 to 50 p.p.m.

B4 drilled to 500 feet in Pound Quartzite in the western limb of the anticline revealed only traces of pyrite on bedding planes and joints without disclosing base metal mineralization.

B5 to identify the source of an I.P. anomaly below manganiferous ironstone cappings with anomalous copper on the eastern limb of the anticline in an area of faulting. The hole was abandoned due to caving at 504 feet after penetrating dolomite (0 to 250 feet), goethitic siltstones (250 to 314 feet) and brown clays with goethite and manganese oxides (314 to 504 feet). Over the interval 308 feet 6 inches to 383 feet average copper content was 0.13 per cent in what core was recovered, and between 445 feet 6 inches and 504 feet average copper content was 0.28 per cent. From 472 to 504 feet zinc content was 710 p.p.m. while lead was 140 p.p.m.

B6 drilled vertically to 531 feet 6 inches, to further test the same zone as B5, penetrated Pound Quartzite after intersecting goethitic silts and clays of weathered Parachilna Formation between 190 and 483 feet. It proved 32 feet of 0.50 per cent copper, 50 to 80 p.p.m. lead and 300 to 600 p.p.m. zinc in the core recovered in the interval between 416 to 448 feet. Recovery of core was extremely poor. Occasional flecks of malachite were detected in the Pound Quartzite between 522 and 527 feet.

Further chip sampling was undertaken on the western limb of the anticline where the Parachilna Formation showed 1,500 p.p.m. zinc over a width of 30 feet, but failure of the drilling to disclose other than minor concentrations of base metals in S.M.L. 127 and the lack of anomalies in S.M.L. 128 led Kennecott Explorations (Australia) Pty. Ltd. to surrender these leases.

The mercury mineralization of the Moro area suggests "introduction or mobilization of mineralization along some of the major faults of the area" but its economic significance has not been determined.

LAKE TORRENS AREA

An area of 14,540 square miles embracing the western flanks of the Flinders Ranges, the Lake Torrens Sunkland and adjoining Stuart Shelf was granted to Mines Exploration Pty. Ltd., (M.E.P.L.) on 15th June, 1966 as S.M.L. 115, for a period of three months, to delineate, if possible, mineralized Lower Cambrian limestones in outcrop or under shallow cover, preferably where these are flat lying.

To the east of the lake the Wilkawillina Limestone is exposed adjacent to Mount Scott Range, in the foothills of the Flinders Ranges between Nilpena and Edeowie Gorge and in the Cotabena Syncline (Dalgarno and Johnson, 1966). The equivalent Andamooka Limestone is exposed at the northern extremity of Lake Torrens and as a thin flat-lying veneer on the Stuart Shelf (Johns, 1965 and 1968). In the sunklands, Quaternary and Tertiary sedimentary cover precludes direct exploration in Cambrian rocks but, in the Wilkatana area, oil exploration drilling has revealed a completely covered basin of Cambrian carbonate rocks.

A broad regional reconnaissance geochemical programme was undertaken by M.E.P.L. Initially stream sediment sampling was carried out with atomic absorption spectrophotometry (A.A.S.) determination of copper, lead and zinc of the minus 80-mesh fraction after leaching by hot 25 per cent nitric acid. This was followed up by rock chip sampling to assist in evaluation of those results and to check base metal contents of exposed basal Cambrian carbonate rocks and distinctive, iron-stained or gossanous rocks (Roberts, 1966).

Rock chip sampling of a distinctive iron-strained basal Cambrian dolomite bed, 20 feet in width, in Parachilna Gorge revealed contents of 310 p.p.m. copper, 8,500 p.p.m. lead and 19,500 p.p.m. zinc, over its full width. However, stream sediment results were considered to be more meaningful, particularly with regard to lead, and using a high threshhold value of 100 p.p.m. for lead, there proved to be a zone with anomalous values extending along the front of the Flinders Ranges between Brachina Gorge and Parachilna Gorge and beyond over a strike length of more than 15 miles.

To the west of Lake Torrens stream sediment sampling proved unsatisfactory because drainage channels are broad, ill-defined and contain considerable wind blown sand. Rock chip sampling revealed an area of interest northeast of the Andamooka Opalfield on the shore of Lake Torrens where a distinctive leached and iron-stained limestone bed showed 630 p.p.m. copper, 115 p.p.m. lead and 270 p.p.m. zinc.

Core from Santos Wilkatana No. 1 bore was analysed to provide data as to background metal values in apparently unmineralized rocks from the same stratigraphic horizon. In addition to traces of chalcopyrite, the presence of galena just above the base of the Cambrian at this site, supports the view that base metal mineralization occurs in areas not formerly suspected. Table 11 shows the metal contents obtained in the Cambrian carbonate rocks of Wilkatana No. 1 bore.

TABLE 11

METAL CONTENTS IN CAMBRIAN CARBONATE ROCKS, WILKATANA NO. 1 BORE

Interval (feet)	Cu p.p.m.	Pb p.p.m.	Zn p.p.m.	Remarks
463- 486	10	35	194	
486- 504	10	25	177	
504- 549	10	35	162	
723- 728	10	35	370	
728- 733	10	25	570	
733- 738	10	15	340	
738- 743	10	25	260	
743- 748	10	25	193	
748- 753	15	35	340	
753- 758	10	15	193	
758- 763	20	25	200	
763- 768	10	15	114	
768- 774	10	15	1,050	
774- 800	85	90	290	
800- 820	95	60	445	
820- 840	205	60	131	
840- 860	40	50	97	
860- 880	15	25	148	
880- 900	400	35	77	
900- 920	50	50	315	
920- 940	80	50	200	
940- 960	70	35	270	
960- 980	15	25	148	
980-1,000	40	35	155	
1,000-1,020	510	60	325	
1,020-1,040	1,200	60	2,400	
1,040-1,060	150	50	200	
1,060-1,080	480	50	120	
1,080-1,100	370	35	50	
1,100-1,120	125	35	89	
1,120-1,140	15	25	120	
1,140-1,160	620	35	81	Traces of chalcopyrite
1,160-1,180	25	35	177	
1,180-1,200	35	35	93	
1,200-1,220	20	35	77	
1,220-1,240	25	50	185	
1,240-1,260	35	50	114	
1,260-1,280	15	35	50	
1,280-1,300	10	25	24	
1,300-1,320	65	700	58	Traces of galena
1,320-1,337	25	50	107	

Cores from Wilkatana bores Nos. 2 and 3 showed low and constant copper and lead values with zinc variable and generally in the range 150 to 300 p.p.m. In the available core from bore No. 4 a sample taken from 936 feet 6 inches contained 5,200 p.p.m. copper, 2,000 p.p.m. lead and 1,480 p.p.m. zinc.

The results obtained were so encouraging that further leases were sought over the areas of interest, the prime target being the occurrence of lead.

ROXBY DOWNS AREA

In the Roxby Downs area S.M.L. 129 was granted over an area of 950 square miles to M.E.P.L. on 14th September, 1966, and was subsequently surrendered on 14th August, 1967, after follow-up rock chip sampling (total 275 samples) revealed no outstanding metal values, though limestones contained up to 80 p.p.m. lead in the vicinity of Purple Downs Homestead (Roberts, 1967d).

ANDAMOOKA AREA

An area of 800 square miles was granted to M.E.P.L. as S.M.L. 130 in the Andamooka locality on 14th September, 1966. At the expiration of S.M.L. 130 on 14th November, 1967, another lease, S.M.L. 130A of 171 square miles, was applied for and obtained within the original area.

