MINERALISATION CONTROLS AT THE YAVA LEAD DEPOSIT, SALMON RIVER, CAPE BRETON COUNTY NOVA SCOTIA

BY

OLIVER J. H. BONHAM

Submitted in partial fulfillment of the requirement for the degree of Master of Science at Dalhousie University Halifax, Nova Scotia, February, 1983

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ABSTRACT

The Yava lead deposit at Salmon River, Nova Scotia, is a sandstone-hosted lead deposit situated in fluviatile clastic sediments, of late Carboniferous age. Ore reserves are estimated to be 5.6 million tonness at 5.3% Pb. During a 2 1/2 year underground production operation (1979-1981), 388,000 tons were extracted.

The host rocks consist of cyclical fining-upward sequences of conglomerate, sandstone and shale, deposited in an upper meandering river environment. These rocks are grey-green in colour and contain abundant coaly matter.

The dominant sulphide is galena, occurring as concordant and discordant bands, clouds and disseminations. Pyrite and sphalerite are present, in association with galena, in minor amounts. These sulphides occur as a cement, infilling pore spaces in the clastic lithologies. The mineralisation is confined to the basal 15 m of the sandstones, above an unconformable contact with Windsor Group shales (Visean) and late Pre-Cambrian/early Cambrian basement rocks. Three ore zones have been outlined at Yava, and these are spatially related to palaeo-depressions in the basement landscape. In the West Zone, the ore horizon, which is up to 8 m thick, occurs in footwall contact with the Windsor unconformity.

Correlation of lead grade distribution, host rock stratigraphy and palaeotopographic features in 135 surface drill cores for the West

Zone, in combination with underground mapping and channel sampling in the upper part of the same zone indicates the following features:

> Regional pre-requisites to base metal concentration at Yava are: a porous sandstone host rock in a reduced state, an impervious footwall lithology, underlying basement of granitic composition, and an unconformity at the base of the mineralised sequence marking a period of emergence and sub-aerial weathering.
>
> Controls to ore localisation in descending order of importance are: negative topographic features in the pre-tectonic footwall relief, internal stratigraphic configuration and compositional variations within the clastic package, and the extent of sandstone diagenesis.

It is proposed that depressions in the buried Windsor landscape acted as basinal traps where metal-bearing solutions (derived from saline groundwater) pooled, while the porous organic-rich clastic host rocks provided the necessary conditions for fluid flow and sulphide precipitation.

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"It is obvious that we can only speculate about the sources and see only parts of the transport plumbing system for most ore deposits. On the other hand the traps (the deposits themselves) are well exposed for observation but are still poorly understood in most cases. There is a pressing need for more careful documentation of the deposits, on scales ranging from regional to the microscopic. The deposits that are best exposed and least altered by metamorphism will obviously reveal the most useful information."

Gustafson L.B. and Williams N. (1981, p.172)
In discussing sediment-hosted stratiform deposits of copper, lead and zinc.

CHAPTER I

INTRODUCTION

I. 1. Introductory Statement

The Yava lead deposit located at Salmon River, Cape Breton Island, is a monomineralic occurrence of stratiform disseminated galena in Upper Carboniferous sandstones, which lies directly above an unconformity over Lower Carboniferous shales and Pre-Cambrian/Cambrian granitic basement.

Three ore zones are outlined at Yava: the West, Central and East Zones. These zones occur within a strike length of 3000 m and extend down-dip for 600 m (north-west at 15 °). Mineralisation is confined to the basal 15 m of the sandstone sequence, with the ore horizon occurring in the bottom portion, and varying in thickness from 3.6 to 8 m.

Due to the low grade disseminated nature of the mineralisation, ore reserve estimates for the deposit vary greatly depending on economic cut-off grade. Overall reserve figures vary from 5.6 million tonnes at 5.3% Pb, using a 4% cut-off, to 16.9 million tonnes at 3.4% Pb, using a 2.5% cut-off (Bonham, 1982).

In 1979, underground operations commenced on the higher grade West Zone at Yava; however in 1981, after only 2 1/2 years of production, the operators, Yava Mines Ltd., encountered financial difficulties and were forced to close the mine. During this period, the upper portion of the West Zone was extensively developed in a first pass room and pillar operation, when some 388,000 tonnes of ore were extracted.

I. 2. Purpose and Scope

Objective

The purpose of this study, which commenced in May 1980 while the author was employed at the Mine, was to try and establish those features which control the distribution and localisation of the lead mineralisation.

The reasons for the study are twofold: firstly, to gain an understanding of those features which determine the boundaries and internal geometry of the ore accumulation, and thereby examine the ore trapping mechanism, (perhaps the most critical phase of the entire metallogenic process); and secondly, in an applied sense, to establish a hierarchy of controls to mineralisation for use in mineral exploration strategy, in the search for additional deposits in this locale and elsewhere.

Limitations

The main study area is limited to the West Ore Zone. It was chosen for two reasons: firstly, the underground development allowed for detailed mapping and sampling within the ore zone; and secondly, extensive close-spaced grid-drilling from surface had been conducted over the zone and over marginal areas providing good three dimensional coverage of the area.

On the basis of certain observations made for the West Zone, some aspects of the entire deposit were investigated further using additional drill hole data.

No regional field work was involved. However, the thesis does include a compilation of known geological information on the Salmon River area. This is used as a basis for more regional observations concerning controls to mineralisation.

Yava is a monomineralic lead deposit containing only minor amounts of associated zinc and silver. Therefore this study confines itself to the examination of lead distribution, using assay returns for split drill core and mine channel samples as the main source of information on lead occurrence.

The study emphasises the gross and more empirical aspects of the mineralisation; it is based on observed field relationships between mineralisation and geological features. Related petrographic and geochemical work was conducted in order to characterise aspects of the geology and mineralisation, and to clarify certain features.

Approach

Before any controls to mineralisation can be considered, it is first necessary to establish, in some detail, the exact pattern of lead distribution within the host environment.

To do this, the following approach is taken:

1. obtain a thorough understanding of the host rock geology and geologic setting of mineralisation
2. investigate the sulphide mineralisation in order to characterise the different styles and assemblages and understand their relative importance
3. with this understanding of host rock geology and mineralisation, make comparisons between lead occurrence and lithologic, palaeotectonic and other features.

Definitions

The terms "Windsor disconformity" and "Windsor contact" as used throughout this thesis refer to the disconformity between underlying Windsor Group shales (Visean age) and the overlying sandstone sequence of the Canso Group (Namurian age), which hosts the mineralisation.

I. 3. Geographical Location and General Information

The Yava lead deposit is located at Lat: 45°51'30"N/Long: 60°24'50"W, in the district of Salmon River, on Cape Breton Island, Nova Scotia. It lies approximately 42 km (by road) south-west of the town of Sydney, mid-way between the Bras d'Or Lake and the Atlantic coast (Figure I.1).

The area is situated some 150 m above sea-level, and the local topography is hilly. The bedrock surface is irregular and is mantled

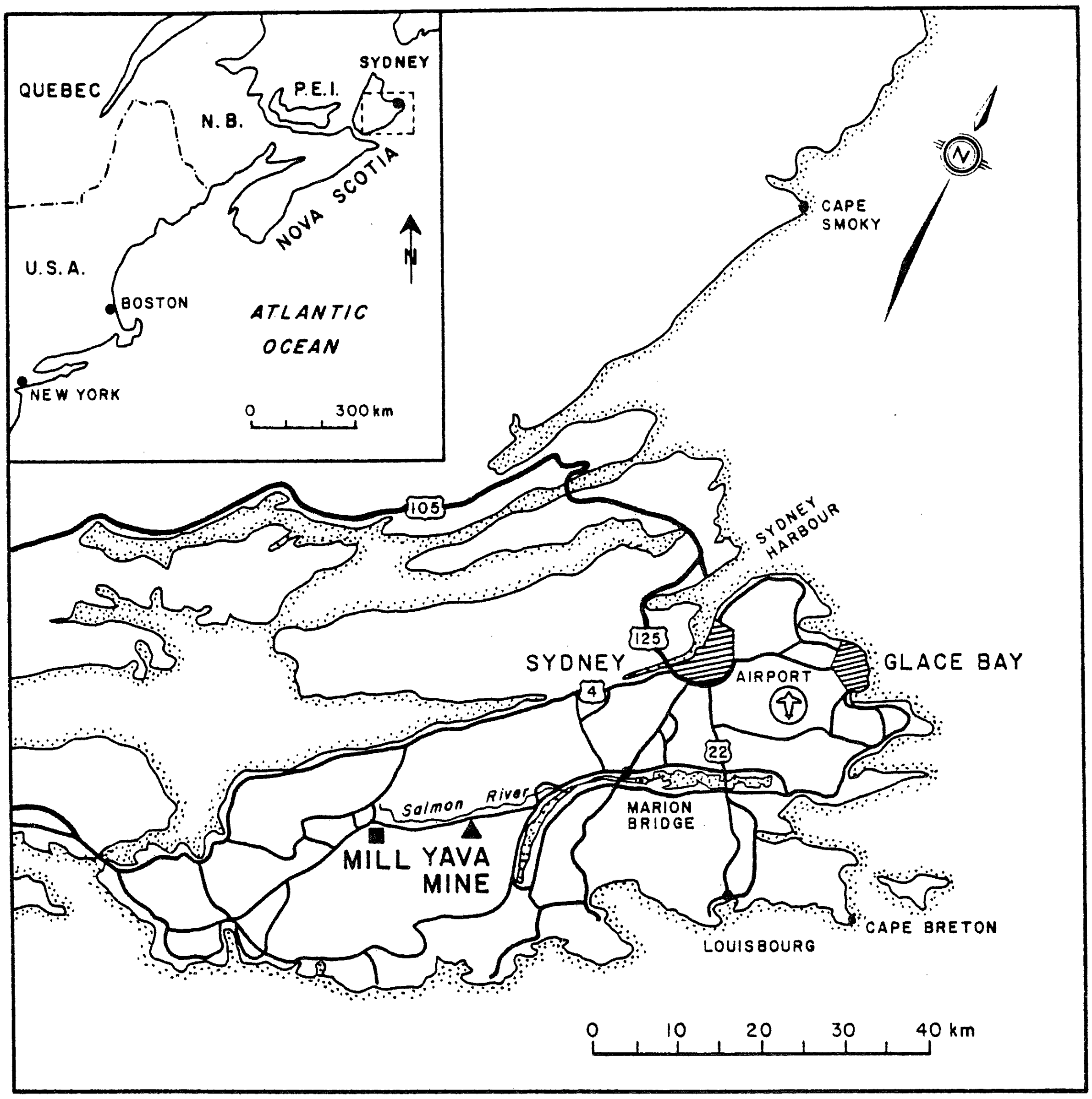


Figure 1.1. Location Map

by glacial ridges composed of tills and outwash sands, up to 30 m in thickness.

