THE GEOLOGY OF THE

MISSISSIPPI VALLEY TYPE LEAD-ZINC ORE DEPOSITS

PART 1 : MAJOR WORLD OCCURRENCES

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This report on Mississippi Valley type lead-zinc ore deposits is the first of a series consisting of three parts :-

Part 1 : Major World Occurrences

Part 11 : Australian Occurrences and Exploration Prospects

Part 111 : Southern Georgina Basin Geology

The aim of this project is to collect all the relevant information, including prospecting techniques, about stratiform deposits and to apply this to favourable Australian areas.

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THE GEOLOGY OF THE MISSISSIPPI VALLEY TYPE LEAD-ZINC ORE DEPOSITS

SUMMARY

Lead-zinc deposits of the Mississippi Valley type have a world wide occurrence. The unifying characteristics of these deposits are :-

(1) They occur in limestones and dolomites and their age ranges from Upper Cambrian to Tertiary. (See Table 7.)

(2) They consist primarily of bedded replacements, veins and cavity fillings. The ore shows great selectivity for certain favourable beds.

(3) Mineralogy is simple and the precious-metal content is low, viz: galena, sphalerite, pyrite, fluorite, with minor Co, Ni, Ag, Cu, Cd, In, Ge, Ga. Gangue is white sparry dolomite, calcite, jasperoid, chert and quartz. Traces of hydrocarbons are common. There is usually little wall rock alteration.

(4) There is a general absence of igneous rocks as potential sources of ore solutions.

(5) Ore bodies are most common in passive structural regions. Faults are common in the Appalachian province, Illinois-Kentucky field, North Africa and Ireland.

(6) Ore is frequently related to positive structures including basement "Knobs", calcareous sand banks, algal reefs and domes. Dips of 20^{o} - 40^{o} in off reef beds are common.

(7) Solution activity, brecciation, slump, collapse, and thinning are commonly in evidence, including old karst topography.

(8) Ores occur at shallow depths (generally less than 1,000 feet) relative to the present surface. This is probably a function of both ease of exploration and mode of formation from brines following porous horizons out of the basin.

(9) On a world wide basis the stratiform ore deposits occur in narrow horizons, (often less than 200 feet), regardless of their regional geologic settings and the thickness of the sequence at that location. Furthermore, deposits are commonly near basin margins.

The most important areas for this type of deposit are :-

(1) U.S.A. (see Diagrams 7, 24 and 25)

(a) Tri-State District (Missouri - Kansas - Oklahoma). In Mississippian limestone/dolomite and cherts. Extends for 135 miles covering 750 sq. miles.

(b) Wisconsin - Illinois District. In Middle Ordovician dolomite.

(c) Southern Illinois - Kentucky Fluorspar-Zinc-Lead District. In Mississippian limestone.

(d) Southeast Missouri Lead District. Ores are in Upper Cambrian dolomites immediately above Pre Cambrian basement. There is a close relationship between ore and sedimentary depositional features such as lime sand banks, algal reefs and facies changes. The district extends for 80 miles and covers 500 sq. miles.

(e) Appalachian Zinc, Lead and Barite Province. (Tennessee, Virginia and Pennsylvania). Light, straw, coloured sphalerite and some galena occurs as fracture fillings in brecciated fine grained dolomite, or disseminated in coarse crystalline dolomite of Lower Ordovician age. The Province extends for 750 miles.

(f) Minor areas include Central Missouri zinc-barite-lead district (Lower Ordovician), North Arkansas zinc-lead district (Mississippian and Ordovician) and Central Kentucky-Tennessee barite-lead-zinc veins.

(2) Districts outside the U.S.A.

(a) Pine Point (Canada). Ores in Devonian dolomite/limestone.

(b) British Columbia (Canada). Lead/zinc in Cambrian limestone/dolomite.

(c) Morrocco-Algeria-Tunesia. Lead-zinc ores have replaced Jurassic limestone.

(d) Belgium, Luxe~~n~~mburg. Lead and zinc ores have replaced Devonian/Carboniferous limestone near large faults.

(e) Ireland. Lower Carboniferous limestone.

Features of these deposits are listed in table 1.

ORIGIN OF MISSISSIPPI VALLEY TYPE ORE BODIES

SOURCE OF ORE MATERIALS - *5, 32, 48.*

General Theories that have been put forward include :

(1) Meteoric water migrating downward or horizontally in previously deposited rocks.

(2) Heated meteoric water circulating upward, after initial downflow and increase in temperature.

(3) Strictly syngenetic processes, with metals and sediments being deposited contemporaneously from sea water.

(4) "exhalative sedimentary" processes, with the metals being supplied from rising fluid (magmatic/juvenile), and discharging directly on the sea floor.

(5) Processes similar to (4) except that deposition is early diagenetic, with the ore fluids rising into uncompacted sediments on the sea floor.

(6) Magmatic hydrothermal water, with the ore fluid rising into previously formed indurated rocks from presumed distant magmatic sources.

(7) Circulating cold or nonthermal connate water.

(8) Hypogene thermal connate water, rising from within the sedimentary pile into already indurated rocks.

(9) Lateral secretion of metals originally dispersed in the same beds that now contain the ore deposits by bulk movement of or diffusion within interstitial connate waters of the beds.

(10) Combinations of the above.

A theory that explains the important features of these deposits has been put forward by Jackson and Beales (1967). Their hypothesis involves two kinds of connate water. The lead and zinc are transported as metal chloride complexes from adjacent basinal sediments in escaping chloride-rich connate brines. The sulphur which causes precipitation of the ores originates from sulphates in, or adjacent to, the carbonate horizons. This sulphate, in the presence of organic matter (oil, bituminous sediment etc), supports growth of sulphate-reducing bacteria with consequent production of H_2S and possibly S. Inorganic reduction of sulphate may also play a role but this is unlikely at the temperatures (approximately 100^oC) ascribed to Mississippi Valley Type deposits.

Carbonate rock forming environments are commonly evaporitic and the resulting sediments carry accessory gypsum and anhydrite (and hence sulphate). These sulphates serve as a source for H_2S in an environment in which it is more likely to persist and accumulate compared to a shale sequence where the H_2S that is formed tends to be fixed by reaction with metallic cations, mainly Fe, thus immobilizing the sulphide.

The hypothesis consists of two parts:

(1) Base metals are transported in sulphide deficient brines escaping from deep sedimentary basins, and

(2) H_2S rich brines from shallow depths mix with the metal-bearing brines and precipitate the ore minerals. Thus precipitation of metallic sulphides occurs when porosity/permeability trends are favourably oriented such that part of a porous carbonate unit is acting as the escape route for basinal waters.

Major points of disagreement among workers concern the form in which the metals are transported, the nature of the transporting solution, and the causes of precipitation of the metals as sulphide ores. It seems that chloride and various sulphide complexes are the most likely modes of transport. Jackson & Beales hypothesis is supported by lead-isotope and sulphur-isotope evidence. Abundant data are available from well records in Canada and U.S.A. to demonstrate the common occurrence of "sour" oil and gas (i.e. carrying H_2S) in carbonate reservoirs, and "sweet" oil and gas in sandstone/shale sequences.

The sediment pile is regarded as a possible immediate source of Mississippi Valley type lead and zinc, since shales contain 20-200 p.p.m. Pb and 50-300 p.p.m. Zn, while carbonates contain 5-10 p.p.m. Pb and 20-30 p.p.m. Zn. *(32)* These metals can be released to interstitial waters during diagenesis and compaction or hydrostatic head will expel these waters. It can readily be calculated that a sedimentary pile carries enormous tonnages of lead and zinc and the migration and precipitation of a small proportion could form large ore bodies.

STRATIGRAPHIC SETTING - *9*

In any effort to delineate environments favourable for ore occurrences, all the facts concerning presently known deposits must be considered. In plan the shape of the environments and ore deposits is characterised by linear elements; mineralisation is truly strata-bound with overlying beds showing no trace of the ore.

The features controlling ore localization are derived from paleophysiography and include (illustrated in diag. 1) :-

(1) Specific sedimentary environments above an unconformity, such as pinchouts, talus-landslide breccias, reefs, mud banks and compaction/drape structures over unconformities. Examples of ores in such environments are the deposits of Southeast Missouri, Ireland and Pine Point. The rocks below the unconformity are commonly not carbonates. Individual ore bodies may be a few thousand feet long, 75-800 feet wide and up to 100 feet thick, though the thickness of most is 20 feet or less.

(2) Sedimentary environments below an unconformity :

(a) Solution collapse breccias under a karst topography. This environment is found at the ore producing areas of East Tennessee, Friedensville (Pennsylvania), Tri-State district and Ymir (British Columbia).

(b) Subsidence structure above a subsurface drainage system which is related to the overlying unconformity. Examples of this occur in East Tennessee and southwest Wisconsin.

The type of rock above the unconformity is usually dolomite, limestone or shale, but this appears to be irrelevant. Favourable environments below unconformities may cover 1,000's square miles but ore bodies are of similar dimensions to those above an unconformity.

(3) (a) Facies changes within a formation. e.g. Austinville (Virginia) ore deposits.

(b) Between basins of dissimilar source and type of sediments e.g. Austinville (Virginia) and Pine Point (Canada).

COMPARISON OF MISSISSIPPI VALLEY TYPE ORE DEPOSITS

(1) Features in common -

(a) Rock type
(b) Porosity
(c) The nature of fluid inclusions
(d) Regional structure

(2) Features at variance -

(a) Accessory metallic minerals
(b) Associated non-metallic minerals
(c) Time of emplacement and age of host strata

(1) Features in Common

(a) Rock Type:

The main host rock type is a shallow water carbonate including a variety of dolomitized and/or chertified limestones (Mississippi Valley), coarse grained (or brecciated fine-grained) dolomites and reef deposits.

In all cases solution, dolomitization, chertification and brecciation were well advanced or completed before mineralisation began.

(b) Porosity and Permeability:

Ore is associated with a permeable layer in the rock representing a zone of tectonic or sedimentary breccia, a reef or bank development (e.g. Ireland, Alps) or a pinch-out of underlying permeable sandstone (e.g. Missouri).

In general, porosity tends to be enhanced by complete dolomitization and the lead/zinc ore bodies lie mainly within such completely dolomitized zones or layers. It seems that most dolomitization preceded the ore deposition. Dolomitic breccias of several types are mineralised:

(i) tectonic (e.g. Tri-State chert breccia zone)
(ii) sedimentary slump-breccias (e.g. Southeast Missouri)
(iii) solution collapse-breccias due to exposure and leaching (e.g. east Tennessee)

(c) Nature of mineralizing fluids:

Field relationships demonstrate that the lead-zinc sulphides were emplaced long after the host rocks were formed. Fluid inclusions are Na-Ca-Cl type brines with up to 200,000 p.p.m. salts. Such fluids can be derived from sediments during diagenesis.

(d) Structural Features:

Ore is generally located near the margins of sedimentary basins and on the edges of major anticlines. Additional smaller scale structures may also effect ore deposition locally. Ore bodies are found to depths of 1,200 feet in central Missouri but this is shallow relative to the depths at which the correlative strata lie in the adjacent basin. The general shallow depths may be explained by the method of formation of these ore deposits or may be partly a function of the accessibility of near surface ore to exploration techniques.

(2) Features at Variance

(a) Accessory Metallic Minerals: *25, 30, 39*

Lead and zinc ratios vary from ore body to ore body, even within the same ore field. Pyrite-marcasite content where present ranges from 3 - 10%. Silver is typically very low, less than 1 oz/ton of lead concentrate. Copper, mainly as chalcopyrite, occurs in erratic high (but <0.5%) concentrations in Missouri, and at Northgate (Ireland). Cobalt and nickel are present in southeast Missouri, mainly as the mineral siegenite, but are not reported elsewhere. Some writers claim the proximity of volcanic exhalations determines whether antimony, arsnic, copper and silver are present in the ores.

Although these deposits are noted for their relative simplicity, in any one locality, several minor elements are present in uncommon abundance and may register in a geochemical survey. The zinc concentrates from Mississippi Valley type deposits represent the main economic source of cadmium, indium, germanium and gallium. These elements are restricted to the zinc ores. Other minor elements sometimes present are bismuth, yttrium, tungsten, tellurium, thorium, niobium and beryllium. Vanadium content of galena in European lead-zinc deposits is 10 p.p.m. c.f. 1 p.p.m. for galena of magmatic/ hydrothermal origin (Brown, 1967).

In east Tennessee the zinc concentrates (64% Zn) contain 0.025% cadmium. In Illinois-Kentucky the zinc concentrates contain 0.8 - 1.08% cadmium and 0.025% germanium. The metal and mineral content of various deposits is shown in Tables 2, 3 and 4.

(b) Accessory non-metallic minerals:

Barite is mined in parts of the eastern Missouri area and in Wisconsin - Illinois, but is not common in other areas.

Fluorite is abundant in southern Illinois and Kentucky, and minor amounts occur in Wisconsin - Illinois, but the other deposits do not contain major amounts.

Chert is the predominent gangue in the Tri-State area but is rare elsewhere and absent in many deposits. Most of the Tri-State chert is a replacement of the original limestone and is pre-ore. The significance of the cherty zones may be that they brecciated more readily and developed better permeability.

(c) Time of emplacement:

The vast majority of the ores were definitely emplaced after consolidation of the enclosing rocks. Only some Alpine ores of the back-reef environment have detrital geopetal fabrics that are of presumed syndepositional origin.

GEOPHYSICAL PROSPECTING - *9*

(1) Magnetic

Topographic relief on an unconformity may be mapped by magnetic methods and environments in younger beds related to such relief. The deposits themselves have no readily detectable magnetic contrast with their environment.

(2) Gravimetric

Except for the relatively high-grade Pine Point deposits, *(44)* there is insufficient density contrast between the ore and its environment to be detectable by conventional gravity measurements. The increase in density due to the mineralisation is often offset by the vuggy and porous nature of the deposits.

(3) Seismic

Topographic relief on an unconformity and the favourable ore loci related to it may be delineated provided a sufficient velocity contrast exists between the rocks bracketing the unconformity.

(4) Radioactive

Tests have failed to disclose any consistent radioactive contrast between the ore and its environment.

(5) Electrical

Sphalerite is a nonconductor, as are the gangue minerals. Only galena and pyrite contribute to the electrical characteristics of the ore relative to its environment. In the Pine Point deposits enough of these two minerals is present to permit detection by IP surveys. *(44)*

A resistivity contrast may exist between the ore and its environment because of the vuggy character of the ore, its galena and pyrite content or to a combination of these features. Water-bearing vuggy ground that is barren of sulphides may be responsible for distracting resistivity contrasts.

Down-the-hole applied potential methods have been helpful in a few cases in indicating trends of environments and of ore and if it extends between mineralized holes.

EXAMPLES OF MISSISSIPPI VALLEY TYPE ORE DEPOSITS

(1) PINE POINT (CANADA) - *5, 10, 11, 15, 32, 33*

Pine Point appears to be an elegant example uncomplicated by local features that have obscured the picture in many other areas.

The ore bodies are in largely undisturbed Middle Devonian carbonate rocks, marginal to a very large sedimentary basin. The area is not complicated by either tectonic or igneous activity, though minor faulting and gentle folding is known and could enhance local porosity, while basement faulting could control reef lineation.

The general Pine Point area is underlain by a thickness of over 1,400 feet of Palaeozoic sediments, which wedge to zero eastward against the Pre-Cambrian basement due to erosional truncation. Outcrop is less than 1% due to low relief. The regional dip is generally less than 10° and in a basinward direction.

The Pine Point ore reserves are 42 million tons of 2.9% lead and 6.8% zinc contained in 26 separate orebodies ranging from 10 million tons to 100,000 tons in size. The ore bodies are elongate, lenticular in plan and flat lying in section. Drilling shows the orebodies and the associated white sparry carbonates to be strata controlled rather than extending to depths.

The ore bodies occur mainly within or close to the Middle Devonian "reefal" sequence, the Presqu'ile Formation. The reef trend is perpendicular to the basinal strike and forms an elongate lens plunging west-southwest. It is 4 miles broad and at least 20 miles long. During deposition this reef formed a barrier between an evaporite basin in the south and a shale basin to the north. (Diags. 3,4,5)

Middle Devonian Stratigraphy

Unit	Thickness (feet)	Lithology
Slave Point Fm	210 +	Dense limestone
Amco Shale 'marker'	10	Argillaceous limestone & dolomite
Sulphur Point Fm	< 170	Dense limestone
Watt Mountain 'marker'	3	Waxy green shale
Presqu'ile Fm	< 200	Coarsely crystalline, very porous to cavernous dolomite
Pine Point Fm	300 +	Sugary dolomite, limestone, shale
Chinchaga Fm	300 +	Evaporites and dolomite finely interbedded.

The reef complex apparently developed as a supratidal shoal, and lenses of anhydrite/gypsum were precipitated. Slump breccias and cavern collapse are common.

The underlying Pine Point Fm. contains some ore and has good porosity. The beds overlying the Presqu'ile Fm. have low porosity and are separated from the Presqu'ile Fm by an irregular disconformity caused by periodic exposure of the reef.

The ore occurs mainly as large "plums" in elongate breccia zones. These breccias occur in the fore-reef position (slump breccia) and back-reef area (solution breccia) of the Presqu'ile Fm. There is probably some tectonic brecciation as well.

Galena, sphalerite, marcasite and pyrite are most common, with some pyrrhotite occurring locally. Dolomite and calcite, both of several generations are ubiquitous, particularly a white sparry dolomite. Native sulphur and bitumen occur but usually are more abundant away from the ore bodies, except for a very concentrated bitumen zone immediately adjacent to some ore zones. Fluorite is extremely rare. The sphalerite is predominantly fine-grained with a colloform structure, but massive crystalline material also occurs. Galena appears to follow the earliest sphalerite but from then on co-precipitation appears to have occurred.

A most striking feature of the ore bodies is the sharp cut-off of mineralization on the margins. Prior to mineralization, the breccia zones in which the ore occurs were probably extremely porous to cavernous, but the adjacent 'reef' rock is also very porous and yet the ore does not penetrate the wall rock appreciably, even along extremely porous bands. This suggests that a hydrodynamic barrier prevented flow of the ore solutions out from the breccia zone.

Porosity appears to have been the most important sedimentary variable when ore-bearing and barren dolostones at Pine Point are compared and thus some generalizations can be made that will have a bearing on the ore capacity of a carbonate host rock of Mississippi Valley type:

(1) Residual primary porosity is most likely in the organic reef bordering a carbonate platform and in reef-flank and reef-top calcarenites.

(2) Secondary solution porosity is common in the organic-reef zone and adjacent back-reef areas when evaporites are present. Particularly on the reef complex top and in flanking beds.

(3) Tectonically controlled secondary solution porosity, sometimes amounting to cavernous trends, is commonly encountered in carbonate rock terrains.

(4) Porosity due to dolomitization may develop where dolomitization has proceeded almost to completion. On the other hand, slightly dolomitized limestones and dolomitic limestones are commonly tight.

The porosity/permeability requirements for an oil reservoir and an ore host rock are similar. Thus the continuous porosity trend, which may have developed in carbonate rocks and may have been associated with basinal de-watering, is the exploration target.

The recognition and interpretation of related limestone facies types, therefore, becomes an important adjunct to any sophisticated exploration programme. A reconstruction of the environment is shown in Diag. 2.

CONCLUSIONS

Porosity of the country rock is the first control. Secondly, the composition of the carbonate rocks plays a role. Such sediments lack the base exchange properties of shale sequences and in contrast to shale/sandstone associations, porosity in carbonate rocks commonly harbours hydrogen sulphide which, on compaction, also must escape with connate fluids. Carbonate-evaporite rock associations are common and, providing that a suitable "plumbing system" existed, metal-bearing fluids from the basin could meet the sulphide-rich waters in the carbonate sequences with resulting precipitation of metallic sulphides. A demonstrated evaporitic association in the limestone paleoenvironment would be regarded as a favourable regional feature in an economic appraisal, since sulphate is the precursor of the H_2S precipitant. At Pint Point a thick sequence of sediments developed in the basin and deep burial allowed compaction to force brines out.

Typical Mississippi Valley type ores carry lead and zinc with very low copper and silver. However, accessory minerals found in some associations suggest volcanic addition. Where contemporaneous volcanism is indicated by field evidence, antimony, arsenic, some Cu and silver are present and also fluorite /barite.

Sulphur isotopes indicate a biogenic fractionation of the sulphur in most of these deposits, suggesting a sedimentary source of the sulphur.

Important aspects are :

(1) origin and distribution of porosity
(2) time and nature of dolomitization

(3) the presence of evaporitic unite within the sequence.

(4) origin of breccia zones (whether syndepositional, solution slump or tectonic).

The Presqu'ile unit interfingers laterally with fossiliferous calcareous shales to the north and an evaporitic sequence to the south resulting in an accumulation of rock lenses, not layers, and the boundaries between the diagnostic environments migrate.

Pine Point ore deposits are not syngenetic because:

(1) orientation of crystalline and colloform textures suggests growth on cavity walls and on breccia fragments, including clasts from overlying formations.
(2) bituminous residues occupied the pores prior to ore formation.
(3) Sulphur isotope and fluid inclusion.

The ore is not of juvenile hydrothermal origin because:

(1) no evidence of igneous activity.
(2) ores are strata bound and follow favourable formations rather than extending to depth along faults or fractures.
(3) mineralogy of both ore and gangue is simple.

Tables 5 and 6 summarise the stratigraphy and ore genesis at Pine Point.

The ore bodies respond to the induced polarisation method of geophysical prospecting and the I.P. anomalies can be checked by gravity methods prior to drilling. *(44)*

(2) SOUTHEAST MISSOURI LEAD DISTRICT - *45, 46, 54.*

In southeast Missouri, galena occurs within 600 feet of the Pre-Cambrian basement and sometimes directly on it. (Diags. 15,16,17,18,19)

Stratigraphic Section

	Feet	
	0 - 180	Davis Shale
Upper Cambrian	450	Bonneterre Formation
	0 - 240	Lamotte Sandstone grading upward into dolomite with algal reefs and limestone
Pre Cambrian		granite and rhyolite.

The Bonneterre Formation contains abundant fine-grained iron sulphide in grey shaly carbonate units and thin black shale beds. These units do not contain carbonaceous matter; the colour is due to finely divided iron sulphide of diagenetic origin.

Lead and zinc occurs only in restricted structural situations. The most extensively mineralized situation is at an interface of two different Bonneterre lithologies, a grey argillaceous dolomite containing iron sulphide and a tan crystalline dolomite containing iron in oxide form. Sulphides occur in the grey unit on top. The beds are horizontal, except near faults.

Ore occurs in sedimentary structures along parallel, north east trending calcarenite bars and algal reefs.

A complex major fault zone crosses the district.

The major faults are at right angles to the major trend of the ore but are not closely associated with the ore. Displacement is up to 600-700 feet. The faults are rarely mineralized but the associated intense fracturing played an important role in ground preparation. Where a fault crosses a bar-reef complex, the ore is wider, higher, and severalfold richer in grade in the fractured area near the fault than on the same sedimentary structure away from the fault. Small scale faults in the mines usually post date mineralization. The control by sedimentary facies that plays a dominant role in unfractured areas is lost in intensely fractured areas.

The Bonneterre Formation dolomite has high porosity; intergranular openings, joints, minute geodal cavities and tubes. All openings of sufficient size are lined with dolomite crystals. Though containing many thin beds, the dolomite is mainly composed of beds 4 or 5 feet thick containing innumerable styolites. Where the beds rest on buried hills and knobs of igneous basement they may have a 20 or 25 degree dip.

Movement of solution eastward was controlled by basement topography and deposition of metals occurred when solutions entered the Bonneterre Formation on the flanks of and over buried hills.

The following points summarise the southeast Missouri lead district :

(1) mineralisation occurs in all formations from Lamotte sandstone to Ordovician strata (the youngest rocks present). Fossils are not abundant, but do occur in shaly phases.

(2) lead of ore grade, often with zinc or copper, occurs from 100 feet below the Bonneterre Formation - Lamotte Sandstone contact, throughout the 400 feet thick Bonneterre and into the Davis shale. The ore contains 4 - 6% Pb.

(3) where basement hills protrude into the Bonneterre Formation mineralization may be present along the sediment-hill contact for several hundred feet, embracing the section from mid-Lamotte to mid-Bonneterre.

(4) mineralization is commonly on the basinward northwest and west sides of basement highs.

(5) when the ore is mined out the sedimentary structure that carried the ore continues without apparent change.

(6) all mineralized structures and lithologies have their unmineralized counterparts.

(7) mineralisation may form a close fit with sedimentary structure; may cross contacts and bedding planes; may fill open spaces both along bedding planes and in fractures.

(8) Lead is alone or with Cu <u>or</u> Zn. Lead with zinc is higher stratigraphically and restricted to the west compared to the lead ore containing copper.

(3) <u>TRI-STATE DISTRICT OF MISSOURI, KANSAS AND OKLAHOMA</u> - *4, 23, 24, 55.*

Lead and zinc ores occur in rocks of Mississippian age on the south west flank of the Ozark Dome which is a structure 200 miles long and 30 miles wide. The maximum thickness of the Mississippian rocks is 400 feet, with unconformities on top and bottom and within the series. Host rocks are limestone/dolomite and cherts. Ores are often in what were solution cavities, sink holes and collapsed caves but some have remained barren. (Diags. 8, 9 and 10)

One of the most characteristic features of the Tri-State ores is the prevalence of silica in two forms - as chert and as a darker fine grained form known as "jasperoid". These are present prior to sulphide formation and the jasperoid has been selectively replaced by sulphides. These ores grade from 3-6% Zn and 0.5 to 1% Pb.

(4) NORTHERN ARKANSAS DISTRICT - *4, 37.*

The ore deposits are also located on the flank of the Ozark structural dome which experienced many tectonic oscillations during Palaeozoic time. These are recorded as 13 unconformities in a stratigraphic section only 3,000 feet in maximum thickness. Principal ore-bearing formations are of Lower Ordovician and Mississippian age. Host rock is medium to coarse grained dolomite and the ore is found particularly in joints and shattered zones.

(5) APPALACHIAN DEPOSITS - *7, 8, 13.*

Ore bodies in this area are of the Mississippi Valley type which have suffered post-mineralization deformation. The three major areas are : (Diags. 11, 12, 13, and 14)

(1) East Tennessee

(2) Friedensville

(3) Austinville

(1) East Tennessee

The ore occurs in a 200 ft. thick zone in Lower Ordovician dolomite. The remarkable selectivity of the mineralization with respect to this very restricted horizon is related to the great permeability which was established initially by post-Lower Ordovician Pre-Middle Ordovician weathering that extended to depths of 800 feet below the surface. Relief of 100 feet is common on the unconformity. The greatest concentration of sphalerite is 600-800 feet below the unconformity. These strata lie in the upper third of a sequence of lower Palaeozoic carbonate rocks more than 5,000 feet thick.

The ore is found in coarsely crystalline clastic dolomite breccia containing silica and chert debris within a sequence of aphanitic limestones.

Thus the principal ore controlling structures are rubble breccia zones that were formed during and after the erosion period when subterranean drainage was widespread.

There is no relationship between ore bodies and structural features such as folds and faults due to their post dating the ore.

The rock-matrix rubble breccias are of complex shape. In their upper parts, above the stratigraphic horizons of the ore zones, they are sometimes circular or oval in plan and pipe like in section. In ore zones they are rudely tabular linear bodies that extend horizontally for thousands of feet with offshoots and spurs.

(2) Friedensville

The ore, sphalerite and pyrite, occurs as a filling of the interstices of a solution-collapse breccia developed below an unconformity. The ore occurs on both limbs and crest of an anticline. The host rock is dolomite of Lower Ordovician age.

(3) Austinville

The ore (sphalerite) is localized at a facies change, not related to a known unconformity, in breccia and reef material stacked through a considerable stratigraphic range.

The host rock is of Cambrian age. The ore is present on all elements of the anticline.

(6) NORTHGATE (IRELAND) - *76*

This Mississippi Valley type ore body was discovered beneath a cover of glacial till. The ore body, near a fault, consists of a boat shaped mass of residual or secondary ore covering primary sulphide ore in limestone of Lower Carboniferous age (Mississippian). The ore limestone is part of the Waulsortian mud-back complex which is an elongate structure up to 2,500 feet thick and over 30 miles long.

The host rock of the primary ore is a reef facies near where it fingers into muddy limestone. A volcanic ash bed occurs in the muddy limestone at approximately the same stratigraphic horizon as the reef. The reef is underlain by muddy limestone and Upper Devonian shale, sandstone and mudstone which forms a Devonian dome over Silurian basement.

The ore body is 2,200 feet long, 500 feet wide and has a maximum thickness of 250 feet. The primary ore contains 4.8% Pb and 4.3% Zn.

(7) LEAD-ZINC DEPOSITS OF THE ALPINE AREA - *(50)*

Lead-zinc deposits occur in the Middle Triassic Alpine geosyncline. The ores are restricted to a few distinct beds of the enormous limestone dolomite sequence, and are characterised by a very distinct facies.

This facies development reflects repeated changes of the sedimentary conditions in time and space within a typical differentiated reef facies.

In the enormous sequence of the geosynclinal sediments in the eastern Alps, which in places exceeds 15,000 ft., the lead-zinc ores are restricted to a few, relatively thin units.

The ore-bearing sequences in the Alps extend over 350 miles, from Grisons (Switzerland) in the west to the Karnian and Julian Alps (Austria, Italy and Jugoslavia) in the east and from the northern Limestone Alps in Bavaria and Austria they extend more than 180 miles to the southern Limestone Alps.

<u>Features of these deposits (see Diag. 6) are:</u>

(1) Wide extent of the ore-bearing units. The sedimentary layers in which the ores are enclosed cover hundreds of square miles.

(2) Limited stratigraphic thickness of the ore-bearing units even though the complete Middle Triassic sequence (Anisian, Ladinian, plus Carnian) reaches a maximum thickness of more than 6,000 feet, the ore-bearing beds are restricted, over the entire extent of the carbonate complex of the eastern Alps, to a few relatively thin units:

Upper Anisian - maximum 120 ft. in thickness
Lower Ladinian - maximum 150 ft. in thickness
Upper Ladinian - maximum 600 ft. in thickness

and (only in the southern Limestone Alps)

Lower Carnian - from 25 ft. (Bleiberg - Kreuth) to 100 ft. (Gorno)

(3) Uniform, Uncomplicated Paragenesis. Sphalerite and galena are dominant (Zn/Pb = 2/1 to 10/1). Also present is calcite, dolomite, fluorite, quartz, barite, celestite and anhydrite. The relationship between ores and volcanic activity is shown in Diagram 6.

(4) Ores are found in special facies, usually consisting of combinations of the following types:-

(a) Well-bedded pure dolomite, passing into rhythmically laminated dolomite - calcilutite.

(b) Laminated bituminous dolomite - calcilutite, passing into bituminous clayey laminae. This is the most mineralised.

(c) Greenish beds of marl (tuffaceous marl and bentonite?) occurring often as matrix of sedimentary (agglomeratic) darkish to black, marly limestone breccia.

(d) Fluorite (showing definite sedimentary fabrics), also quartz and barite, with celestite and anhydrite as minor components.

(e) " Back-reef facies" consisting of composite pisolites, algal pellets, coquina, dolomitic mudstone breccias, biogenetic detritus and different types of calcarenites.

(f) Cross-bedding, cut-and-fill structures, mud cracks, graded bedding, load casts, glide folds and convolute bedding.

(8) UPPER MISSISSIPPI VALLEY, WISCONSIN-ILLINOIS ZINC-LEAD DISTRICT, *(1,2,27)*

This district includes the S.W. part of Wisconsin, N.W. corner of Illinois, and a narrow fringe of Iowa. Total area is 4,000 square miles (Diagram 20).