Analysis of some 500 predominantly rock chip samples taken throughout the area, established that a distinctive leached, manganese and iron-stained basal Andamooka Limestone bed, occurring northeast of the Andamooka Opalfield and on the edge of Lake Torrens, gave geochemical assays up to 1,700 p.p.m. copper, up to 410 p.p.m. lead and up to 650 p.p.m. zinc. Background values had been established in the range 5 to 25 p.p.m. copper, 10 to 35 p.p.m. lead and 10 to 80 p.p.m. zinc (Roberts, 1967a, 1967b and 1967c). Two samples taken from the western shore of Lake Arthur contained 430 p.p.m. and 180 p.p.m. lead respectively. A total of 281 rock chip samples were collected within the area of S.M.L. 130 to define the principal area of interest.

To check the possibility that the anomalous geochemical results northeast of Andamooka were indicative of sulphide mineralization below the level of oxidation, induced polarization surveys (3.8 line miles) were undertaken, including follow-up work (Roberts, 1967e, 1968a and 1968d). Shorter electrode spread follow-up surveys revealed zones of possible anomalous I.P. effects which were tested by diamond drilling (Roberts, 1968e; 1968g and 1968i) (see Fig. 27). The results of the diamond drilling are summarized as follows:

LTA1 (total depth 303 feet) penetrated partly leached (with coatings of iron and manganese oxides in vughs) massive off-white to grey-blue Andamooka Limestone to 112 feet 6 inches. Sandy sections and intraformational conglomerates were reported. Fine pyrite mineralization was intersected from 49 feet to 111 feet 6 inches as aggregates and single crystals in vughs, on fractures and in dark chloritic aggregates. Purple, green and grey Yarloo Shale was penetrated at 112 feet 6 inches to 303 feet.

LTA2 (194 feet) in Andamooka Limestone to 121 feet disclosed numerous vughs lined with iron and manganese oxides to 54 feet and fine pyrite in chloritic aggregates and in fractures between 58 and 98 feet. Yarloo Shale was intersected from 121 to 194 feet when drilling was terminated.

LTA3 (145 feet) disclosed Andamooka Limestone to 134 feet with pyrite between 58 and 98 feet in fractures, as fracture coatings, in dark irregular inclusions and vughs. A transition zone comprising silts, shale, limestone and calcarenite one foot in thickness separated the carbonate sequence from Yarloo Shale below.

No base metal mineralization was revealed and finely disseminated pyrite in the Andamooka Limestone proved to be the source of the geophysical I.P. anomaly being tested. The lease expired on 14th January, 1969.

PARACHILNA AREA

Special Mining Lease 131, granted to M.E.P.L. on 14th September, 1966, comprised two separate areas, the Parachilna—Mernmerna area of 672 square miles where definite anomalies for lead, zinc and copper had previously been established, and the Wilkatana area of 73 square miles. The latter area was surrendered on 14th November, 1967 without further investigation and the rest of the area embraced by S.M.L. 131 was expanded to cover an area of 984 square miles as S.M.L. 131A on 15th November, 1967. It was in this region that effort was directed until the surrender of the lease on 24th April, 1969.

The extent of the Lower Cambrian carbonate rocks in this region are depicted on the PARACHILNA geological map (Dalgarno and Johnson, 1966) (see Fig. 28). Sampling of regular traverses (Johns, 1967; Olliver and Cramsie, 1967a and 1967b) and diamond drilling (Cramsie, 1967) has demonstrated that the lower part of the carbonate sequence is dolomitic and includes beds of relatively pure dolomite while the upper part comprises high grade limestone. The occurrence of coarse-grained galena on the flank of the ranges five miles north of Brachina Gorge, on which limited earlier mining activity had been conducted, marked the only known base metal mineralization in the zone until investigations by M.E.P.L. disclosed widespread anomalous lead occurrence in stream sediments between Brachina Gorge and Parachilna Gorge and beyond. Regional geochemical surveys were used as the initial exploration method. Subsequently detailed geochemical surveys, geological mapping, geophysical surveys and diamond drilling were undertaken.

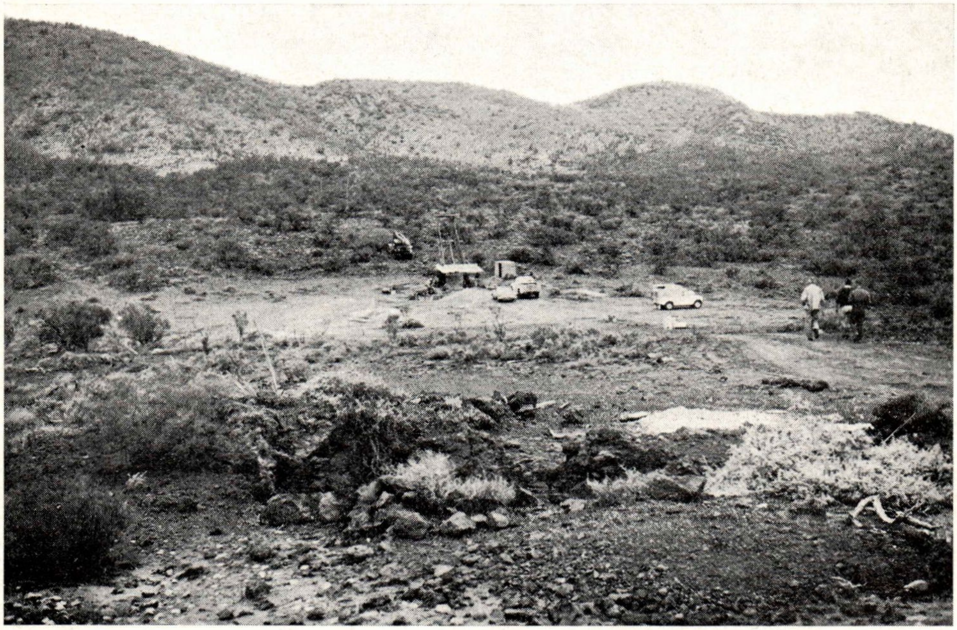
Over a length of 20 miles extending from eight miles north of Parachilna Gorge to Edeowie Gorge stream sediment samples taken from the majority of creeks draining the Lower Cambrian carbonate rocks have disclosed anomalous lead contents, with insignificant amounts of copper (see Fig. 28). Over 3,300 stream sediment samples were taken to reveal very strong, persistent, anomalous dispersion trains with lead contents as high as 1,480 p.p.m in stream silt (Roberts, 1967a, 1967b, 1967c and 1967f). To the north of Parachilna Gorge lead and zinc contents of gully sediments were lower than those between Parachilna Gorge and Edeowie Gorge. In detail, stream sediment geochemistry has variously revealed zones of anomalous lead-zinc dispersion trains, areas of anomalous lead dispersion trains and areas of anomalous zinc dispersion trains.

Minor copper carbonate mineralization has been discovered, generally in association with galena-bearing horizons, about six miles north of Brachina Gorge.

One of the more interesting zones where there are consistently anomalous lead and zinc contents is centred in geophysical line 1 (approximately six miles north of Brachina Gorge and termed the "Galena Creek area"). This zone extends for a distance of almost five miles along strike in a drag folded sector disrupted by minor faulting. The most extensive outcropping of galena has been discovered in this area and rock analyses indicate significant contents of zinc, probably occurring as zinc silicate (Roberts, 1968b). Concentrations of lead and zinc are also apparent adjacent to the fault at Brachina Gorge.