The vegetation consists of forest (75% spruce, 25% hardwood) on dry ground, and marsh flora in low boggy areas. Drainage in the area is generally good: the Salmon River flows eastwards across the West and Central Zones.

The Yava dressing plant, formerly owned by Kaiser Ltd., is located at Lake Enon, approximately 12 km west of the Mine site. A gravel road runs between the Mine and the Mill.

I. 4. Discovery, Exploration and Mining History

Exploration interest at Salmon River dates back to 1929 when Aconda Mines Ltd. drilled seven widely-spaced holes to test showings of argentiferous galena, known in the area since the 1880's (Nova Scotia Department of Mines and Energy, 1977). Weak vein mineralisation was established in Windsor shales following this programme. Further drilling was then conducted by Minda Scotia Mines Ltd. in 1957; two holes were drilled and additional vein mineralisation was intersected.

In 1961, following the discovery of the baryte and base metal deposit in Windsor sediments at Walton in Hants County, Nova Scotia, Talisman Mines Ltd. staked large tracts of ground underlain by Carboniferous sediments in the Salmon River area, in the vicinity of the old showing (W. Dix, pers. comm.). After the completion of soil geochemistry and electromagnetic surveys in the area, diamond drilling commenced. Hole No. 2 intersected disseminated galena in sandstones overlying the Windsor shales. Talisman continued drilling to complete a total of 28 holes; this work established the presence of a continuous and extensive horizon of mineralisation (Patterson, 1979a).

After the discovery and preliminary drilling of Talisman in 1962, the Phelps Dodge Corporation took on the major phase of exploration and evaluation of the property. This comprehensive study, which continued through to 1969, consisted of delineation drilling (some 220 holes) in a central grid pattern, with staggered step-out holes, which delineated the three zones and checked for blind mineralisation along strike. In addition, extensive regional geological mapping and geochemical exploration were also completed (Watson 1963, Mudford 1964, Watson 1964 and Mudford 1969).

In 1976, Barymin Explorations Ltd. acquired the property outright through the purchase of interests held by Phelps Dodge and Talisman. Following this, Barymin conducted further drilling and metallurgical testing, and in 1978, after the purchase of the complete celestite concentrator at Enon from Kaiser Ltd., a decision to commence underground production from the West Zone was made. Initial ore reserves for the West Zone were 1.09 million tonnes at 5.6% Pb (Patterson, 1979b).

Production commenced in 1979, and during the next two and a half years, some 388,000 tonnes of 4.69% Pb were extracted (Bonham, 1982). In September 1981, after Yava encountered financial difficulties, operations ceased and the Mine was abandoned. During the preproduction and production phase, 110 additional holes were drilled in the West Zone to completely delineate this orebody.

I. 5. Previous Work

Salmon River Area and Yava Deposit

The earliest recorded geological mapping in the Salmon River area was conducted by Fletcher in the 1870's for the Geological Survey of Canada. The resulting maps (on a scale of 1 inch to 1 mile) were published in 1884 as part of a regional series for this part of Nova Scotia.

South-eastern Cape Breton was later remapped by Weeks (1954), and Weeks and Hutchinson (1958), also for the Geological Survey of Canada; this represents the most recent published government mapping for the area.

Following the discovery of significant mineralisation at Yava in 1962, detailed mapping of the entire outlier was carried out by geologists of Phelps Dodge Corporation. This work, which combines surface observations with drill hole information, is well-documented and described by Watson (1963 and 1964) and Mudford (1964). These descriptions, in unpublished company reports, provide the most recent and comprehensive account of the geology of the area.

Apart from early accounts of mineral showings recorded with the Nova Scotia Department of Mines and Energy, the first investigations and descriptions of the mineralisation are those of Phelps Dodge (Watson 1963, 1964 and Mudford 1964, 1969).

During the pre-production period in 1979, several update-compilations were made by Patterson. For these, new drill hole information was incorporated into the existing understanding of the geology and mineralisation. They appeared as presented papers (Patterson: 1979a, 1979b), and a publicaton (Patterson 1979c).

Also at this time, a study of the geochemistry and petrography of the deposit using a line of drill holes through the West zone, was conducted by Scott (1980), for an M.Sc. thesis.

Most recently, the deposit has been featured as one key example in a review paper on sandstone-hosted lead-zinc deposits, published by Bjorlykke and Sangster (1981).

From the time of discovery of the Yava and Lake Enon mineralisation at Salmon River in the early 1960's up until the present time, the area has seen considerable exploration activity by industry. Assessment reports on this work, (filed with the Nova Scotia Department of Mines and Energy) contain additional pertinent geological, geophysical and drill hole information.

Regional Mineral Occurrence

Yava is the only occurrence of lead mineralisation in sandstone known in the region. It is worth noting, however, that at Lake Enon (12 km west of Yava along strike) significant base-metal sulphide (Pb-Zn-Cu) and celestite-barite mineralisation occur towards the base of the Windsor sequence. Aspects of the mineralisation and geology at Enon have been described by Hudgins (1969), Crowell (1971), Choo (1972) and Binney (1975). More recently, a stratigraphy for the Enon area was compiled by Boehner (1980).

Also of interest in the area is the Mindamar massive sulphide (Zn-Cu-Ag) deposit at Sterling, some 20 km south of Yava. This deposit (occurring in Cambro-Ordovician felsic volcano-clastic sediments) has been described by Miller (1979).

Regional aspects of base-metal mineralisation in the Carboniferous of Nova Scotia have been studied by Binney and Kirkham (1974) and Van der Poll (1978).

Regional Geology and Stratigraphy

The Carboniferous stratigraphic nomenclature used in the Maritime area has evolved from the original work of Bell (1944), with later modifications by Barss and Hacquebard (1967) and Schenk (1969). Regional studies of Nova Scotian Carboniferous geology have also been presented in the literature by Stacy (1953), Belt (1968), Hacquebard (1972), Geldsetzer (1977), Boehner (1980) and Giles (1981).

Structural and stratigraphic aspects of pre-Carboniferous basement rocks which underlie the Mine area and outcrop to the south-east have been studied by Helmstaedt and Tella (1973), and later by Smith (1976), while the granitic intrusions of south-eastern Cape Breton have been investigated by O'Reilly (1978). Isotopic dates for the Loch Lomond pluton (basement in the mine area) were published by Cormier, (1972) and Keppie and Smith (1978).

I. 6. Methods

Underground mapping: Underground wall mapping was conducted throughout the West Ore Zone at Yava at a scale of 1:50. This was later plotted at 1:200 scale, as overlays to the surveyed Mine plans*. In this mapping, emphasis was placed on lithologic relationships, while observations with regard to mineral distribution and mineral styles were made only in areas of interest.

A more detailed record and analysis of gross mineral styles were later completed using sketches and flash photography underground.

Drill core logging: During the course of geological duties at the Mine, some 27 drill cores had been logged by the Author, at a scale of 1 cm:5 ft. Of these, five cores were chosen for more detailed correlation logging, as part of the investigaton of host rock geology for this study.

* A complete set of these engineering base plans and geological overlays for the underground workings at Yava are on file with the Nova Scotia Department of Mines and Energy, Halifax.

Sample collection: In the process of mapping and core logging, samples were collected to make up a suite of lithotypes and mineralisation styles representative of the deposit.

Thin section petrography: For more detailed examination of host rock petrography and ore mineralogy, 18 thin sections and 39 polished thin sections of material selected from the sample suite were prepared.

Drill log analysis: For the study of lead distribution using drill holes covering the West Ore Zone, core cards were drawn up, one per drill hole, for a total of 135 holes. Each card contained key data on lithological thicknesses, assay values and location. The drill sites, which covered the entire orebody and marginal area, were then used as data points from which a series of isopleth and contour plans were constructed to demonstrate aspects of the geology and mineralisation.

Underground channel sampling: In the underground follow-up to this drill hole study, assay values for channel samples (collected as part of routine grade-control procedure at the Mine) were used. This additional information on grade distribution was utilised in two instances, documented in Chapter IV.

Lead assay determinations: The assay determinations for lead and other metals (for split drill core and channel samples) quoted in this thesis are those obtained from commercial labs or the Mine assay lab. In all instances, commercial labs have used either atomic absorption spectrophotometry with HNO_3 or combinated HNO_3-HCl digestion, or X-ray Fluorescence techniques. At the Mine lab, however, an atomic absorption HNO_3 procedure was used for samples less than 10% Pb; for those above 10% Pb, an ammonium molybdate wet titration was used. An outline of the lab procedures used at the Mine is included as Appendix 1, and a four-lab comparison of 10 selected samples, using the same and differing methods, appears as Appendix 2.

Additional geochemical analysis: In a limited test for indications of metal association and zonation in the West Zone, 36 samples were analysed for the following elements: Pb, Zn, Cu, Cd, Ag, Ca, Mg and Mn, using an Aqua Regia digestion and atomic absorption spectrophotometry. Of these, a further selection of 16 were also analysed for Ba, Sr, Bi and Sb, using Quantitative Spectrographic Analysis. These analyses were performed by the CLIM Laboratory at the Atlantic Industrial Research Institute in Halifax; particulars of the lab procedures are included as Appendix 3 and 4.

Microprobe: Microprobe, with energy dispersal system, was used to verify mineral determination of host rock and ore petrology. Also, some whole rock analysis of representative material was also performed using glass melts of sample fused on tantalum and molybdenum strips.

I. 7. Organisation of the Thesis

This thesis will be organised as follows:

After the introduction in Chapter I, a general description of the geology of the Salmon River area is given in Chapter II, in order to outline the regional setting of the deposit. This is followed, in Chapter III, by a general description of the local geology and ore mineralisation in the Yava Mine area. Chapter IV encompasses the "field-work" of this project, which is concentrated on the West Ore Zone. The chapter is divided into three major sections: Section 1 covering host rock geology; Section 2 describing the sulphide mineralisation; and Section 3 dealing with the investigations into the distribution of lead mineralisation. The pilot geochemical study is presented in Chapter. In Chapter VI, there follows a discussion with comparisons between this deposit and other sediment-hosted sulphide occurrences. At the close of the chapter, a proposal of controls to the mineralisation at Yava, an explanation of the trapping mechanism, and a model for orogenesis are presented.

Chapter VII then outlines the main conclusions of the project.