The mining district lies within about 100 miles of the northern edge of Palaeozoic sedimentary rocks that overlap the North American Precambrian shield. The Wisconsin arch, a broad northward-trending anticlinal arch, lies east of the area. The Illinois basin lies south, and the Forest City basin lies west and southwest of the district in Iowa.

The regional dip is about 17 feet to the mile towards the south-southwest. The rocks of the district are folded into low broad undulations that trend north-eastward, eastward or northwestward.

The larger broad folds range from 20 - 30 miles in length, 3 to 6 miles in width, and 100 - 200 feet in amplitude. Rarely do the folds have dips greater than 15° on their limbs.

Many of the ore deposits in the district are localised along small faults - chiefly bedding-plane and reverse faults on the limbs of folds. Bedding-plane faults are present in the incompetent uppermost Platteville and Lower Decorah strata.

The ores average 4-8% Zn and 0.5 - 1% lead, with most ore bodies being between 100,000 and 500,000 tons with some up to 3 million tons.

The ore occurs as vein fillings along fractures and bedding planes, cavity fillings in solution breccias and as disseminations by replacement and impregnation in favourable beds, particularly in shaly strata.

Deposits of sulfides have been found in all the geologic formations exposed within the mineralised part of the district. However, the commercial zinc and lead deposits are in the Platteville and Decorah formations and the Galena dolomite, which is a coarsely crystalline, massive dolomite with vughs. Most of the zinc deposits are in the upper Platteville formation, the Decorah formation and the lower part of the Galena dolomite, while most of the joints-controlled lead deposits are in the Galena dolomite. (Diagram 21)

The ore bodies lie along N.E. and N.W. trends and are traceable for miles. In many places zinc ore bodies are associated with secondary synclines which occur where cross-folds are present.

Ore bearing strata include the cherty unit of the Galena dolomite, the Decorah formation, and the Quimbys Mill and McGregor members of the Platteville formation. (See Diagram 22)

A useful marker strata is the Prosser cherty member within the Galena dolomite and 110 feet below the top of the Galena dolomite. This chert occurs as separate nodules and when traced reflects the structure of the area.

Within the Decorah formation is the Guttenberg member which is mineralised particularly where its thickness is reduced due to the removal of limestone beds by the mineralising solutions. When this occurs a concentration of brown shale residue remains with the ore. (Diagram 23)

The following four points are indicators of ore strata and are useful in prospecting:

(1) thinning and shalification;

(2) dolomitization;

(3) silicification;

(4) the increased moisture above mineralised joints causes increased plant growth.

Exploration of large areas was done by drilling on a grid pattern, using 660 or 1,320 ft. centres, or as lines of drill holes at right angles to regional structural trends. Percussion drilling was found to be most effective as recovery of cores from mineralised or altered rock was low. Several ore bodies were located during this exploration programme in the 1940's.

CONCLUSIONS

Porosity, rock type and structure are important in localization of this type of ore body. Points at variance between different deposits represent local variations, some of which may be explained by volcanism.

Ore bodies are found along regional permeable porous trends and basinal saline connate waters carry the ore metals, emphasising the importance of brines and their migration. Faults cut up potential source rocks and restrict artesian flow, hence the time of formation of faults and other potential trap structures is important.

Generally the localisation of ore bodies is governed by sedimentary principles with unconformities and old shorelines being particularly important.

Patchy sphalerite/galena segregations are common in many carbonate rocks and may be explained by diffuse porosity and the lack of structurally controlled plumbing systems.

Primary screening of potential areas is commonly done on a pattern of widely spaced drill holes to delineate environments and to discover ore. The main effort is to delineate environments favourable for ore occurrence.

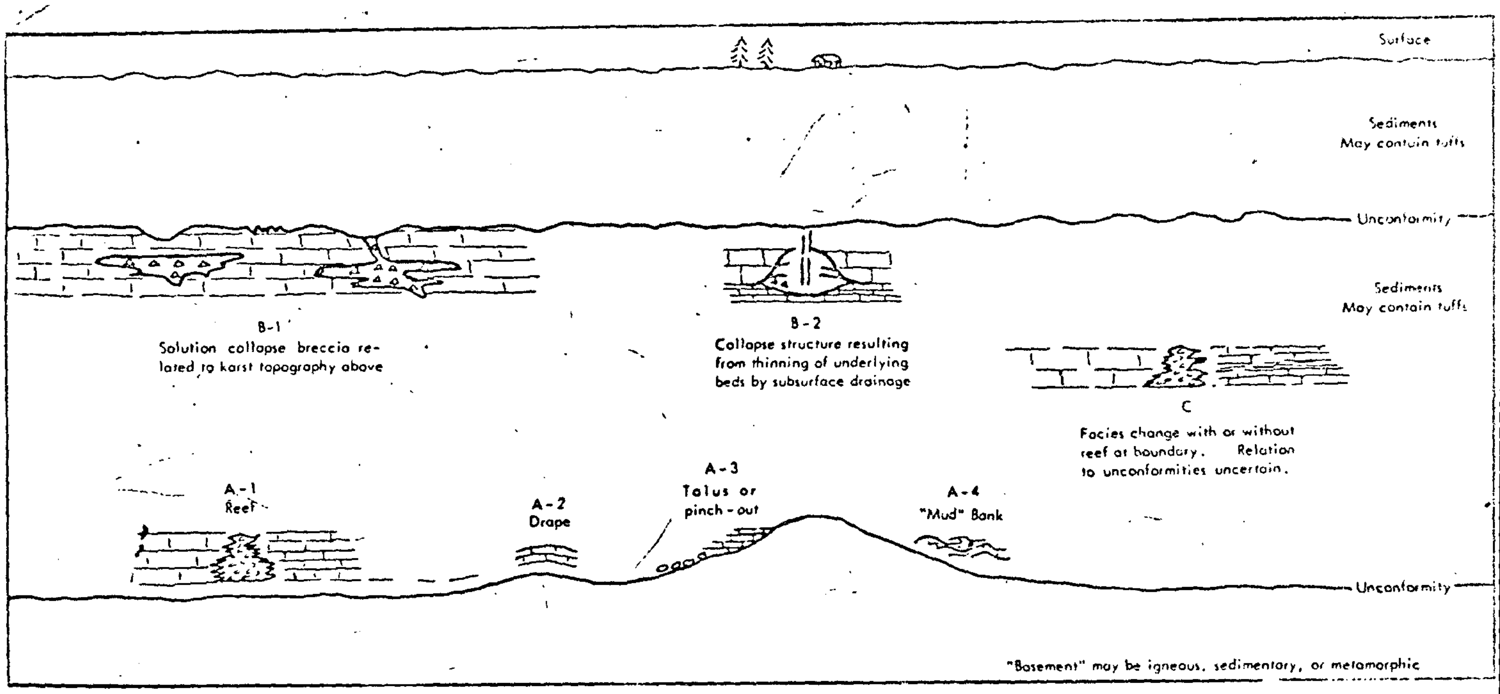


Diagram 1. Environments responsible for localization of Mississippi Valley type mineral deposits.

(after Callahan and McMurry, 1969.)

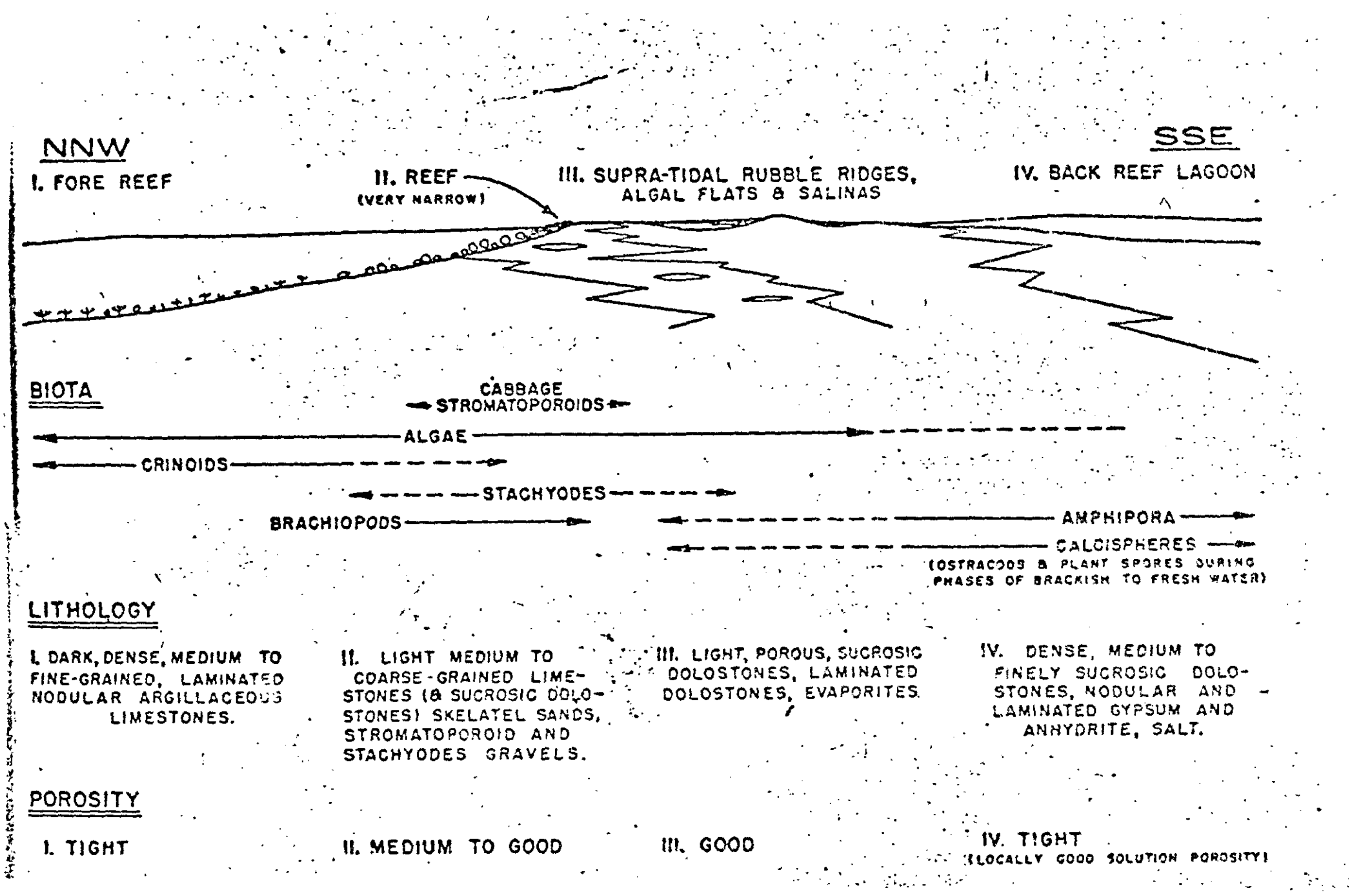


Diagram 2. Reconstruction of a Devonian Reef based on the Presqu'ile Barrier, Pine Point.

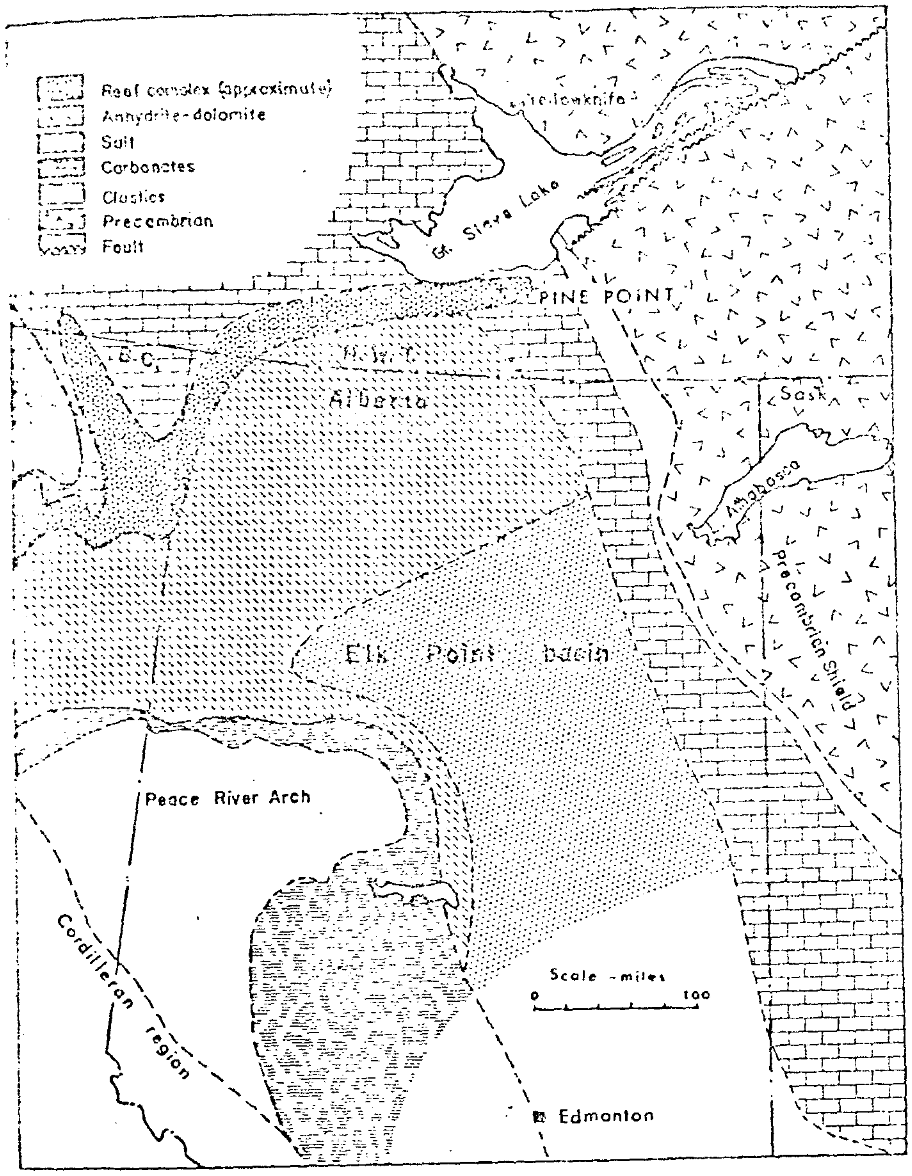


Diagram 3: Approximate distribution of middle Devonian formations in relation to Pine Point area.
(after Campbell, 1967)

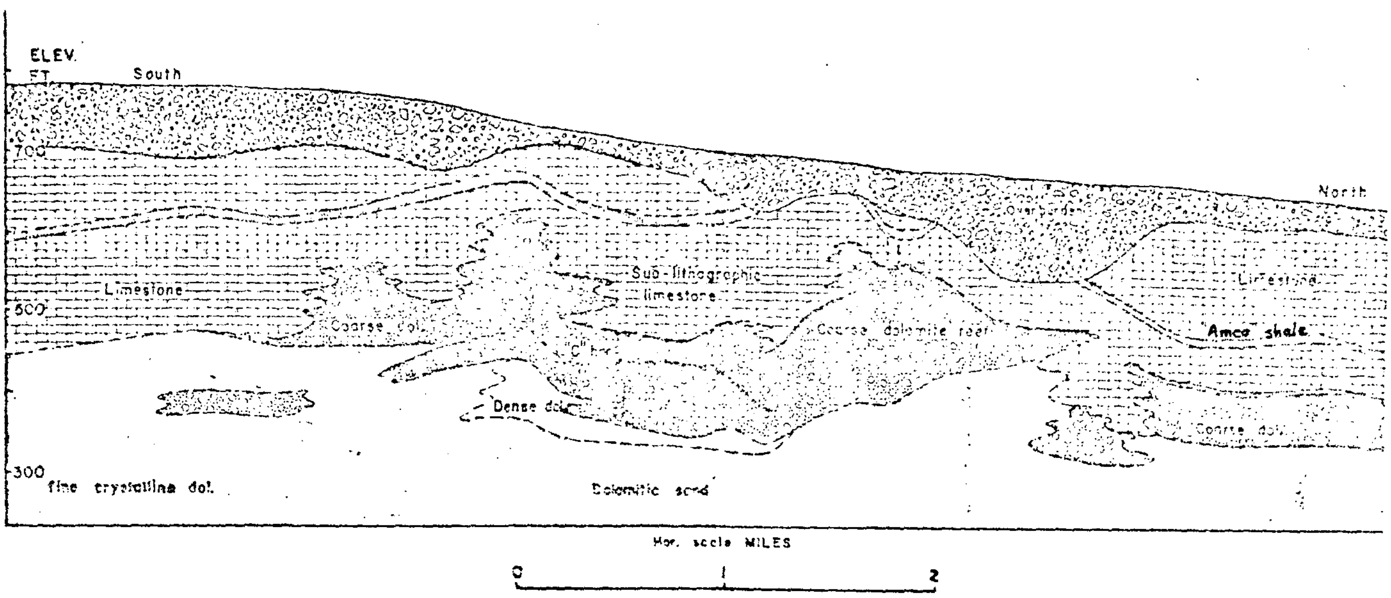


Diagram 4: Section across the Presqu'ile reef showing the main lithological types. Most ore presently known lies in the reef above the "C" horizon but it also occurs at about the stratigraphic equivalent of the "C" horizon south of the reef and at a horizon stratigraphically below the reef.
(after Campbell, 1967)

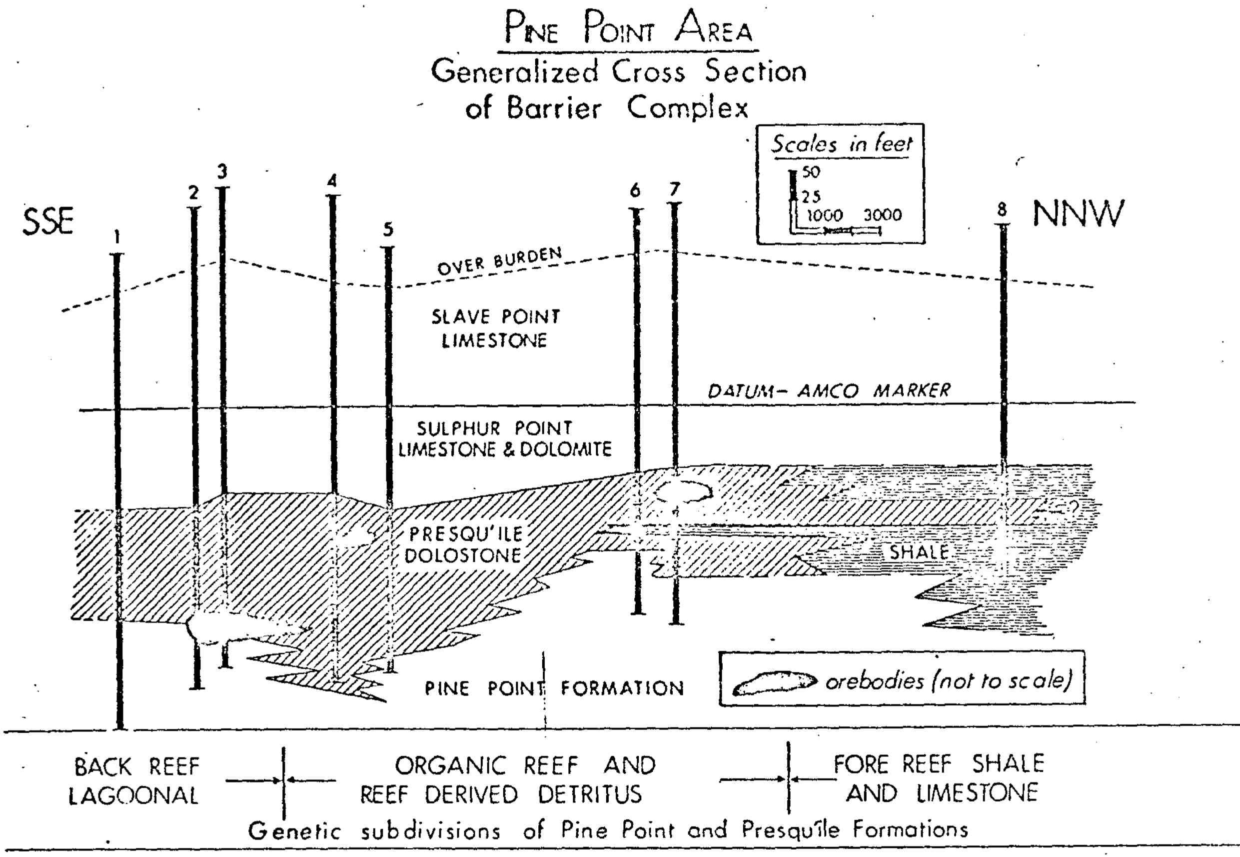
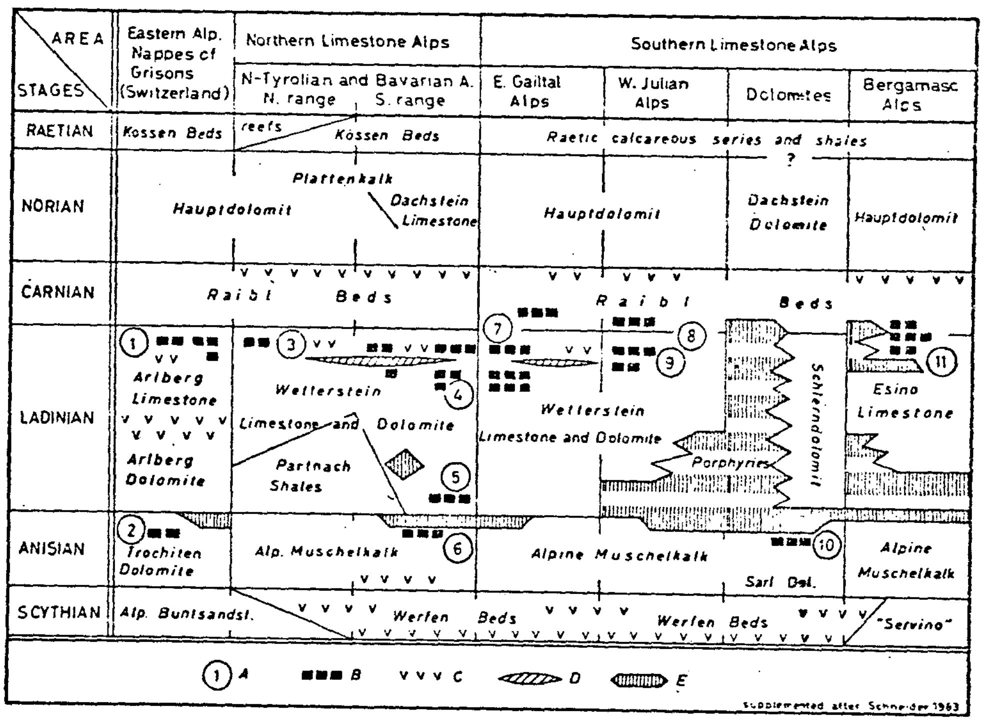


Diagram 5: The ore bodies at Pine Point occur in the Presqu'ile dolostone and at its interface with the Pine Point formation and are controlled in part by the paleoecology of the barrier complex. (after Jackson and Folinsbie, 1969)



Ore occurrence, volcanism and their time relation during the Triassic period in the eastern Alpine geosyncline. A: typical deposits of the different areas: 1 = Bleiberg-Ramoz (Grisons, Switzerland); 2 = Silberberg-Davos (Grisons, Switzerland); 3 = Säuling-Füssen (Bavarian Alps, northern border ranges); 4 = Lafatsch-Karwendel (N. Tyrolean Alps, Austria); 5 = Mursee-Mieminger (N. Tyrolean Alps, Austria); 6 = St. Veit-Heiterwand (N. Tyrolean Alps, Austria); 7 = Bleiberg-Kreuth (E. Gailtal Alps, Austria); 8 = Cave del Predil, Raibl (Julian Alps, N. Italy); 9 = Mežica, Mies (Karawanken Alps, NW Jugoslavia); 10 = Auronzo (E. Dolomites, N. Italy); 11 = Gorno-Dossena (Bergamasc Alps, N. Italy). B: ore-bearing units. C: weak evaporitic facies (deposition of dolomite and anhydrite, gypsiferous beds). D: indications of volcanism (tuffaceous marls, agglomeratic breccias etc.). E: tuff layers, porphyritic and basaltic eruptions.

Diagram 6: (after Maucher and Schneider, 1967)

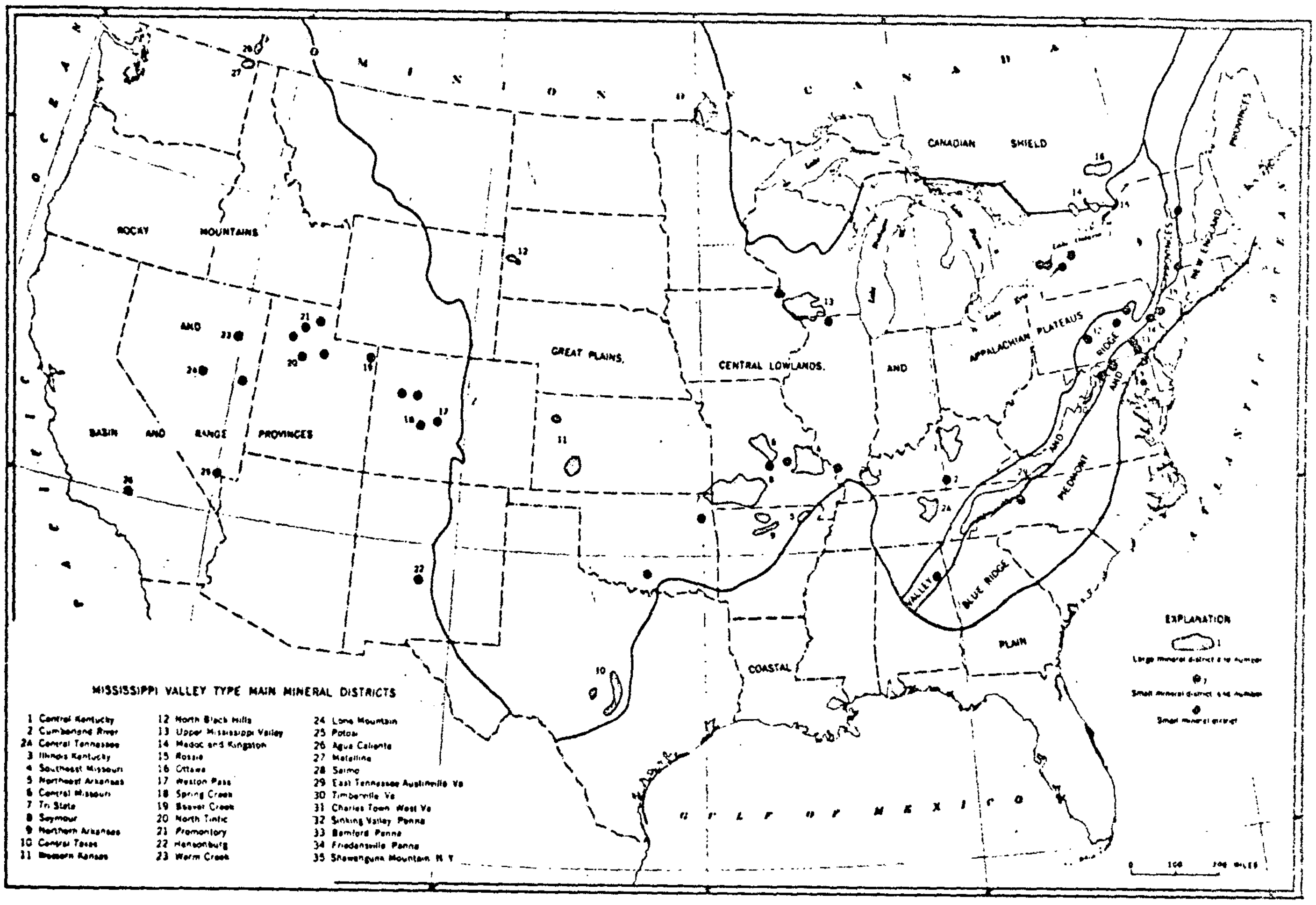


Diagram 7: Lead-zinc-fluorite-barite stratiform deposits of the Mississippi Valley type in the United States.
(after Heyl, 1967)

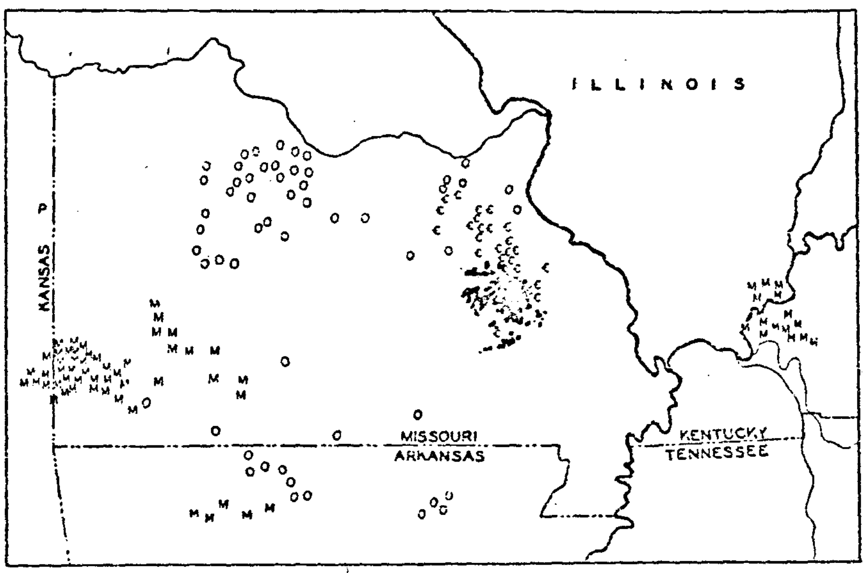


Diagram 8: Map showing geologic ages of ore-bearing rocks in the Ozark region and in the southern Illinois-western Kentucky district.

€ = Cambrian, O = Ordovician, M = Mississippian, P = Pennsylvanian. Solid black indicates area of pre-Cambrian outcrops in the St.Francis Mountains.