In grid "A" area adjacent to a major fault south of Brachina Gorge there is a zone of anomalous zinc values with minor lead. This is followed to the south by a zone of increasing lead values which is markedly concentrated in the Bunyeroo Gorge area, extending for some two miles north and three miles south of Bunyeroo Gorge. Minor galena mineralization has been located in outcrop in the gorge within the Lower Cambrian carbonate rocks. Southwards to Edeowie Gorge the stream sediments show high zinc contents.

Some anomalous lead and zinc values were indicated in the Cotabena Syncline area, particularly in the southeastern sector where a gossan-like horizon in the



Old workings in zinciferous manganese "gossan" concentrated on fault separating Pound Quartzite and Wilkawillina Limestone, south of Brachina Gorge, grid area "A". View south to drilling plant. *Neg.* 17775

basal Cambrian has been located. Of some 260 samples taken in the Cotabena area the highest base metal contents recorded were 700 p.p.m. lead and 2,700 p.p.m. zinc.

The geochemical investigations and follow-up mapping led to the discovery of lead sulphide mineralization of two broad types (Roberts, 1968b, 1968c, 1968f and 1968h):

1. Generally conformable galena occurrences form two distinctive horizons usually varying from five to 10 feet but up to 70 feet in width, and traceable in outcrop up to 1,000 feet along the strike at various locations in the same general stratigraphic position, particularly within the lower, blue, dolomitic member of the Lower Cambrian Wilkawillina Limestone. This extends discontinuously from two miles south of Bunyeroo Gorge to seven miles north of Brachina Gorge.

Galena occurs as disseminations, as isolated small cubes and in fine fracture fillings, films and veinlets commonly less than an eighth of an inch in width; zinc is considered to be present as zinc silicate. Several bulked composite samples taken from outcrop six miles north of Brachina Gorge assayed as follows:

	Lead (per cent)	Zinc (per cent)	Silver (oz per ton)
Sample 1	5.4	1.4	0.20
Sample 2	9.8	8.0	1.20

Also at this general stratigraphic level more extensive iron and manganese-stained and, in part, gossan-like developments have anomalous lead and zinc contents.

2. Less extensive galena mineralization is present in the upper limestone member in association with breccia zones and with calcite veining. An attempt has previously been made to mine lead ore in this environment five miles north of Brachina Gorge, near the flanks of the range. Galena occurs sporadically as fine- to medium-grained disseminations and veinlets and in occasional masses up to 12 by 8 by 4 inches.

Widely spaced orientation lines were surveyed, designed to check the nature of I.P. response over mapped galena-bearing horizons, to check this horizon where sulphide mineralization had not been sighted and to establish whether it was possible to penetrate the Quarternary and Tertiary cover at least immediately west of the ranges where the Lower Cambrian carbonate rocks dip beneath the plain. All lines exhibited a sharp drop in apparent resistivities west of the ranges indicating that the younger cover was not being penetrated on the relatively short electrode spread lengths used (200 feet). On line 1 possibly anomalous effects were disclosed in the vicinity of the lowest galena-bearing horizons, with definite anomalies over the upper wider galena-bearing horizons to the west. On line 2 possible anomalous effects were recorded over the galena-bearing horizons and similar results were achieved in the vicinity of known narrow galena-bearing beds on line 4.

Manganese-rich gossan-like developments were located in a number of areas during the survey, several of the largest and most accessible of which (north of Parachilna Gorge and north of Bunyeroo Gorge) had been formerly tested by shallow pits and ore had obviously been taken from them. Some 642 soil and rock samples were taken from the various gossans which showed high lead and, in particular high zinc contents. It was recognized that manganese and iron-rich "gossans" are not uncommon in limestones. The alkali pH conditions associated with outcropping limestone could cause precipitation of manganese and iron from percolating groundwaters and form gossanous cappings not directly related to deeper metallic mineralization and scavenge anomalous amounts of base metals from solutions which might originate from known lead and zinc-bearing Lower Cambrian carbonate rocks.

Two such zones were located north of Parachilna Gorge (grid "B"). The westernmost zone outcrops intermittently over a strike length of about three miles, as pod-like manganese-rich gossan developments of variable length and width, on the flank of the ranges on limestone which lies stratigraphically higher than the lead-zinc-bearing dolomites. Limited prospecting for manganese was carried out in this zone some 30 years ago. Rock chip samples did not reveal any high lead values and only two samples contained more than 1,000 p.p.m. zinc. Situated immediately to the north and east is a rather different distinctive iron and manganese-stained, partly gossanous horizon, which lies at the base of the Cambrian carbonate sequence, close to or at the same stratigraphic horizon as that which contains lead-zinc mineralization further to the south. Rock chip analyses revealed up to 590 p.p.m. copper, 1,100 p.p.m. lead and 8,700 p.p.m. zinc. Soil geochemistry was undertaken at 50 feet intervals on grid "B" and 13 line miles of geophysical I.P. survey were undertaken to indicate possible I.P. effects on a number of lines. No magnetic anomalies were detected in a ground magnetometer survey of the gridded area.

Samples taken from gossanous pods up to 200 by 100 feet, which occur on limestone one mile south of Parachilna Gorge (grid "E"), contained up to 760 p.p.m. copper, 1,200 p.p.m. lead and 560 p.p.m. zinc.

A small gossan-like mass located 400 feet north of geophysical line 1 in the Lower Cambrian carbonate member proved to have the following metal contents—30 p.p.m. copper, 1,300 p.p.m. lead and 900 p.p.m. zinc.

A narrow but persistent gossan-like horizon at least 5,000 feet in length, located in the Bunyeroo Gorge area and situated at the base of the Lower Cambrian carbonate sequence, showed the following contents on analysis—190 p.p.m. copper, 2,100 p.p.m. lead and 8,000 p.p.m. zinc. A manganese-stained bed, three feet in width near the base of the sequence and located 1,000 yards north of Bunyeroo Gorge, contained 1,275 p.p.m. lead and 750 p.p.m. zinc. An iron-stained band, six feet wide, at the base of the carbonate sediments and located 1,000 feet south of Bunyeroo Gorge showed 2,450 p.p.m. lead and 1,850 p.p.m. zinc. In the extreme southwest of the area at grid area "C" a heavily iron-stained and gritty Cambrian bed showed on analysis 3,950 p.p.m. lead and 1,050 p.p.m. zinc. An I.P. survey in this area proved abortive.

In grid "A" area detailed geochemical and geophysical work was undertaken along a major fault zone separating Pound Quartzite and Wilkawillina Limestone on an extensive gossan development almost 4,000 feet long and up to 100 feet wide, located two miles north of Bunyeroo Gorge. Bulk samples taken from six groups of old shallow workings had zinc contents of almost 1 per cent (see Table 12).