CHAPTER II

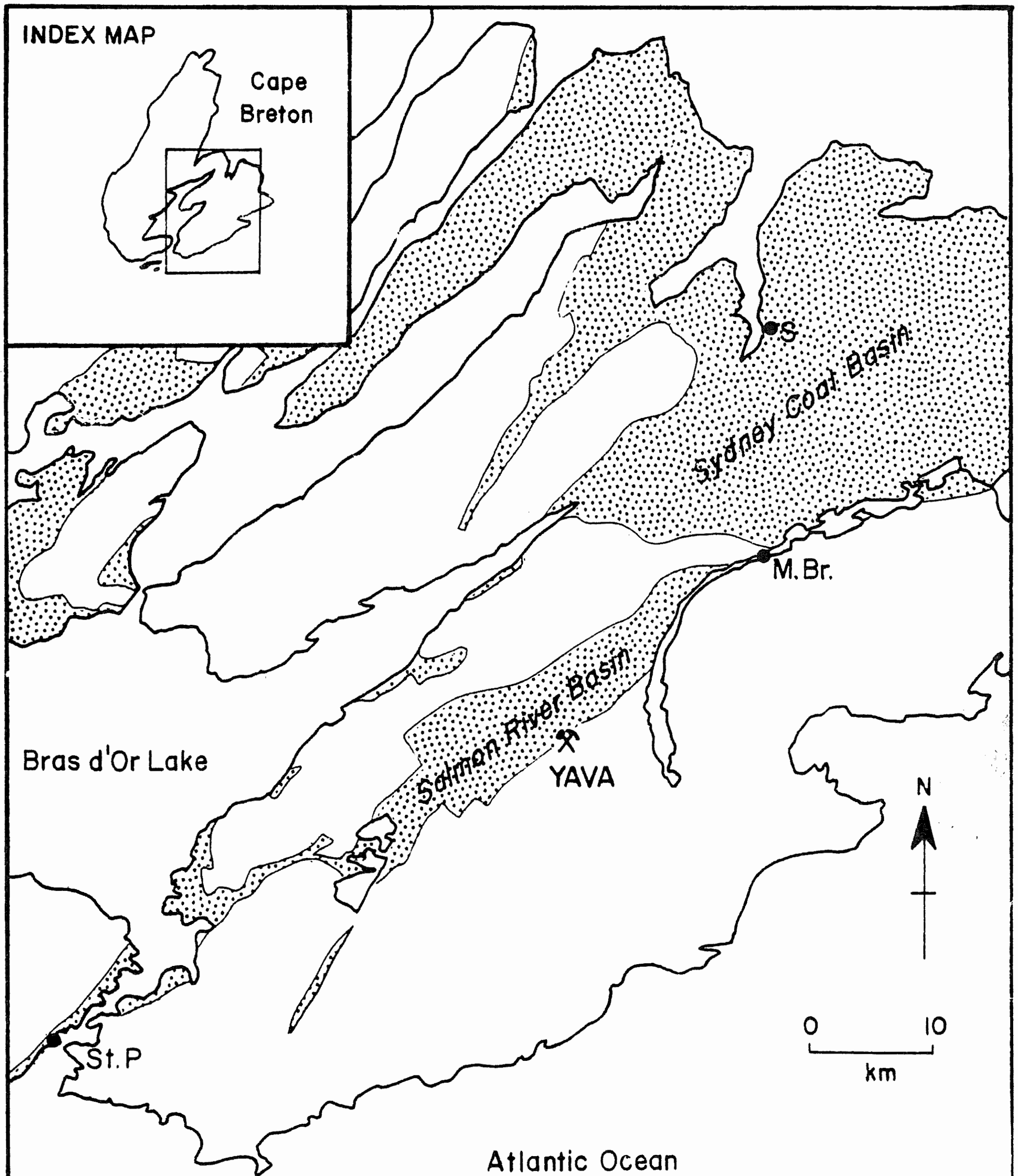
GEOLOGY OF THE SALMON RIVER DISTRICT

II. 1. General Statement

The Yava deposit is located on the south-eastern flank of the Salmon River sub-basin, (Figure II.1), an outlier predominantly composed of late Carboniferous (Namurian and Westphalian) continental clastic deposits of the Canso and Morien Groups. The Salmon River outlier forms an elongate wedge-shaped synclinal feature, 30 km long and 10 km wide (at the centre), plunging gently to the south-west. It is truncated by normal faults along the north-western flank; on the south-east flank, where the deposit is situated, the sediments dip gently to the north-west at 14-15°.

The basement rocks, flanking the outlier to the north-west and south-east, consist of Late Proterozoic and Early Cambrian meta-sediments and meta-volcanics of the Forchu and Bourinot Groups, which are themselves intruded by intrusive complexes of granitic and dioritic composition (Huntington and Loch Lomond Plutons). Also, on the south-eastern flank at the north-east end, a small area is underlain by later Cambrian sediments of the Kelvin Glen Group.

Early Carboniferous marine shales and carbonates of the Windsor Group, which immediately underlie the Canso Group in the area, are exposed in a linear strip along the south-eastern margin. Due to



S - Sydney

M.Br. - Marion Bridge

St.P - St.Peter's

Distribution of Carboniferous sediments
in southeast Cape Breton Island.

Figure II.1

faulting, this unit is only locally preserved along the opposite flank of the outlier.

Figure II.2 (back pocket) is a geological map, and Figure II.3 a stratigraphic column for the area. Both were compiled by the author from detailed geological maps and stratigraphic columns, included in the Phelps Dodge company reports.

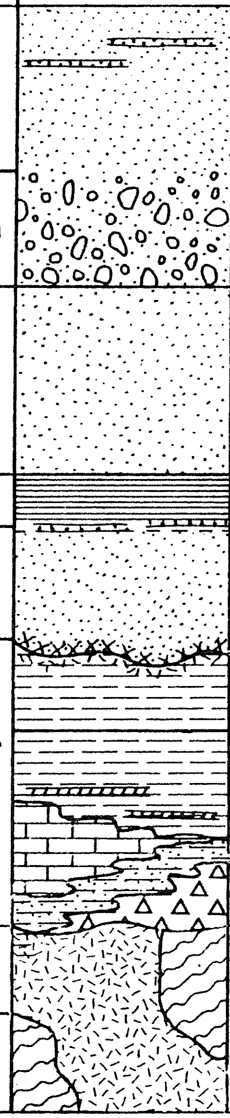
II. 2. Basement Rocks

Forchu, Bourinot and Kelvin Glen Groups

The area of metamorphic basement rocks to the north-west side of the area, which is designated as Forchu Group (Late Hadrynian) on the Geological Survey map of Nova Scotia, has been divided informally by Mudford (1964) into two "groups": basic meta-volcanics, locally altered to chloritic schist; and undifferentiated acid and intermediate meta-volcanics and minor meta-sediments, which are commonly altered to sericite and chlorite schists. This complex is frequently cut by acid and basic intrusions, assumed by Mudford (1964) to be Devonian in age.

Granitoid Intrusions

The Pre-Cambrian and Cambrian sequences on either side of the outlier are intruded by granitoid plutons: the Huntington Mountain Pluton of dioritic composition to the north-west, and the Loch Lomond Pluton of more varied granitic composition to the south-east. Both of these complexes form the basement along most of the present flanks of the outlier. The portion of the Loch Lomond Pluton which underlies the sediments hosting mineralisation at Yava, consists of a brick-red



AGE			THICKNESS	GRAPHIC COLUMN	UNIT NOS.	LITHOLOGIES
CARBONIFEROUS	NAMURIAN	CANSO GROUP ?	<400m		13	Grey sandstone with interbedded grits, shales and conglomerates, occasional coal seams. Sandstone dominant
			up to 300m		12	Brown, purple and rusty red conglomerate with minor sandstone interbeds
			up to 450m		11C	Variable sandstone - Purple and rusty red sandstones interbedded with grey sandstone and conglomerate
			160 m		11B	Maroon and green siltstones and shale, transitional sandy base with minor coal seams
			240 m		11 11A	Grey green arenaceous sandstone with interbedded congl. (Lst pebble-shale flake-and coal lag) and shales. Sandstone dominant. 11A mineralized horizon. Windsor surface weathered — calcrete and palaeosol u/c
	VISEAN	WINDSOR GROUP	0-170m		10C	Laminar bedded maroon and green shale, mottled appearence, occasional thin limestone interbeds
			Limestone 10 A 0-15 m thickening west		10B	Laminar bedded black shale with interbedded bands of fibrous, pink gypsum in lower part.
					10A	Pale grey to brown bioclastic limestone, massive and locally dolomitized. Pinched out in mine area. Thickens west
			Basal Breccia 0-18m		9	Conglomerate - siltstone transition Basal conglomerate and talus breccia u/c
CAMBRO-ORDOVICIAN	LOCH LOMOND PLUTON				5	Interbedded purple brown pebble conglomerates, siltstones and shales.
CAMBRIAN	KELVIN GLEN GROUP				3	Pink granites containing bodies of brick red qtz. porphyry.

Figure II.3. Stratigraphic Column, Salmon River Area

quartz porphyry, considered to be a high-level intrusive body within the pluton.

Age information on these intrusive complexes is best summarised by Scott (1980):

> "The rhyolite beneath, and immediately south of the mine is part of the Loch Lomond pluton (Keppie, 1979). This has been dated at 563 ± 24 Ma by a Rb-Sr whole rock isochron (Cormier, 1972), and recalculated by Keppie and Smith (1978) at 548 ± 18 Ma."
> (Scott 1980, p. 8)

He continues:

> "The Huntingdon Mountain pluton, which intrudes the volcanics, has been dated at 573 ± 30 Ma, using a Rb-Sr whole rock isochron (Cormier, in press)."
> (Scott 1980, p. 8)

This late Pre-Cambrian/Early Cambrian age, indicated for these intrusive events, is adopted in the study of Pre-Carboniferous structural history of the area, reported by Helmstaedt and Tella (1973). Originally, these intrusions were considered to be Devonian events by Weeks (1954); more recently, a re-examination of field relationships by O'Reilly (1978) appears to support this view. O'Reilly proposes a post Middle-Cambrian to pre-Devonian age. The exact age relationships are, therefore, presently unclear.

II. 3. Carboniferous Rocks

Windsor Group

The Early Carboniferous rocks of the Windsor Group, exposed along the south-eastern flank of the outlier, have been divided informally by Mudford (1964) into two main units, numbered 9 and 10 on the map

(Figure II.2) and in the column (Figure II.3). Unit 10 is then subdivided into three subunits: A, B, and C. Mudford's lithologic descriptions of these units, with additional observations by the author, are summarised below.

Basal Conglomerate and Talus Breccia (9)

This basal conglomerate unit, is of discontinuous distribution and variable thickness (0-18 m). It consists of either: a red-brown and grey conglomerate composed of pebbles of quartz, limestone, volcanics and granite, with occasional narrow beds of gritty sandstone and shale; or (as in the area of the Mine) highly angular and closely-packed fragments and pebbles of the underlying "rhyolite" held in a green clayey matrix. The latter is interpreted to be a talus breccia; it has a transitional top, passing up into grey and brown siltstones.