(after Bastin 1939)

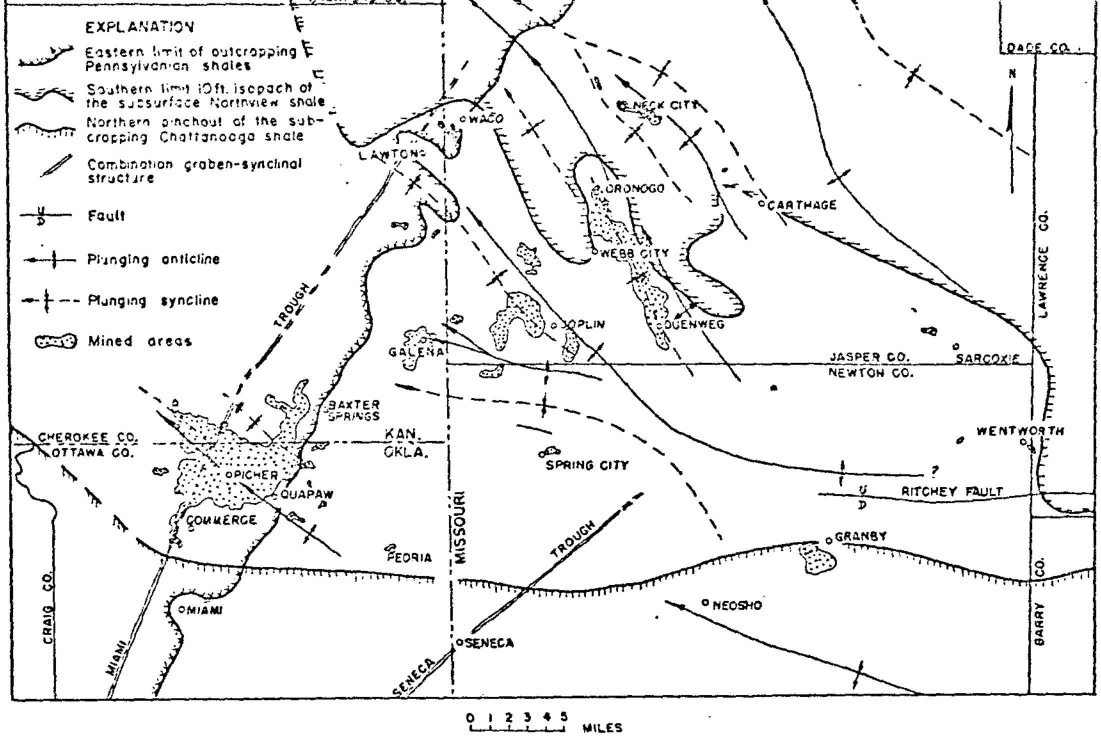


Diagram 9: Map of the Tri-State District, showing the major structural and geological features.
(after Brockie, et. al. 1968)

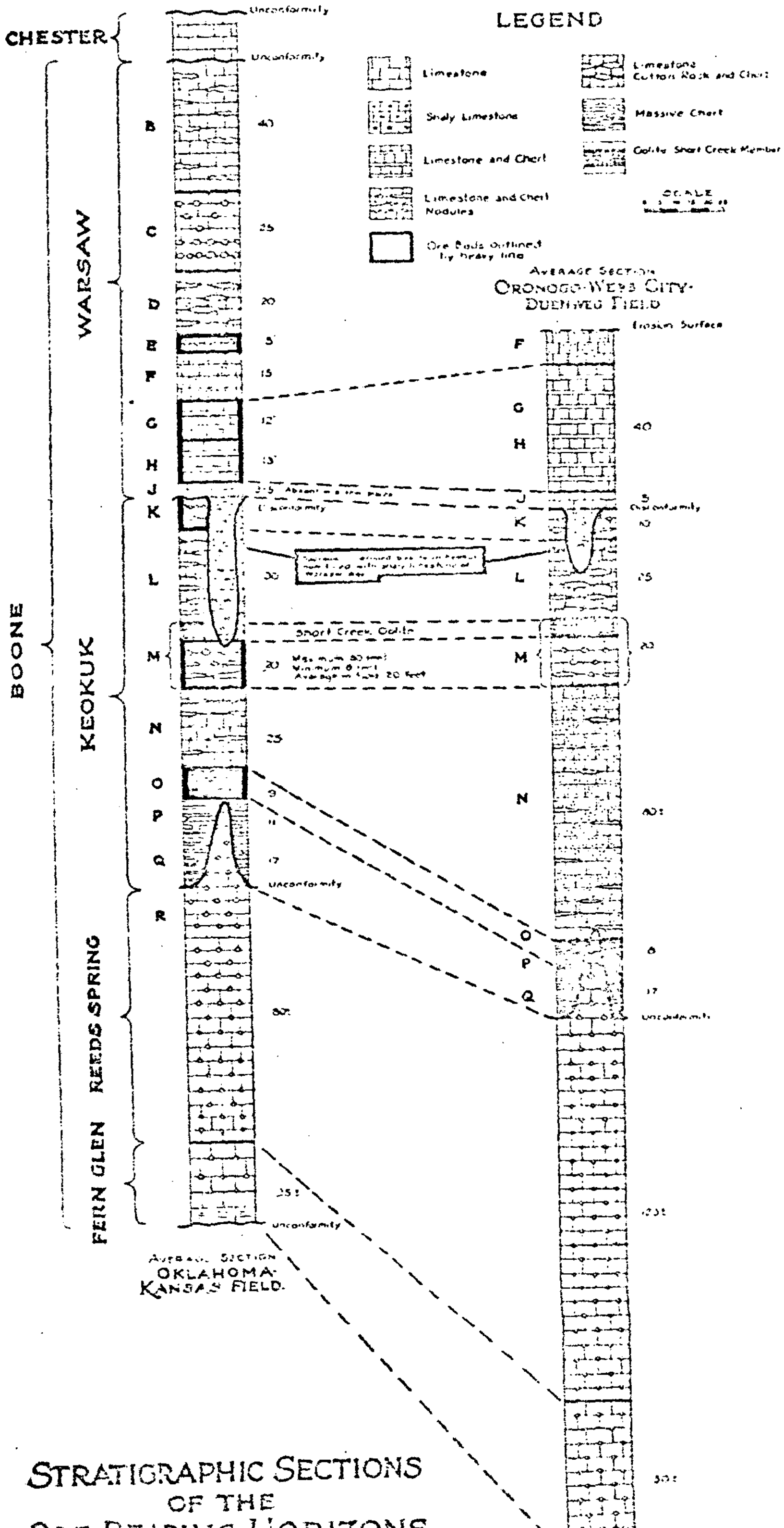


Diagram 10:

Average stratigraphic sections in Kansas-Oklahoma and Oronogo-Webb City-Duenweg, Missouri Fields.

Showing ore-bearing Mississippian formations and their subdivision into zones (B to Q).

(after Bastin, 1939)

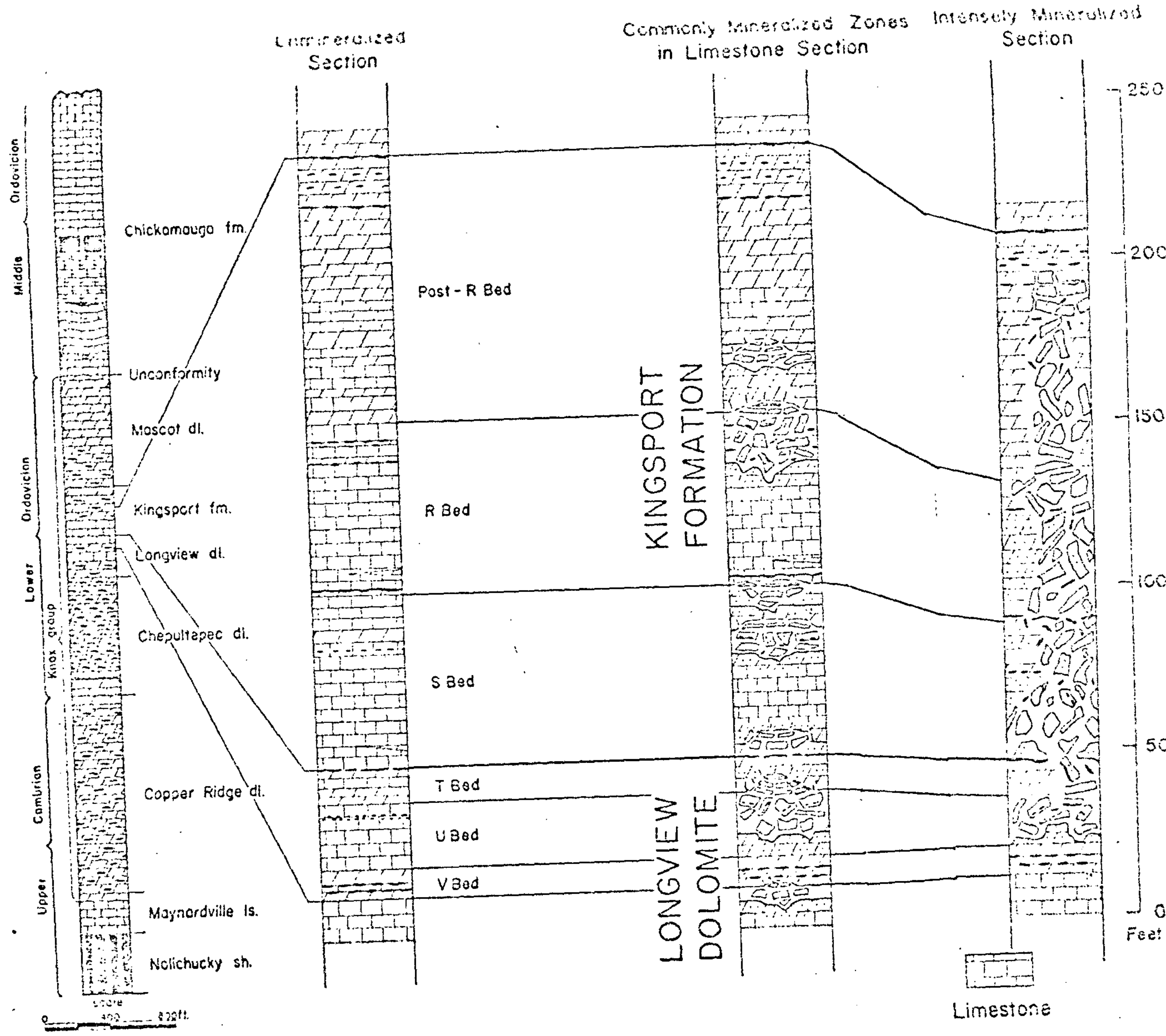


Diagram 11. Detailed Stratigraphic Relationships of the Ore Beds of the Lower Kingsport and Upper Longview Formations. Appalachian Type. (Crawford and Hoagland, 1968)

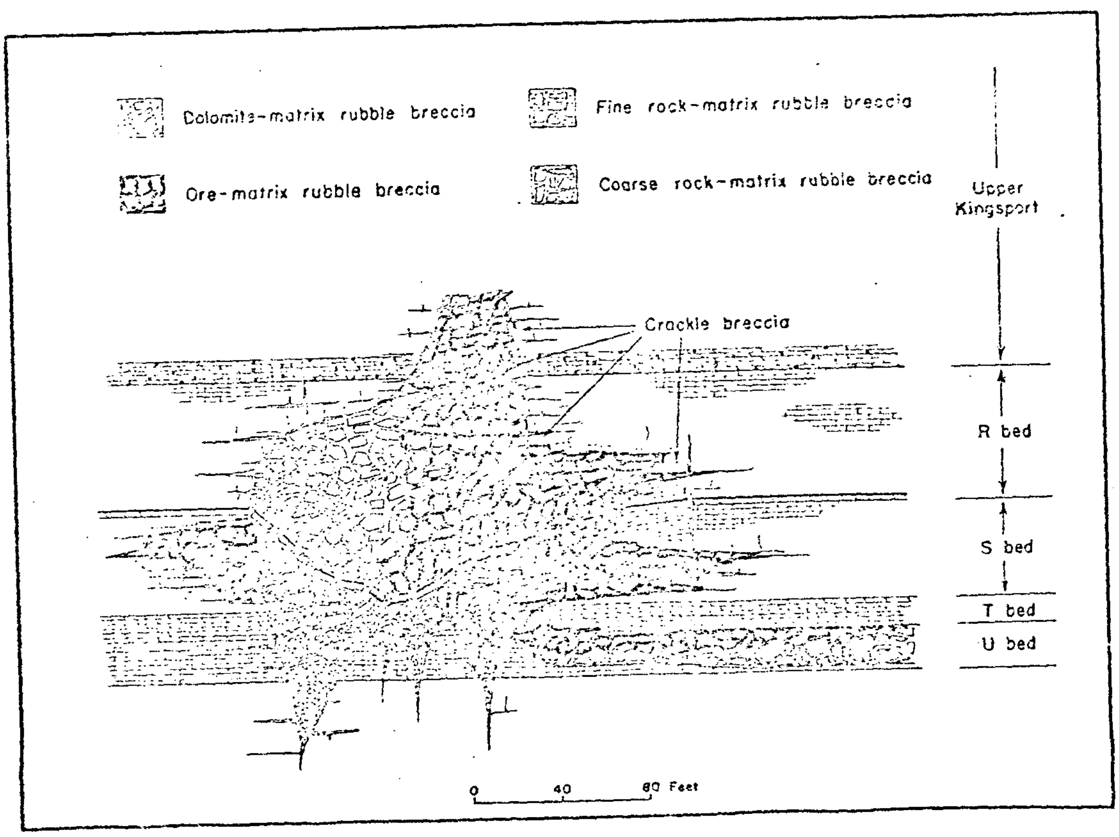


Diagram 12: Generalized Section through a portion of the Jefferson City Mine. Appalachian type.

(Crawford and Hoagland, 1968)

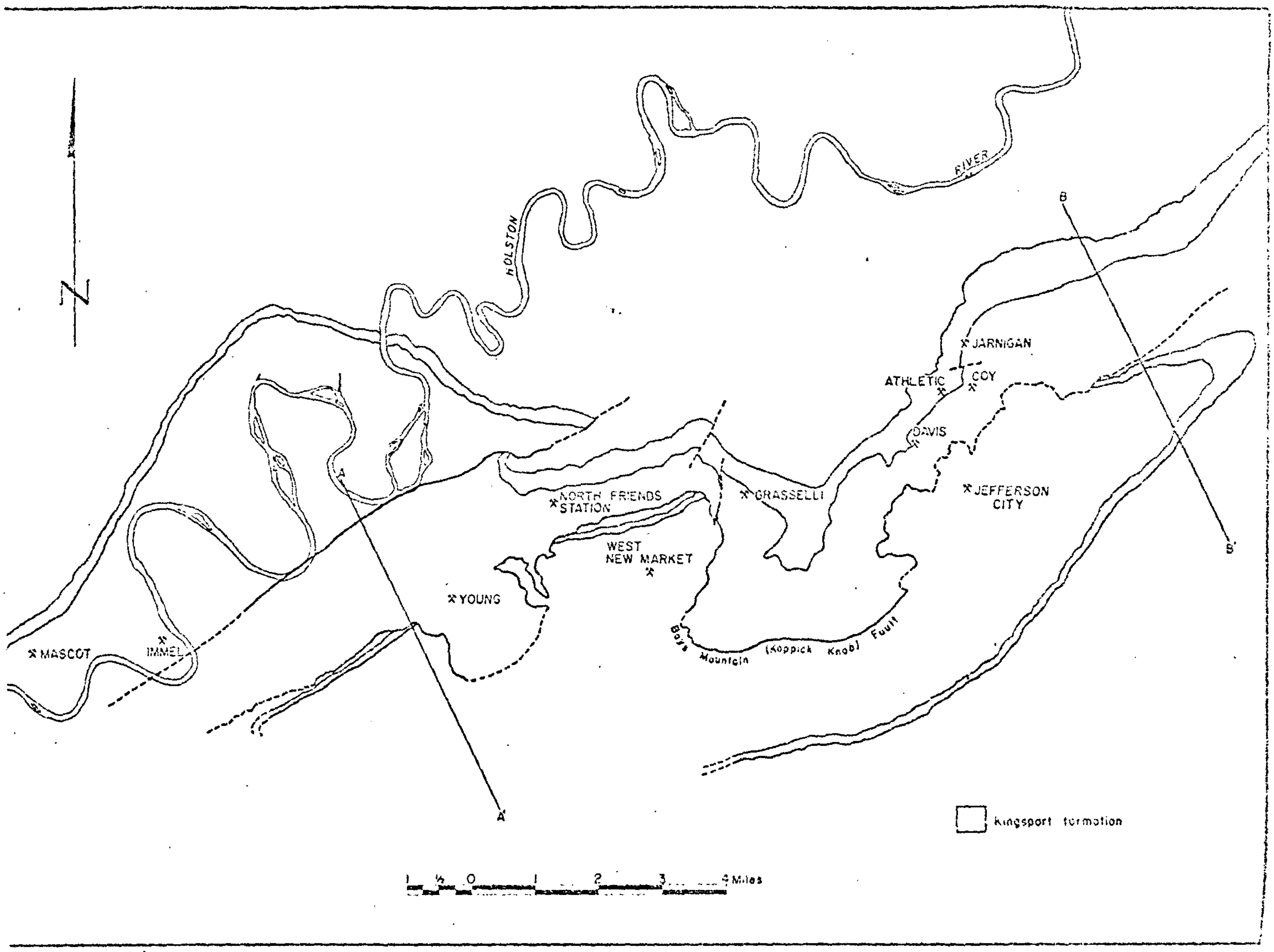


Diagram 13: Map showing location of mines in the Mascot-Jefferson City Zinc District and relationship to Kingsport Formation Outcrop. Appalachian Type. (Crawford and Hoagland, 1968)

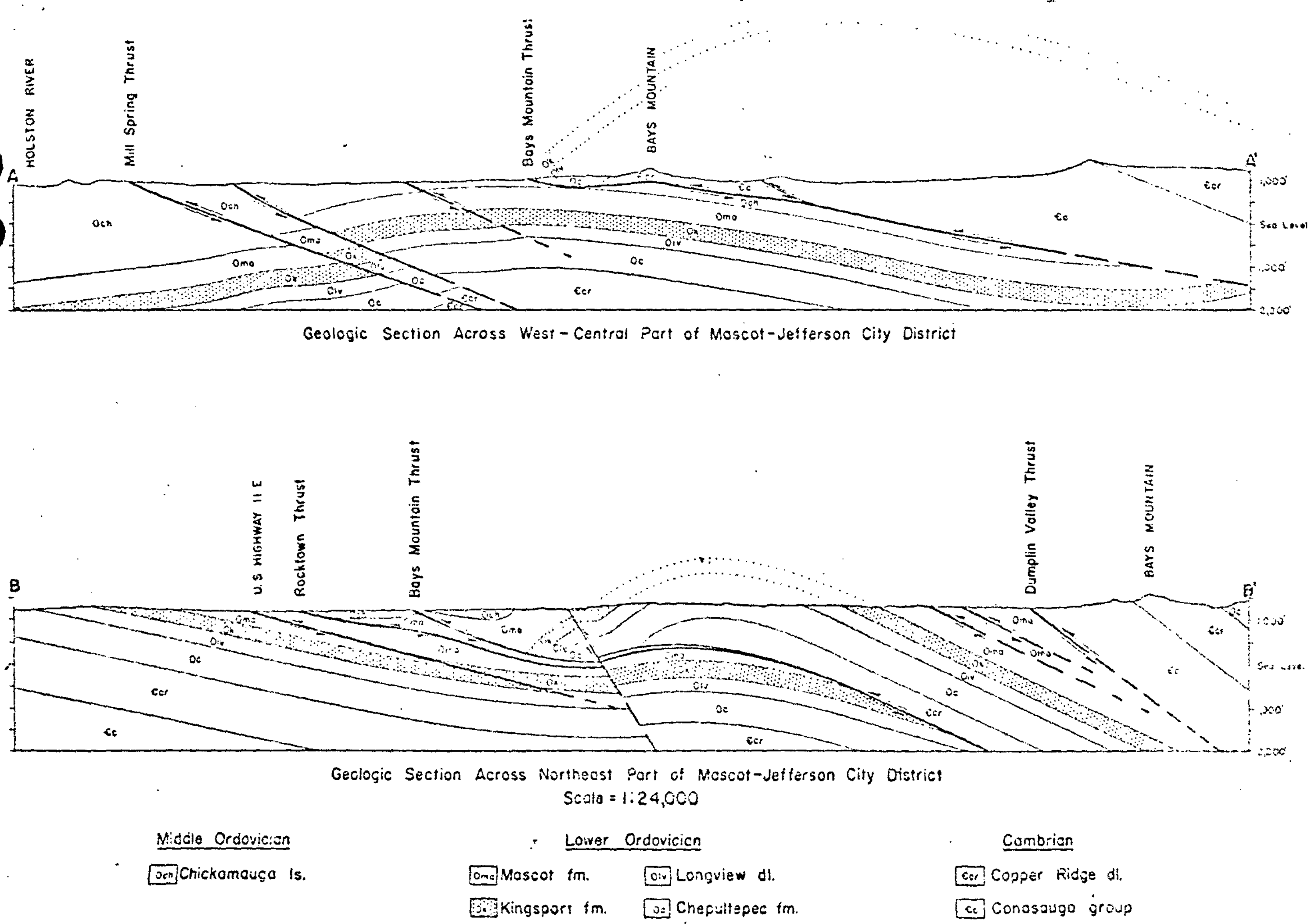
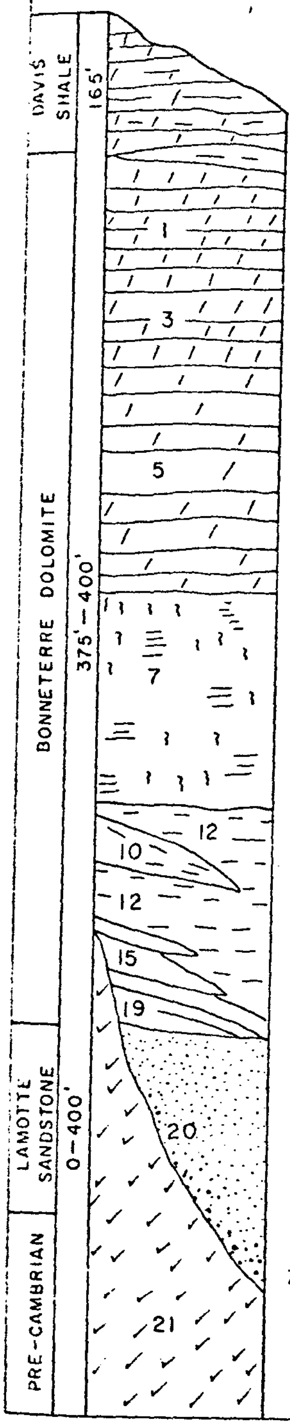


Diagram 14: Geologic Sections across Mascot-Jefferson City Zinc District. Appalachian Type. (Crawford and Hoagland, 1968)



1. Dense, gray dolomite.

3. Mottled blue and white dolomite. Chocolate brown dolomite at Bonne Terre.

5. Thick-bedded tan and brown oolitic dolomite.

7. Main algal reef zone. Commonly thick massive reef throughout on ridge structures in Federal area. Thin and scattered reefs in Leadwood area. Non-reef rock is generally thin, wavy bedded, fine-grained, gray or tan dolomite. Contains black shale partings and gray spotting.

10. Thick, fine-grained, even-bedded tan dolomite on southwest side of district. Coarse-grained, lenticular tan dolomite over ridge structures. Thin or absent between ridges.

12. Thin, wavy bedded, fine-grained and spotted dolomite, contains black shale partings. Algal beds common at base. Thin over ridges.

15. Light colored, coarsely crystalline. Often glauconitic. Frequently thick over ridges.

16. Brown compact dolomite. Algal mat, sometimes with digitate columns. Usually found at 15/19 contact.

19. Tan or gray sandy dolomite. Thickens to form ridges.

20. Sandstone with occasional siltstone beds. Poorly cemented in upper part. Thin dolomitic beds in upper part. Residual igneous boulders at base.

21. Precambrian, volcanics and granite.

Diagram 15: Subdivision of the Bonneterre Formation. Southeast Missouri. (after Synder and Gerdemann, 1968)

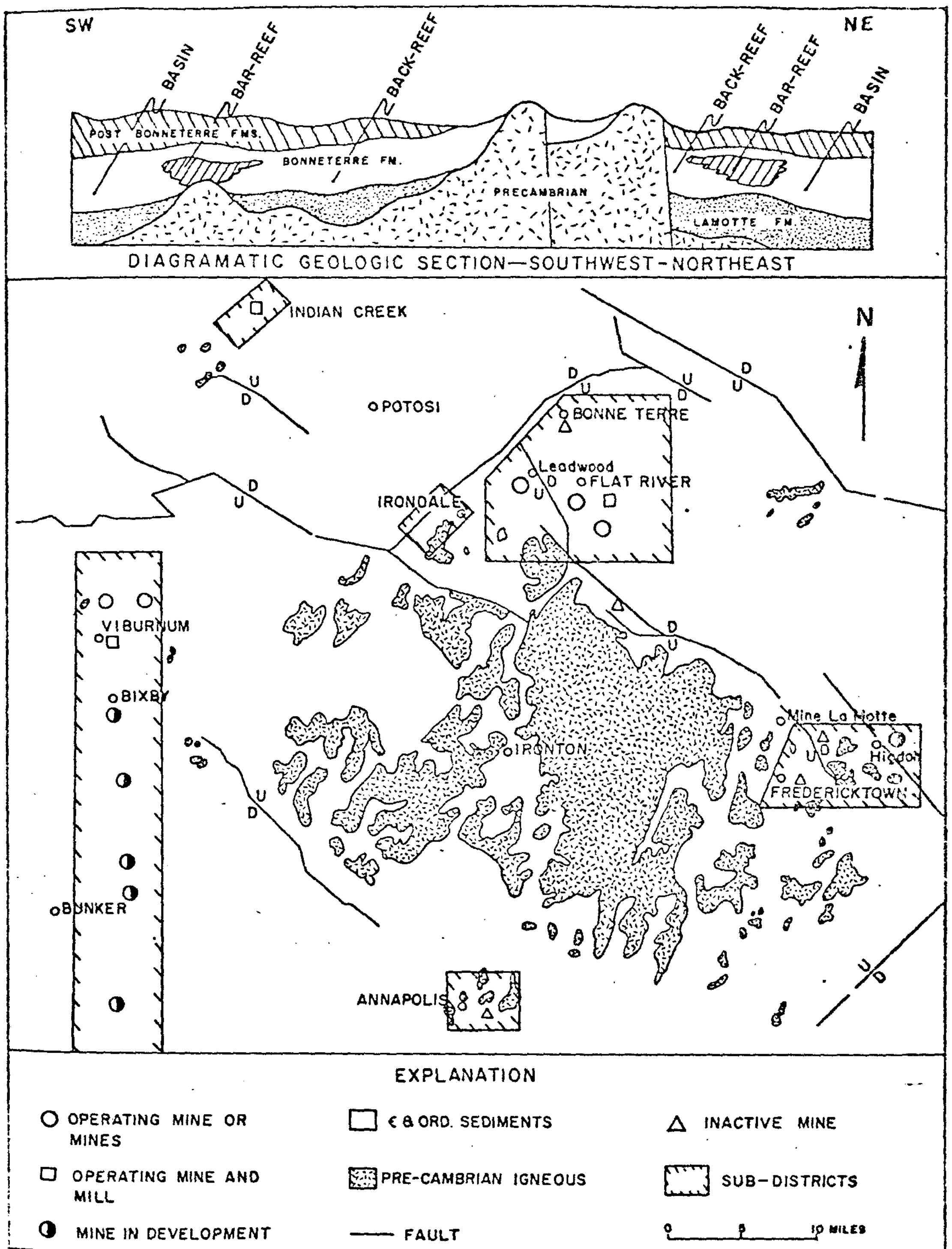


Diagram 16: Major Geologic Features and Lead Districts of Southeast Missouri. (after Snyder and Gerdemann, 1968)

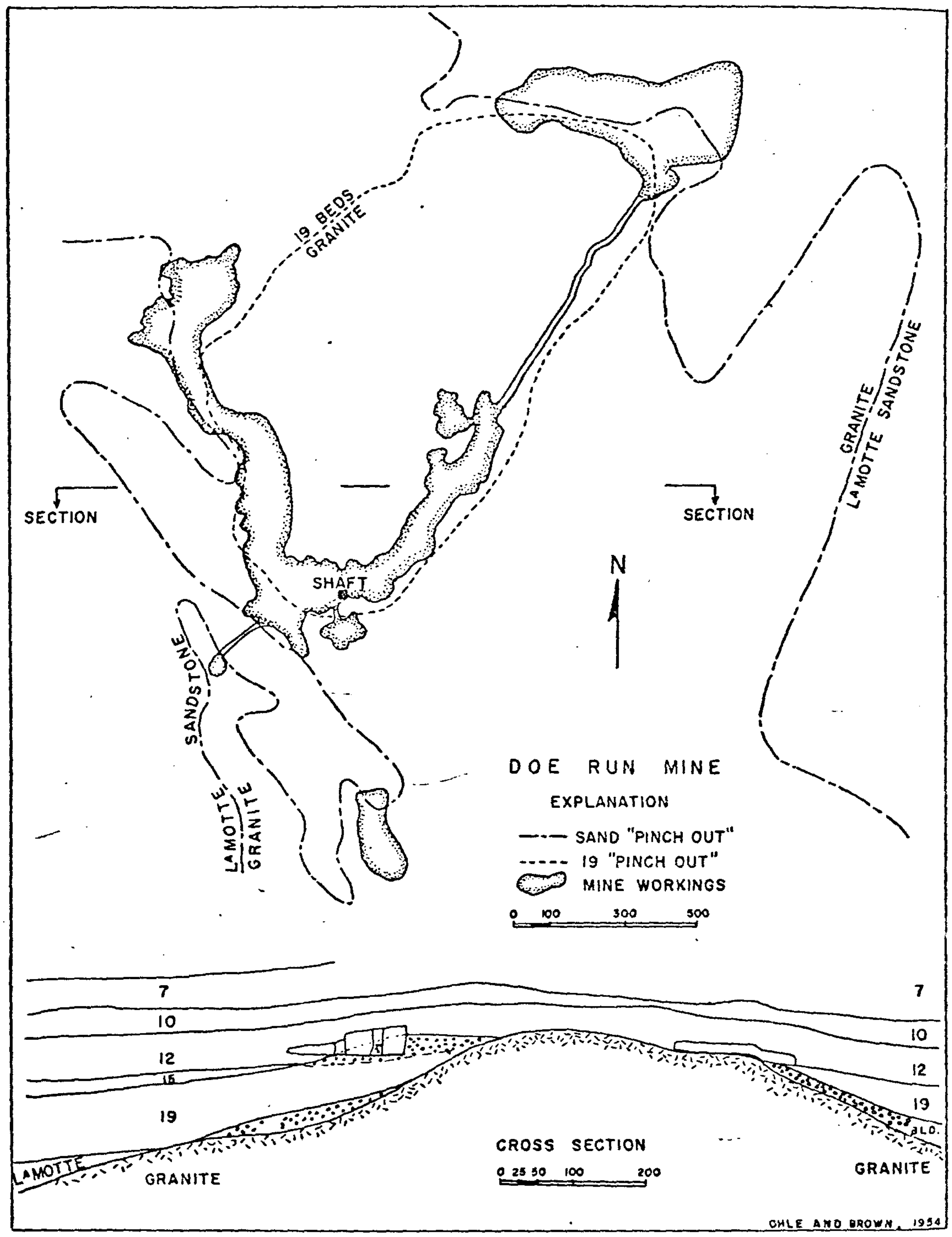


Diagram 17: Plan and Section of Pinchout-Type Ore Body, Doe Run Mine, Southeast Missouri. (after Synder and Gerdemann, 1968)