TABLE 12

METAL CONTENTS OF BULK SAMPLES FROM SHALLOW WORKINGS, GRID "A" AREA, SOUTH OF BRACHINA GORGE

Sample No.	Zn per cent	Pb per cent	Ag oz per ton
1	0.73	0.08	0.20
2	0.95	0.15	0.25
3	0.95	0.15	0.30
4	0.95	0.07	0.25
5	0.95	0.07	0.38
6	0.80	0.05	0.25

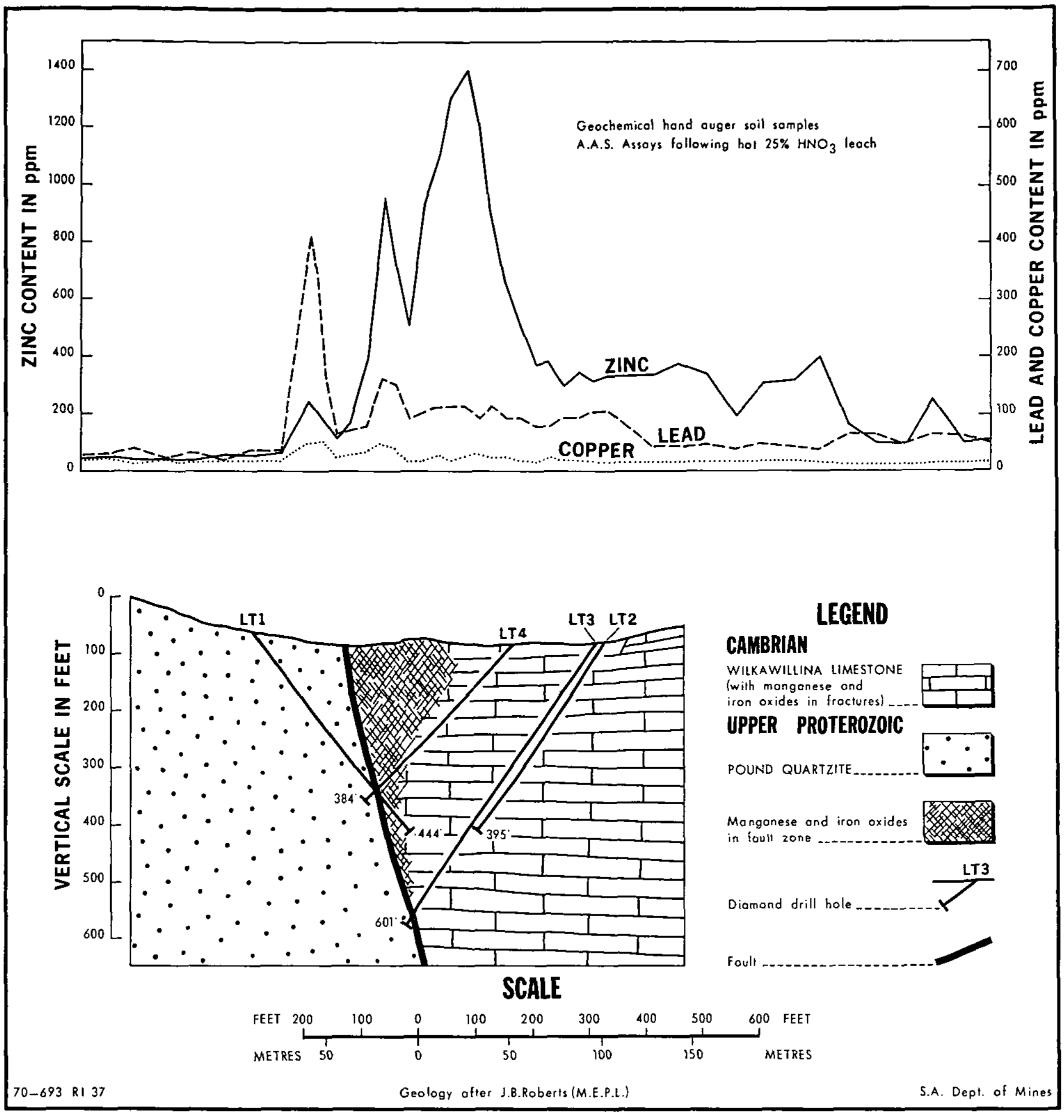


Fig. 29. Metal contents of surface samples and geological cross section through diamond drill holes, Brachina "gossan", Grid "A".

Though a survey with magnetometer disclosed no magnetic response definite I.P. anomalies were indicated in the gossan zone. To determine whether the gossan was related to deeper metallic mineralization diamond drilling was undertaken as follows (see Fig. 29):

LT1, depressed 55 degrees E, abandoned at 444 feet.

0-370 feet. Pound Quartzite, partially weathered and fractured.
370-444 feet. No core.

LT2, depressed 60 degrees W, abandoned at 395 feet.

0-395 feet. Wilkawillina limestone, fractured, iron and manganese-stained oolitic limestone with narrow manganese-rich bands. Selected sections assayed as follows:

feet	Zn per cent	Ag oz per ton
100-127	0.60	0.40
127-140	0.60	0.60
140-142	0.60	0.40

LT3, depressed 60 degrees bearing 310 degrees, designed to complete the test planned for LT2.

0-538 feet. Wilkawillina Limestone, manganese- and iron-stained fractured and brecciated limestone with short sections of massive manganese and iron oxides. Selected sections assayed as follows:

feet	Zn per cent
493ft.-497ft. 6in.	1.05
503ft. 10in.-510ft. 6in.	1.32

583-601 feet. Pound Quartzite.

LT4, depressed 50 degrees, bearing 310 degrees.

0-355 feet. Wilkawillina Limestone, manganese- and iron-stained fractured and brecciated limestone with short sections of massive manganese and iron oxides.

355-384 feet. Pound Quartzite.

Assays for split core of selected sections are shown in Table 13.

TABLE 13

METAL CONTENTS FOR SPLIT CORE OF SELECTED SECTIONS, DIAMOND DRILL HOLE LT4, GRID "A" AREA, SOUTH OF BRACHINA GORGE

Interval (feet)	Zn per cent	Pb per cent	Ag oz per ton
60 – 70	0.85	0.43	0.40
70 – 89	1.02	0.39	0.50
89 –100.5	0.50	0.48	0.40
100.5–108.5	1.02	n.d.	0.20
108.5–122.5	0.50	n.d.	0.20
187 –194	1.40	n.d.	0.20
194 –204.5	1.30	n.d.	0.20
204.5–214	1.02	n.d.	0.10
219 –224	1.60	n.d.	0.20
224 –234	0.60	n.d.	0.20
234 –244	1.00	n.d.	0.20
244 –258	0.95	n.d.	0.10
258 –262	1.40	n.d.	0.10
272 –284	1.90	n.d.	0.10
284 –294	1.80	n.d.	0.20

n.d.—not determined.

In the intervening sections zinc values of 0.5 per cent or less were recorded.

It was considered (Roberts, 1968h) that this is a "false" gossan, comprising transported manganese and iron oxides which includes appreciable zinc by ionic substitution but "the outcome of this drilling in no way detracts from the exploration potential of the known galena-bearing dolomite horizons".

To test an I.P. anomaly associated with the base of the Lower Cambrian sequence where there are anomalous contents of lead (8,500 p.p.m.) and zinc (19,500 p.p.m.) in a 20 feet wide dolomitic bed one diamond drillhole (LT5) was collared close to the Parachilna-Blinman road in Parachilna Gorge on a bearing 87.5 degrees, depressed 50 degrees. Insignificant mineralization was detected to total depth of 681 feet.