Limestone (10A)

This limestone, also of variable thickness (0-15 m), consists of a pale grey-to-brown massive calcarenite, which is locally bioclastic (containing crinoid and brachiopod debris), and frequently dolomitised. It is missing from the Windsor section in the Mine area, but is present west of the Mine and increases in thickness in a westward direction.

Black Shale (10B)

The overlying unit is a dark grey-to-black shaley mudstone, containing minor limestone intercalations up to 10 cm thick. The lower portion locally contains bands and irregular veins of white and pink fibrous gypsum, which in places, can make up as much as 50% of the section.

Red and Green Shale (10C)

The upper unit of the Windsor, is a mottled and banded maroon and green silty mudstone, with only narrow limestone intercalations. The lower contact of this unit is transitional with the underlying black shale.

Weathering Zone

The surface of this upper shale unit is unevenly overlain by a nodular calcareous horizon, described in detail in Chapter IV, and interpreted to be a calcrete. This, in turn, is overlain by a soft green clay, apparently the remains of a soil horizon. Both are the products of a period of emergence, marking the disconformity prior to the onset of continental clastic sedimentation.

The overall thickness of the Windsor Group varies from zero (where it is presumed to have been removed by contemporaneous erosion) to a maximum of 160 m to the west of the Mine.

Late Carboniferous

The thick sequence of clastic rocks (the major part of the outlier) is Late Carboniferous in age and designated to the Canso Group of the Namurian. A summary of the lithologic units is continued through this part of the section.

This sequence of sediments, which lies unconformably on Windsor

Group, or directly on basement porphyry, where the Windsor is absent, is divided into 3 major units: 11, 12, 13. Unit 11 is then subdivided into sub-units 11A, 11B and 11C.

Lower Grey Sandstone (11 and 11A)

Unit 11 consists predominantly of medium-grained, grey-green arenaceous sandstone, with interbedded conglomerate and mudstones up to 1 m thick. Coalified plant material is common throughout this unit. The conglomerate beds comprise three types: pebble conglomerates (mostly comprising limestone and calcrete clasts), shale flake conglomerates, and coal lag. The mudstone is dark grey and laminar bedded, occurring in discontinuous horizons. Unit 11A was designated by Mudford (1964) to cover the zone of mineralisation in the basal part of this unit. The total thickness of this unit is known from drilling in the Mine area to be 240 m.

Mudstone-Siltstone (11B)

The sequence then passes up through a transition zone of interbedded sandstone and shale, into a major shale-siltstone unit 160 m thick. It consists of green, grey and brown siltstones and muddy shales, which show rusty brown colouration towards the top. This unit is known from drilling to extend along strike, in the Mine area, for almost 3 km. Due to poor exposure it cannot be traced further.

Variable Sandstone (11C)

This unit immediately overlies the shale-siltstone unit; it is poorly exposed in the area, and is hence poorly defined. It consists of interbedded sandstone and minor conglomerate. The rocks are red, purple and grey in colour, and inferred to be up to 450 m thick.

Conglomerate (12)

The overlying unit is a major conglomerate, inferred from the outcrop mapping to be up to 300 m thick. To quote Mudford's (1964) description:

> "the conglomerate is composed of limonite coated, well-rounded pebbles and cobbles of quartz, shale and volcanics. The matrix is a rusty red to brown coarse silt and sand. Granite pebbles were not seen. Intercalated with the conglomerates are occasional narrow beds of red and brown sandstone and grit. These are often cross-bedded."
>
> (Mudford 1964, p. 16)

Sandstone (13)

This unit, which is exposed poorly only in the Glengarry area in the north-west part of the outlier, is very similar to the lower sandstone unit (Unit 11); it consists of fine to coarse-grained grey sandstone with minor conglomerate and shale interbeds. It is within this unit that the coal seams exploited in the old Glengarry mine are situated. From the map, this unit is inferred to be 400 m thick; however, Watson (1964) estimated it to be 1500' (450 m) thick.

The total thickness of this entire clastic sequence (consisting of five distinct lithostratigraphic units) measures 1550 m.

II. 4. Depositional Environment

The Carboniferous rocks forming the Salmon River outlier were deposited in four main episodes, representing different environmental conditions.

1. Sub-aerial fan (Breccia Conglomerates)

The irregular basement surface in the area is locally overlain by boulder conglomerates and breccia (at the Mine). Deposition is concentrated in the bottoms and on the flanks of basement depressions, and thicknesses are highly variable. These lithologies are interpreted by Scott (1980) to be deposited in an alluvial fan. The author would disagree, as these are not debris flow conglomerates. The clasts are in point contact and are considered to represent dry sub-aerial scree accumulation.

2. Visean Marine Transgressioan (Windsor Group)

In late Visean times, the area was submerged by a marine transgression; this resulted in deposition of shales and siltstones with interbedded limestones and evaporites. Deposition commenced in the basement depression and extended up the valley sides.

3. Emergence (Windsor Disconformity)

A period of emergence occurred at the end of the Visean or early Pennsylvanian when calcretes and a soil horizon developed on weathered Windsor shale.

4. Continental Clastic Deposition (Canso Group)

Then followed deposition of continental clastics in a fluvial environment. These deposits were also initially confined to the depression, later overstepping the Windsor to cover the basement highs. Clastic sedimentation continued until Westphalian times to accumulate over 1500 m of sediment.

More detailed discussion of a depositional environment for the rocks hosting mineralisation is presented in Chapter IV.

II. 5. Age Determination and Stratigraphic Nomenclature

On the recent geological map for Nova Scotia (Keppie, 1979), the Upper Carboniferous sandstone of the Salmon River outlier is designated part of the Morien/Pictou Group (Westphalian); while the Lower Carboniferous, siltstones and limestones are designated Windsor Group (Visean). This concurs with the earlier interpretation of Hacquebard (1972). Also, Weeks (1954), following field mapping, states (p. 81), "it would appear to be a reasonable assumption that the beds of the Salmon River-Gaspereaux River basin are partly or wholly of the Morien Group."

The implication of these stratigraphic designations is that the time lapse of the Windsor unconformity, underlyng the Yava mineralisation represents almost 40 my. In order to verify the age of host and footwall rocks at Yava, shale samples were collected, first by D. Sangster and later by the author, for palynological examination by

S. Barss at the Geological Survey of Canada.

Bjorlykke and Sangster (1981), in discussing the Yava mineralisation, refer to the host sandstones as being Canso Group (Namurian) on the basis of resulting spore dates. Palynological analyses, presented to the author by Barss, indicates that samples of shale from within the host sandstone contain polymorph types: *Florinites guttatus*, *F. visendus*, *Potonieisporites elegans* and *Schopfipollenites ellipsoides*. These can be assigned to the *Potonieisporites elegans - Knoxisporites seniradiatus* zone (Barss et al., 1979), thus confirming correlation with the Canso Group (Late Namurian). Samples of Windsor shale from below the ore zone were found to contain few spore fossils and could not be properly dated.

The uppermost section of the Windsor, in the Lake Enon area to the west (which is lithologically similar to the Windsor in the Mine area) has been designated to the Upper Windsor C subzone (Crowell, 1971). It is assumed, on this basis, that the Windsor at the Mine is also Windsor C subzone.

These assignments for footwall and host rocks indicate that the host rocks at Yava are late Namurian in age, while footwall rocks are late Visean, thus suggesting a shorter period of emergence (c 15 my), marked by the disconformity.

It can be speculated that the major conglomerate unit (Unit 12), up-section in the outlier, which underlies the Glengarry coal field sequence, may follow a later unconformity marking the base of the Morien Group in this area.

II. 6. Structure and Tectonism

The structural history of the area appears to be simple. As stated in the introduction, the outlier forms a north-easterly trending syncline plunging to the south-west (Figure II.2). The south-eastern limb of the syncline dips gently to the north-west at 14-15°, while along the north-west limb the dip steepens, in places to vertical (the result of drag folding against the faulted contact with basement rocks). The axis of the syncline runs close to this fault.

In the area of the Glengarry coalmine, Watson (1964) and Mudford (1964) outlined several west and north-west trending cross-faults with normal displacement. The two north-west faults are inferred from the apparent displacement of the conglomerate unit (Unit 12), which forms a topographic ridge in the area, and from air photograph lineaments.

Likewise, the east-west trending fault which extends from Glengarry to the Yava area, is inferred from outcrop displacement, and can be traced in air photographs. A north side downthrow of 60 to 90m is estimated for this fault by Watson (1964). Interestingly an interpretation of aeromagnetic coverage of this area filed by Amax (1973), shows no suggestion of these faults. Several marked cross-cutting discontinuities (interpreted to be faults) are outlined trending in a perpendicular direction, namely north-south.

The main fault along the north-western contact of the outlier is considered to be a complex feature, consisting of a series of discontinuous and sub-parallel normal faults over most of its length. Movement on this feature is considered to have resulted in the overall tilt to the north-west to form the present synclinal/monoclinal configuration of the outlier. Total displacement along this fault contact is inferred to be approximately 1000 metres.

The south-western termination of the outlier is improperly understood. The contact between sediments of the Salmon River area and those in the Lake Enon area (along strike to the west) is poorly exposed. Changes in lithology and an abrupt thickening of the Windsor, occurs in the Lake Enon area. Mudford suggests that this may be explained either by faulting, or by the presence of a basement high separating two centres of sedimentation. R. Boehner (pers. comm. 1981) also suggested the presence of major faulting: an indication for this he saw in the increased dolomitisation of Windsor limestone along the Salmon River road approaching this break in exposure.

CHAPTER III

LOCAL GEOLOGY AND MINERALISATION AT YAVA

III. 1. Introductory Statement

In order to set a background to the specific investigation of geology and mineralisation in the West Ore Zone of Yava, the following is a brief outline of the local geology and mineralisation of the deposit.

III. 2. Local Geology

In the vicinity of Yava, the basement porphyry forms a palaeotopographic high. This high, which extends along strike for 3 km through the area of mineralisation, is intersected by three depressions or palaeovalleys (as illustrated in Figure III.1). The Windsor Group shales, which lie unconformably on this buried landscape, are preserved as a thick succession either side of the high, and as a reduced succession infilling the local valley features. There is no Windsor present over the intervening ridges. This is either a feature of non deposition, or the result of erosion during the period of emergence following Windsor deposition.