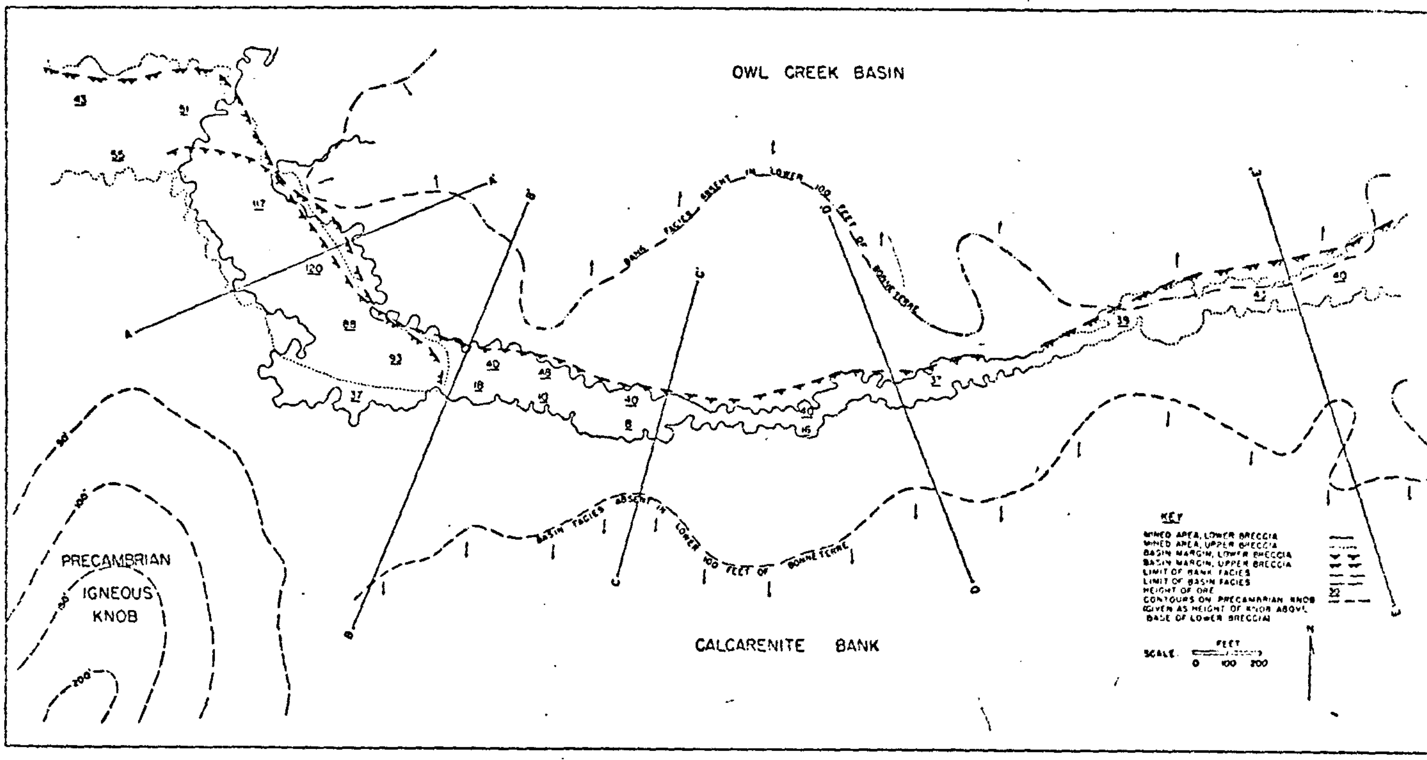


Diagram 18: Breccia Ore Body and Facies Relationships, South Rim, Owl Creek Basin, Southeast Missouri. (after Snyder and Odell, 1958)

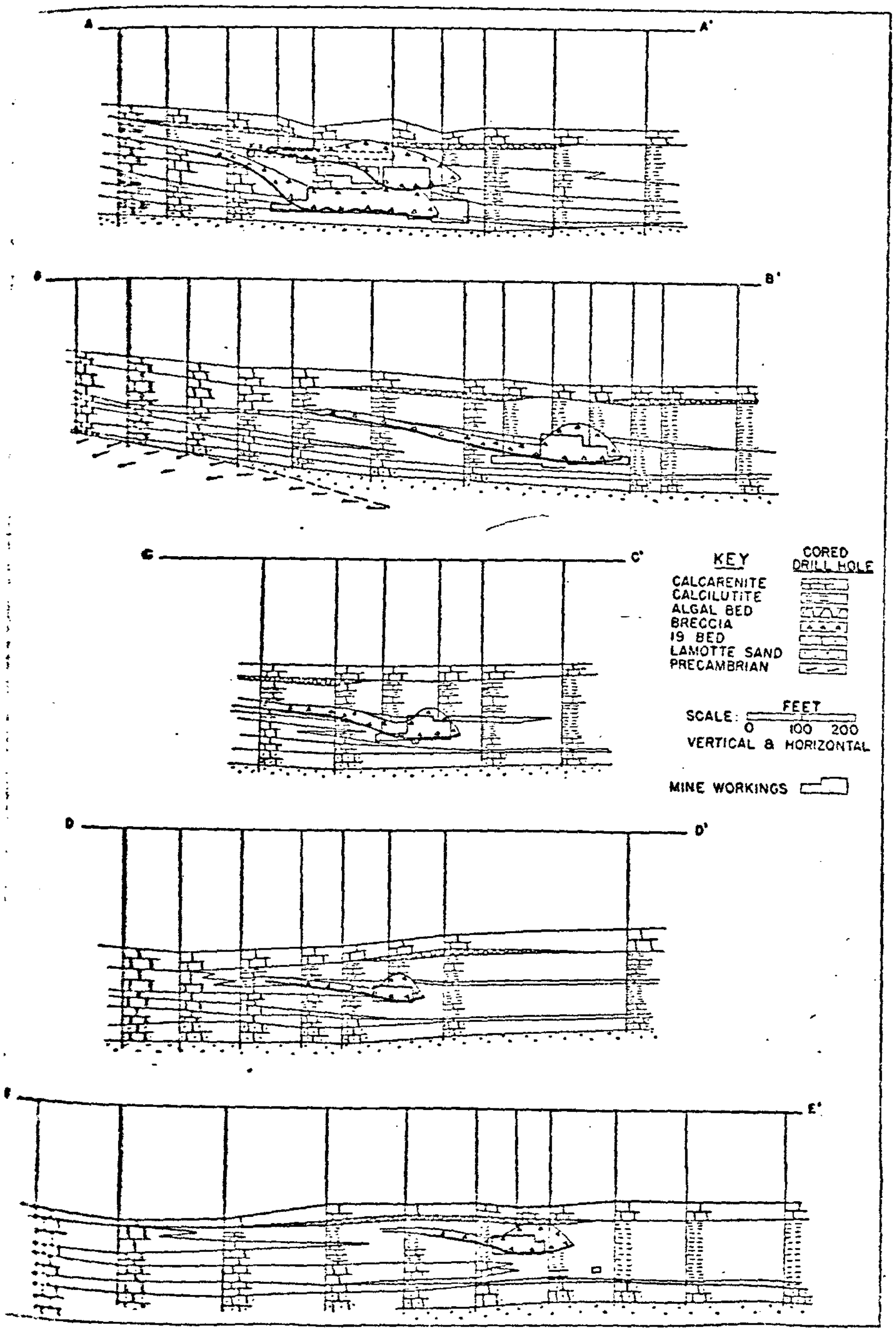


Diagram 19: Sections Across South Rim, Owl Creek Basin, Southeast Missouri

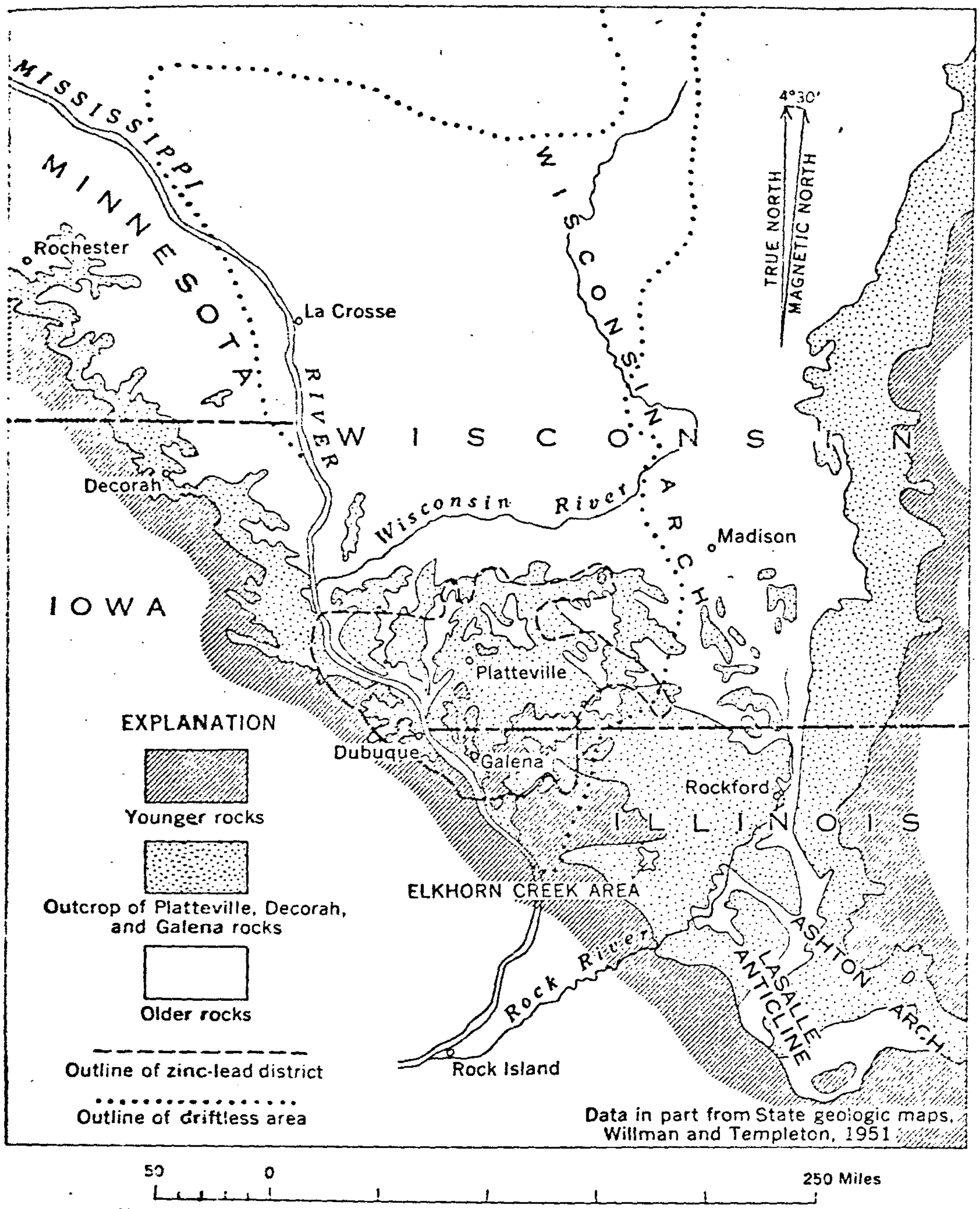
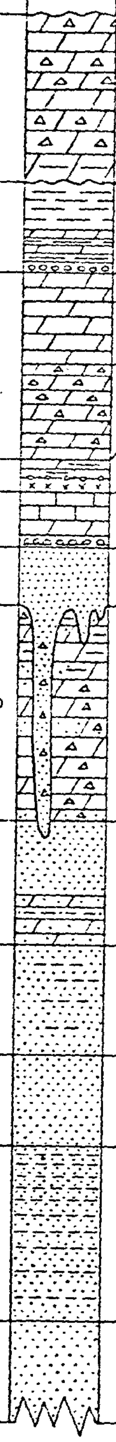


Diagram 20. Upper Mississippi Valley region, showing Driftless Area, zinc-lead district, and bedrock distribution of Platteville, Decorah, and Galena strata.

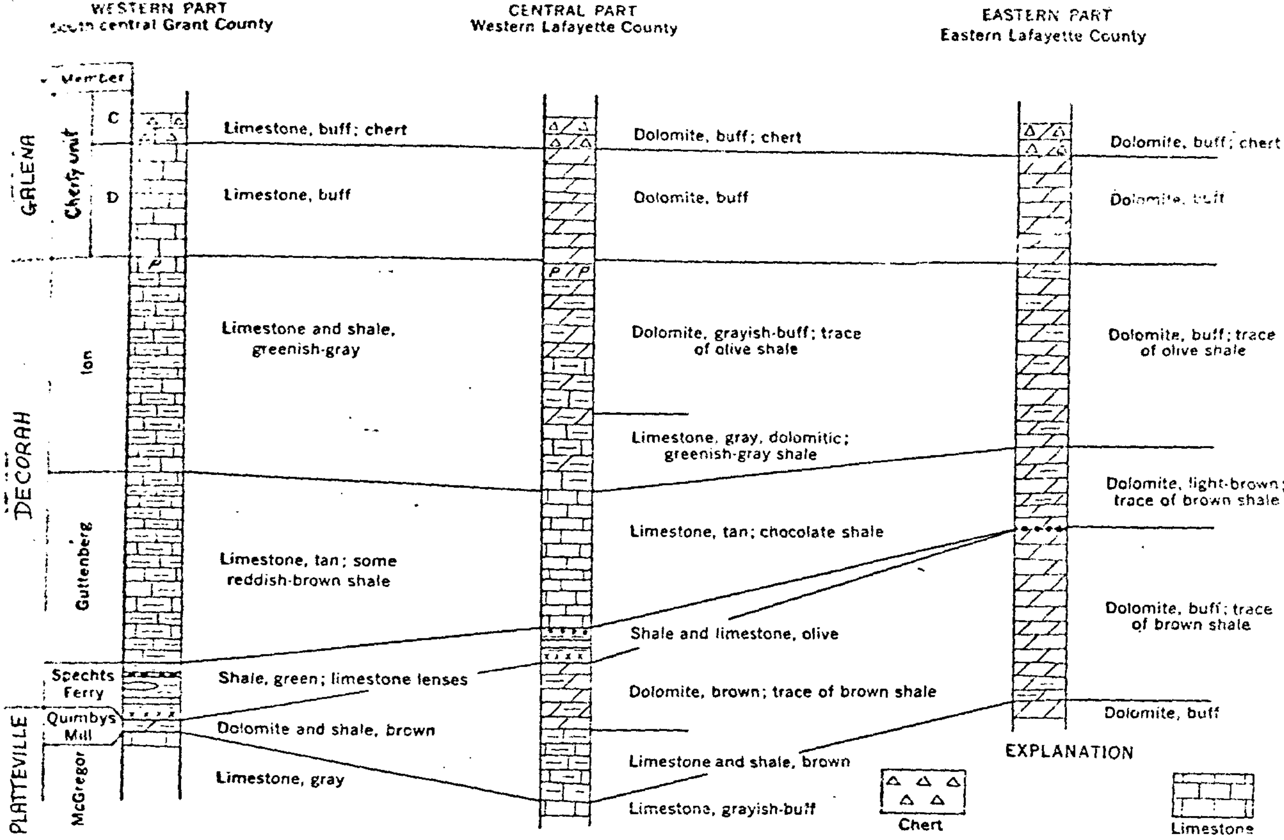
(after Agnew, Heyl, Behre, and Lyons 1956)



System	Series	Group or formation	Description	Average thickness, in feet	
SILURIAN	Lower and Middle		Dolomite, buff, cherty; *Pentamerus* at top.	90	200
			Dolomite, buff, cherty; argillaceous near base	110	
ORDOVICIAN	Upper	Maquoketa shale	Shale, blue, dolomitic; phosphatic depauperate fossils at base	108-240	
	Middle	Galena dolomite	Dolomite, yellowish-buff, thin-bedded, shaly	40	225
			Dolomite, yellowish-buff, thick-bedded; *Receptaculites* in middle	80	
			Dolomite, drab to buff; cherty; *Receptaculites* near base	105	
		Decorah formation	Dolomite, limestone, and shale, green and brown; phosphatic nodules and bentonite near base	35-40	
		Platteville formation	Limestone and dolomite, brown and grayish; green, sandy shale and phosphatic nodules at base	55-75	
		St. Peter sandstone	Sandstone, quartz, coarse, rounded	40+	280-320
	Lower	Prairie du Chien group (undifferentiated)	Dolomite, light-buff, cherty; sandy near base and in upper part; shaly in upper part	0-240	
CAMBRIAN	Upper	Trempealeau formation	Sandstone, siltstone, and dolomite	120-150	
		Franconia sandstone	Sandstone and siltstone, glauconitic	110-140	
		Dresbach sandstone	Sandstone	60-140	700-1050
		Eau Claire sandstone	Siltstone and sandstone	70-330	
		Mount Simon sandstone	Sandstone	440-780	

Diagram 21. Generalized stratigraphic column for zinc-lead district. Upper Mississippi Valley, Wisconsin-Illinois.

(after Agnew et.al. 1956)



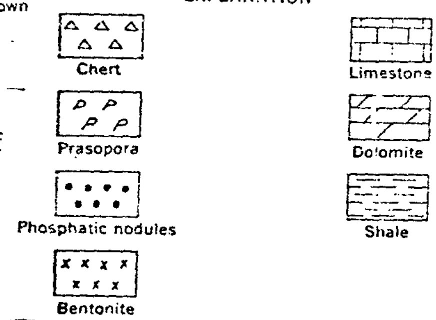


Diagram 22: Generalized west-east cross section of the Decorah formation and adjacent strata. Upper Mississippi Valley, Wisconsin-Illinois.

(after Agnew et.al. 1956)

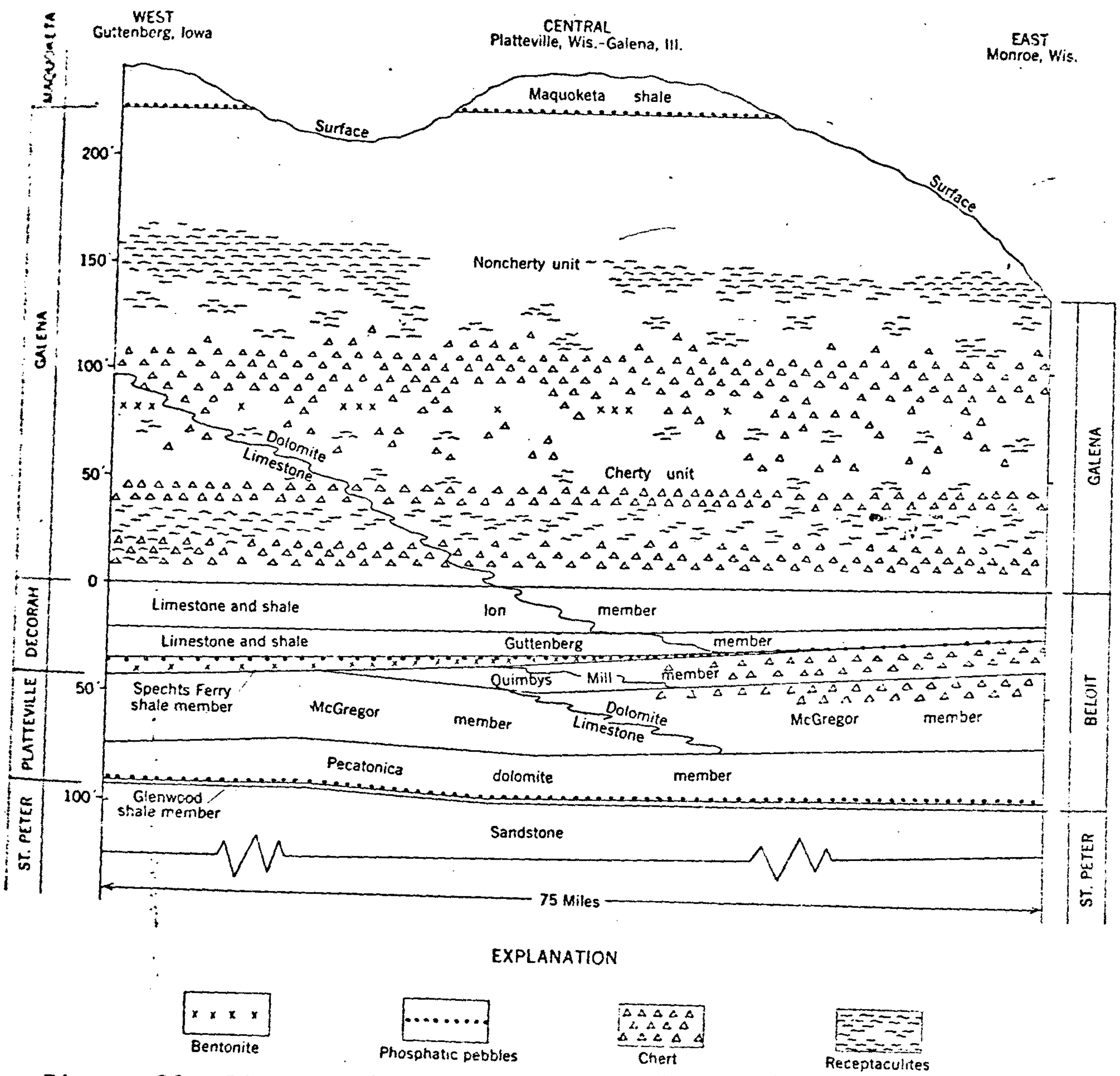


Diagram 23: Diagrammatic cross section of Platteville, Decorah, and Galena strata eastward across the mining district, showing facies relationships. Upper Mississippi Valley, Wisconsin-Illinois.

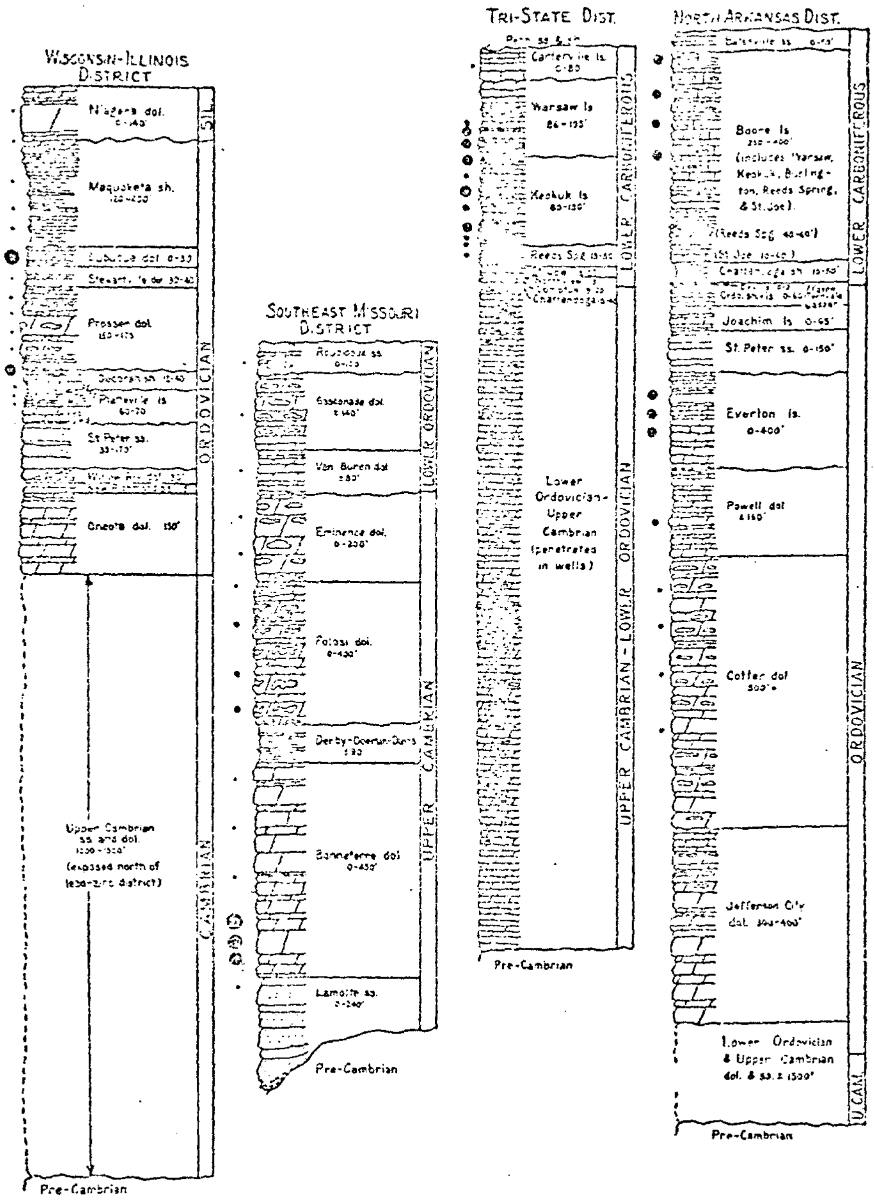
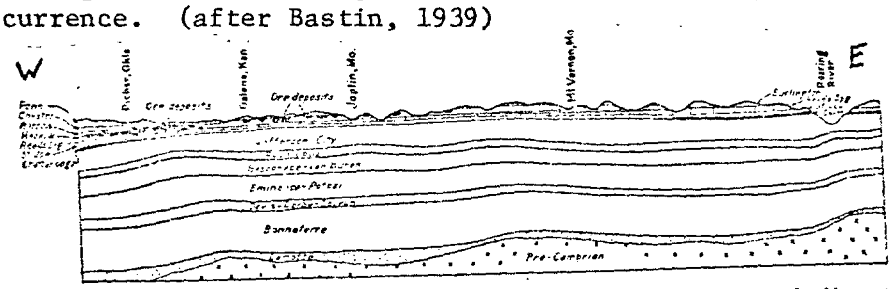
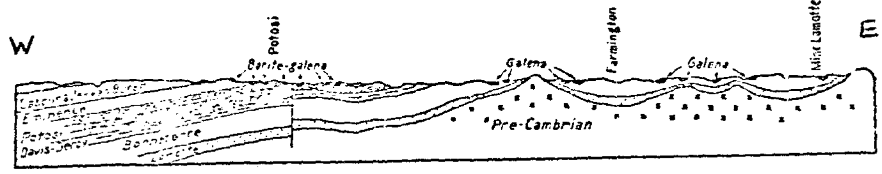


Diagram 24: Columnar sections representing sequence of formations in parts of the Mississippi Valley region, which contain chief deposits of lead and zinc ores. The stratigraphic position of ore occurrences is indicated by black circles at left of each section, the large circles marking the horizons of most important ore occurrence. (after Bastin, 1939)



Diagrammatic section of the Tri-State lead and zinc district and adjacent parts of southwestern Missouri

Showing stratigraphic relations of ore deposits

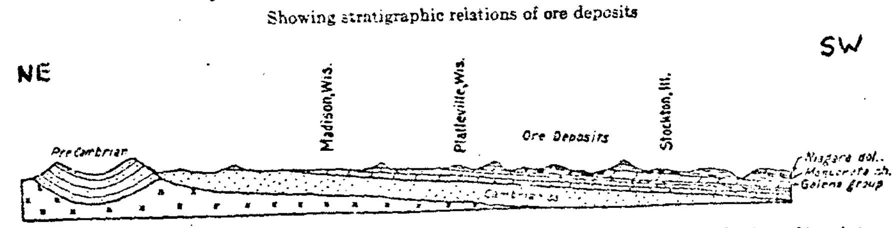


Diagrammatic section of part of the southeastern Missouri lead district

Showing stratigraphic relations of ore deposits

Diagram 25:

(after Bastin, 1939)



Generalized section of the Illinois-Wisconsin lead and zinc district

Showing structural and stratigraphic relations of the ore deposits. (Modified from Trowbridge and Shaw.)

TABLE 1

(after Jackson & Beales 1967) Locality	Lime-stone	Dolo-mite	Poros-ity	Occurrence adjacent to a basin	Associated igneous activity	Evaporite Association	Reef Type	Depth	Main Sulfide	Underlying sediment	Overlying sediment	Control by sedimentary features
(1) Mississippi Valley	A	P	P	Many basins	Minor not related to ores	A	Biohermal in some deposits	Shallow and deep 500' +	Pb, Zn, Fe	Sandstone commonly	Varied	yes
(2) Calcareous Alps	P	P	P	Reef-basin	volcanics, tuffs, etc.	(back reef lagoon)	Bioherms	Shallow and deep	Pb, Zn, Fe	Bit. Lst. & Cherts	Algal Lst.	yes
(3) Northgate	P	A	P	Reef-basin	volcanics	(back reef lagoon)	Bank (biogenic)	Shallow ?	Pb, Zn, Fe	Sandstone	Argil Lst.	yes
(4) Pine Point	A	P	P	Reef-basin	A	back reef evap.basin	Bank (biogenic)	Shallow	Pb, Zn, Fe	Evaporites and dolomite	Lagoonal Lst. and Argil. dol	yes

A = Absent

P = Present

p = Minor

TABLE 2

METAL CONTENT

(after Jackson & Beales 1967)

	Pb	Zn	Fe	Cu	Ag	Sb	As	Co	Ni	Barite	Fluorite	Fault Control	Fold Control	Massive Zones	Mineralised Veins	Bedded
Mississippi Valley	P	P	P	p	p	A	A	P	P	p	p	p	P	P	P	A
Calcareous Alps	P	P	P	P	A	P	P	A	A	P	p	A	A	P	p	P
Northgate	P	P	P	P	P	P	P	A	A	P	A	?	A	P	p	?
Pine Point	P	P	P	A	A	A	A	A	A	A	A	?	A	P	p	A

A = Absent

P = Present

p = Minor

Table 3. Primary minerals of the lead-and zinc-producing districts (after Bastin, 1939)

Minerals classified	Tri-State	Central Missouri	Southeastern Missouri	Northern Arkansas	Illinois-Iowa-Wisconsin	Central Kentucky	Illinois-Kentucky fluorspar district
Elements							
Silver (native?)	x						
Sulphides							
Pyrite	x	x	x	x	x	x	x
Marcasite	x		x	x	x	x	x
Chalcopyrite	x	x	x	x	x	x	x
Millerite	x						
Siegenite			x				
Galena	x	x	x	x	x	x	x
Sphalerite	x	x	x	x	x	x	x
Wurtzite (primary?)	x				x		
Sulpho-salts							
Enargite	x			x			
Haloids							
Fluorite	[1]					x	x
Oxides							
Quartz	x	x	x	x		x	x
Chert	x			x			
Carbonates							
Calcite	x	x	x	x	x	x	x
Dolomite	x		x	x	[3]		
Aragonite	x						
Witherite						x	
Silicates							
Dickite			x				
Adularia				x			
Sulphates							
Barite	[2]	x			x	x	[4]
Celestite						x	
Strontianite						x	
Miscellaneous							
Petroleum							[5]
Bitumen							[5]

[1] Fluorine present, but combination uncertain.
[2] Present but possibly secondary.
[3] Present but possibly not related to the mineralization.
[4] Occurs in the blanket deposits but is probably secondary.
[5] In part contemporaneous with the ores but derived probably from the wall rocks.

Table 4. Secondary minerals of the lead-and zinc-producing districts.
(after Bastin, 1939)

	Tri-State	Central Missouri	Southeastern Missouri	Northern Arkansas	Illinois-Iowa-Wisconsin	Central Kentucky	Illinois-Kentucky fluorspar district
Elements							
Sulphur					x		
Sulphides							
Greenockite	x						
Wurtzite	x						
Covellite	x						
Haloids							
Fluorite							x
Oxides							
Limonite	x	x	x		x		x
Hematite	x		x		x		
Pyrolusite	x				x		
Psilomelane					x		
Cuprite	x						x
Melaconite			x				
Asbolite			x				
Wad					x		
Carbonates							
Cerussite	x	x	x	x	x	x	
Smithsonite	x	x		x	x	x	x
Hydrozincite	x			x	x		
Malachite	x	x		x	x	x	x
Azurite	x	x		x	x		
Aurichalcite	x			x			
Calcite				x			x
Aragonite				x			
Silicates							
Calamine	x			x	x	x	
Chrysocolla	x						
Allophane	x						
Sulphates							
Gypsum	x			x	x	x	x
Barite	x						x
Epsomite	x			x			
Anglesite	x			x	x	x	
Goslarite	x			x	?		
Melanterite	x				x		
Leadhillite	x						
Caledonite	x						
Linarite	x						
Chalcanthite	x						
Copiapite	x			x			
Brochanthite			x				
Bieberite			x				
Morenosite			x				
Phosphates							
Pyromorphite	x			x			
Molybdates							
Wulfenite				x			

Slave Point Fm.	±210 ft	Dense limestone. Stromatoporoids and small brachiopods common. Abundant argillaceous and carbonaceous partings.
Amco Shale 'marker'	10 ft	Argillaceous pyritic limestone and dolostone. Very uniform in thickness, but extends only a little beyond the general Pine Point Mines property area. Used to define the base of the Slave Point fm. in this area.
Sulphur Point Fm.	up to 170 ft	Dense limestone, in large part of a bioclastic and pelletted lagoonal mud nature. Some large stromatoporoids and brachiopods. In part laterally equivalent to, and interbedded with, Presqu'ile dolostone.
Watt Mountain 'marker'	±3 ft	Waxy green shale bed usually 2-3 ft thick; sometimes several beds occur, separated by white limestone. Lies 30-50 ft below top of Sulphur Point fm.
Presqu'ile Fm.	up to 200 ft	Coarsely crystalline dolostone with vuggy to cavernous porosity. Sparry dolomite lines most of vugs. Abundant amphiporid remains in places, but other fossils are mainly obliterated by dolomitization. In part, or possibly largely, a diagenetic facies of the Sulphur Point fm. Orebodies occur locally.
Pine Point Fm.	±300 ft	Medium- to coarse-grained, sucrosic to dense, brown dolostone; argillaceous limestone and dolostone. Orebodies occur in upper part.