The investigations of M.E.P.L. have revealed concentrations of lead and zinc over some 60 strike miles of similar stratigraphy. "The exposed Lower Cambrian carbonate rocks represent only a small proportion of the potential Cambrian limestones and work has been concentrated in the eastern limb of a large regional anticline, which is generally covered by Quarternary and Tertiary sediments west of the Flinders Ranges. Reasonably good prospects also exist for the presence of other Cambrian basins in the belt between the ranges and Lake Torrens" (Roberts, 1968h).

CONCLUSIONS

Investigations relating to the occurrence of base metal minerals in Lower Cambrian sediments in the Flinders Ranges which were initiated by the Geological Survey of South Australia and subsequently followed up by exploration companies has disclosed widespread lead, zinc and minor copper mineralization within narrow stratigraphic limits.

Geochemical prospecting, which has included stream sediment sampling, followed up by rock sampling and drilling, has resulted in the delineation of a number of areas over which there are, previously unsuspected, significant concentrations of lead and, in particular, zinc. High grade zinc deposits have been discovered at Puttapa.

Lead sulphide is discernible in outcrop in many localities as disseminations and in minor massive concentrations but small scale mining operations have formerly been limited to a few localities.

Oxidized near-surface secondary concentrations typify the previously exploited copper deposits and several newly discovered willemite occurrences. Structural control in their localization is apparent. Accumulations of manganese and iron oxides in these situations constitute "false gossans". Manganese is a notorious scavenger of zinc and appreciable amounts of zinc and minor lead, cobalt, nickel and arsenic have accumulated with manganese wad and goethite by adsorption of ionic substitution through the circulation of ground waters adjacent to fault zones.

Lead, zinc and copper sulphides in Lower Cambrian carbonate sequences are known also from Yorke Peninsula and Fleurieu Peninsula and within the Kanmantoo Group in the eastern Mount Lofty Ranges and on Kangaroo Island. The search for those metals throughout the Adelaide Geosyncline and adjoining shelf is being intensified, while the Torrens "hinge zone" constitutes an almost wholly concealed tract wherein the possibility exists of concentrations of metals in flat lying or only gently deformed strata.

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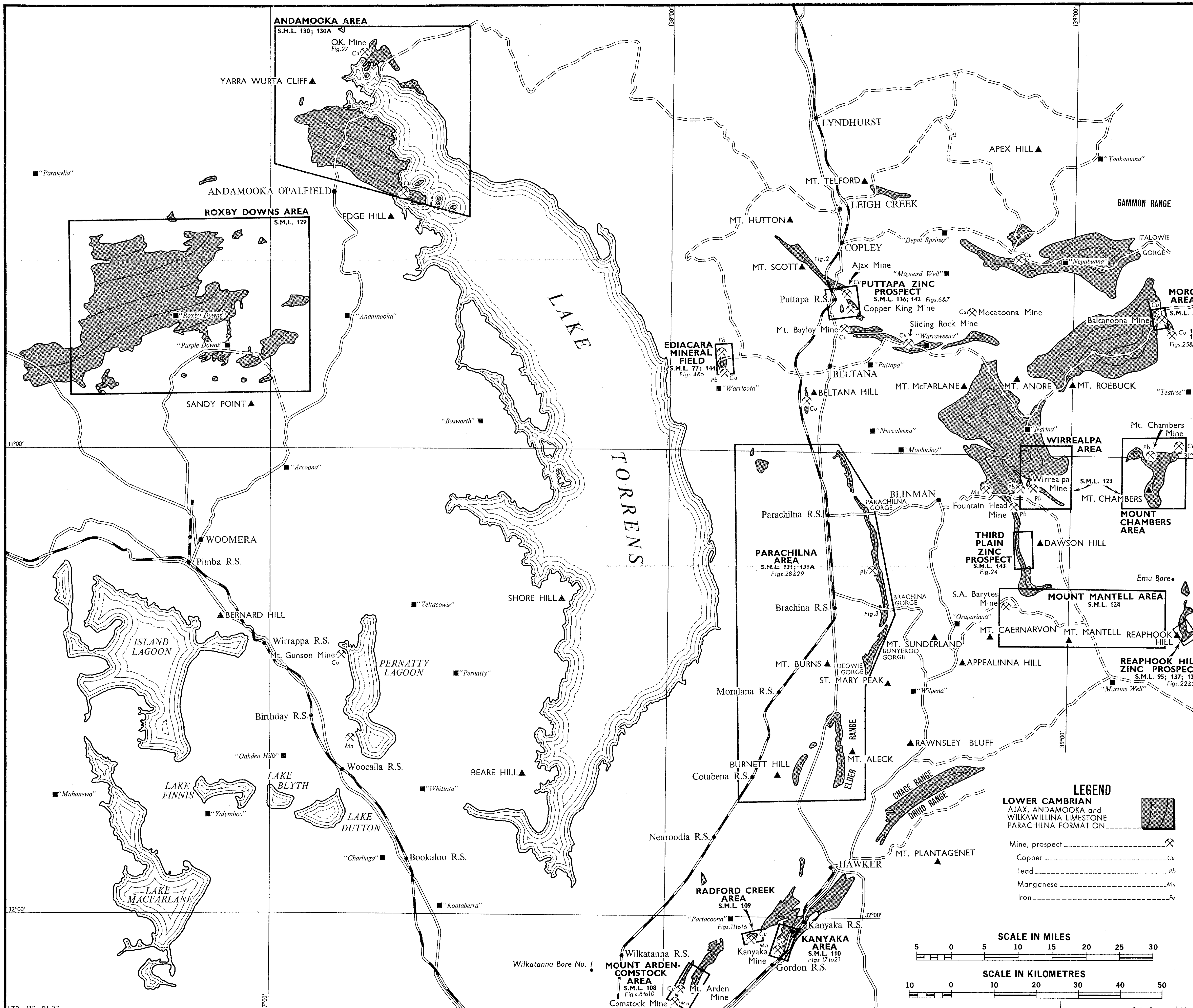

Fig.1-Map showing distribution of Lower Cambrian sediments, mines, prospects and base metal mineral occurrences