The basal unit of the Windsor in the Mine area consists of a breccia conglomerate of highly variable thickness, interpreted to

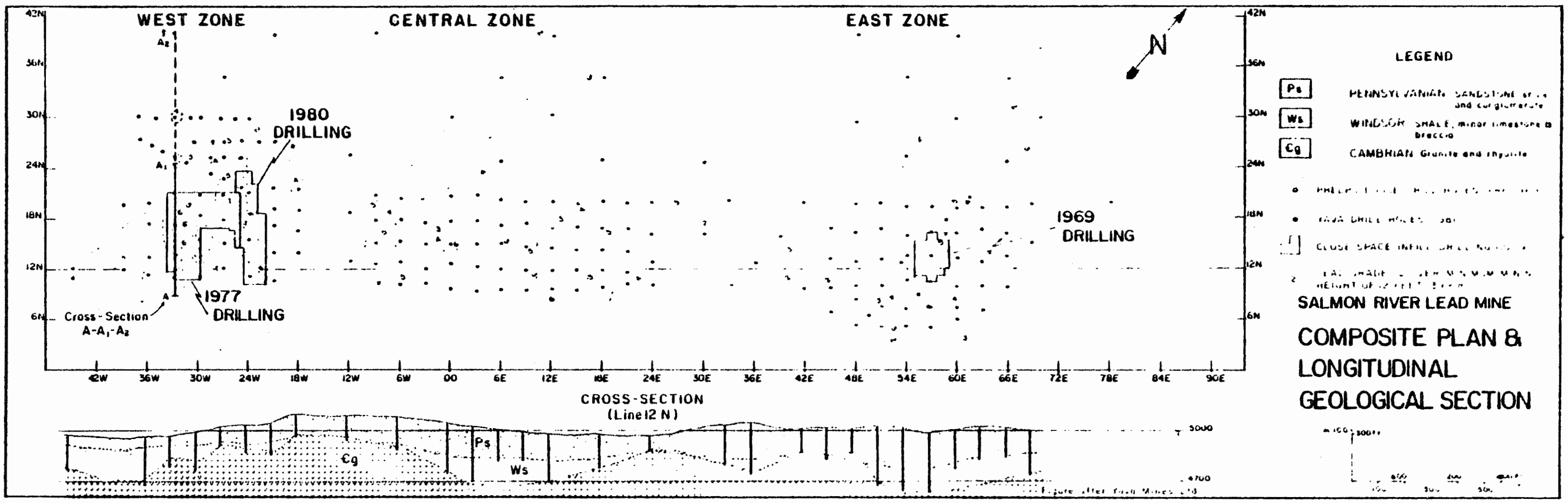


Figure III . 1 Composite Grade Plan & Longitudinal Section

be a talus breccia (Mudford 1964), infilling minor negative features in the basement landscape. The exposure of this unit in sub-Canso outcrop, and the presence of abundant calcrete and Windsor shale clastic fragments in conglomerates (interbedded within the sandstone sequence above), indicate that erosion of the Windsor Group must have taken place during the period of this disconformity.

Drilling in the area of the deposit indicates that the Windsor Group also thickens in a north-westerly direction, down dip (Figure III.2), suggesting that the basement high does not extend far down-dip.

Below the disconformity marking the base of the Canso Group sandstones, the underlying Windsor Group is weathered to form a calcrete and palaeosol. This is present through the area of the deposit. The sandstone-dominated sequence of conglomerate, sandstone and shale overlies this disconformity, infilling the palaeovalleys and extending over the intervening highs. This monotonous sandstone sequence (Unit 11), which hosts the mineralisation within the basal 15 m, reaches a total thickness of 240 m before a transition into thick mudstones (Unit 11B).

III. 3. Mineralisation

Apart from the Cu-Pb-Zn-Ba-Sr sulphide-sulphate assemblage at Lake Enon, at the western extremity of the Salmon River area, the only significant sulphide mineralisation in the area is the galena at Yava. It is known to occur in three different stratigraphic situations: in

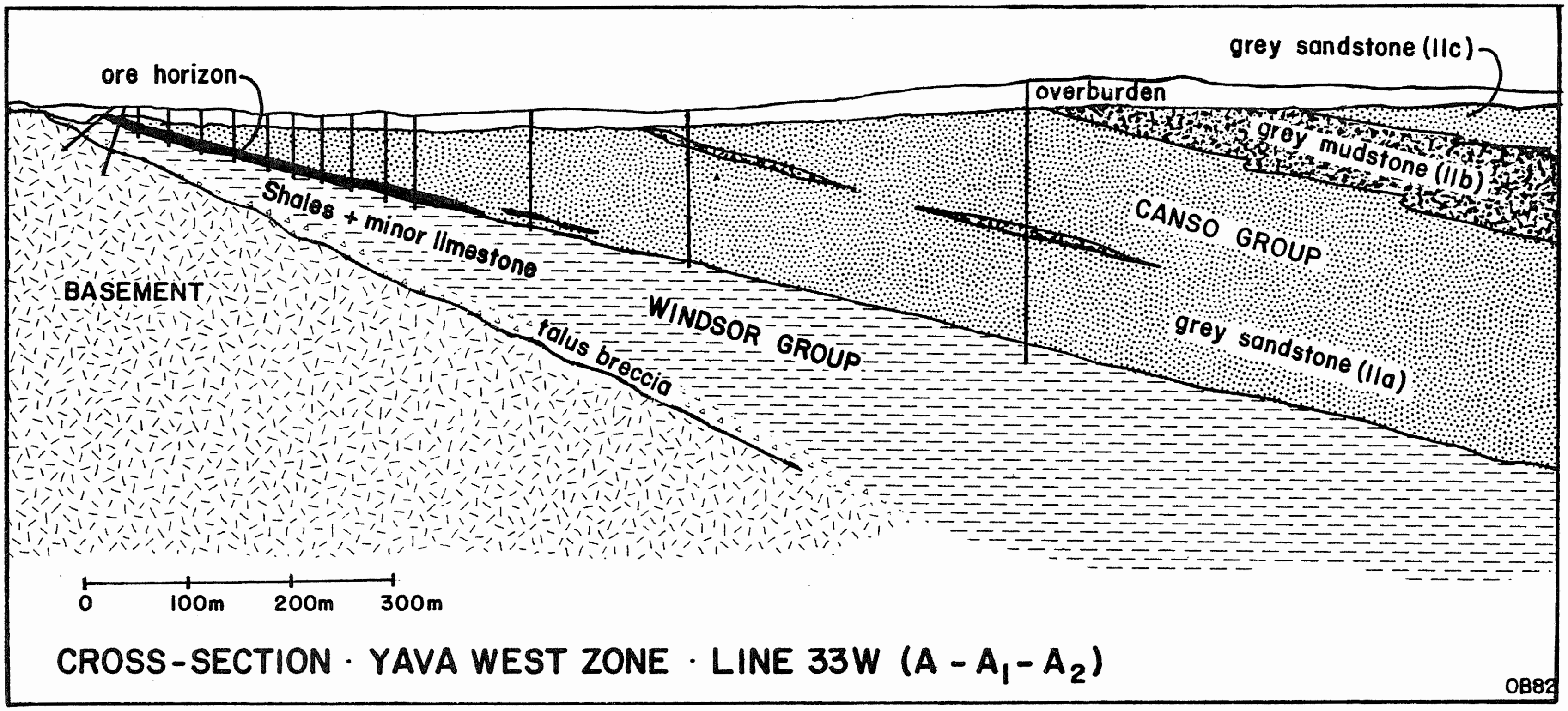


Figure III. 2 Cross-section Through Yava West Zone along line 33w (A-A_1-A_2)

fractured basement porphyry and overlying talus breccia, in Windsor Group lithologies and in Canso Group sandstones.

Porphyry and talus breccia mineralisation

This form of galena occurrence is described by Mudford (1964):

> "Galena occurs in the rhyolite (porphyry) talus breccia and where the underlying rhyolite is heavily fractured it often extends into the rhyolite. It is accompanied by grey and brown alteration and minor interstitial white carbonate. In general the galena is very sparse occurring mainly as thin smears along fracture planes, but in a few instances, narrow irregular stringers and blebs were present and the grade approached economic significance.
>
> This type of occurrence has been known in the area for many years. On line 6 west about 200 feet north of the base line a very old pit exposes a face of heavily fractured and discoloured rhyolite containing sparse galena as thin films on the fracture faces and as very fine and sparse grains enclosed in the rhyolite itself."
>
> (Mudford 1964, p. 23)

It is assumed by the present author that this is the same occurrence as recorded in the 1880's. Watson indicated that occasionally this mineralisation reached a significant grade; a section of coarse galena blebs in calcite within a talus breccia in one drill hole, apparently returned an assay of 6.65% lead over a 6 foot interval. He concluded, however, that this mineralisation is an isolated feature of little depth or lateral extent, and therefore of no economic significance.

Mineralisation in Windsor Sediments

Sparse galena mineralisation also occurs in the Windsor limestone unit (10A), present west of the Mine. This mineralisation can be seen today in outcrop, along the Salmon River road midway between Yava and Lake Enon. It consists of isolated blebs and cubes of galena in white calcite veins, cutting a grey-brown granular dolomite. This is no doubt the same occurrence described as follows by Fletcher in 1878:

> "On the Salmon River road, a mile and a half east of the L'Ardoise road, is a bed of dark-grey, shaly bituminous limestone, three feet thick, composed in part of stems of encrinites and other fossils; containing also, small speckes of galena, and cavities filled with scalenohedrons of clear calcispar."
> (Fletcher 1877 p. 447)

Isolated occurrences of mineralisation of this type were intersected in reconnaissance drilling conducted by Phelps Dodge to the west of the Yava area.

As part of the overall examination of sulphide mineralisation at Yava, samples of this mineralisation were collected from drill core for thin section examination. Unfortunately, much of the drill core from this exploratison work outside the Mine area has not survived. Therefore it was not possible to study this mineralisation in any detail.

Mineralisation in Canso Group Sandstone

The major mineralisation in the area occurs as a horizon of disseminated stratiform galena, within the basal 30 m of the sandstone sequence. Weak disseminated galena is widespread at this level in the sandstones along this flank of the basin; however, it is only at Yava that grades reach a significant level (>3% Pb). Pyrite and sphalerite do occur associated with the galena, but in minor amounts. Trace silver, of unclear association, reaches 5 gms/tonne in typical 4.75% Pb ore. The lead mineralisation occurs as concordant bands outlining sedimentary structures, and as more discordant and diffuse clouds, cusps and bands. In detail, the galena occurs as a cement infilling pore spaces in the clastic rocks.

III. 4. Ore Zones

The three ore zones which make up the Yava deposit, (West, Central and East Zones) are situated along strike from one another; each ore zone is located in an area of basement depression separated by weak mineralisation over intervening palaeotopographic highs.

All three zones are broadly similar in character: (a) they are all underlain by Windsor Group shale forming the stratigraphic foot-wall; (b) the zones typically have a higher grade central area surrounded by lower grade material, which in turn is surrounded by a halo of weak mineralisation; (c) the ore isopachs show a similar pattern of distribution, with the thickest ore (5-7 m) occurring in the central and higher grade area, surrounded by a wedge of thinner, lower grade ore. The style and nature of the mineralisation is the same in all three zones. There are certain differences between the zones, which are outlined below.