Table 5. Middle Devonian Stratigraphy, Pine Point.

Hypothesis	**Remarks**
SOURCE — Sea Water	A source for the metals is seen in the weathering of continental rocks (together with any mantle-derived solution which may fortuitously join a local system; but these are seen as an ore-sweetener, not as an essential element of the model).
CONCENTRATION — Adsorption	The metals are adsorbed preferentially in basinal shales and subsequently released preferentially to connate fluids
RELEASE —	On burial, connate fluids mature and meteoric additions may take place. Formational brines evolve and metals are released to these interstitial fluids, probably to form metal chloride and organic complexes, during the later stages of sediment diagenesis.
TRANSPORTATION —	The above interstitial fluids are expelled from the strata by compaction and hydrostatic drive. Recent studies of formational brines suggest that they may include fluids from both meteoric and connate sources and have a complex history. Pending better understanding, a purely descriptive term, *stratafugic*, is preferred for these basin-derived solutions (Jackson & Beales, 1967).
ROUTE —	Fluids expelled from the basinal strata escape through the most permeable routes and ultimately back to surface. Complex natural plumbing systems act as the conduits through which large quantities of stratafugic fluids are channelled back to surface.
PRECIPITANT —	Oil and gas trapped in carbonate reservoirs is likely to come in contact with sulphate-bearing waters, and dormant anaerobic bacteria will reactivate and generate H_2S. Most gas trapped in carbonate rock reservoirs is, in consequence, "sour."
PRECIPITATION —	Precipitation takes place in the main fluid escape route, where H_2S from the carbonate rock reservoir mingles with the escaping metal bearing fluids.

Table 6. Ore genesis at Pine Point.

(After Beales & Jackson, 1968)

Table 7	Distribution of Mississippi Valley type deposits with respect to time and location.
Tertiary	Tunisia (one example).
Mesozoic	
CRETACEOUS	Reocin, Spain; Rekkame, Morocco; Iran (3 deposits); Tunisia.
JURASSIC	(mainly *Liassic*): Touissit-Bou Beker, Morocco; Tunisia.
TRIASSIC	Les Malines, France; Mezicia, Bleiberg and other deposits in the Austrian and Italian Alps; Upper Silesia, Poland; Sedmochislenitsi, Bulgaria.
Palaeozoic	
PERMIAN	Italian Alps.
UPPER CARBONIFEROUS	*(Pennsylvanian)*: Tri-State; English Pennines
LOWER CARBONIFEROUS	*(Mississippian)*: Tri-State; South Illinois - Kentucky; Ireland; English Pennines; Moresnet, Belgium; S. Kazahkstan, U.S.S.R; Kheufra, Morocco; Derbyshire, England.
DEVONIAN	Pine Point, Canada; Moresnet, Belgium.
SILURIAN	Sardinia
ORDOVICIAN	East Tennessee zinc field; Friedensville, Pennsylvania; Upper Mississippi (Illinois-Wisconsin)
CAMBRIAN	Old and New Lead Belts of Missouri; Austinville, Virginia; Sardinia; Swedish Caledonides, including Laisvall; Le Malines, France; certain deposits in the U.S.S.R.

(compiled from Brown, 1967 and others)

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THE GEOLOGY OF THE

MISSISSIPPI VALLEY TYPE LEAD - ZINC ORE DEPOSITS

PART 11 : AUSTRALIAN OCCURRENCES AND EXPLORATION PROSPECTS

BY: J.B. KEENE

This report on Mississippi Valley Type Lead-Zinc ore deposits is the second of a series consisting of three parts :-

Part 1	:	*Major World Occurrences*
Part 11	:	*Australian Occurrences and Exploration Prospects*
Part 111	:	*Southern Georgina Basin Geology*

18th February, 1971 - (1971/12)

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OCCURRENCES OF MINERALISATION IN THE GEORGINA BASIN

(1) THE OCCURRENCE OF LEAD NEAR BOX HOLE BORE

(Huckitta 1 : 250,000 Sheet) (Wolley & Rochow, 1961.)

Summary

The ore consists mainly of galena as lenses in Upper Cambrian dolomites, partly silicified, of the Arrinthrunga Formation. The lenses are restricted to two horizons with the main lens averaging 20 feet in thickness, and extending for about 8,000 feet along the strike. Mineralisation exposed at the surface is lenticular, and has been considerably affected by leaching, hence a worthwhile estimate of tonnage and grade is not possible without subsurface data.

Enterprise Exploration Pty. Limited and C.R.A. have drilled the deposit but without success. (B.M.R. Record 1961/42, Company Reports)

Regional Geology

A generalized section in the Box Hole Area is:

Devonian	Dulcie Sandstone
unconformity	
L. Ordovician - U. Cambrian	Tomahawk Beds (sandstone)
? unconformity	
Upper Cambrian	Arrinthrunga Formation (Limestone, dolomite, siltstone with Eurowie Sandstone Member)

The contact between the Tomahawk Beds and Arrinthrunga Formation was considered to be conformable by Smith et. al. (1960) but detailed air photo interpretation and further field work suggested an unconformity (Woolley, 1961).

The Arrinthrunga Formation consists mainly of limestone and dolomite with abundant algal structures and some oolitic beds. Fine-grained, creamy brown, laminated siltstone is interbedded with the limestone and dolomite but has poor outcrop. The carbonate rocks are generally grey, cream and brown. In the Box Hole area, the majority of the beds are from three inches to one foot thick, but they become thicker (commonly more than two feet) near the top of the formation. The proportion of siltstone appears to be lower near the top of the formation.

In the immediate vicinity of the prospect the outcrops are mainly thin-bedded, cream or pale grey dolomites and limestones. Algal structures are common immediately below the mineralised beds. Silicification, ranging from slight to intense, is present in these beds, and barite occurs as irregular nodules up to two inches long.

The thickness of the Arrinthrunga Formation in the Box Hole area is thought to be about 3,000 feet.

The Eurowie Sandstone Member, within the Arrinthrunga Formation, has been used as a marker unit. It is medium-grained, medium-bedded, poorly sorted pale brown sandstone and commonly contains pseudomorphs after halite. The Member's thickness is about 100 feet in the Box Hole area.

The lead-bearing beds appear to be up to 300 feet above the top of the Eurowie Sandstone Member.

A geologic map and cross-section is shown in Diags. 1 and 2.

Structure

The regional structure is a gentle dip to the south-west. The lead-bearing horizons crop out along part of the eastern flank of a north-trending ridge which rises about 100 feet above the surrounding plain. The geological structure of the sediments in this ridge is a shallow syncline whose axis trends approximately north-south. The limbs of the syncline dip at 10^{o}-20^{o}. A cross-fold has created a constriction of the syncline and lead mineralisation occurs south of this.

The syncline is bounded on the east by a monoclinal structure, which dies out to the north and becomes a fault in the south. This fault truncates the mineralised zone.

Occurrence of Lead

The mineralisation is in the form of abundant disseminated cubes of galena ranging from about 1/8" to 1" in size, with some irregular crystal aggregates up to 3" long, and occurs within lenses of silicified carbonate rock. The algal and oolitic structures present suggest that the host rock was originally limestone.

The main mineralised bed varies in thickness (but averages 20 feet) and lies between two dolomite beds. The dips of the lead-bearing bed range from 5^{o} to 15^{o} W.

Cavities are very common, and are in many places the only indication of mineralisation in surface exposures; some have cubic outlines, but the majority have no regular shape or are roughly hemispherical. Cerussite is commonly found in the cavities or in the dolomite. The lead minerals are found in silicified carbonate rocks of the following types :

(1) Massive: Mostly random distribution of galena.

(2) Massive thinly laminated: Galena commonly concentrated along lamination planes.

(3) Intraformational breccia: Distribution random with the mineralisation apparently post-dating the brecciation.

(4) Algal: Random distribution of galena.

Individual mineralised lenses generally are less than 100 feet long and less than 2 feet thick. The lead-bearing bed appears to thicken to 60-70 feet at the northern and southern extremities of the mineralised zone.

A surface sample obtained by Woolley (1961) assayed 4.5% Pb and a sample of hand-picked ore assayed:

Pb	- 66.1%
Au	Nil
Ag	1 oz. 18.4 dwt. per ton
Bi	0.43%

Conclusions

As the stratigraphic position of the mineralised horizon has been approximately established, it should be possible to check this part of the sedimentary sequence in other areas.

Features that appear to be significant include :

(1) lead-bearing beds are commonly strongly silicified and dolomitic.

(2) algal structures are common.

(3) porosity is, or was, high in mineralised zones due to vughs and breccia. The breccias may be collapse structures.

(4) the mineralised lenses appear to be concentrated near the pinching out of a bed, which is probably due to lateral facies change. This represents a stratigraphic trap for the mineralising fluids.

All these features can probably be found in unmineralised areas, however, any such area is worthy for prospecting.

(2) OORATIPPRA LEAD OCCURRENCE

(Centamin N.L. Prospectus, 1970) (B.M.R. Record 1964/127)

This area is 40 miles north-east of the Box Hole Bore occurrence. Centamin claims the area contains numerous showings of lead-silver mineralisation in limestone.

The rocks involved are the Upper Cambrian - Lower Ordovician Tomahawk Beds. A geological map of the area is shown in Diag. 3.

Generally the strata in this area are flat lying with some minor faulting trending north-west. Smith (1964) recorded that the strongest Palaeozoic Orogeny in the south-western part of the Georgina Basin occurred in post Upper Devonian time. It was severe in the southern part of the Huckitta Sheet area but its effects hardly exist in the Ooratippra area (Elkedra Sheet).

This mineralised area is only ten miles west of Metals Investment Holdings' Mt. Hogarth prospect and ten miles south-east of B.M.R. 13 Well. This well reached Precambrian basement at 3,300 feet. It penetrated 2,200 feet of Upper Cambrian Arrinthrunga Formation containing four major dolomite beds (40-203 ft., 451-940 ft., 1,600-1,800 ft., 2,000-2,200 ft.). Both quartz sandstone and dolomite aquifers occur in the Arrinthrunga Formation in this area and in B.M.R. 13; water bearing aquifers were encountered at 242 ft. (dolomite), 325-340 ft. (sandstone), 1,680 ft. (dolomite). The stratigraphic column for B.M.R. 13 is shown in Diagram 4 (from B.M.R. Record 1964/127). The well entered the Arrinthrunga Formation immediately below the Eurowie Sandstone Member, called Unit 2 by Smith, Vine and Milligan (1961), and penetrated Unit 1 at about 1,480 feet. This division correlates lithologically with outcrop of the Arrinthrunga Formation 12 miles north of B.M.R. 13.

The Tomahawk Beds, which crop out to the south of the well site, and the top two units of the Arrinthrunga Formation are not present in the well. It seems likely that the Arrinthrunga Formation was eroded and the Tomahawk Beds transgressed over the eroded surface and this is supported by a similar stratigraphic relationship suspected in the Lucy Creek Homestead area to the south (Smith et. al. 1961). It is possible that the lead occurrences are associated with the unconformity between the Arrinthrunga Formation and the overlying Tomahawk Beds.

The geological report in the prospectus states: "The carbonate beds are flat lying and mostly soil covered, with the result that surface information is very limited. The galena is present as small veins and lenses within the limestone, which is commonly silicified in the vicinity of the mineralisation. The mineralised outcrops occur over an area of more than three square miles to the north of Trackrider Bore".

There is no other information available concerning this deposit.

(3) TARLTON RANGE LEAD OCCURRENCE
(B.M.R. Record 1960/71)

The B.M.R. report states: "Samples of galena have been obtained from the area east of the southern tip of the Tarlton Range. These almost certainly were obtained from small pockets of galena contained in the Ninmaroo Formation".

This area is within Fimiston's Tarlton Downs prospect. No information is available on the exact location of the mineralised area, but it is likely local inhabitants would be able to provide such information.

It is probable that the occurrence is in the Tomahawk Beds rather than the Ninmaroo Formation, since no outcrops of Ninmaroo Formation have been mapped in the area.

There is no information concerning the geological setting of the mineralised area, thus while this reported occurrence is encouraging, details about it are vague and the initial exploration of the area should concentrate on locating and studying this occurrence.

(4) B.M.R. Grg. 12 (TOBERMORY)
(B.M.R. Record 1963/68)

This cored drill hole is located in the western portion of the Tarlton Downs Prospect and to the west of the Tarlton Range.

The hole was drilled vertically and reached a depth of 755 feet; it did not reach basement.

Galena is present in the core over the interval 733-734 feet. The bedding throughout the drill hole is approximately horizontal.

The sequence penetrated was (according to B.M.R. logs):

11 - 92 feet	claystone with coquinite	M. Ordovician Nora Fm.
92 - 325 feet	mainly sandstone	L. Ordovician Kelly Creek Fm
325 - 755 feet	125 feet mainly dolomite	L. Ordovician - U. Cambrian
	90 feet mainly sandstone	Tomahawk Beds
	85 feet mainly dolomite	
	35 feet mainly sandstone, siltstone becoming more dolomitic towards base	

Gypsum and anhydrite are common in the Kelly Creek Formation. Vughs, pyrite and glauconite are common in the dolomite from 325 - 450 feet, together with an occurrence of marcasite (385 feet) and intraformational breccia (355 feet). Vughs and intraformational breccia are very common in the lower dolomite beds (540-625 feet and 733-746 feet).

The galena occurs at the top of a dolomite bed 13 feet thick (733-746 feet). The bed is overlain by dolomitic siltstone containing brachiopods and trilobites, cross-bedded in part. The dolomite is underlain by fine grained but porous sandstone containing thin claystone beds. The hole terminated after penetrating 9 feet of this bed.

The core was studied in the immediate vicinity of the galena occurrence and the following details noted:

(1) A few galena cubes partly fill two vughs, the cubes usually being attached to the top of vughs. The vughs are lined with crystals of calcite/dolomite.

(2) Fine grained pyrite has completely filled several vughs which are now surrounded by a brown halo.

(3) A yellowish/brown mineral occurs in some vughs in very small quantities. This could be sphalerite.

(4) The rock containing the mineralised vughs is a coarsely crystalline, white dolomite which is not silicified. The vughs range in size up to 1 inch and their density is at a maximum at the top of the bed.

(5) Above the mineralised vughs the dolomite contains no vugs and becomes thinly bedded (2-5 inch pinkish bands), finer grained and sandy with some claystone beds.

(6) Below the mineralised vughs the dolomite becomes finer grained, tighter, and thinly bedded at the base.

It is possible that the lower part of the cored hole belongs to the Arrinthrunga Beds, and if so the lead occurrence is in a similar position, stratigraphically, to the Box Hole Bore deposit.

In this occurrence, porosity and rock type are the most important factors and mineralising brines could have travelled laterally within this permeable horizon of dolomite. The presence of anhydrite and gypsum in overlying beds is encouraging as an evaporite sequence is considered necessary by some workers for the deposition of the sulphides (Jackson and Beales, 1966).

The two thick, porous and pyritic dolomite sequences higher in the drill hole could be favourable for lead mineralisation in their lateral extensions, particularly if the intraformational breccias are collapse structures which have enhanced permeability and if stratigraphic or structural traps occur.

OCCURRENCES OF MINERALISATION OF THE MISSISSIPPI VALLEY TYPE IN AREAS SURROUNDING THE GEORGINA BASIN

(1) LAWN HILL, QUEENSLAND (Murray, 1965)

Lead-zinc-silver deposits are mined in the Precambrian Lawn Hill Formation (sandstone, siltstone, carbonaceous shale, quartz greywacke, calcareous siltstone). The deposits occur as fissure lodes in northeast and northwest trending faults and probably pre-date the Cambrian deposition in the area.

The ore deposits outcrop near the margin of the Georgina Basin and the faulting continues beneath the Cambrian sediments. The Thorntonia Limestone (Middle Cambrian) is the nearest outcrop of Georgina Basin strata, some five miles west of the mineralisation.

It is possible that mineralisation occurs in faults beneath the Georgina Basin sequence and, furthermore, the known mineralised areas could have formed a potential source of metals that could have later been deposited in the carbonate sequences.

(2) MACARTHUR RIVER NORTHERN TERRITORY (Cotton, 1965)

Mt. Isa Mines Limited has found a zinc-lead-silver orebody near MacArthur River Station, Northern Territory. The orebody is in unmetamorphosed sedimentary rocks of the Amelia Limestone Formation within the MacArthur Group (Upper Proterozoic).

The actual ore bearing beds are predominantly black, carbonaceous, pyritic shale, which is finely bedded and sometimes associated with jasper and dolomitic breccia. The maximum thickness of the orebody is 400 feet. Other lithologies within the formation are dolomites, siltstone and some tuffs.

It appears that this deposit is not a Mississippi Valley Type deposit.

(3) MT. MARUMBA, NORTHERN TERRITORY (1 : 250,000 Explan. Notes)

Lead-zinc mineralisation has been found in horizontal limestone, dolomite and chert beds in the upper part of the Dook Creek Formation (Middle Proterozoic).

The carbonate sequence contains algal structures and the orebearing strata is unconformably overlain by sandstone.

AVAILABLE AREAS FAVOURABLE FOR PROSPECTING WITHIN THE GEORGINA BASIN

(1) ROXBOROUGH DOWNS (Glenormiston 1 : 250,000 Sheet) (12)

This area is located around latitude 22°15', longitude 139°. A geological map of the area is shown in Diag. 5.

The sequence here consists of:

Upper Cambrian - Lower Ordovician	Ninmaroo Formation
Middle - Upper Cambrian	Mungerebar Limestone
Middle Cambrian	Steamboat Sandstone

The area is situated along the edge of the Georgina Basin outcrop and some 80 miles to the north east of the Toko Syncline. The Cambrian and Ordovician sequences continue to the east and south, largely beneath Mesozoic strata. The area is located on the margin of an extension of Precambrian outcrop into the Georgina Basin

Structurally the area was described by Opik (in Hill and Denmead, 1960, P. 97) as the Smoky Anticline. The anticline is mainly an old Precambrian ridge over which Cambrian sediments have been deposited. The structure was moving during Middle and Upper Cambrian and this has resulted in several disconformities. In Diagram 5, the anticline commences in the north-east and plunges south-west.

The Steamboat Sandstone is a medium grained, porous sandstone, with minor siltstone beds, 270+ feet thick. It rests disconformably on the underlying Quita Formation and Thorntonia Limestone (observed in outcrops north of this area) and interfingers laterally with the lower parts of the Mungerebar Limestone. The upper part of the Steamboat Sandstone interfingers with and represents a near-shore facies of the lower Mungerebar beds which were deposited deeper in the marine environments.

The Mungerebar Limestone consists mainly of dolomitic limestone, oolitic limestone, well-bedded sandy limestone and limestone containing chert lenses. Intraformational limestone and dolomite breccias have also been reported. The sequence is estimated to be 100 feet thick, and overlain disconformably by red/white sandstone and siltstone up to 30 feet thick, which is mapped as the leached, local basal beds of the Ninmaroo Formation, but which could be a separate formation (Reynolds and Prichard 1964).

The Ninmaroo Formation in this area consists of sandy dolomite, calcilutite, oolitic limestone, algal limestone, calcarenite and marl. Intraformational breccias are common and the sequence is 1,200 feet thick. There is a disconformity between the Ninmaroo Formation and the underlying Mungerebar Limestone (Reynolds, 1965).

Subsurface information is lacking, however from Netting Fence No. 1, 70 miles to the southwest, 265 feet of Mungerebar Limestone (4,090-4,355 feet) was reported and described as calcarenite and calcilutite with traces of oolites.

The Brothers No. 1 Well (French Petroleum Coy.), 100 miles south of the area, penetrated 3,000 feet of Cambrian Limestone and shale (1,153 ft. - 4,173 ft.). Beantree No. 1 (Phillips Petroleum) and Black Mountain No. 1 to the south-east penetrated a similar Cambrian sequence.

Shales, siltstones and claystones become predominant in Netting Fence No. 1 from 5,000 - 6,400 feet and it is this area of the basin that could be the source of the metals required for a Mississippi Valley Type deposit.

Within this area several features make it a favourable prospect for exploration:

(1) The lithology consists of gently dipping (0 to 20° S.W.) limestone/dolomite sequences.

(2) Porous beds, including underlying sandstone units, appear to be present, however no subsurface information is available.

(3) Cherty layers and intraformational breccias have been reported.

(4) Algal beds, lateral facies changes and disconformities may provide suitable stratigraphic traps.

(5) Some minor faulting occurs and could provide a site for secondary mineralisation if ore horizons are present.

The air photos that cover this prospect are:

Run	Nos.
5095	78-88
5105	13-21
5184	69-75
5006	18-22
5089	72-75
5099	12-15

(2) LUCY CREEK (Huckitta - Sheet)

This area contains the favourable Arrinthrunga Formation and is immediately south of the known mineralised areas. The area is already held for prospecting.

(3) ALEXANDRIA HOMESTEAD (Rankin Sheet)

Southeast of Alexandria Homestead a Precambrian basement high is exposed as the core of an anticline. Silicified limestone and dolomite of Middle Cambrian age occur. The area is near the northern outcrop margin of the Georgina Basin.

However, there is no other evidence to support this area and the potential source rocks do not exist.

CONCLUSIONS

Lead mineralisation does occur in carbonate rocks of the Georgina Basin and this fact does encourage further prospecting.

The southern area of the Georgina Basin appears most favourable for prospecting and it is here that there are reasonably thick sandstone/shale sequences that could supply the metal bearing brines which, if deposited, could form ore bodies.

Other factors, such as good permeability, thick carbonate sequences, lack of deformation and lack of igneous intrusions appear to provide favourable environments for deposition of ore.

The topographic relief in the Tarlton Downs area is generally less than 200 feet and much of the outcrop is obscured by scree material and soil. However, the ridges provide good exposures. The climatic conditions in this area are drier than the areas of Mississippi Valley type deposits in the U.S.A. The climate and soil conditions will have an effect on the distribution of elements in the soil, which in turn affects any geochemical survey.

The exploration of a potential area should be based on detailed geological mapping to locate favourable horizons, disconformities and structural traps, and this should be done in conjunction with a geochemical survey and later a drilling programme.

Appendix To Part 1.

GEOCHEMICAL PROSPECTING TECHNIQUES: CASE HISTORIES

(1) DISTRIBUTION OF ZINC IN SOILS OVERLYING AN APPALACHIAN TYPE DEPOSIT (3)

The Flat Gap Mine is an important zinc deposit of the Appalachian type in the Valley of Tennessee (Fig.1).

The ore is found in large stratigraphically linked deposits in solution and collapse breccias of the Kingsport, Longview and, to a minor extent, Mascot formations of Lower Ordovician age. The principal ore mineral is sphalerite and the principal gangue minerals are dolomite and accessory pyrite. There is local minor galena and very rare barite and fluorite.

The ore-bearing horizons are covered by about 20 to 100 ft. or more of residual clay except where active streams have exposed bedrock. Considerably less than 5% of the favourable host rocks are exposed in outcrop, and this nearly complete soil cover creates a serious obstacle to exploration. Comprehensive surveys of the base metal content of soils furnish a useful substitute for outcrop geology, and under favourable conditions, this technique is a very valuable prospecting tool. The analysis is carried out by a titrametric dithizone method, which detects copper, lead and zinc as an undifferential group reported as "zinc equivalent."

At Flat Gap we are dealing with a residual soil modified by topography, mechanical erosion and slight local alluviation. In this discussion we are concerned exclusively with the residual case and the much more difficult prospecting situation involving transported soil is not considered.

At Flat Gap, background values of soil mineralisation range from 50 p.p.m. to 200 p.p.m. heavy metal, mainly zinc. Anomalous values range up to 3,000 p.p.m. or more.

The zinc is largely tied up with the hydrous iron oxides (30% to 60%) and in the crystal lattice of the clay minerals (20% to 45%). In strongly mineralised soils, such zinc accounts form from 80% to 90% or more of the total. It is extremely stable and may be regarded as fixed permanently in the soil. Probably less than 10% of the soil zinc is relatively mobile and occurs largely as base exchangeable zinc associated with the clay minerals.

Figs. 2 and 3 show the general structural relationships of the main elements of the Flat Gap orebodies in the bedrock, the general monoclinal structure of the host rocks, the geochemical anomaly and the gross topographic features. It will be noted that the zone of significant soil mineralisation (more than 1000 p.p.m. heavy metal) lies in or on the footwall side of the surface projection of the favourable beds. Because of the fairly steep dip, the surface projection of these beds makes a narrow belt which is the most important zone to be examined for anomalous metal values in the soil. The topographic relief is moderate and the downslope movement of debris from the ridge crest a short distance to the northwest is of minor significance at most.

The soil anomalies at Flat Gap appear to represent the retention of a relatively small percentage of the zinc originally contained in the weathered part of the ore.

Discovery of the Flat Gap ore and the successful outlining of the general form of this ore deposit has been at least a partial result of the application of the theory that the main soil anomalies are vestigal and are contiguous with unweathered ore.

(2) PROSPECTING FOR LEAD-ZINC VEINS IN THE MISSISSIPPI VALLEY *(1)*

Samples of normal soils and soils near metalliferous veins were tested to investigate the behaviour of copper, lead, and zinc during the formation of residual soil. The copper, lead, and zinc content of unmineralised bed rock ranges from 20 - 200 p.p.m. of each metal, and is of similar magnitude in normal soils (table 1). The soil directly over, or immediately downhill from a mineralised vein contains much higher concentrations (up to 10,000 p.p.m.). The ratios of the highest to the lowest metal value determined near each vein range up to 106 to 1 for Cu, 170 to 1 for lead, and 11 to 1 for zinc. Prospecting by sampling surface soil at 50- to 100- ft. intervals, and analyzing by quick tests can locate some veins concealed by residual soil.

TABLE 1

Average Copper, Lead and Zinc Content in p.p.m. of Normal Rocks and Soils

		Cu	Pb	Zn
	Average igneous rock	70	16	132
Rock	Sandstone	-	20	20
	Shale	192	20-200	200-1,000
	Limestone	20	5-10	50
Soil	Residual soil	20-30	12	30-70
	Alluvial soil	20		94

Modern

Huff (1952) concluded that copper and zinc content of soil is influenced by :

(1) clay content
(2) organic content
(3) acidity

Both copper and zinc tend to accumulate in soils of high organic or clay content and tend to leach out of acid soils.

Zinc tends to be leached from the zone of oxidation, whereas lead tends to be residually enriched. In one area examined there was 2 - 3 feet of weathered soil over dolomite. However, the soil is a dark-brown, humus-rich silt loam at the surface, and grades to a reddish-brown clay loam overlying weathered dolomite. The sampling found up to 4,000 p.p.m. Pb in surface soil (minus 2 m.m. mesh).

However, surface soils that are not of residual origin may not exhibit a geochemical anomaly related to an underlying ore deposit. It should be remembered that geochemical methods are of little practical value if they merely confirm what could be found by geological observation.

(3) <u>GEOCHEMICAL STUDIES IN THE SOUTHERN WISCONSIN LEAD-ZINC DISTRICT</u> *(2)*

Geochemical work done by Kennedy (1956) included a study of the loess in some parts of the mining district, and of the distribution of metals in soil, rock and ground water adjacent to known ore deposits.

The southwest Wisconsin mining area has relief of 100 to 300 feet and is often covered by loess in the upland parts, and by alluvium in the stream valleys. The loess is commonly 2 - 8 feet thick, but in some areas it reaches a thickness of 15 feet or more.

In southwestern Wisconsin most of the lead deposits occur as vertical veins, whereas the zinc ore bodies commonly have their longest dimensions in a horizontal plane.

Residual material was sampled and the lead content ranged from 70 to 1,700 p.p.m. and zinc 200 - 1,100 p.p.m. The best results came from the layer of residual clay lying just above the layer of partially decomposed bed rock.

Of four ore bodies lying at depths of 50 - 100 feet below the surface - at points where soil samples were collected - all were indicated by concentrations of either lead or zinc or both in the residual soil. Of the three ore bodies lying at depths of 100 -

150 feet below the surface, one gave evidence of its presence by the unusual amount of lead and zinc in the soil. This shows that exploration techniques can not assume a primary or secondary halo will exist at the surface above an ore body, particularly if it is overlain by barren strata.

Unusually large quantities of chert were found in the residual soil overlying the ore bodies, while the surrounding soils were free of chert. This suggests that silica may be part of a halo in and around these deposits.

The results of this study of the zinc and lead content of soils, rocks and waters in the S.W. Wisconsin zinc-lead area indicate that geochemical prospecting techniques can be partially successful in prospecting for these types of deposits. However the climatic conditions and soil types vary from the Georgina Basin areas and due to this the metals may behave differently.