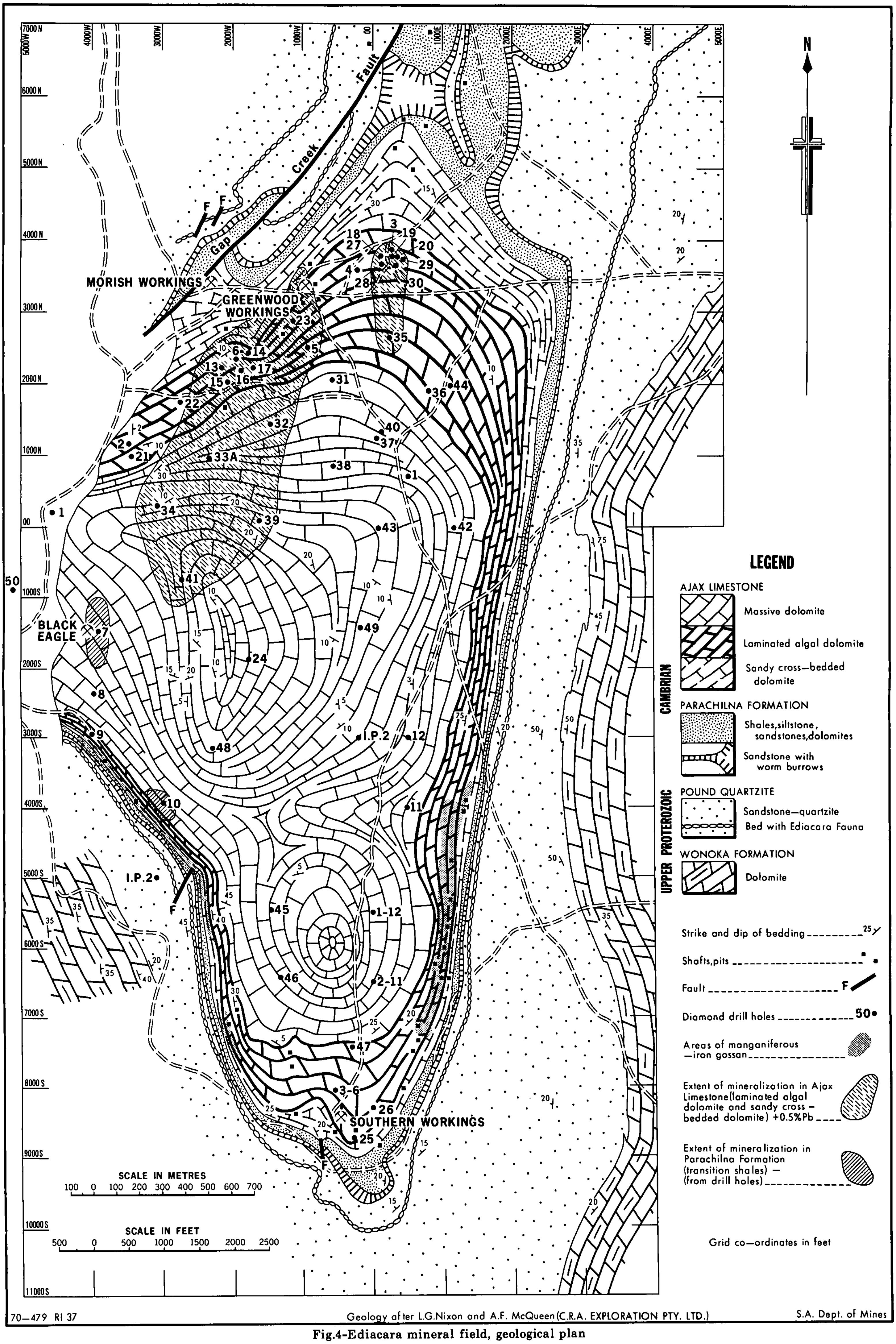

Fig.4-Ediacara mineral field, geological plan

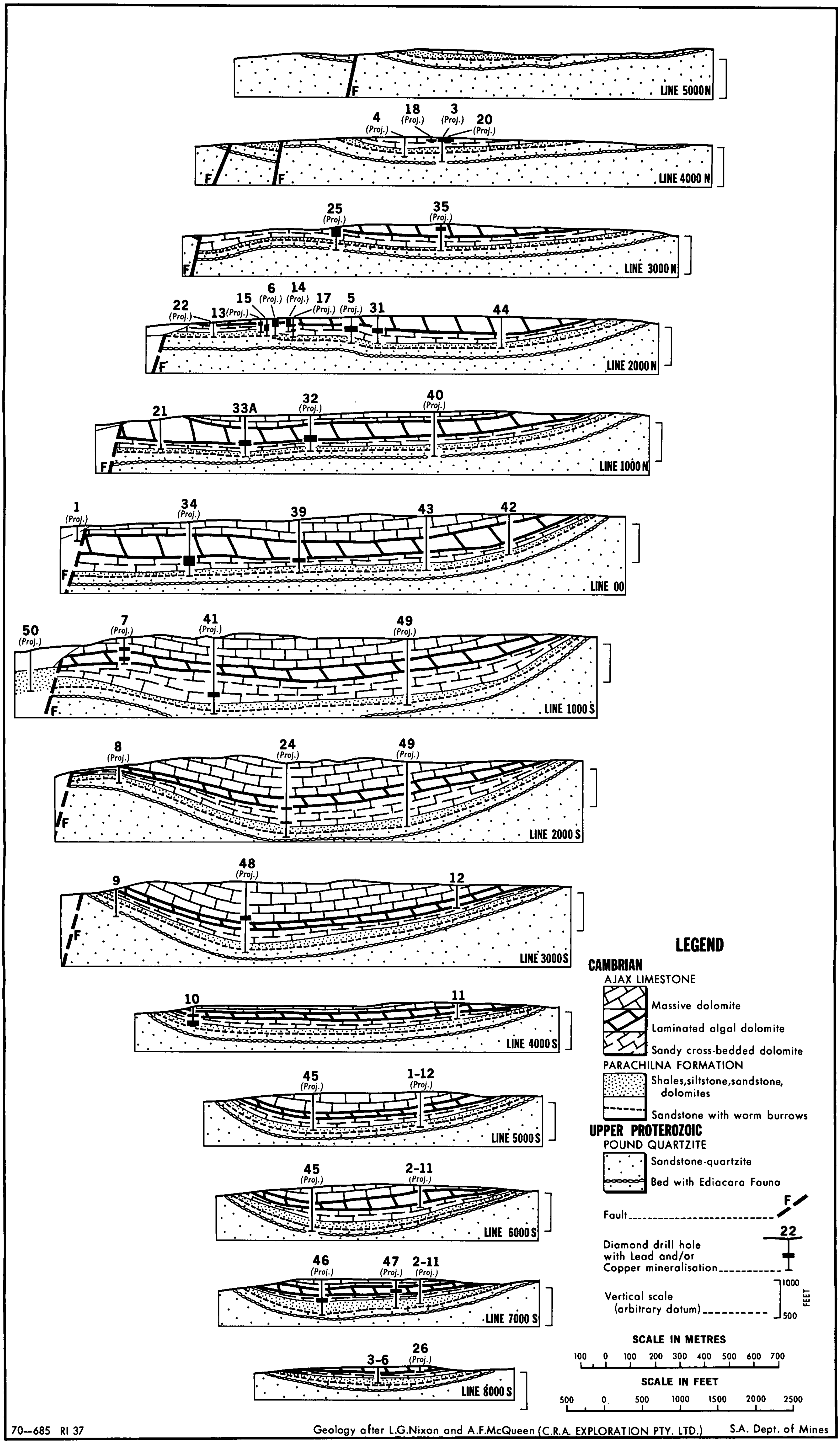

Fig.5- Ediacara mineral field, geological cross sections

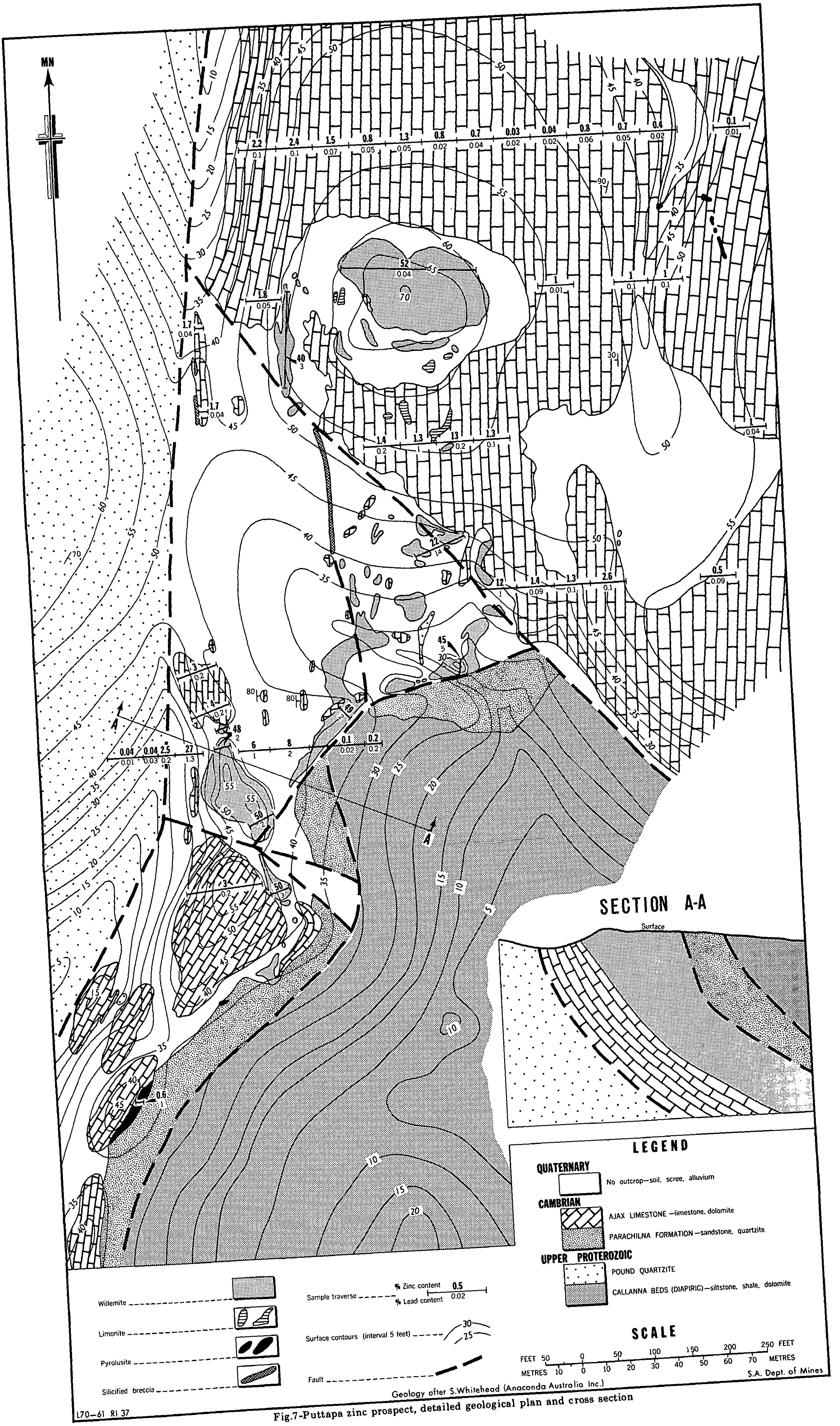