West Zone

In the West Zone (the study area) the ore occurs directly in footwall contact with the Windsor disconformity, as a horizon 3-7 m thick, extending for 360 m along strike and some 500 m down-dip. The ore-body consists of two north-west trending lobes: the Portal Lobe, and the South-East Lobe, which merge into a central ore area down-dip.

The overall ore reserves for this zone were calculated by Patterson (1979) to be 1.1 million tonnes at 5.6% Pb (4% cut-off). During the recent mining operation (concentrated in this area only) half of the West Zone was mined out (388,000 tonnes) in a first-pass through the up-dip portion (Figure III.3).

Central Zone

The Central Zone is a larger (900 m x 600 m) somewhat erratic area of mineralisation. To the west and up-dip, ore occurs in footwall contact with the Windsor shale, as it does in the West Zone. However, to the east and down-dip, the ore forms a horizon located within the sandstones at a position 5 m above the Windsor contact. Interpretation of this early drilling (Metallgesellschaft 1981) suggested that these two horizons form separate units. However, following an examination of the drill hole data by this author, it is proposed that the ore in this zone may just as easily be a single horizon of mineralisation,

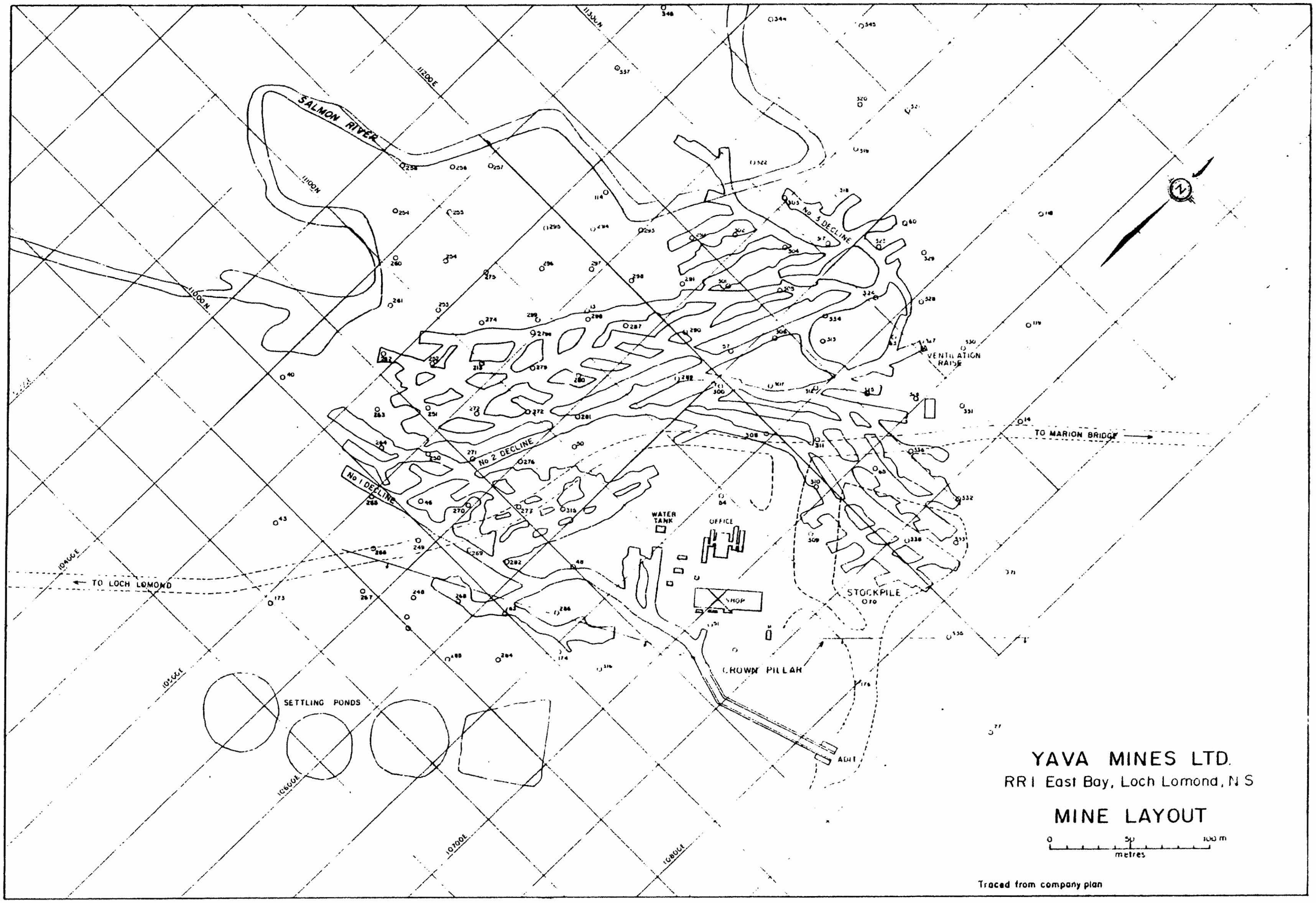

SALMON RIVER
No 1 DECLINE
No 2 DECLINE
No 3 DECLINE
VENTILATION RAISE
TO MARION BRIDGE
TO LOCH LOMOND
WATER TANK
OFFICE
SHOP
STOCKPILE
CROWN PILLAR
SETTLING PONDS
ADIT
YAVA MINES LTD.
RR1 East Bay, Loch Lomond, N S
MINE LAYOUT
0 50 100 m
metres
Traced from company plan

Figure III. 3

passing discordantly through the sandstone sequence.

A brief evaluation of this zone was conducted by Metallgesellschaft (1981); the ore was considered too erratic in distribution and too low in grade to be considered as more than potential reserves. The zone is known to contain 340,000 tonnes of 4.34% Pb.

East Zone

The ore in the East Zone occurs as a single elongate lobe, 360 m wide, aligned down-dip for 500 m. The ore lies in footwall contact with Windsor to the east; within the sandstone in the centre (8.5 m above Windsor contact), and in the western part it lies directly on basement. The sandstone hosting the ore in this area is coarser-grained, and contains more coal material and fewer shale interbeds, than the West or Central Zones.

Drilling has not been completed to fully outline this zone down-dip. Presently the zone is known to contain some 800,000 tonnes at 4.1% Pb. The main feature of difference between these three zones is the location of the ore with respect to the Windsor disconformity. In the West Zone, the ore occurs in footwall contact (i.e. in the basal sandstone beds) while in the other two zones it can occur either in footwall contact or removed some metres from the contact.

CHAPTER IV

CONTROLS TO MINERALISATION

Explanatory Introduction

In the preceding introductory chapters, the regional and Mine geology for Yava have been presented. From this synthesis, certain observations about the Yava mineralisatison are clear. These can be summarised as follows:

1. The three ore zones are spatially related to the location of palaeodepressions in the basement topography.
2. Thickest ore intersections tend to correspond with the better grade, with a corresponding drop off in grade and thickness in the surrounding marginal areas.
3. Mineralisation occurs within a basal section of the sandstone sequence, but it is not exclusively confined to the basal sandstone beds.
4. The host rock sandstone assemblage consists of laterally discontinuous beds of conglomerate, sandstone and shale.
5. Mineralisation predominates in the coarser sandstone and conglomerate bands, and is generally absent in the intervening shales.
6. The mineralisation occurs as a cement, infilling pore spaces in the sandy sediment.

In order to be in a position to qualify these points and make reasoned objective proposals on controls to mineral distribution and localisation, two fundamental aspects must be clearly understood, namely: the local geological environment or host rock geology, and the nature and character of the mineralisation itself. From this foundation, an examination of the relationship between changes in grade distribution and change in the host environment is considered. Only then can control mechanisms be objectively proposed.

SECTION A

IV. A. HOST ROCK GEOLOGY

IV. A. 1. General Statement

The mineralised horizon on the West Zone occurs as a single coherent sheet of ore, in the basal 10 m of a thick pile of Canso Group sandstones. It lies directly above a disconformity separating footwall and host rocks.

IV. A. 2. Footwall Rocks

In the West Zone, Canso Group sandstones lie in unconformible contact with a palaeosurface, on which the following sequence of footwall lithotypes are exposed:

Youngest	Green siltstone	
	Regolith †	
	†	Weathered zone
	Calcrete †	
	Green and maroon Windsor Shales	
	Talus breccia	
Oldest	Quartz Porphyry	

To consider each rock type in turn:

Quartz Porphyry

The term "rhyolite" was used in the early reports of regional mapping in this area, to describe the crystalline basement rock. This term was later adopted during the exploration phase at Yava, and from there, it has passed on to become part of mine terminology.

In hand specimen, the rock is brick-red in colour, and exhibits abundant phenocrysts of quartz, and minor feldspar, supported in a fine-grained granular groundmass (Plate IV.A.1). The field term "quartz porphyry" is preferred by the author, and has been adopted for this study. The name "rhyolite" is not justified, because there is no evidence (either from field evidence or texture) to indicate that it formed as the result of an extrusive process.

In thin section, phenocrysts are composed of quartz and microcline. Quartz predominates and occurs in euhedral crystals .5 to 1 mm in diameter; while microcline phenocrysts are fewer (.3-.8 mm in diameter), these are commonly altered to sericite and have a ragged

PLATE IV.A.1. Quartz porphyry and overlying talus breccia (DDH 337 - core BQ size).

anhedral outline. The groundmass is composed of fine quartz (.05 mm size) and granular alteration minerals, mostly sericite.

The porphyry typically shows alteration; the degree of alteration varies. Typical brick red porphyry is extensively altered; both the groundmass and phenocrysts are highly sericitised (leaving phenocrysts as ghost-like remnants), and the rock contains many opaque minerals, mostly hematite, causing the red colouration. Pale creamy coloured porphyry shows less alteration, when only the feldspars are sericitised.

As part of the pilot geochemical study, representative samples of fresh and weathered pre-Carboniferous quartz porphyry were analysed for major elements and a range of trace elements. The results are presented and discussed in Chapter V. Whole rock determination for fresh material indicates a composition of 75% SiO_2, 13.8% Al_2O_3, 5.0% K_2O and 4.3% Na_2O, that of a potassic granite.

As stated in Chapter II, this porphyry is part of the Loch Lomond Plutonic complex which also contains bodies of alkali microgranite. The latter is interpreted by O'Reilly (1978) to represent a high level, sub-volcanic environment, where cooling has been relatively rapid. A similar mode of formation can be inferred to explain the textures of this quartz porphyry.

Talus Conglomerate

In the Mine area, the basal unit of the Windsor consists of a sedimentary breccia which is variable in thickness, reaching a maximum of 14.5 m under the West Zone.