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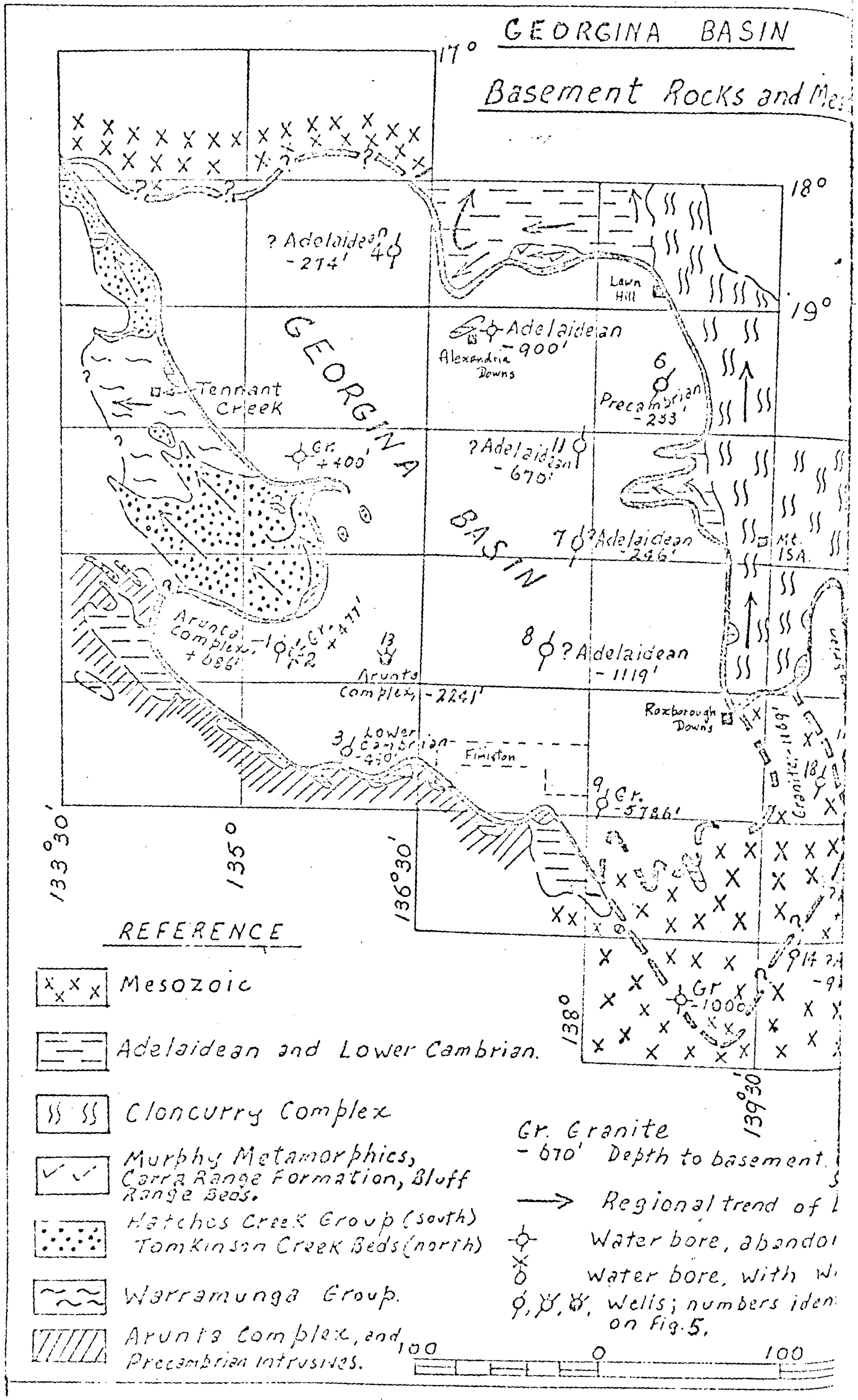
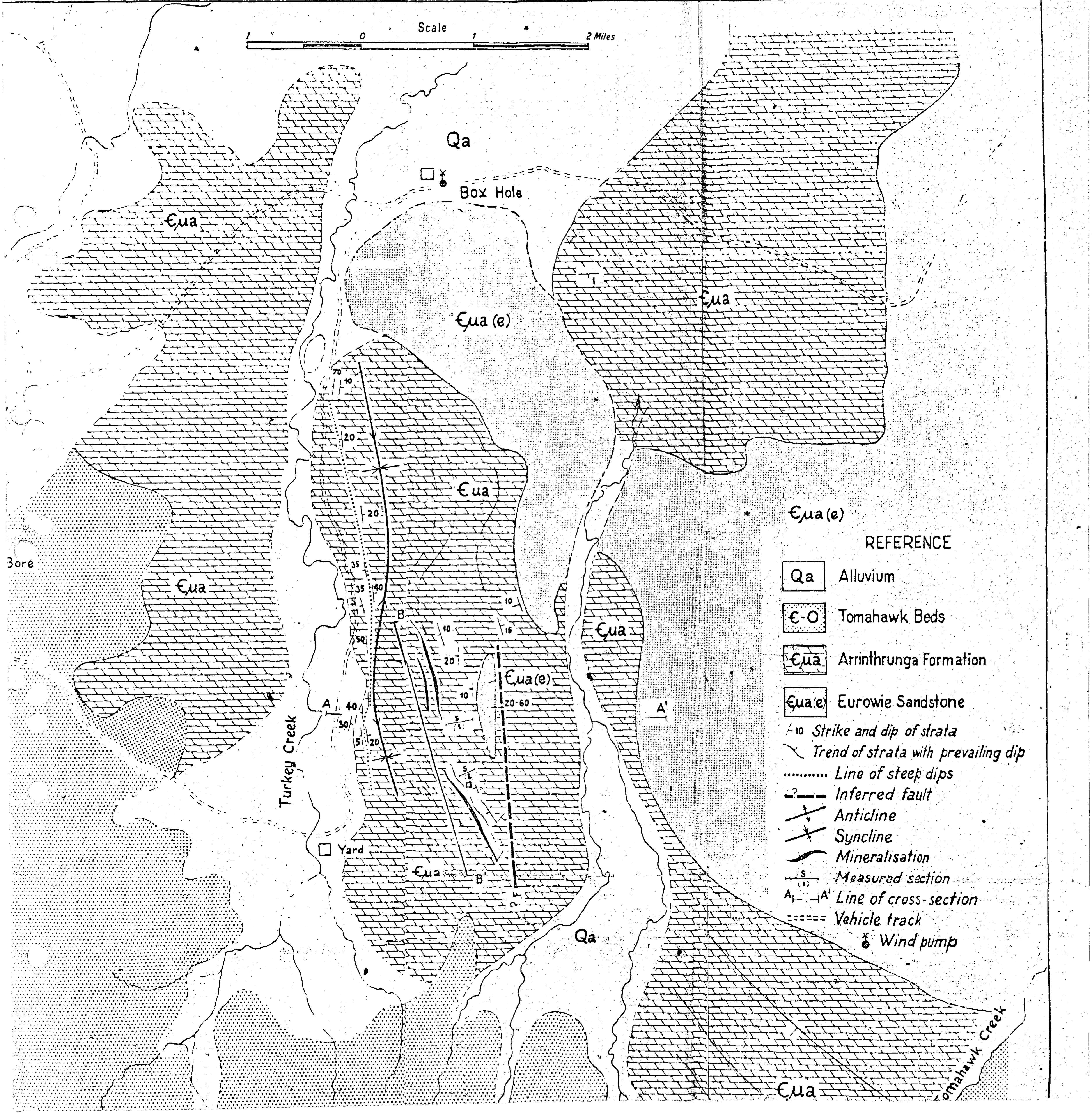
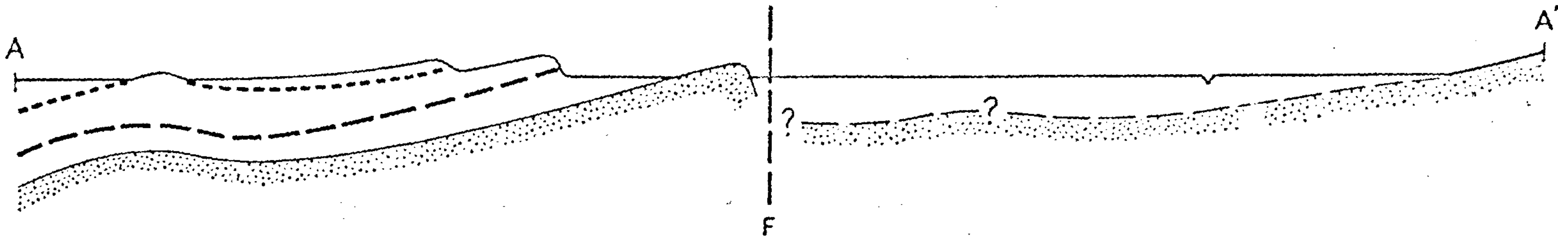


GEORGINA BASIN
Basement Rocks and Mes
17°
18°
19°
GEORGINA BASIN
? Adelaidean 4
- 214'
Adelaidean
- 900'
Alexandria Downs
Lawn Hill
6
Precambrian
- 253'
Tennant Creek
Gr.
+ 400'
? Adelaidean 11
- 670'
7 ? Adelaidean
- 296'
Mt. ISA.
Arunta Complex, + 686'
1 Gr. + 477'
2
13
Arunta Complex, - 2241'
8 ? Adelaidean
- 1119'
Roxborough Downs
3 Lower Cambrian
- 450'
Finiston
9 Gr.
- 5786'
Granite - 1169'
18
Gr
- 1000'
14
133°30'
135°
136°30'
138°
139°30'
REFERENCE
Mesozoic
Adelaidean and Lower Cambrian.
Cloncurry Complex
Murphy Metamorphics, Carra Range Formation, Bluff Range Beds.
Hatches Creek Group (south) Tomkinson Creek Beds (north)
Warramunga Group.
Arunta Complex, and Precambrian intrusives.
Gr. Granite
- 670' Depth to basement
Regional trend of
Water bore, abando
Water bore, with w
Wells; numbers iden on Fig. 5.
100
0
100

GEOLOGICAL MAP OF BOX HOLE AREA

PLATE 1





LEGEND

DOLOMITE

SANDSTONE

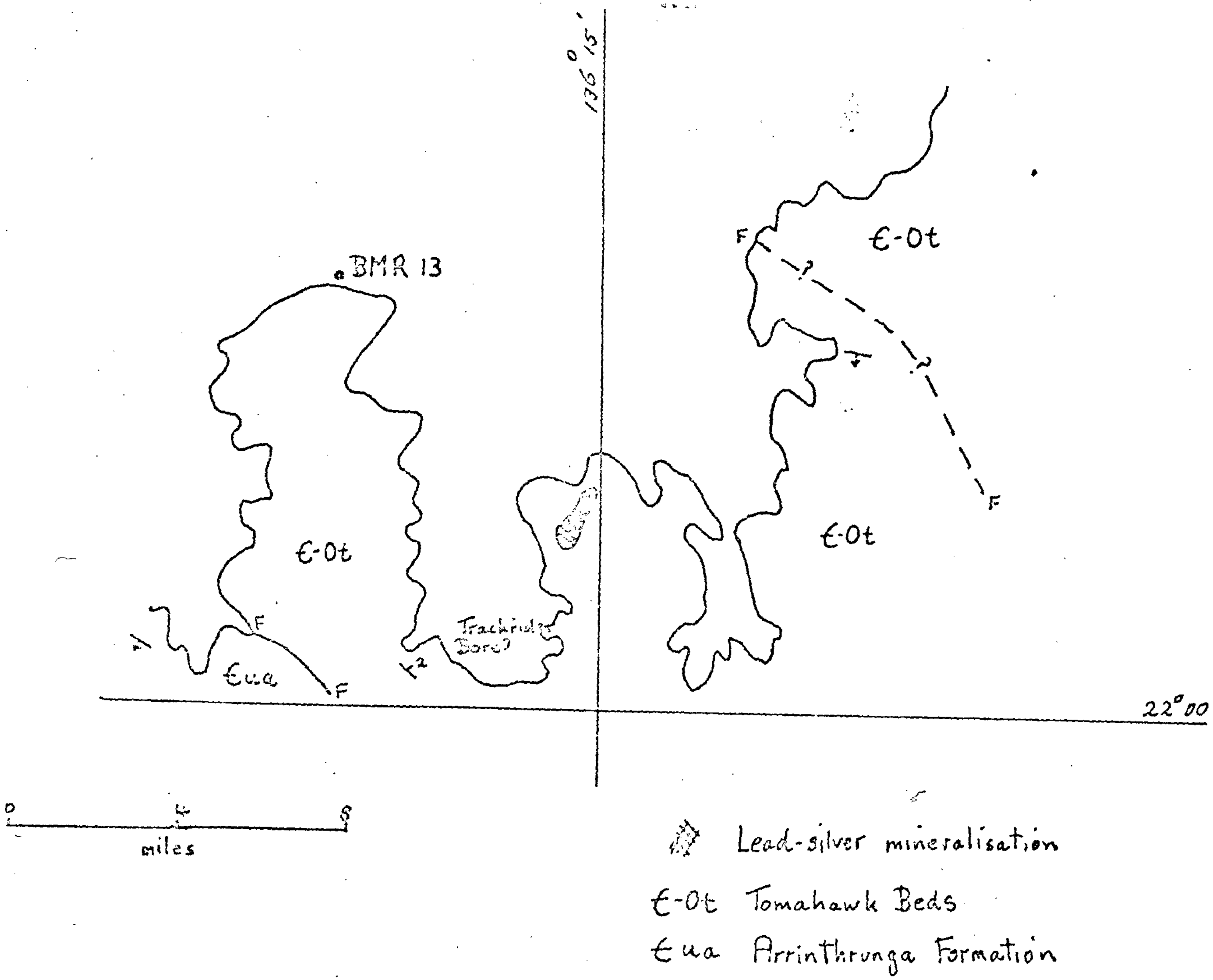
MAIN (LOWER) ORE BEARING HORIZON

UPPER ORE BEARING HORIZON

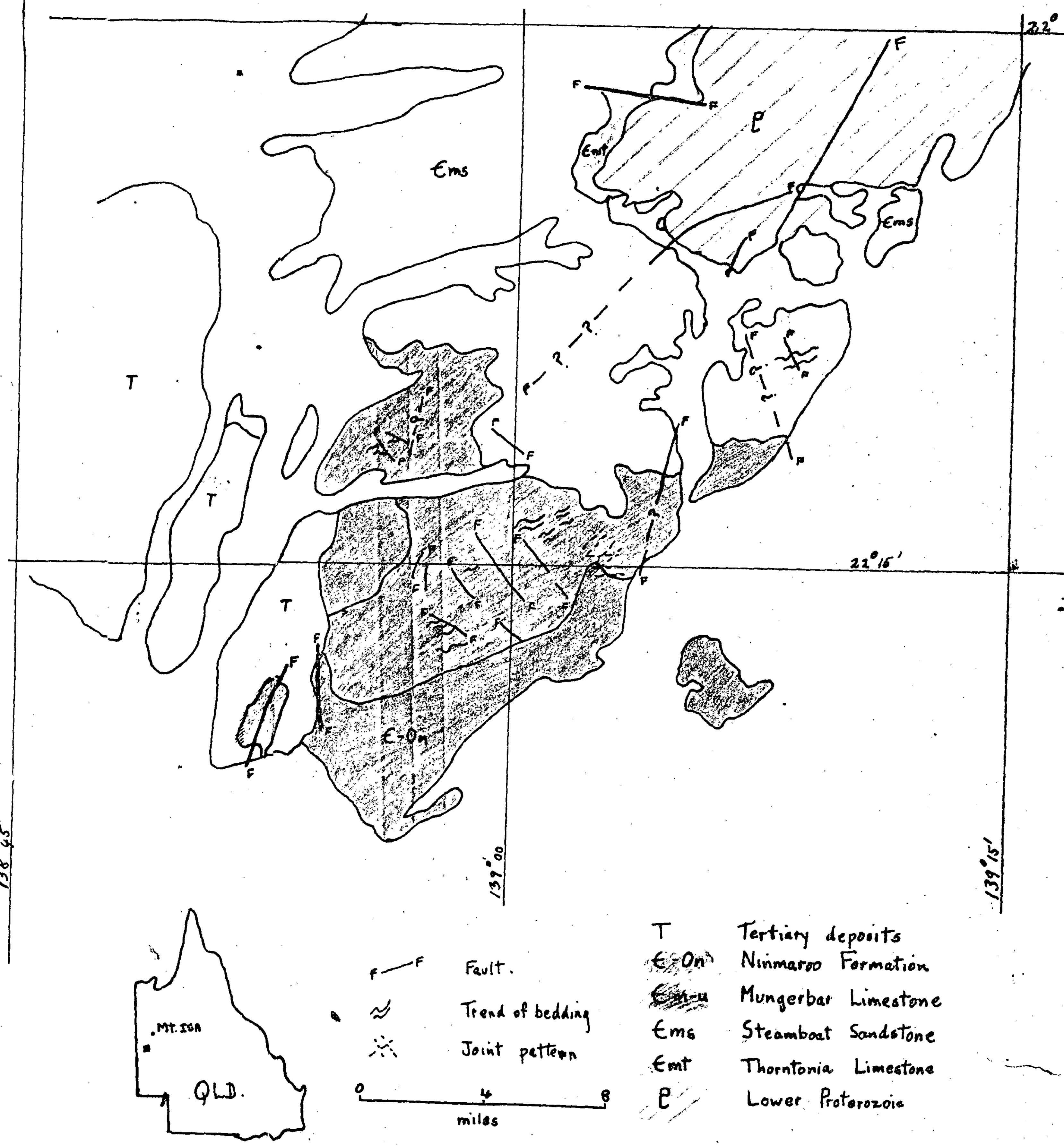
SCALE

0 3000' 6000' 9000'

Diag: 2 PROBABLE SECTION THROUGH AA', PLATE I
(from BMR Record 1961/42)



Diag: 3. Geological Map of the Ooratippra Lead Occurrence.



Diag: 5. Geological Map of the Roxborough Downs Area.

THE GEOLOGY OF THE

MISSISSIPPI VALLEY TYPE LEAD -ZINC ORE DEPOSITS

PART 111 - SOUTHERN GEORGINA BASIN GEOLOGY

1971/18

By: J.B. KEENE

This report on Mississippi Valley Type Lead-Zinc ore deposits is the third of a series consisting of three parts :-

Part 1	:	*Major World Occurrences*
Part 11	:	*Australian Occurrences and Exploration Prospects*
Part 111	:	*Southern Georgina Basin Geology*

22nd March, 1971.

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INTRODUCTION

This report describes the stratigraphy and structure of the southern Georgina Basin and suggests possible environments of deposition in the area. In this part of the Georgina Basin lead mineralisation of the Mississippi Valley type has been found and it is possible other deposits occur. Emphasis is placed on the geology of the exploration areas held by Metals Investment Holdings N.L. and Fimiston Minerals N.L. These areas are shown on Map 1.

From the structure and palaeoenvironments, together with the information on the stratigraphy, it is possible to define features which are considered necessary for the location of ore bodies. The features characteristic of Mississippi Valley type ore bodies have been described in Part 1 of this report. This study helps to locate exploration targets, which can then be tested.

REGIONAL STRATIGRAPHY

The Cambrian-Ordovician stratigraphy, described below, has been taken largely from Smith (B.M.R. Record 1967/61) who has collected and summarised all the relevant information from the authors listed in the bibliography. Table 1 summarises the stratigraphic sequence described below and Diag. 1 is an index of maps covering the Georgina Basin.

(1) MARQUA BEDS (lower to upper Middle Cambrian)

Smith & Vine (1960) applied the name to a sequence of fossiliferous blue chert, silicified shale and siltstone, limestone and calcareous sandstone which lies between the Field River Beds below, and the Arrinthrunga Formation above.

There may be breaks in the sequence.

Type section: lat. 22°53'S, long. 137°39'E, about ½ mile north of the junction of station tracks leading to Noakes Bore and to Craigie Dam, about 50 yds. west of an old track which lead north from this junction.

Occur in B.M.R. (12)
Netting Fence No. 1.
Lucy Creek No. 1.

Lithology

Blue and white chert, buff and white silicified shale and siltstone, blue, grey and black fine-grained flaggy limestone, grey sandy limestone, brown and cream medium-grained calcareous sandstone. In the subsurface, light grey calcareous sandstone, light grey microcrystalline, argillaceous limestone, and minor dark grey and black pyritic siltstone (B.M.R.12); light grey to dark grey siltstone, grey and fawn limestone, black micaceous shale, dolomitic limestone and sandstone (Netting Fence No. 1).

Thickness: Reference section is 675 feet thick.

South-east Tarlton Range	-	925 feet
B.M.R. 12	-	1,279 feet (2,721-4,000 ft.)
Netting Fence No. 1	-	1,300 feet
Lucy Creek No. 1	-	1,200 feet (2,400-3,600 ft.)

Contacts: In outcrop the Marqua Beds rest unconformably on the Field River Beds or have a fault contact.

In Netting Fence No. 1 the Marqua Beds rests on a granite.

The Marqua Beds are overlain by the Arrinthrunga Formation in outcrop and in B.M.R. 12. No evidence of an unconformity is known, but a disconformity may separate the two units. In Netting Fence No. 1 an unconformity is suggested.

Fossils: Trilobites and phosphatic brachiopods common. (trilobite species identical to Sandover Beds).

Correlates: The Arthur Creek Beds. (Huckitta Sheet)

Description and Comment: Except for a basal band of blue chert the lower units do not crop out strongly.

Higher units consist mainly of limestone, sometimes as prominent ridges, but often poorly exposed. Pattern is evident on air-photos; the limestone usually supports a dense vegetation of gidyea. Lenses of sandstone occur in the top of the unit.

Type section is:

Unit 3	- 30 ft.	Sandstone;	calcareous, brown & buff, medium-grained, flaggy, trilobite fragments.
Unit 2	- 530 ft.	Limestone;	blue, fine-grained, medium and thin bedded, trilobite fragments.
Unit 1	- 105 ft.	Shale;	buff, white, hard, silicified, thin-bedded, abundant trilobites.
	10 ft.	Chert;	blue.
	675 ft.	Unconformably overlying Field River Beds Dolomite.	

The sequence measured south-east of the Tarlton Range is similar but contains a 250 ft. section of blue and blue-black laminated limestone having a petroliferous odour when freshly broken. The overlying sandstone is cross-bedded with worm trails.

The sandstone of unit 3 occurs in B.M.R. 12 (2,721-2,790 ft.) as a calcareous sandstone and sandy and argillaceous limestone. The beds in the well are horizontal.

Netting Fence No. 1 (Marqua Beds 5,080-5,680ft.), limestone and interbedded siltstone (5,680-6,420 ft.) and dolomite (6,420-6,590 ft.)

The subsurface extent of the Marqua Beds is unknown; they could be present on the eastern (downthrown) side of the Toomba Fault and have not been identified east of B.M.R. 12, but are assumed to extend northwards and to be contiguous with a thin Middle Cambrian sequence in Mulga No. 1.

The Marqua Beds are unmetamorphosed but they have been affected by strong faulting movements during the Alice Springs Orogeny.

B.M.R. 12 has more limestone in upper half; sandy in bottom half. Netting Fence has a lot of shale/siltstone. Lucy Creek is quite sandy except basal dolomite (3,530-3,600 ft.) and near top limestone (2,500-2,600 ft.)

(2) ARRINTHRUNGA FORMATION

The type section is near the north-western end of the Elyuah Range (22°41'15" S, 135°40'E). (Huckitta)

Distribution: Outcrop extensively in the north-eastern corner of the Huckitta Sheet does not occur as outcrop or in subsurface west of this. Tobermory Sheet: Outcrops south-east of the Tarlton Range and continues south-east in narrow belts, on the eastern side of the Craigie Fault.

Identified in:	B.M.R. 13	-	50 - 2,235 feet
	B.M.R. 12	-	490 - 2,720 feet
	Netting Fence No. 1		

Lithology: Dominantly carbonate rocks, with interbeds of siltstone and sandstone. Main lithologies are crystalline dolomite, algal dolomite, oolitic and pelletal limestone and dolomite. Red and green siltstone is common in the middle part of the sequence, and thin quartz sandstone interbeds are common throughout, but usually crop out poorly. One quartz sandstone is the Eurowie Sandstone Member.

Thickness: Maximum measured thickness is 3,200 feet, east of Yam Creek (Huckitta Sheet). The sequence is about 3,000 feet in much of the Huckitta Sheet area; it thins eastward to about 2,000 feet in the Tarlton Range - Toko Range area, e.g. 2,236 feet in B.M.R.12.

Contacts: Conformably overlies the Middle Cambrian Arthur Creek Beds in the Lucy Creek Station area (eastern Huckitta Sheet). The formation may be unconformable on the Mount Baldwin Formation in the Elyuah Range; in the east, it is apparently conformable on the Marqua Beds, and in many places is faulted against the Adelaidean Field River Beds.

In the west (Huckitta Sheet) it is overlain disconformably by the Tomahawk Beds in some places, and apparently conformably in others; in the east it is overlain apparently conformably by the Ninmaroo Formation.

Fossils: These are rare; some trilobites, brachiopods and hyolithids.

Age: Upper Cambrian.

Correlates: Part of the Meeta Beds, and the Georgina Limestone of western Queensland.

Description and Comment: In the type section the sequence is steeply-dipping and overturned. Carbonate rocks and interbedded siltstones and sandstones are typical of the formation in the western and central parts of the Huckitta Sheet with rare 50 ft. beds of limestone (partly oolitic), a 30ft. sandstone (quartz, brown, coarse-grained, cross-laminated, numerous mud pellets), 36 ft. dolomite (blue/brown, medium-bedded).

To the east the formation can be subdivided into 4 units, in descending order:

Unit 4: Hard, brown dolomite, some prominent interbeds of blue and blue-black oolitic and algal limestone, minor interbeds of thin quartz sandstone, red and green siltstone, buff, soft, fine-grained dolomite.

Unit 3: Brown quartz sandstone with ripple marks and halite casts - the Eurowie Sandstone Member.

Unit 2: Poorly-outcropping blue oolitic limestone, blue algal limestone, buff dolomite, thin quartz sandstone, minor red and green siltstone; numerous concealed beds, probably siltstone.

Unit 1: Hard, thick and medium-bedded, brown and dark brown dolomite with chert nodules, and minor quartz sandstone. This unit crops out strongly.

There are many changes along strike from limestone to dolomite and from dolomite to quartz sandstone, particularly in unit 4. The broad division of units is easily recognisable in the eastern Huckitta Sheet area, and can also be recognised, in part, in ourcrops in the eastern part of the Tobermory Sheet area. However, unit 3 is not known in the western part of the Huckitta Sheet area, nor is it known in the Tobermory Sheet where, in general, outcrops contain more limestone and less dolomite than the sequence in the Huckitta Sheet; however, this is not borne out by the interpreted lithology log of B.M.R. 12 (Cockroach), which shows a preponderance of dolomite.

There may be a disconformity between the Arrinthrunga Formation and underlying sequences.

The only well which has penetrated the complete sequence is B.M.R. 12 (Cockroach), but B.M.R. 13 (Sandover)provided a good record of unit 2.

The Arrinthrunga Formation has not been recorded in Netting Fence No. 1 but a dominantly carbonate sequence in the interval 2,381-5,080 feet, below the Ninmaroo Formation, is best placed in the Arrinthrunga Formation.

The contacts of the Arringhrunga Formation with underlying and overlying sequences are seldom definitive. At the lower boundary the formation is, in most places, apparently conformable on Middle Cambrian Units, but in the Elyuah Range it may be disconformable on the Mt. Baldwin Formation or Arthur Creek Beds.

There is ample evidence north-west of Huckitta homestead that the Cambro-Ordovician Tomahawk Beds have transgressed several older units, but in the Huckitta area itself, i.e. in a deeper part of the Georgina Basin, the Arrinthrunga Formation and the Tomahawk Beds appear conformable and gradational, although the sandstone at the base of the Tomahawk Beds could indicate a new set of environmental conditions. Further east in the Lucy Creek area, the top unit of the Arrinthrunga Formation is thinner than normal; this may indicate erosion, and another erosional break is indicated in the region of B.M.R. 13 (Sandover), where the Tomahawk Beds overlie beds high in unit 2 of the Arrinthrunga Formation. In the Tobermory, Hay River and Mount Whelan Sheet the Arrinthrunga Formation is succeeded by other carbonate formations, and the boundary is difficult to determine. In all areas there is a lack of palaeontological data.

In the subsurface, the Arrinthrunga Formation has a wide extent and is almost certainly contiguous with the Meeta Beds, which are correlated ligholologically with lower parts of the formation.

The formation may be concealed in the west.

A striking feature of the lithology of the Arrinthrunga formation is the abundance of oolites and algae, particularly in the upper parts of unit 2 and the lower parts of unit 4. The algae are usually in dome shaped colonies, each dome consisting of many individual "rods" of Collenia. One easily-accessible algal locality is 4 miles S.E. of Lucy Creek homestead, near the track leading to the Tarlton Downs - Jervois road.

The main structural features in the Arrinthrunga Formation are faults trending north-west, with the eastern blocks downthrown. In the Dulcie and Toomba Range areas these can be dated as post-Upper Devonian and it is assumed that most, if not all, of the other faults are of the same age. Some of the faults are up to 60 miles long and the throws are of the order of several thousands of feet but cannot be determined accurately because it is not known what has been eroded from Adelaidean rocks.

Associated with the faults are several small drag folds, both anticlines and synclines; however, folding movements have not affected the Arrinthrunga Formation.

Both Huckitta No. 1 and Lucy Creek No. 1 were drilled on anticlines which appear to be the result of basement highs.

(3) EUROWIE SANDSTONE MEMBER

Derivation of Name: From Eurowie Yard (lat. 22°29', Long. 135°55')

Lithology: Quartz sandstone, red-brown, medium-grained, laminated to thin-bedded, with some beds of fine-grained quartz sandstone and siltstone near the base; some sandstone is dolomitic and grades vertically and laterally to dolomite in its upper levels.
Abundant ripple-marks, small-scale cross-beds, halite casts,

mud cracks and mud pellets are features of the member.

Thickness: Ranges from 50-100 feet.

Contacts: The base usually has a sharp, conformable contact with the underlying limestone and dolomite, but the top usually grades vertically, and sometimes laterally, into dolomite.

Fossils: None found.

Description and Comment: The weathered red-brown colour of the Eurowie Sandstone Member gives a dark, easily followed pattern on air photographs. Fresh sandstone samples are white. Many beds are slumped and dips are often very irregular.

The member has no known equivalent in the Tobermory or Hay River Sheets.

(4) MEETA BEDS

Derivation of name: From Meeta Bore (lat. 21°27', long. 137°15').

Distribution: Neither the base nor the top of the sequence is exposed.

Lithology: Predominantly dolomite on the surface, with interbeds of quartz sandstone and siltstone. Fragmentary secondary chert is very common on the surface and some oolitic limestone beds are known.

Thickness: A complete sequence is unknown but the thickness probably exceeds 1,000 ft. in most localities. Core holes Grg. 4 and Grg. 14 penetrated 739 ft. and 720 ft. respectively without reaching the base of the sequence.

Fossils: Some gastropods and algae from dolomite beds.

Age: Upper Cambrian (based on lithological correlation with part of the Arrinthrunga Formation).

Correlates: Part of the Arrinthrunga Formation (unit 2 and below).

Description and Comment: The Meeta Beds usually crop out poorly in low rises, often covered with chert scree. These rises are separated by expanses of black soil plains with protruding dolomite blocks or quartz sandstone rubble.

Nichols (1964,1965) reported the lithology of the Meeta Beds in the Sandover River Sheet area as buff, microcrystalline to coarse crystalline dolomite and dolutite; pelletal, medium to thick bedded, medium to well-sorted dolarenite; algal dolomite; buff intraclastic (2-3 cm. long) dolarenite and medium to coarse-grained, ripple-marked, cross-bedded quartz sandstone. In outcrop, the boundary between the Meeta Beds and the overlying Tomahawk Beds is not seen. The Tomahawk Beds consist of dark brown, thick-bedded coarsely crystalline dolomite, with fossiliferous interbeds of sandy dolomite, quartz sandstone and siltstone.

The boundary between the Meeta Beds and the Ninmaroo Formation, in the western part of the Sandover River Sheet, is more difficult due to lack of outcrop.

Subsurface information: In Grg. 14 vughs and pyrite were common in the core from dolomite beds. The Meeta Beds were not logged in Mulga No. 1, however they may be present from the base of the Ninmaroo Formation at 190 feet to 1,060 feet. This was logged as Arrinthrunga Formation.

(4) TOMAHAWK BEDS

The type section is at the south-eastern end of the Dulcie Range. (lat. 22°38', long. 135°50').

Lithology: Usually a basal sandstone with interbeds of siltstone grading laterally and vertically into dark brown and grey-brown dolomite, grey limestone, grey and brown sandstone, and green siltstone; this is succeeded by grey and brown sandstone with brown, sandy dolomite. Northwest of the Bundey River the outcrops contain much more sandstone and conglomerate and less carbonates.

Contacts: In the central part of the Huckitta Sheet area the Tomahawk Beds are conformable on the Arrinthrunga Formation, but in other parts they are either faulted against that formation or are disconformable on it. Northwest of the Bundey River, the Tomahawk Beds transgress several units of Precambrian rocks, on the Sandover River Sheet they are probably disconformable on the Meeta Beds; on the Tobermory Sheet the Beds are equivalent to the Kelly Creek and Ninmaroo Formations.

In the Huckitta - Alcoota - Barrow Creek Sheets area Devonian rocks unconformably overly the Beds.

Fossils: Trilobites, bivalves, brachiopods and ribeirioids are abundant.

Age: Upper Cambrian - Lower Ordovician.

Description and Comment: The beds form an extensive sheet of flat lying sediments which are always gently dipping except near faults and on the limbs of sharp folds. High fossil content and abundant glauconite are characteristic. The sandstone and sandy siltstone beds are often slumped. In the Tarlton Range area the Upper Cambrian - Lower Ordovician sequence consists of carbonate rocks, sandstone and siltstone with rapid lateral changes. Weathering gives an effect of more "sandstone" in the sequence.