Fig.7-Puttapa zinc prospect, detailed geological plan and cross section

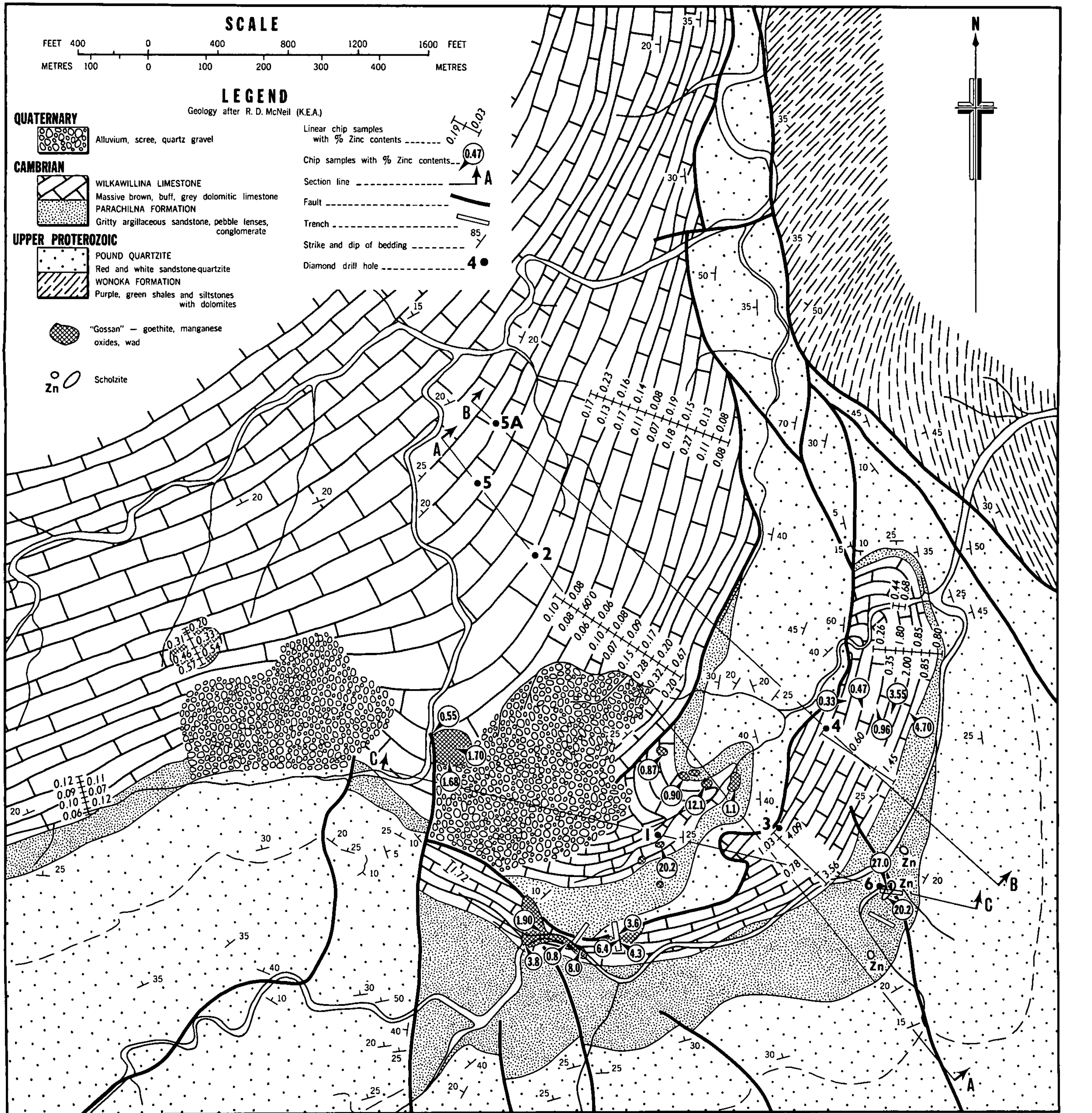

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Fig.22-Reaphook Hill zinc prospect, geological plan