In drill core, this unit is composed of angular to sub-angular fragments of brick-red quartz porphyry of mixed cobble to pebble size (0.5-25 cm). The clasts are generally in point contact with one another, and the matrix consists of a massive olive green silty clay. The outer margins of the clastic fragments are commonly bleached to a pale pinky yellow on all sides. This unit is interpreted to be deposited on a talus-scree slope.

Windsor Shales

The complete section for the Windsor Group in this area has been outlined in Chapter II. It is only the upper unit (unit 10C), consisting of laminar-bedded maroon and green shales and siltstones, which is known to occur in footwall contact with the ore. This unit is characterised by its mottled green and maroon colouration. It is otherwise very little different from the underlying black shale unit (Plate IV.A.2), except that limestone and gypsum intercalations are generally absent.

It is suggested that this variegated colouration is the result of diagenetic redox alteration changes, occurring during the period of emergence and weathering at the end of the Visean.

PLATE IV.A.2. Windsor Group shales with gypsum bands (DDH 337 - core BQ size).

Calcrete

A calcareous horizon, up to 2 m in thickness overlies the top unit of the Windsor over most of the Mine area.

This unit was first described by Watson (1963 p.5) as a "pale creamy limestone highly shattered and fractured", which he interpreted to "result from failure or slumping of a relatively competent limestone bed in incompetent mudstone". The same unit was later described as a "limestone breccia" by Scott (1980 p. 18), and was interpreted as follows: "Moore (pers. comm.) has suggested that this unit is a solution collapse breccia, and could have formed from solution of limestone by circulating groundwater".

Excellent exposure of this unit in much of the Mine workings, has allowed for a more detailed examination (Plate IV.A.3). In hand specimen, it consists of interlocking angular nodules of pinky grey cryptocrystalline carbonate, with a characteristic splintery fracture.

The nodules are of various sizes, ranging from 1-15 cm; these are separated by irregular cracks and fractures, filled with either soft green clay or clear sparry calcite. The horizon has a set vertical profile, comprising an irregular transitional lower contact with underlying shales, a massive nodular central part, and a cap of laminar bedded carbonate up to 10 cm in thickness. This top unit is only locally preserved. After several months of exposure in the Mine atmosphere, this unit takes on a characteristic rusty pink weathering

PLATE IV.A.3. Footwall calcrete and regolith, and host sandstone - underground (rule = 10 cm).

appearance.

It is proposed that this unit most probably is a calcrete, which developed on the surface of the Windsor, under arid sub-aerial conditions during emergence late in the Visean. The textures and profile compare well with calcrete described by Allen (1974).

Regolith

In the Mine area, the uneven upper surface of the calcrete is locally blanketed by a soft and massive green silty clay, which reaches a maximum thickness of 15 cm. Thin section examination of this material was not possible. Analysis of this unit (presented in Chapter V), indicates a composition that is predominantly aluminum silicate, with minor associated iron, potassium and magnesium.

This unit can be interpreted as either a volcanic tuff, or a palaeosol/regolith. The latter explanation is preferred, because there is no evidence of Visean volcanism in the region from which a tuff might originate; also, although there is no trace of rootlets or organic material within this unit, the very massive homogeneous texture of this fine-grained material is most likely the result of bioturbation.

Green Siltstone Assemblage

In certain parts of the West Zone (most noticeably in the southwestern end of the Portal Lobe) the calcrete and regolith horizons are unconformably overlain by a sequence of interbedded silty sandstones, mudstones and shale flake conglomerate. The mudstones are generally laminar-bedded, while the silty sandstone exhibits small-scale trough cross-stratification. The entire assemblage is characterised by the distinct olive-green colouration of all lithotypes, and the fine silty nature of the sandstone. It is locally preserved (on the disconformity), as isolated mounts with pronounced relief, reaching a maximum thickness of 5 m.

This assemblage is interpreted to represent a period of fluviatile sedimentation early in the Namurian, which ceased and suffered erosion (save these remnants) prior to the major phase of fluviatile sedimentation, later in the same period.

This unit (which contains only weak galena mineralisation as small flecks in silty sandstone) forms the stratigraphic footwall to the ore horizon, where it is present.

This completes the description of the range of footwall lithotypes underlying the ore in the West Zone. In studying an ore horizon so close to an unconformity, the possible influence of footwall lithotype on grade distribution must not be overlooked. This aspect is considered in Section C of this chapter.

IV. A. 3. Host Rocks

The sandstone assemblage of the Canso Group (which hosts the Yava mineralisation and occurs above the mineralised zone) consists of interbedded conglomerates, sandstones and shales, occurring in a series of laterally discontinuous fining-upwards cycles. The entire assemblage can be divided into a set of distinct lithotypes, as shown in Table IV.1. Each lithotype is described systematically, before the cyclical organisatison of these units is discussed.

Lithological Descriptions

Conglomerates

The various conglomerates recognised in this assemblage, represent distinct end-members to a multi-faceted continuum, subdivided on the basis of clast type. Conglomerates commonly contain varying proportions of the different clast types, and the composition of a conglomerate horizon can change laterally from one type to another. Common to all these lithotypes is that the matrix material is of sandy composition.

Composite conglomerate: This unit is a polymictic extraformational conglomerate (Pettijohn, 1975), containing assorted clasts of Windsor shale and limestone, vein quartz, quartz porphyry, and exotic material (including metamorphic clasts) in varying proportions. The clasts are generally poorly sorted, and range in size from cobbles to pebbles (25 cm-1.5 cm).

Windsor shale pebble conglomerate (oligomictic extraformational): This is a more common form of conglomerate, easily recognised in drill core;

LITHOTYPES	FIELD NOMENCLATURE	FEATURES
Shale	Dark shale	Laminar bedded
	Heterolithic shale	
Sandstone	Gritty sandstone	Coarse-grained
	Sandstone (typical)	Med - fine-grained
	Silty sandstone	
Conglomerate		
Oligomictic Intraformational		
	Coal lag	
	Shale flake conglomerate	
Oligomictic Extraformational		
	Limestone pebble conglomerate	
	Windsor shale pebble conglomerate	
Polymictic Extraformational		
	Composite conglomerate	

TABLE IV.A.1. Yava West Zone: Sandstone Assemblage of the Canso Group.

the clasts consist of rounded, normally elongate or discoid fragments of green and black Windsor shale. Pebbles (1.5-3.5 cm) are generally aligned with the long axis parallel to bedding.

Limestone pebble conglomerate (Oligomictic extraformational): This is the dominant form of extraformational conglomerate; it is composed of sub-rounded to rounded cobbles and pebbles (10 cm-1.5 cm) of pinky grey splintery micrite and fine dolomite with a poorly-sorted sandy matrix. Most of the clastic fragments are in point contact. Scott (1980), in discussing the origin of this unit, noted that the presence of abundant clastic limestone must record unusual depositional conditions, when physical rather than chemical erosion of carbonate was permitted. He suggested that this could result from sharp uplift, caused by faulting, to form local high relief close to the environment of deposition. The author is in agreement; but he feels that the presence of abundant, friable, calcrete material on the weathered Windsor surface, provided an exceptional local source for carbonate clastic material during this early phase of humid erosion and continental sedimentation.

Shale Flake Conglomerate (Oligomictic intraformational): This conglomerate type consists of flakes, chips, and (more rarely) slabs of locally-derived grey laminar bedded shale. Clasts range in size from 1.5 to 45 cm, and are held in a matrix of well-sorted, clean, sandy material.

Coal lag (oligomictic intraformational): Chips and slabs of coaly material also occur as a distinct clastic component to conglomerates.

This coal (or bark vitrain) results from "in situ" coalification of plant debris incorporated as sediment load. Coalified plant stems occur commonly as cylindrical and flattened elongate sandstone casts with a rind of coaly material. Fossils of Calamites and Lepidodendron can be identified. In places coalified tree trunks (up to 5 m long and 70 cm in diameter) are preserved (sometimes complete with root system) as lag debris.

On the premise that this plant material is derived locally, (i.e. from within the sedimentary environment) this unit is considered intraformational.

Sandstones

Sandstones have been measured from drill core to comprise 74% of the clastic assemblage. They are predominantly arenaceous in composition, well-sorted, and range from coarse-grained sandstone or gritty sandstone, through to fine-grained sandstone. The bulk of the sandstone at Yava is of medium grain size (Plate IV.A.4).

In hand specimen, it is grey-green in colour, and characteristically has a dull soft appearance with a visible clay matrix. It is composed predominantly of quartz (80%), rock fragments (15%), potassium feldspar (1-3%), with the remainder, mica, chlorites, and heavy minerals (mostly zircons). Grain size ranges from .05 to .35 mm, but is mostly within the range of .1 to .2 mm; this indicates a moderately sorted medium to fine grained sand. Original roundness of clasts is

PLATE IV.A.4. Typical sandstone host rock - Working face No 3 decline. (ranging rod = 2 m)

PLATE IV.A.5. Calcareous concretions and bands (weathered rusty brown) in grey mineralized sandstone. (hammer marks Windsor contact, ranging rod = 2 m)

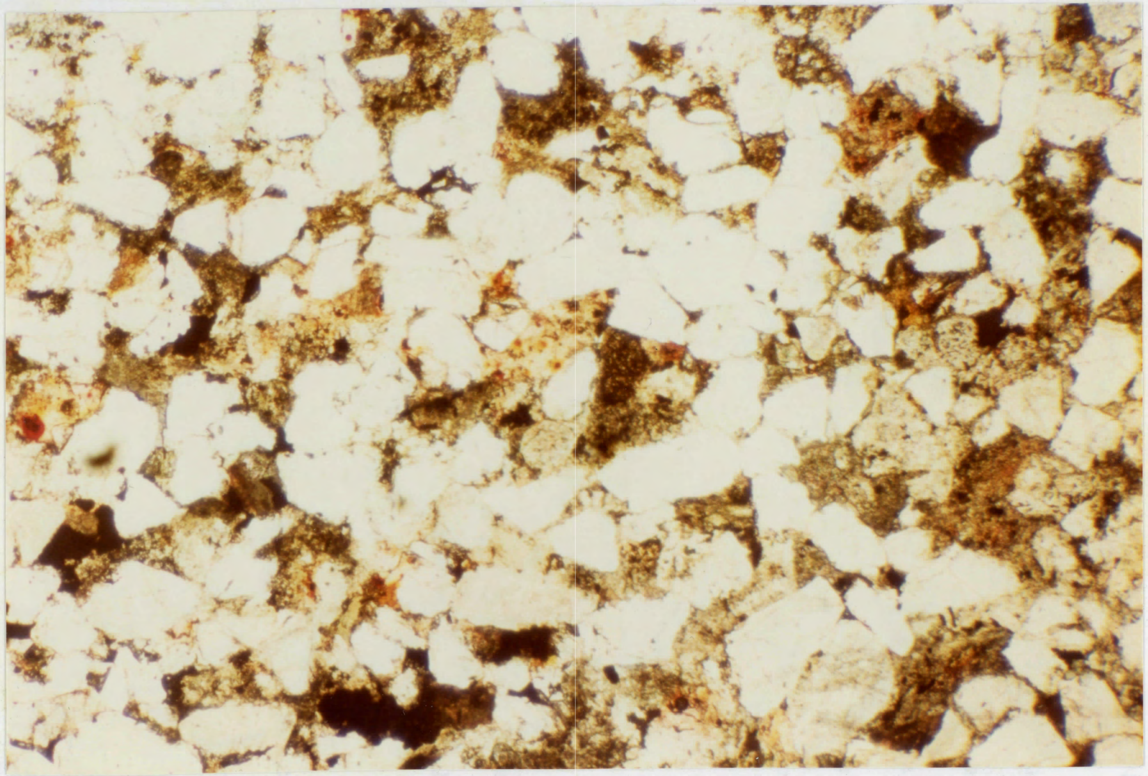


PLATE IV.A.6. Thin section typical host sandstone with clay silicate cement. (PPL 45x) best seen in sandstone with carbonate cement, where no clast overgrowth has occurred; here clastic grains are subangular to sub-rounded in character. These characteristics indicate the sandstone to be a sub-mature, fine to medium grained, sublitharenite (Folk, 1980).