The boundary between the Tomahawk Beds and the Ninmaroo Formation is a broad division between a fossiliferous sandy formation in the west, and a less fossiliferous carbonate formation (Ninmaroo Formation) on the east. This relationship is shown in Diag. 5.

(6) NINMAROO FORMATION

The type section is at Mount Ninmaroo (lat. 22°32', long. 140°18').

Lithology: Calcarenite, quartz sandstone, siltstone, dolarenite, limestone, oolitic limestone and dolomite in the Tobermory Sheet and Sandover River Sheet.

Thickness: 1,120 feet in Netting Fence No. 1 (1,261-2,381 ft.) about 900 feet in the western flank of the Toko Syncline (Smith and Vine 1960) and 425 feet plus in the Sandover River Sheet (Nichols, 1964).

Contacts: The Ninmaroo Formation is ? disconformable on the Arrinthrunga Formation and the Meeta Beds. It grades laterally into the lower part of the Tomahawk Beds and is overlain conformably by the Kelly Creek Formation.

Fossils: Contains nautiloids, gastropods, brachiopods, ribeirioids, trilobites, echinoderms and algae.

Age: Late Upper Cambrian - Lower Ordovician.

Description and Comment:	Grg. 11	-	0 - 456 feet
Subsurface:	B.M.R. 12	-	0 - 485 feet
	Mulga No. 1	-	0 - 190 feet

The dip is usually low (towards the Toko Syncline) except in slump structures and near the Craigie and Toomba Faults. Strong joint patterns are common in the Formation.

In the Sandover River Sheet the Ninmaroo Formation and the Meeta Beds are distinguished by the presence of oolitic chert and quartz sandstone in the Meeta Beds.

(9) KELLY CREEK FORMATION

The type section is from Gaphole Creek (lat. 22°58', long 137°54').

Lithology: Quartz sandstone, calcareous sandstone, siltstone, dolomite, calcarenite, coquinite with lenses of white chert.

Thickness: 550 feet in the type section, 400+ feet in the Toomba Range, 250 feet in the Tarlton Range and 361 feet in Netting Fence No. 1 (900 ft. to 1,261 ft.).

Contacts: The Kelly Creek Formation conformably overlies the Ninmaroo Formation and is overlain disconformably by the Coolibah Formation in the Toko Range, and disconformably by the Nora Formation in the Tarlton Range.

Fossils: Contains abundant nautiloids, trilobites, brachiopods, ribeirioids and gastropods.

Age: Lower Ordovician.

Description and Comment: Good outcrops are available in the scarp on the eastern side of the Tarlton Range, and in isolated mesas near the southeastern end of this Range.

In the Tarlton Range the Kelly Creek Formation consists of calcareous micaceous sandstone, with interbeds of dolomite, sandy dolomite, green siltstone, and some calcarenite. Glauconite is common in many beds, and fossils are abundant although less numerous than in the Toko Range. The beds of the Formation are gently dipping, except near the Tarlton Fault, and northwest of the Range the formation grades laterally into the Tomahawk Beds. Part of the formation crops out well in several benches, while can be followed for several miles along the scarp of the Tarlton Range. The sequence is considerably thinner than in the Toko Range, and most sections are about 250 feet thick.

West of the Tarlton Range the formation has been identified in Grg. 12 (Milligan, 1963);here it is preserved in a downfaulted block, whose westward extent beneath soil cover is unknown.

(8) TOKO GROUP

The Toko Group consists of four units - in ascending order:

(1) Coolibah Formation

The type area is at lat. 22°45', long. 137°45' on the road from Tobermory homestead to Craigie Dam. The formation has not been recognised in the Tarlton Range.

Lithology: Grey and white limestone, sandy limestone, calcilutite, dolomite and marl, with lenses of white chert.

Thickness: 25 to 50 feet in the type area, 175 feet at Gaphole Creek and 117 feet in Netting Fence No. 1 (783-900 feet).

Contacts: The formation is probably disconformable on the Kelly Creek Formation and is overlain conformably by the Nora Formation.

Fossils: Nautiloids, gastropods, sponges, and ribeirioids.

Age: Lower Ordovician.

(2) Nora Formation

The type area is on the western side of the Toko Range at lat. 22°53', long. 137°49'.

Lithology: Olive-brown and dark brown dolomite and coquinite near the base, succeeded by olive, yellow, grey and purple siltstone and sandy siltstone, and green and brown fine-grained glauconitic sandstone.

Thickness: About 200 feet in the north and north-east of the Toko Range, thickening to about 400 feet in the south-western limb of the Toko Syncline. In the Tarlton Range it is 200 feet thick and in Netting Fence No. 1 it is 373 feet.

Contacts: In the Toko Syncline the Nora Formation is apparently conformable on the Coolibah Formation and is conformably overlain by the Carlo Sandstone; in the Tarlton Range the Nora Formation probably has a disconformity with the Kelly Creek Formation and there is evidence of a disconformity with the overlying Carlo Sandstone at the Pinnacles (Smith, Vine and Milligan, 1961).

Fossils: The lower part of the Nora Formation contains a rich fauna of pelecypods, brachiopods, nautiloids, trilobites, gastropods and bryozoa; shelly fossils are uncommon in the upper part of the formation, but tracks and trails are abundant.

Age: Middle Ordovician.

(3) Carlo Sandstone

The type area is at lat. 23°30', long. 138°40'.

Distribution: Forms the top 20 feet of the Toko Range scarp, and continues south-east on both limbs of the Toko Syncline; also forms the rim of the scarp in the Tarlton Range.

Lithology: Thick and medium-bedded, fine to medium-grained quartz sandstone, with ripple marks and flute casts; in the Tarlton Range clay pellets are common in the lower half of the unit.

Thickness: 60-120 feet in the Tarlton Range; here the top is eroded. Netting Fence No. 1 penetrated Carlo Sandstone from surface to 410 feet.

Fossils: Fossils are not abundant but some nautiloids, brachiopods, pelecypods and worm trails are found in the upper part.

Comment: Measurements of current directions during deposition have been made and the results show that the currents came from the southeast.

(4) Mithaka Formation

The type area is near Wheelaman Bore (lat. 22°52', long 138°16').

Lithology: Brown and grey gypsiferous siltstone and sandstone, white glauconitic quartz sandstone, gypiferous green shale, calcareous siltstone and some thin coquinites.

Thickness: 200-400+ feet in the Toko Syncline, 60+ feet in the Tarlton Range.

Contacts: Conformable on the Carlo Sandstone and overlain unconformably by the Cravens Peak Beds (Silurian - Devonian) in the Toko Syncline.

Fossils: Trilobites, nautiloids, sponges (Receptaculites), and tracks and trails are common.

STRUCTURAL GEOLOGY

The Georgina Basin sediments of the Huckitta and Tobermory-Glenormiston areas were deformed in ? Carboniferous time during an orogeny named locally as the Alice Springs Orogeny (Smith, 1967), but the Boulia area was not affected by this orogeny and the main tectonic events there occurred in Lower Ordovician time with some further faulting near the end of Lower Cretaceous.

The Alice Springs Orogeny was not accompanied by igneous intrusions. Structural deformation is locally intense and consists mainly of parallel faults trending north-west, with the north-eastern blocks down-thrown. These faults are parallel to, and in some cases coincident with, faults in Precambrian basement rocks. The faults are mainly normal with throws of several thousands of feet in some cases, but some overthrusting may have occurred along the south-western flank of the Toko Syncline, in Queensland. The faults shaped the south-western preserved margin of the Georgina Basin, and the south-western flanks of the asymmetric Dulcie and Toko Synclines. A complementary set of faults trending north-east is evident in the northern part of the Toko Syncline; these are normal faults, with the south-east block down and with throws not exceeding 200 feet.

Generally the sediments of the central/southern Georgina Basin are flat lying and contain no pronounced fold structures.

The folding that does exist in the Tobermory-Sandover River area is either related to faulting, due to slumping or a compaction structure over Precambrian highs. Lake Nash No. 1 and Lucy Creek No. 1 were drilled on "draped" structures.

The Tarlton, Craigie and Toomba Faults trend parallel to the major north-west trend of Precambrian rocks and major faults in them.

A series of small anticlines extend from the Craigie Fault in the east, westward to the Tarlton Fault. On the surface this anticline affects the Arrinthrunga Formation, Tomahawk Beds and Kelly Creek Formation.

The dips and distribution of the Arrinthrunga Formation indicate a regional anticline with a shallow pitch to the northwest. The axis of this fold would be roughly midway between the Southern Cross Bore and the eastern edge of the Tarlton Range (Smith and Vine 1960). Field River Beds (Precambrian) in the Red Heart Bore area form the core of this anticline.

Some minor folding and faulting occurs in the western part of Metals Investment Holdings' prospect. Magnetic basement suggests large Precambrian highs in this area.

ENVIRONMENTS OF DEPOSITION

In the north, west and south-west Middle Cambrian sediments were deposited on a broad epicontinental platform with a maximum relief of about 1,200 feet and with several parallel depressions trending north-west. In the eastern part of the Basin the platform opened southwards into deeper water.

Carbonate rocks predominated in early Middle Cambrian and were deposited in shallow water.

Continuous sedimentation from Middle to Upper Cambrian time occurred in the Huckitta-Tobermory area.

Uplift and erosion occurred in Franconian time in the Huckitta-Tobermory area, and the next event was the ingress of a late Upper Cambrian sea which covered the previously deposited Upper Cambrian sediments and in the north-west transgressed onto Precambrian basement; in the north it lapped over early Middle Cambrian sediment. Sedimentation was continuous from late Upper Cambrian until near the end of Lower Ordovician time. The Huckitta area had reverted to platform conditions and only 800 feet of sediment was deposited, while the Toko Syncline area became established as a site of thicker deposition and accumulated about 1,600 feet of sediments in its north-western end and a thicker, but unknown, amount to the south-east. In the vicinity of Mulga No. 1 a magnetic basement of 8,000 feet is indicated and this could be a site for deeper water sediments. A minor break in sedimentation, indicated by fossil evidence, occurred between the Lower Ordovician Kelly Creek and Coolibah Formations.

Only in the Toko Group does the deposition of sand exceed that of carbonate rocks.

Marine sedimentation ended in Middle Ordovician time. The northwesterly trends in the basement could have provided the shallow water environment around which carbonate reefs and banks could develop.

FACTORS RELATING TO POSSIBLE MISSISSIPPI VALLEY TYPE LEAD-ZINC OCCURRENCES

SOURCE OF METALS

Shale and shale-siltstone sequences occur east and north east of the Tobermory area in the Toko Syncline (Netting Fence No. 1 and Mulga No. 1) and could supply the necessary elements. These elements could be transported to the margin of the basin by brines, and, under favourable conditions, be deposited as ores.

ROCK TYPES

Both dolomites and limestones are common in all the beds older than the Toko Group. They are both thick bedded and thin bedded. Evaporite deposits are common in the Kelly Creek Formation. Hydrocarbons, as small quantities of gas, have been found in Ammaroo No. 1, and globules of oil, with some gas, in B.M.R.13. Both of these occurrences were in Middle Cambrian sediments. In B.M.R. 13 the show of oil and gas was from a calcareous, argillaceous and bituminous dolomite between 2,952 and 2,975 feet. Water from this level contained 800 p.p.m. NaCl (Lloyd and Bell, 1964). Petroliferous odours have been reported from fresh specimens of limestone and dolomite in many localities.

POROSITY AND PERMEABILITY

Permeable trends are required for the movement of metal bearing brines and if such horizons can be found they should be examined. Coarsely crystalline carbonate with vughs and/or intraformational breccia enhances permeability.

In Grg. 12 vughs and intraformational breccia are common from 326-410 feet and from 535-755 feet.

In B.M.R. 12 aquifers are found in vuggy and fissile intervals and include:-

DEPTH
260 feet in limestone
290 feet in limestone
505 feet in dolomite
610 feet in dolomite
910-915 feet in fissile dolomite
1,350 feet in dolomite
2,800 feet in limestone

Grg. 11 contains some cavernous horizons in dolomite, namely 110-135 feet, 220-260 feet and 355-360 feet. The total depth of the hole is 456 feet and vughs and pyrite are common throughout.

In Lucy Creek No. 1 the porosity and permeability in the Middle and Upper Cambrian was found to be good. Particularly permeable horizons occur in the Arrinthrunga Formation from 130-310 feet (limestone/dolomite) and in basal Arrinthrunga Formation dolomite at 2,316-2,410 feet. This later interval contains excellent vughs (the velocity log over this interval shows a porosity exceeding 20%). In comparison the limestone of the underlying Marqua Beds is tight. Tables 2 and 3 give the stratigraphic sequence for B.M.R. 12 and Lucy Creek No. 1.

UNCONFORMITIES

The major unconformity is between the Cambrian sediments and underlying Precambrian sediments. Within the Cambrian - Ordovician sequence disconformities occur and it is possible more could be found.

Disconformities occur bwtween the Marqua Beds and Arrinthrunga Formation, Arrinthrunga Formation and Tomahawk Beds, Meeta Beds and Tomahawk Beds, Kelly Creek Formation and Coolibah Formation, Kelly Creek Formation and Nora Formation. The Ninmaroo Formation is ? disconformable on the Arrinthrunga Formation and the Meeta Beds (Smith 1965). These disconformities do not occur throughout the southern Georgina Basin but where located could provide a deposition site for lead and zinc.

STRUCTURE

Anticlines and faults provide good exploration targets. The anticlines are often over Precambrian highs.

CONCLUSIONS

Diagrams 2, 3 and 4 show generalised sections across the area being discussed (see Map 1). Section BB is roughly parallel to the dominant northwest structural trend in this part of the Georgina Basin. All wells in this section bottomed in granite basement and no proven Lower Cambrian or Upper Proterozoic sediments were found. It is likely that the arbitrary pick of 207 feet of Lower Cambrian in B.M.R. 12 (Sandover) is incorrect as it is not supported by fossil evidence and the unit is lithologically similar to the basal dolomite unit of the Marqua Beds in Lucy Creek No. 1. Table 4 shows the analysis of cores from B.M.R. 13. The values for Cu, (up to 100 p.p.m.) and V (up to 500 p.p.m.) are not unusual considering the rock analysed was shale.

Section AA cuts the structural trend almost at right angles and section CC is similar, but related to outcrop along the southern margin of the basin. Several porous dolomite beds occur.

The most promising areas for mineralisation occur in the southern portion of Fimiston Minerals' prospect where dolomites of the Arrinthrunga Formation outcrop. Porous beds, perhaps related to algal reefs, if located along the flanks of the anticlines which occur in the area would provide an exploration target. This area is further enhanced by the pinching out of Cambrian strata, particularly Arrinthrunga Formation, against the basement rocks and by the occurrence of faults which may help to localise mineralisation.

In the Tobermory and Hay River area there is evidence that Middle Cambrian sediments (Marqua Beds) rest unconformably on various units of the Field River Beds. Around the margins of the Basin the Arrinthrunga Formation overlaps the Middle Cambrian and consequently lies unconformably on older rocks. This only occurs if the basin margin is not faulted.

On the Sandover River Sheet the Meeta Beds (probably equivalent to the Arrinthrunga Formation) outcrop sporadically above sand and alluvium. However, some folding is present in outcrop on the western part of Metals Investment Holdings' area and dolomite/limestone beds favourable for mineralisation do occur.

APPENDIX

SOIL SAMPLES ANALYSED BY THE C.S.I.R.O. FROM THE TARLTON DOWNS AREA

(Murray and Woolley, 1968)

A small tree, called gidyea, which grows in the Georgina Basin is often poisonous for livestock and the C.S.I.R.O. has attempted to determine the cause of this toxicity. Gidyea is toxic only when growing within outcrop areas of the Ninmaroo Formation.

Soil samples were obtained down to the base of the soil profile or to a depth of 10 feet (where bedrock was not reached) at the following localities:

Area		Formation	Depth (ft.)	Deep Soil pH	Deep Soil Total fluoride p.p.m.	Surface Soil pH
2	No.2 Bore Tarlton Downs	Nora	- 10	6.9-8.6	34- 870	6.3-8.6
3	No. 6 Bore Manners Creek	Ninmaroo	- 8	6.0-9.3	36-2060	5.3-8.8
4	Coles Bore Manners Creek	"	- 6	7.2-9.0	34-1130	5.3-8.9
5	No.11 Bore Manners Creek	"	- 8	6.1-9.0	44- 255	6.0-8.9
6	No. 2 Bore Tobermory	"	- 10	5.7-8.5	77- 415	5.3-8.7
7	Goatyard Bore Tobermory	"	- 9	6.3-8.9	20- 354	6.3-8.9

Some surface soil samples were analysed for a number of additional factors. The range of results were:-

Available phosphorus	2 - 70 p.p.m.
Carbonate	0 - 3.4%
Clay	3.7 - 23.7%
Zirconium	0.035 - 0.055%
Calcium (HCl sol.)	0.048 - 0.60%

More than 100 samples were taken from each location. In all areas bedrock was fresh or weathered limestone/dolomite with sandstone occurring at five holes in one small section of area No. 2 and at one hole in area No. 3.

Further details including samples if required can be obtained from Mr Murray (National Biological Standards Laboratory, P.O. Box 462, Canberra City).

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TABLE 1.

TOBERMORY - SANDOVER RIVER STRATIGRAPHY

Age	Name	Symbol	Thickness (ft.)	Comment
M. - L. Ord.	Toko Group			
	(1) Mithaka Fm.	Omm	5-200	
	(2) Carlo Sandstone	Omc	100-250	
	(3) Nora Fm.	Omn	200-300	
	(4) Coolibah Fm.	Olc	175	
L. Ord.	Kelly Creek Fm.	Olk	250-550	laterally equivalent to upper Tomahawk Beds.
L. Ord. - U. Camb.	Ninmaroo Fm.	Є-On	500-840	laterally equivalent to lower Tomahawk Beds.
	Tomahawk Beds	Є-Ot	200-400	
U. Camb.	Meeta Beds	Єum	1,000 +	
U. Camb.	Arrinthrunga Fm.	Єua	400-2,000	
M. Camb.	Marqua Beds	Єmf	1,280	

TABLE 2.

B.M.R. 12 (COCKROACH) - STRATIGRAPHIC TABLE

Interval(ft)	Lithology	Thickness	Age	Unit
25- 180	Limestone, claystone	155	L.Ord.	
180- 485	Limestone, dolomite Clay-siltstone Quartz sandstone	305	U. Camb.	Ninmaroo Fm.
485-1,035	Dolomite Limestone Clay-siltstone	550	U. Camb.	
1,035-1,160	Limestone, dolomite	125		Arrinthrunga Fm.
1,160-1,315	Dolomite, limestone	155		
1,315-1,510	Dolomite, limestone, quartz sandstone	195		
1,510-2,721	Limestone, dolomite, clay-siltstone, quartz sandstone.	1,211		
2,721-3,250	Limestone, Calcareous, quartz, sandstone	529	M. Camb.	Marqua Beds
3,250-4,000	Calcareous, quartz sandstone, limestone	750 +		

TABLE 3.

LUCY CREEK NO. 1 - STRATIGRAPHIC TABLE

Tomahawk Beds (14-66 ft.)

Sandstone (tan, very fine to fine, porous, gypsiferous) with interbedded yellow/green argillaceous siltstone. Red, yellow, black mottled chert at base.

Arrinthrunga Formation (66-2,410 ft.)

66-905:	dolomite, buff to brown, cryptocrystalline to medium crystalline, occasionally sandy. Bed of grey/green dololutite at 884 ft. Two cherty zones in lower 60 feet. Rare vuggy porosity (540-550 ft.). Pyrite.
905-987:	sandstone, clean white, fine to very fine, well sorted. Towards base is interbedded with buff, cryptocrystalline cherty dolomite. (occurs stratigraphically lower than Eurowie Sandstone Member).
987-1,280:	Interbedded dolomite, sandstone, shale, siltstone, limestone. Scattered vughs. Partly oolitic dolomite and limestone in last 80 ft. Large vughs 1,170-1,180 feet.
1,280-2,316:	limestone beds 120 feet thick. Also siltstone, shale sandstone, dolomite. Vuggy.
2,316-2,410:	dolomite, light grey to dark brown. Excellent vughs.

Marqua Beds (2,410 - 3,600 ft.)

2,410-3,535:	fine sandstone and limestone. Poor porosity. Black shale towards base.
3,535-3,600:	dolomite, fine grained, pyrite, partly porous.

Precambrian Granite

TABLE 4.

SPECTROGRAPHIC ANALYSIS B.M.R. 13

ANALYSIS OF DARK GREY AND BLACK SHALES

(p.p.m.)

DEPTH (ft.)	SEQUENCE	Ni	Co	Cu	V	Pb	Mo
250 - 260	Shale	10	20	25	150		
270 - 280	Shale	12	20	5	500		
280 - 290	Shale	12	20	10	300		
440 - 450	Shale	5	12	10	100		
470 - 480	Dolomite	15	30	25	300	10	
520 - 530	Shale and dolomite	15	20	20	300	5	
560 - 570	Shale and some dolomite	15	20	15	50	10	50
570 - 580	Shale and some dolomite	5	12	15	50		
600 - 610	Shale	5	12	15	50	10	
620 - 630	Shale and dolomite	10	20	100	200		
1010 -1020	Siltstone and some dolomite	10	30	50	300	5	
1030- 1040	Siltstone and some dolomite	20	60	50	300	5	
1055 -1060	Shale	15	15	10	300		
1140- 1150	Siltstone	20	30	10	50	5	
1610- 1620	Shale, becoming dolomite	5	20	20	200	10	
1620- 1630	Shale, becoming dolomite	5	12	15	50	50	50

Sn, Zn and P were sought but not detected in any sample.

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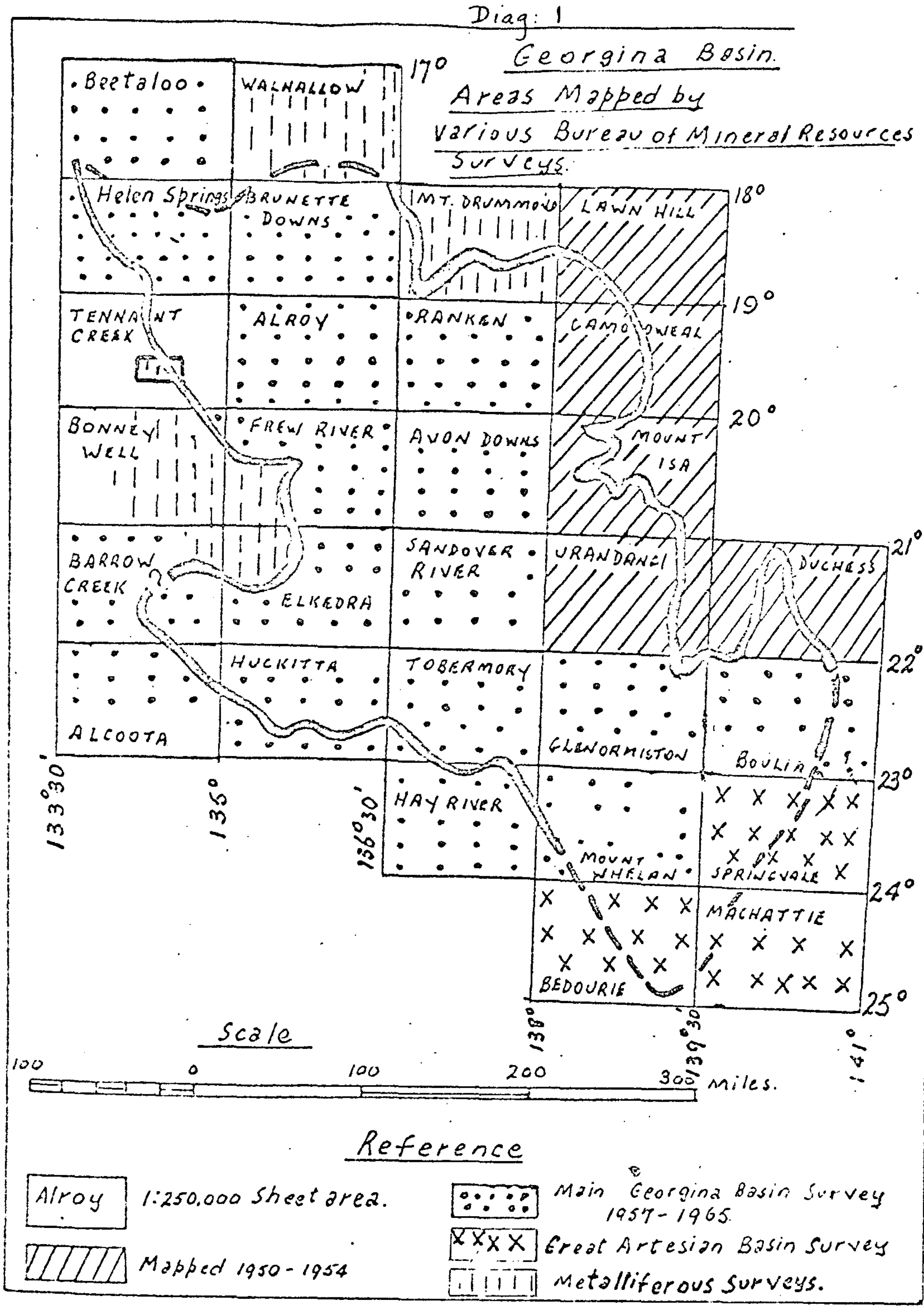

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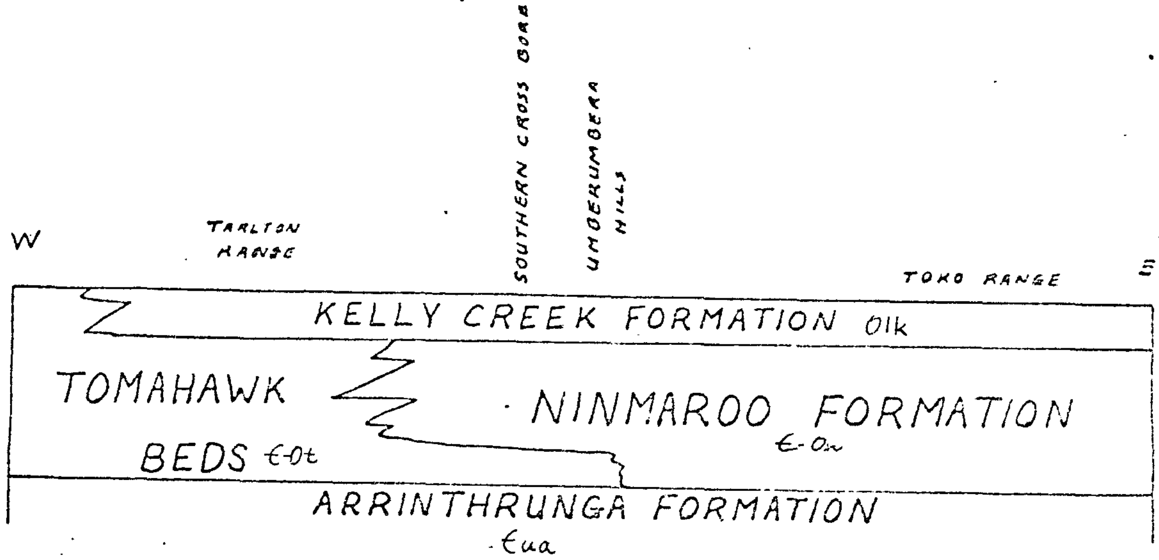
DIAGRAMATIC SECTION THROUGH UPPER CAMBRIAN & LOWER ORDOVICIAN ROCK UNITS



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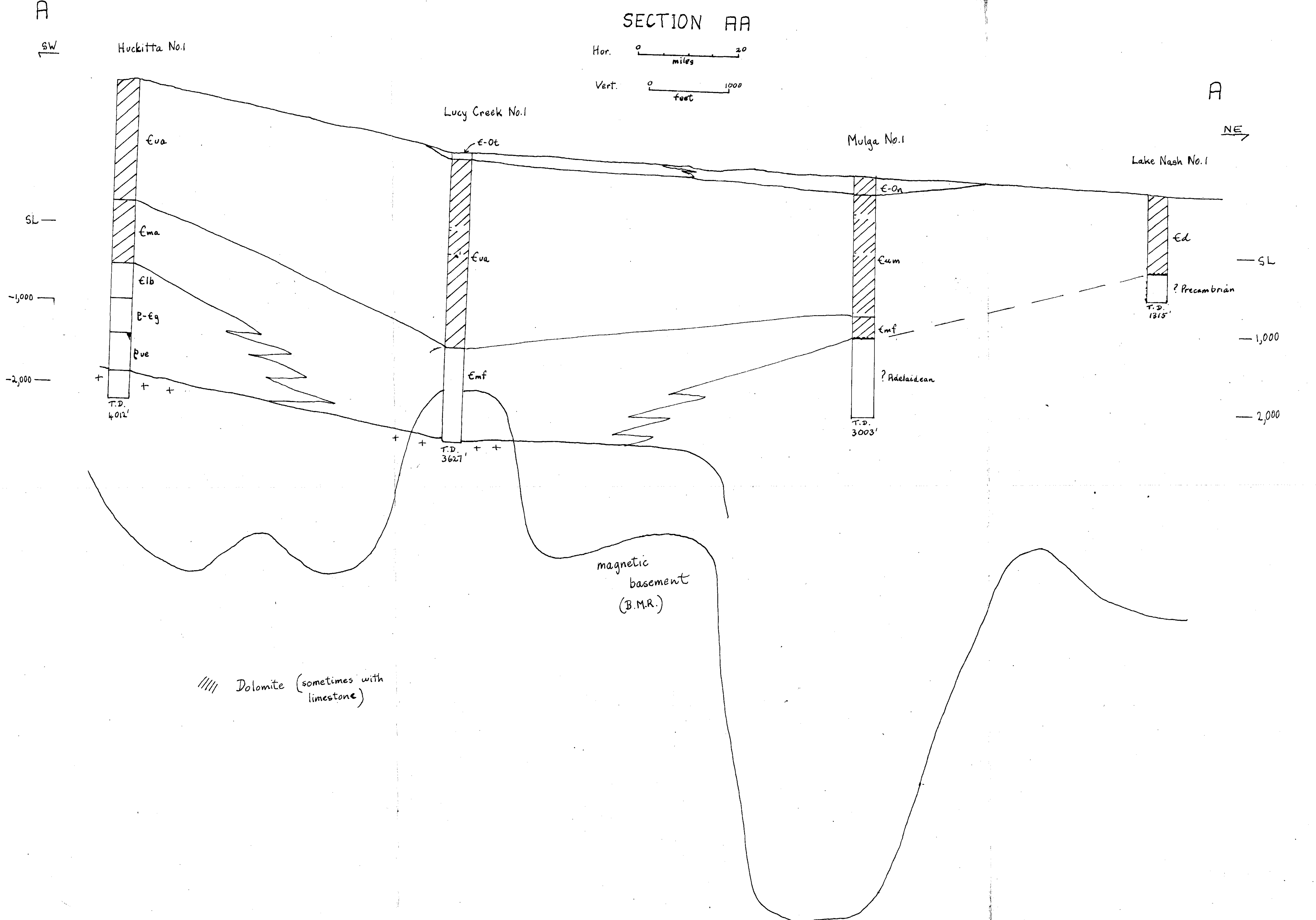
SECTION AA