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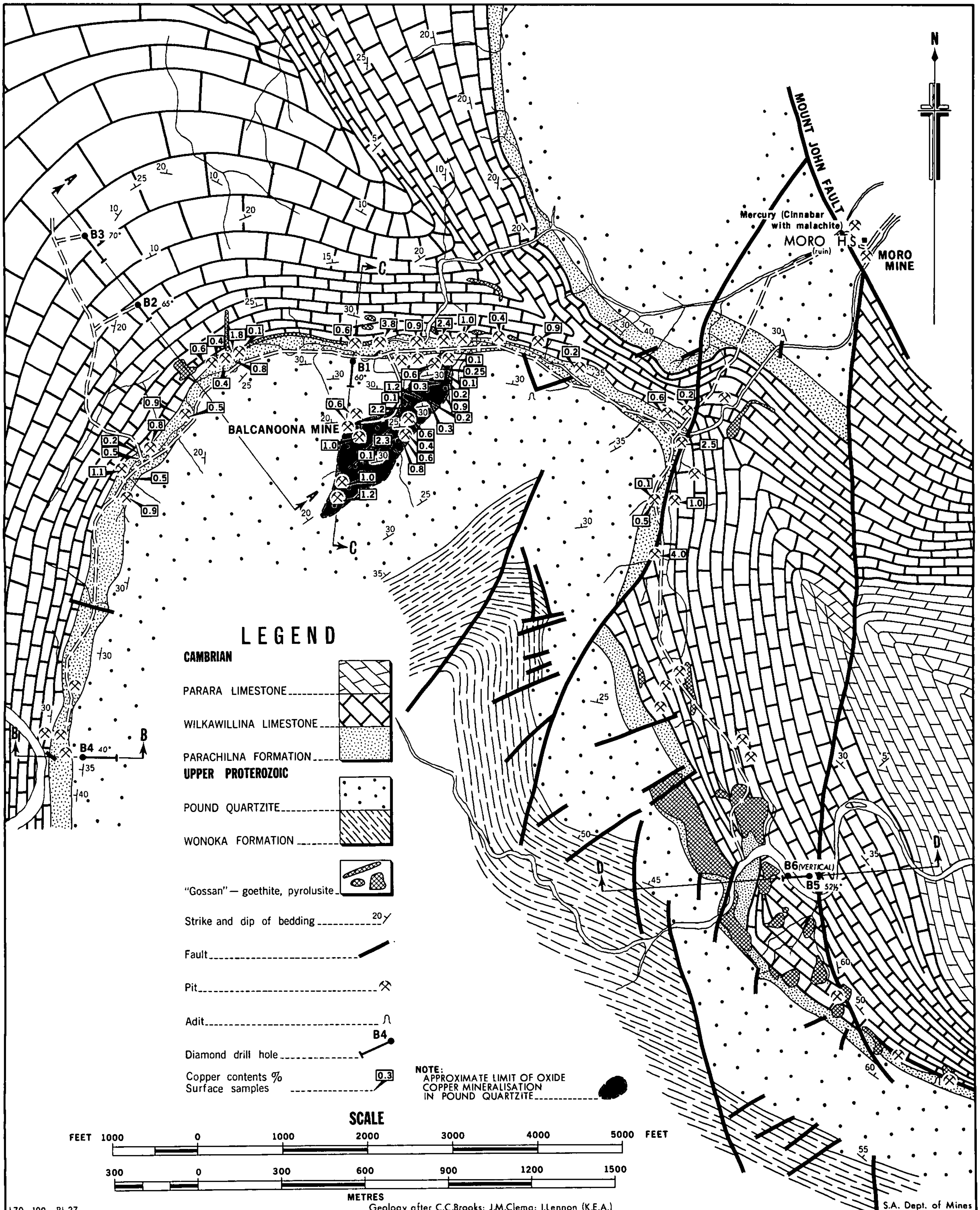

Fig.25-Moro area, geological plan and section through diamond drill sites

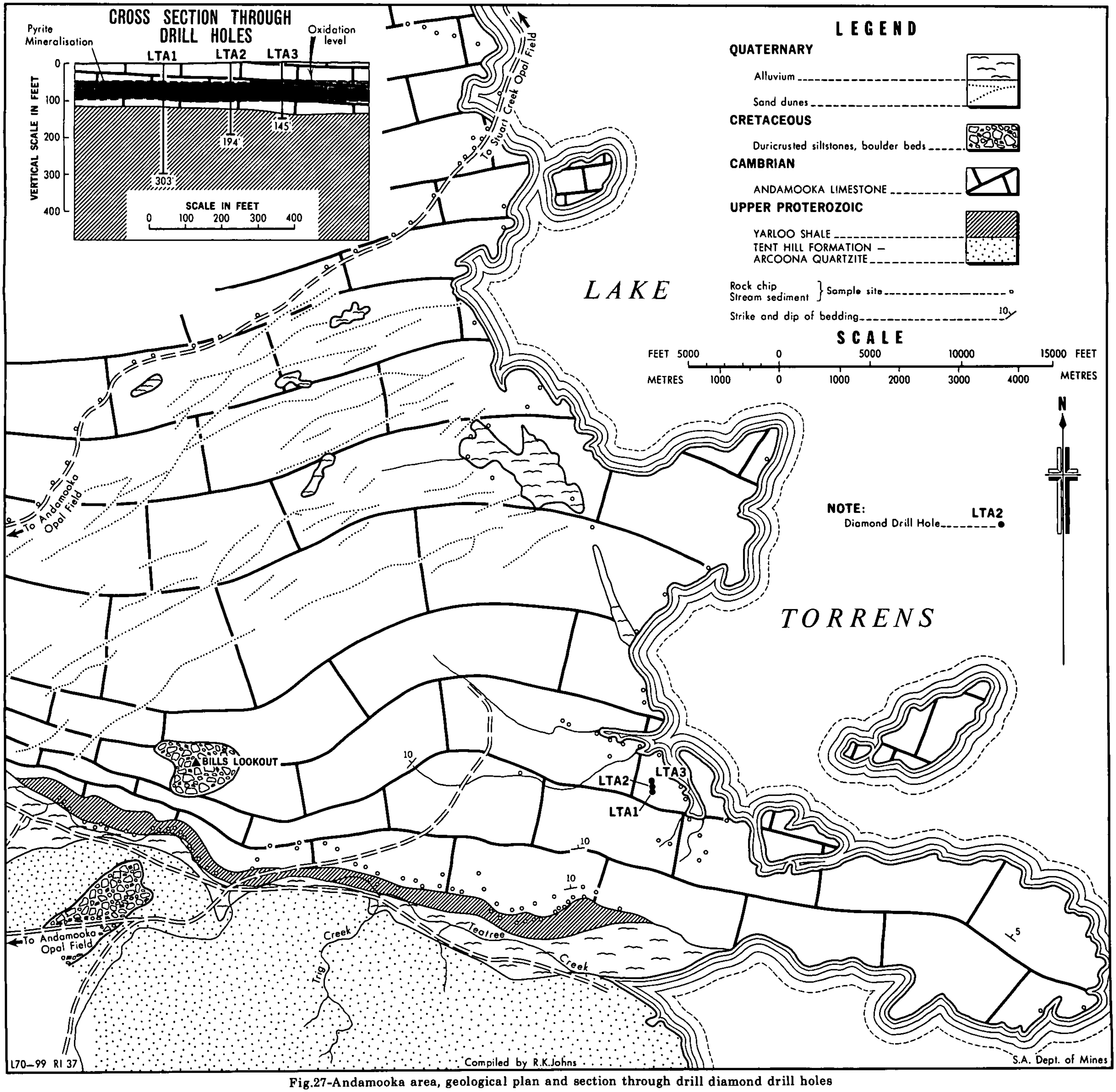

Fig.27-Andamooka area, geological plan and section through drill diamond drill holes

Fig.28-Parachilna area, geological plan, showing stream sediment samples and diamond drill sites