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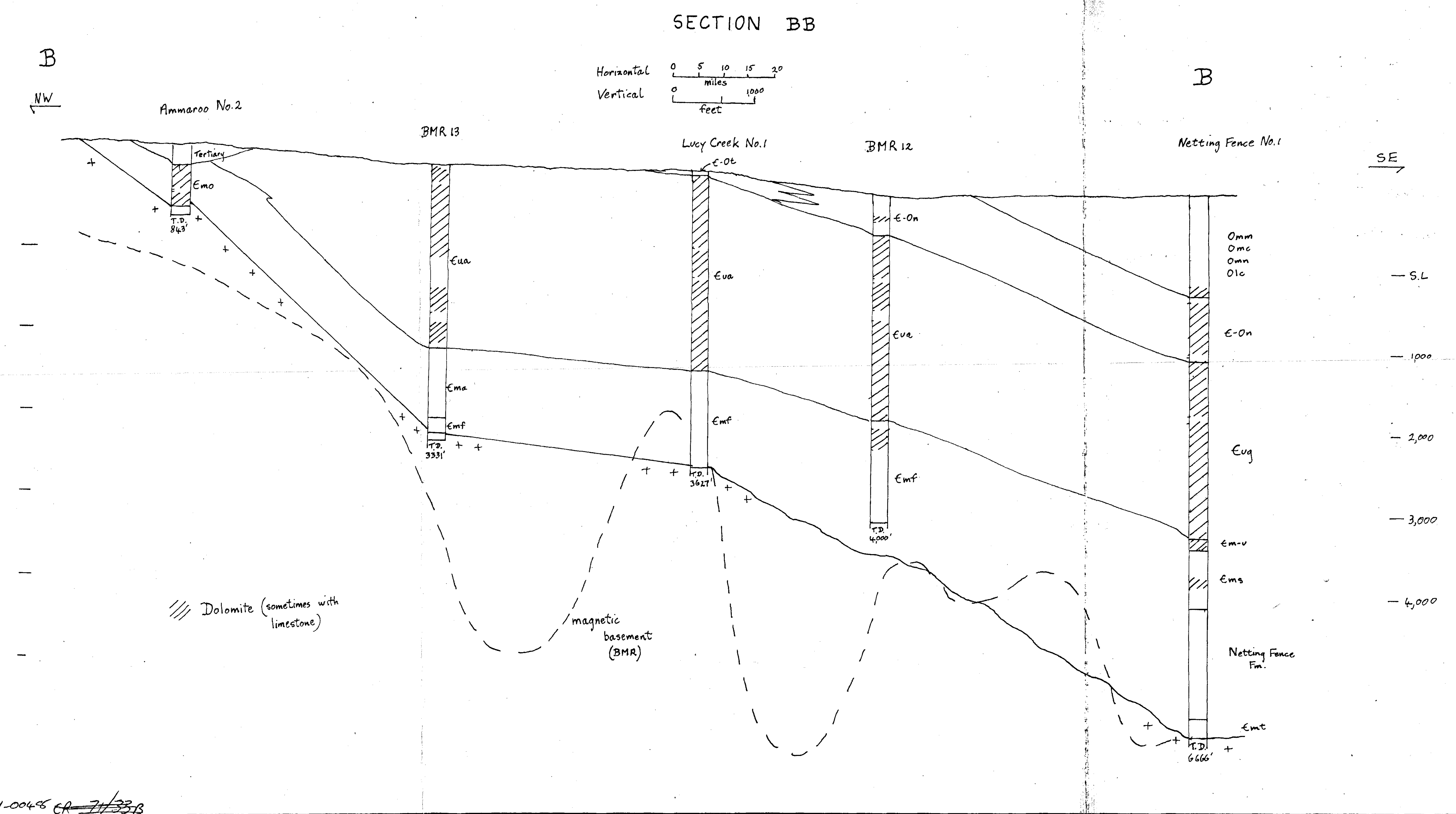

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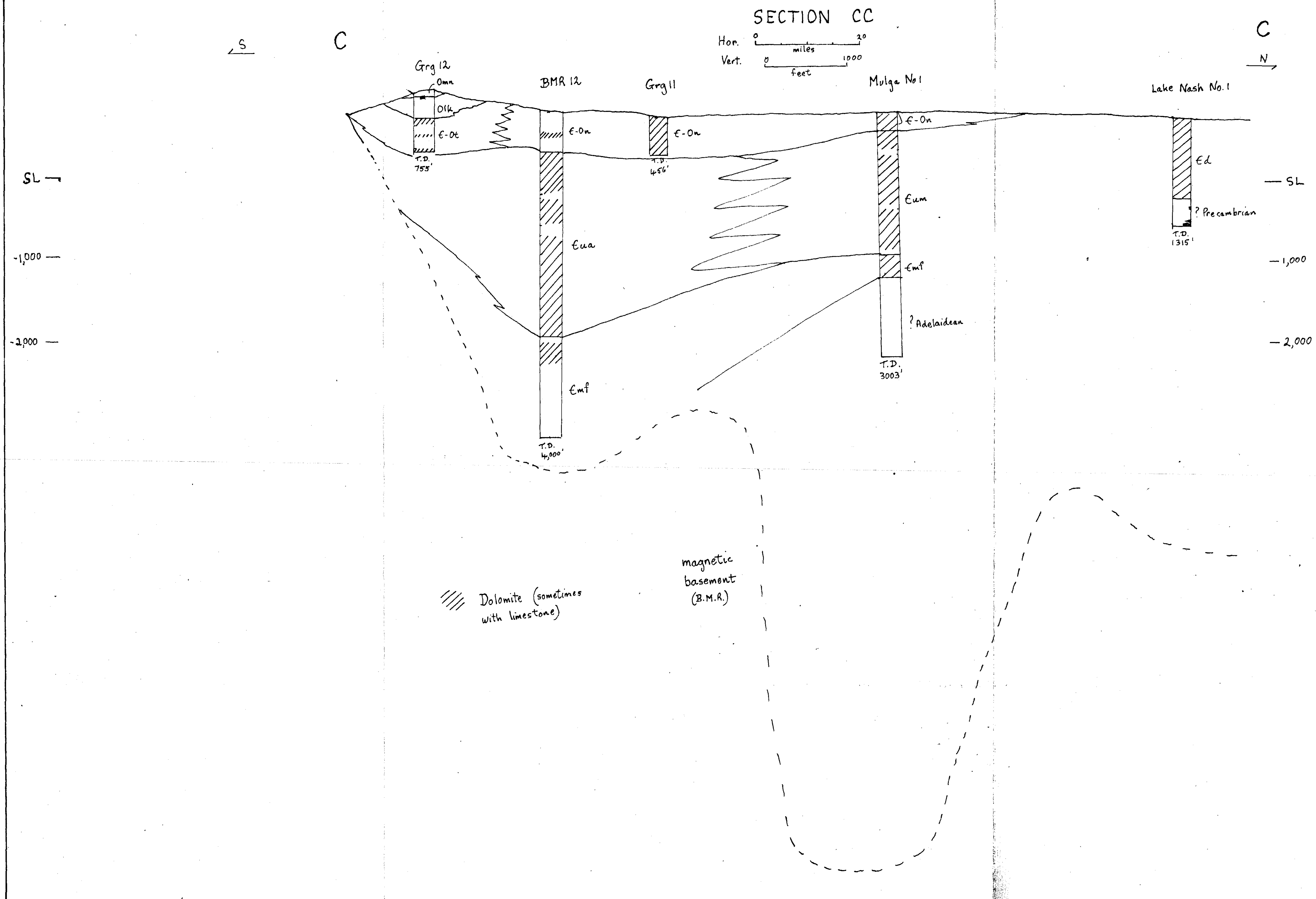

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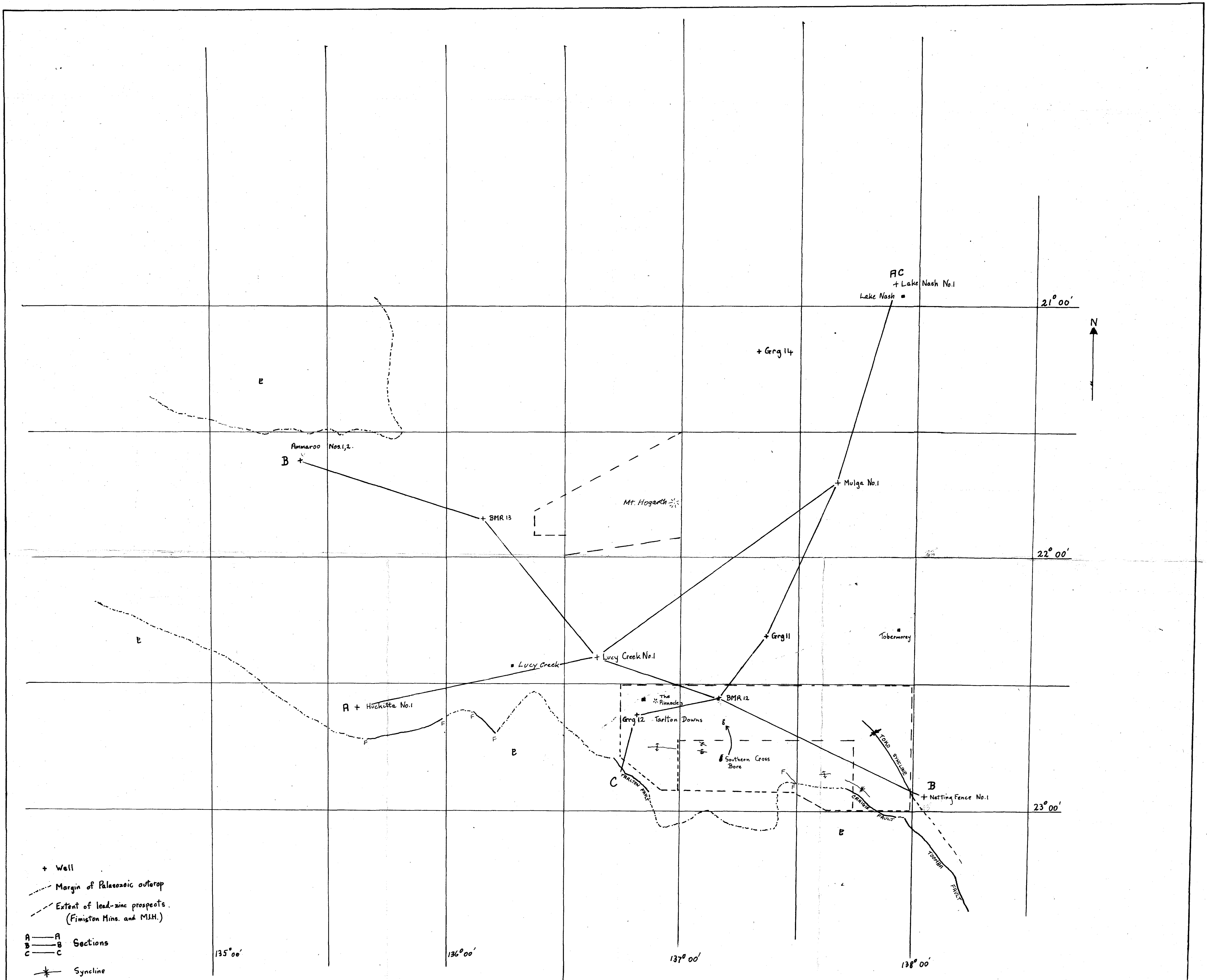

MAP 1. LOCATION MAP : SOUTHERN GEORGINA BASIN

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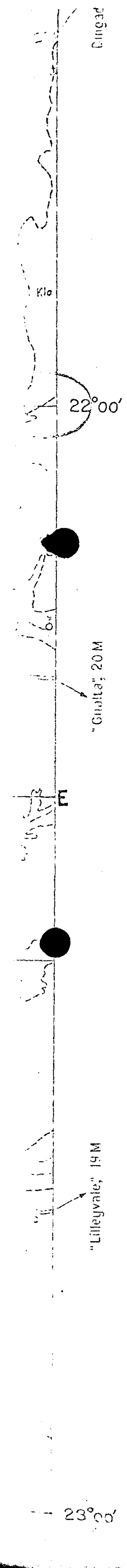
KEY TO MAPS 2 AND 3.



Era	Period	Unit	Symbol	Lithology
CAINOZOIC	QUATERNARY	Undifferentiated	Q	*Sand, soil, alluvium, kunkar, gravel*
	TERTIARY	Undifferentiated	T	*Limestone, chalcedony, sandstone, siltstone, conglomerate*
MESOZOIC	CRETACEOUS	Mackunda Formation	Klm	*Arkose, siltstone*
		Wilgunya Formation	Klw	*Claystone, siltstone*
		Toolebuc Member	Klo	*Calcareous siltstone*
		Longsight Sandstone	Kll	*Sandstone*
	TRIASSIC	Tarlton Formation	Rt	*Conglomerate, siltstone, sandstone*
	UNDIFFERENTIATED		M	*Sandstone*
PALAEOZOIC	PERMIAN ?	Undifferentiated	P	*Conglomerate, shale*
	SILURIAN - DEVONIAN ?	Cravens Peak Beds	S-Dc	*Sandstone*
	MIDDLE ORDOVICIAN	Toko Group: Mithaka Formation	Omm	*Siltstone, sandstone*
		Toko Group: Carlo Sandstone	Omc	*Sandstone*
		Toko Group: Nora Formation	Omn	*Siltstone, sandstone*
	LOWER ORDOVICIAN	Toko Group: Coolibah Formation	[illegible]	*Limestone, dolomite, chert*
		Kelly Creek Formation	Olk	*Sandstone, dolomite, siltstone, coquinite*
		Swift Formation	Ols	*Siltstone, sandstone, chert, calcarenite*
	UPPER CAMBRIAN - LOWER ORDOVICIAN	Tomahawk Beds	€-Ot	*Sandstone, dolomite, limestone, siltstone*
		Ninmaroo Formation	€-On	*Dolomite, limestone, siltstone, sandstone*
	UPPER CAMBRIAN	Georgina Limestone	€ug	*Limestone*
		Chatsworth Limestone	€uc	*Limestone, dolomite*
		Gola Beds	€uc	*Limestone*
		O'Hara Shale	€uh	*Shale, chert, sandstone*
		Pomegranate Limestone	€up	*Limestone*
		Meeta Beds	€um	*Dolomite, chert, sandstone*
		Arrinthrunga Formation	€ua	*Dolomite, limestone, siltstone, sandstone*
	MIDDLE - UPPER CAMBRIAN	Mungerebar Limestone		*Limestone*
	MIDDLE CAMBRIAN	Selwyn Range Limestone, Devoncourt Limestone, Roaring Bore Siltstone, Steamboat Sandstone	€ms	*Limestone, sandstone, shale, siltstone*
		Quita Formation, Blazan Shale	€mm	*Limestone, shale, sandstone, conglomerate*
		Inca Creek Formation		*Shale, chert, limestone, siltstone*

KEY TO MAPS 2 AND 3.

Age	Unit	Symbol	Lithology
	Beetle Creek Formation Thorntonia Limestone		*Shale, chert, siltstone, sandstone, limestone, dolomite*
	Marqua Beds		*Limestone, siltstone, calcareous sandstone, shale*
	Camooweal Dolomite	€d	*Dolomite with chert lenses*
LOWER CAMBRIAN	Mount Birnie Beds		*Arkose, sandstone, shale*
	Riversdale Formation		*Conglomerate, sandstone, dolomite*
ADELAIDEAN - LOWER CAMBRIAN	Grant Bluff Formation	Ė-€g	*Quartz sandstone*
	Makbat Sandstone		*Quartz sandstone, conglomerate*
ADELAIDEAN	Sylvester Sandstone		*Sandstone, siltstone*
	Sun Hill Arkose		*Arkose, conglomerate, sandstone, siltstone, dolomite*
	Field River Beds	Ėuf	*Boulder beds, siltstone, arkose, dolomite, quartz sandstone*
CARPENTARIAN	Sybella Granite		*Granite*
	Eastern Creek Volcanics		*Metabasalt and metasediments; some schist and gneiss*
	Marraba Volcanics		*Metabasalt, tuff, metaquartzite, slate, schist, limestone*
PROTEROZOIC			*Granite*
	Kalkadoon Granite	p€k	*Granite*
	Undifferentiated	p€	*Migmatite, gneiss, schist, metaquartzite, rhyolite, dacite, basalt, quartz sandstone, conglomerate, limestone, dolomite, siltstone, shale, slate, calc-silicates, tuff, and agglomerate*
ARCHAEAN ?	Arunta Complex	Aa	*Gneiss, schist, metaquartzite*

PRECAMBRIAN

Geological boundary

Unconformity, section only

Anticline showing the plunge

Syncline

Monocline

Fault

Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

20 *Measured strike and dip of strata*

Prevailing strike and dip of strata

Horizontal strata

Vertical strata

Dip < 15° } *air-photo interpretation*

Trend lines } *air-photo interpretation*

Joint pattern } *air-photo interpretation*

Macrofossil locality

Microfossil locality

Dry oil exploration well } *abandoned*

St *Dry oil exploration stratigraphic well* } *abandoned*

Water-bore

Abandoned water-bore

Well

Windpump

WH *Waterhole*

Spring

Highway or road

Vehicle track

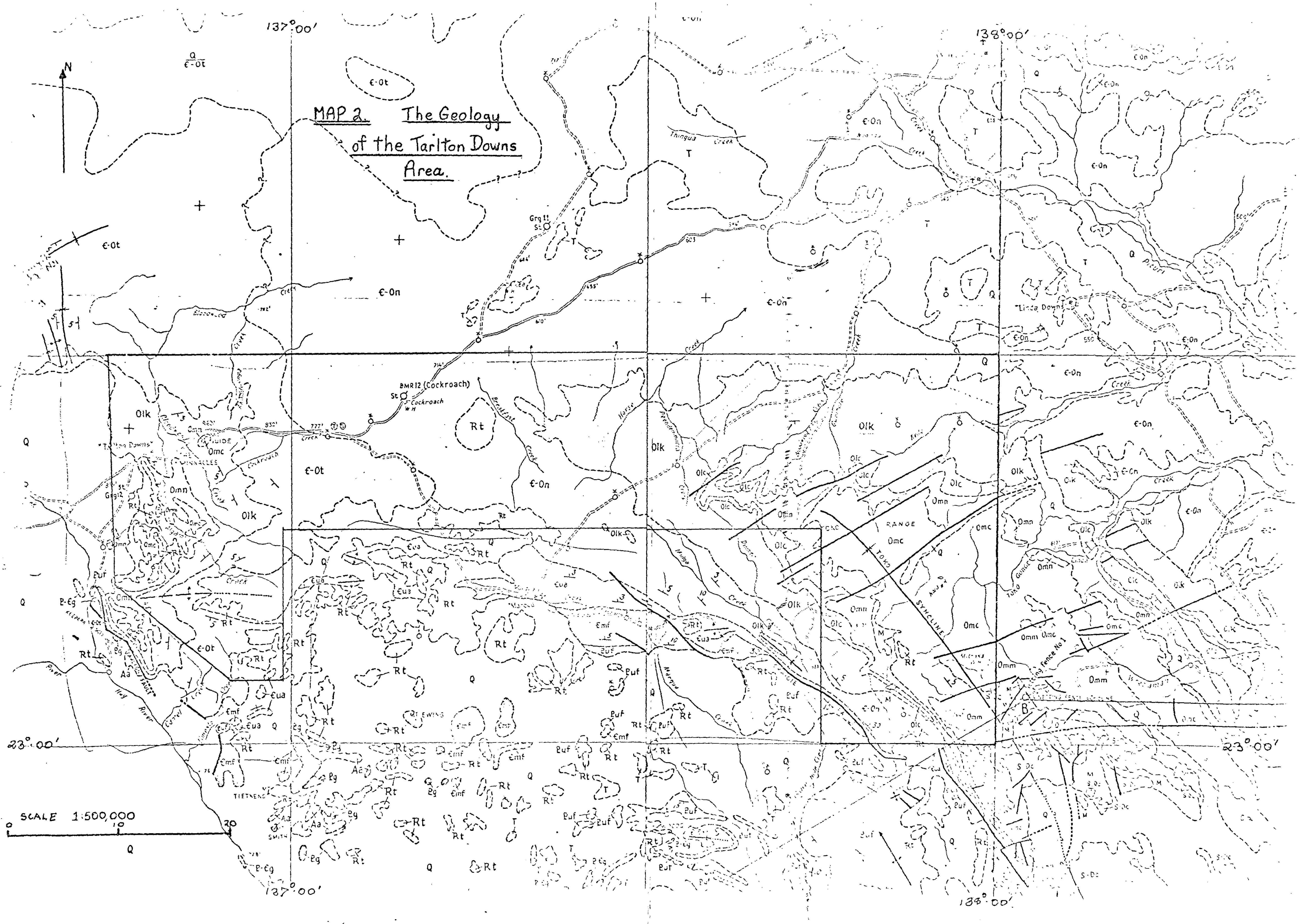
Railway

"Boulia" *Homestead*

Landing ground

State boundary

·700′ *Height in feet, instrument levelled*



MAP 2. The Geology of the Tarlton Downs Area.
137°00'
138°00'
23°00'
SCALE 1:500,000
0 10 20
"Tarlton Downs"
BMR12 (Cockroach)
Cockroach W.H.
Grg 11 St.
Grg 12
"Linda Downs"
TOKO SYNCLINE
RANGE
Thingua Creek
Cockroach Creek
Breakfast Creek
Horse Creek
Marqua Creek
Hay River
Pituri
Fencing Fence No. 1
Rt EWING
TIETKENS
SMITH

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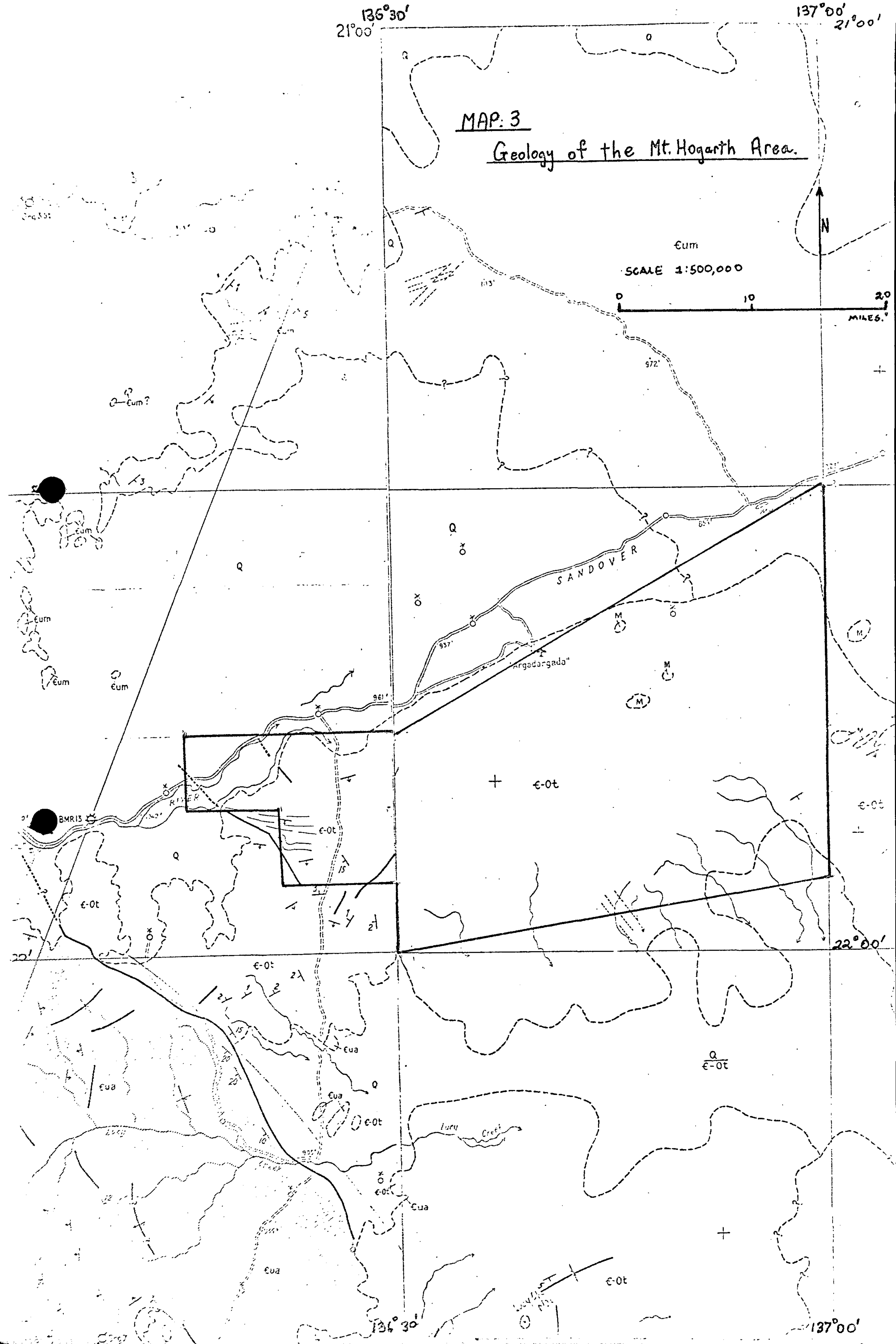
MAP: 3
Geology of the Mt. Hogarth Area.
SCALE 1:500,000
0
10
20
MILES.
N
136°30'
21°00'
137°00'
21°00'
22°00'
136°30'
137°00'
SANDOVER
RIVER
"Argadargada"
BMR13
Lucy Creek
Q
€um
€um?
€-0t
€ua
M
961'
937'
972'

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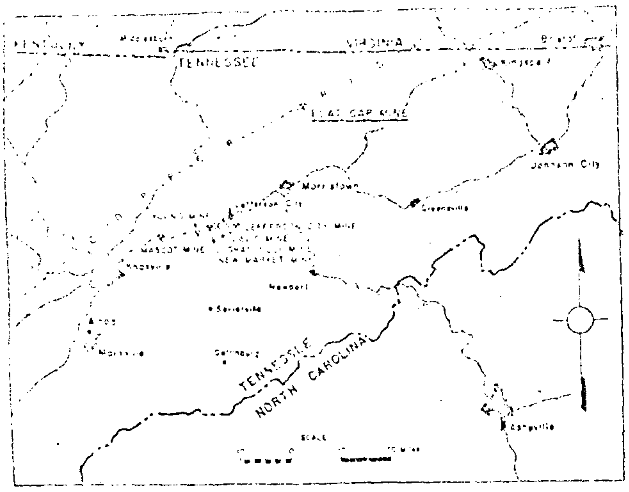

Fig. 1. Map of northeast Tennessee showing location of the Flat Gap mine.

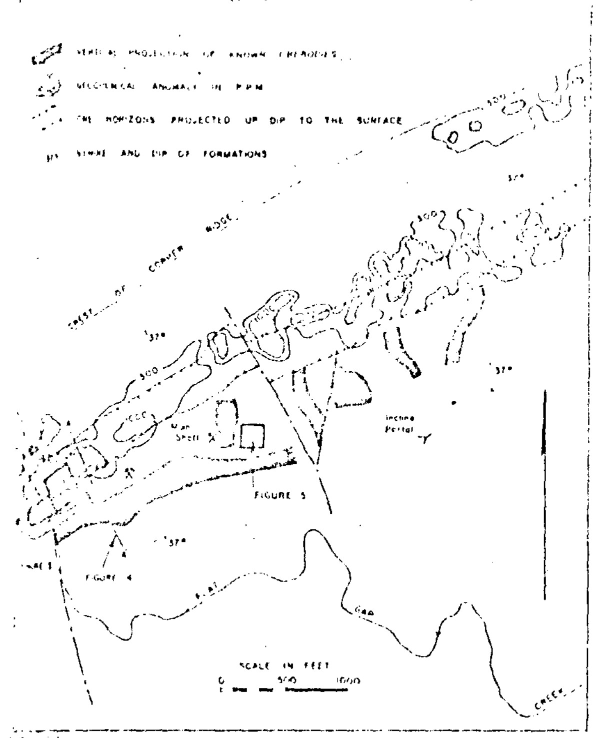

Fig. 2. Generalized plan showing relationships between orebodies, outcrop of ore horizons projected up dip to the surface, and general outline of the mineralised overburden at Flat Gap. Dip of beds averages about 37° southeast.

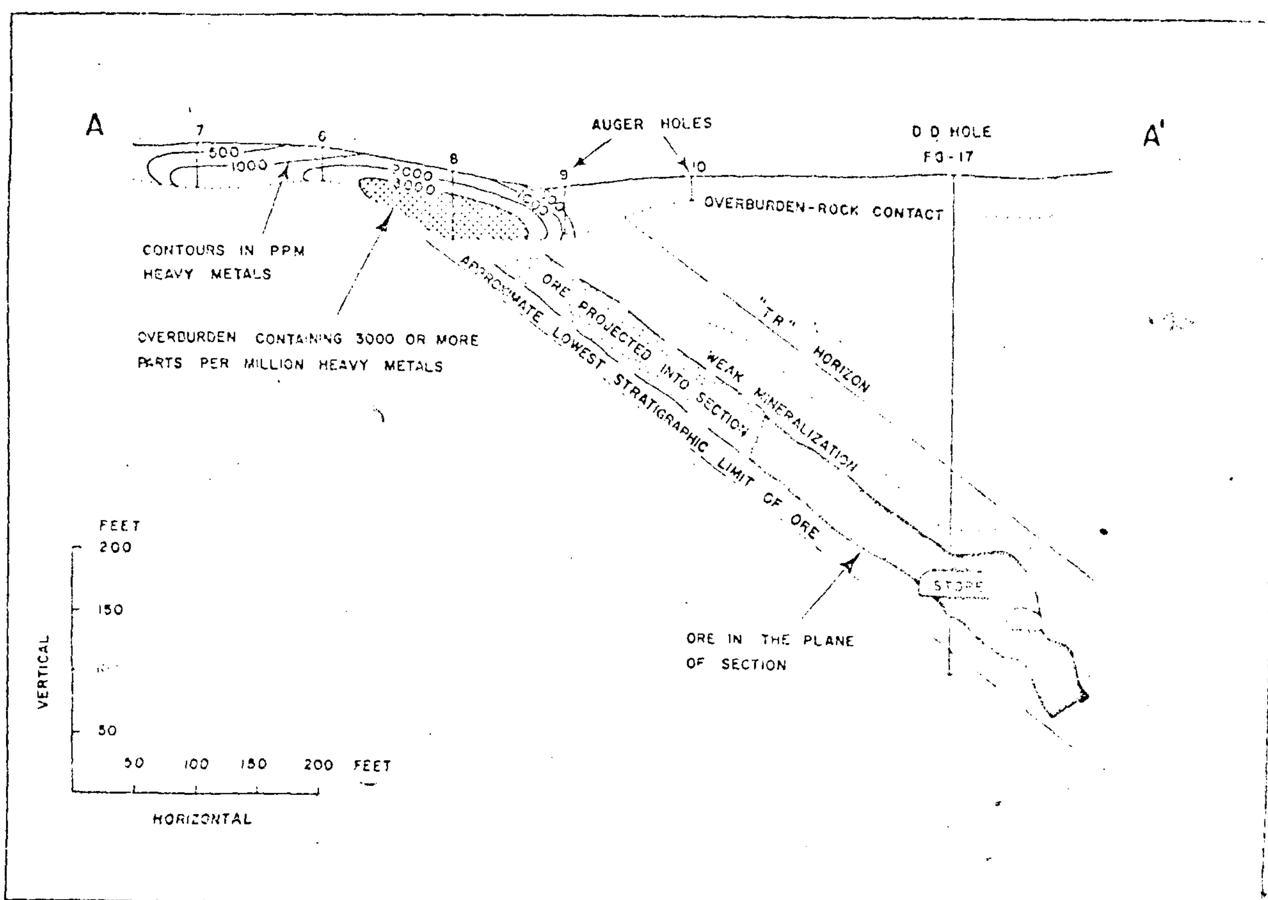

Fig. 3. Cross section of a portion of the Flat Gap orebody showing relationship of ore to geochemical anomaly.

FIG 4

STRATIGRAPHIC COLUMN for BMR Nº 13 (Sandover)