Characteristically, sandstones are cemented by authigenic quartz overgrowth and a granular clay silicate matrix; more locally they are cemented by carbonate (Plate IV.A.5) or sulphide. Quartz overgrowth can be observed to increase clast size by 15% and also weld former clastic point contacts to form interlocking grain boundaries (see Plate IV.B.7 in Section B). Plate IV.A.6 is an illustration of typical host sandstone with clay silicate cement.

X-ray diffraction studies conducted by Scott (1980), on selected samples of sandstone from the West Zone indicate that the clay fraction is composed of 75-90% kaolinite, with minor amounts of illite, chlorite and occasional montmorillonite.

In localised areas, particularly close to the Windsor disconformity, sandstones are carbonate cemented. The carbonate consists of crystalline calcite, which grows with a poikilotopic texure (a single crystal surrounds groups of clasts). There is no evidence of quartz overgrowth prior to the formation of carbonate cement. Silty Sandstone: Towards the top of sedimentary cycles, the sandstone becomes more fine-grained in appearance. This lithology comprises the same clastic assemblage as the main sandstone, while overall clastic grain size drops to the range 0.1 to 0.25 mm.

Shales

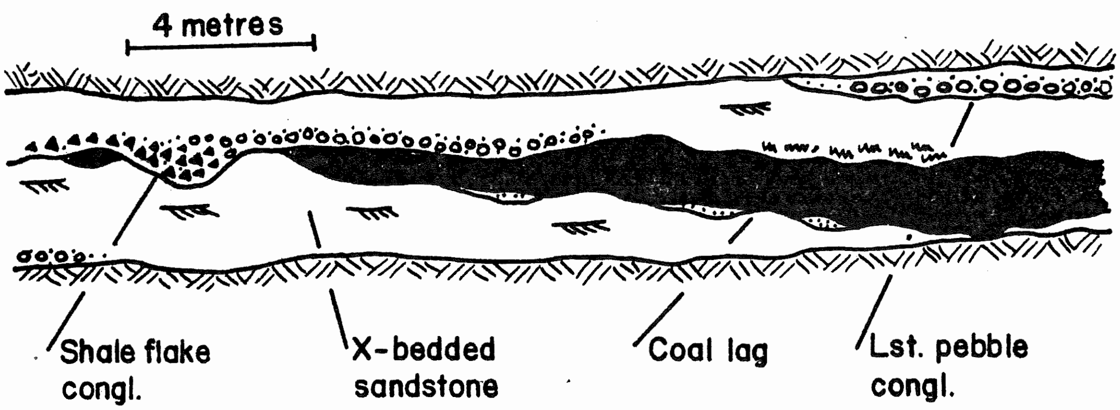
Two types of shale lithology can be recognised: a laminar-bedded dark grey shale and a heterolithic silty shale comprising alternating bands, 1-2 cm thick, of pale grey siltstone and dark shale. The contact between siltstone and overlying shale is generally gradational. Grain size for shale is in the range .05-.1 mm and most visible grains are of quartz composition. The internal fabric and brown colour (under plain polarised light) suggests that organic detritus is present along with clay minerals.

Stratigraphic relationships

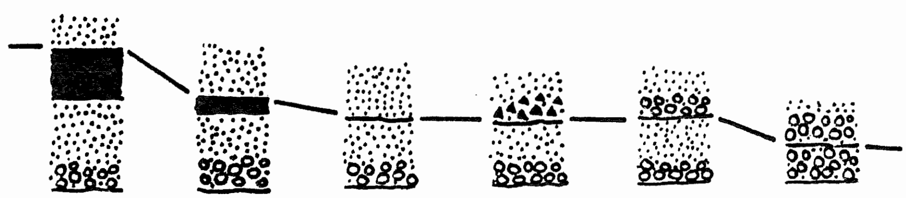
It was not until the Canso Group sandstones were exposed in underground opening, and underground mapping had commenced (May 1980) that the internal stratigraphic relationship of these various lithotypes was properly appreciated. The sediments are deposited in fining-upward cyclical packages, with a basal conglomerate overlain by sandstone, which is in turn overlain by a shale. These graded cycles are seldom completely preserved (because of intraformational erosion). Occasionally both the shale and sandstone components are missing, to leave conglomerate lying in direct erosional contact with conglomerate. Also, the tracing of single cycles underground, shows lateral changes in lithology at the same stratigraphic level (i.e. the conglomerate marking the base of a cycle in one area, might pass into a sandstone marking the base of the same cycle some distance away (30 m)). In this

PLATE IV.A.7. Cyclical sedimentation (1) - No. 2 decline wall. (ranging rod = 2 m)

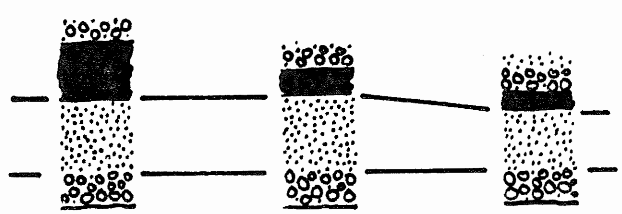
PLATE IV.A.8. Cyclical sedimentation (2) - no. 2 decline wall. (hand points to line of disconformity)



TYPICAL DOWN-DIP WALL SECTION, YAVA MINE, TO SHOW LITHOLOGIC RELATIONSHIP



CORRELATION USING DISCONFORMITIES AND COARSE-GRAINED CYCLE BASES



CORRELATION USING GRADATIONAL CONTACTS

Figure IV. A. I. Stratigraphic Relationships and Correlation of Litho-types, Yava, West Zone way, cycles were generally recognised with respect to the erosional disconformities marking the top and bottom. Individual beds could only be correlated where top or bottom contact showed no erosional break. These relationships are illustrated in Plates IV.A.7 and IV.A.8 and in sketch form in Figure IV.A.1. Once an understanding for these relationships had been achieved, more realistic correlations between surface drill holes were possible.

Sedimentary Cycles

The base of each sedimentary cycle is marked by an erosional contact overlain by a conglomeratic horizon, which varies in thickness from 30 cm to 2 m. The conglomerate is generally of specific composition: shale flake conglomerate, limestone pebble conglomerate or coal lag.

Laterally, conglomerates can change in composition from one type to another, or may pinch out and pass laterally into sandstone. Within this continuum, there are certain patterns: the basal conglomerate at the base of the lowermost cycles (viz. in disconformable contact with the Windsor surface) is characteristically a limestone pebble conglomerate. Higher in the sequence, internal erosion channels in the sediment are characteristically filled by shale flake conglomerates, which are in turn overlain by limestone pebble conglomerates. This pattern marks a change from a phase of high-flow regime (with much internal reworking of material) to more normal flow conditions. Conglomerates infilling large channel features, (6-10 m in diameter) can reach an

PLATE IV.A.9. "Ridge and furrow" moulds on back sandstone, caused by deposition over slump folded and truncated mudstone beds, (visible at top of wall), 2-5-4 drift. (ranging rod = 2 m).

overall thickness of 2 m.

The overlying sandstone, which comprises the bulk of each cycle, can be deposited as a massive unit, but it is generally internally stratified. The sandstones contain large-scale trough cross-stratification of variable set thickness (averaging 70-80 cm); less frequently, large-scale planar cross-stratification of similar set thickness is present. Towards the top of sandstone intervals, where it becomes more silty, small scale cross-lamination (4-5 cm sets) and parallel lamination can often be observed. Associated with this small-scale cross-lamination, undulating type ripples occur on bedding surfaces. Also, small-scale slump folding, can be observed locally, where internal laminations are enhanced by mineralisation.

Shales occur as either: thin, relatively extensive horizons (maximum thickness 20 cm), marking the top of graded cycles; or, as locally preserved, thick accumulations (2 m), infilling abandoned erosional channel ways. Volumetrically, the latter is most important, due to its higher preservation potential. The channel-fill shales comprise both dark grey shale and heterolithic shale-siltstone couplets. These erosional depressions, infilled with shale, are characteristically lined with a layer of coarse gritty sandstone, up to 20 cm thick.

In certain areas, shales have been subjected to soft-sediment deformation, where multidirectional chevron folding and local thrust movement can be seen. Field observations indicate that this slumping occurred immediately following deposition, because erosional activity, preceding deposition of the overlying unit, appears to have acted upon upended and folded shale beds, producing ridge-and-furrow features on the erosion surface (Plate IV.A.9).

During underground wall mapping through the Mine area, cyclical units have been followed laterally, to the point of pinch-out. Examples of the lateral distribution of cycles and lithotypes within the Mine, are presented in Figures IV.A. 2 and 3 (back pocket).

With an understanding of these relationships, a stratigraphy for the West Zone ore column was drawn up. This is presented in Figure IV.A.4.

Within the ore column for the West Zone (i.e. the basal 3.5 to 8 m of the Canso Group), there are two areas of contrasting cyclical stratigraphy: the South East Lobe (where 1 to 2 sedimentary cycles are represented) and the Portal Lobe, on the western side of the orebody (where as many as 4 cycles can be present over the same general thickness).

In the South East Lobe, a limestone pebble conglomerate up to 1.5 m thick marks the base of the first cycle. This is overlain by massive and cross-bedded sandstone 1-4 m thick. Locally preserved over this is a shale, which is generally 20-30 cm thick, but reaches a maximum of 2 m in abandoned channels. Erosion at the base of the next cycle is variable; locally it extends well into the underlying unit to erode all but the basal metre. The overlying cycle consists of conglomerates of

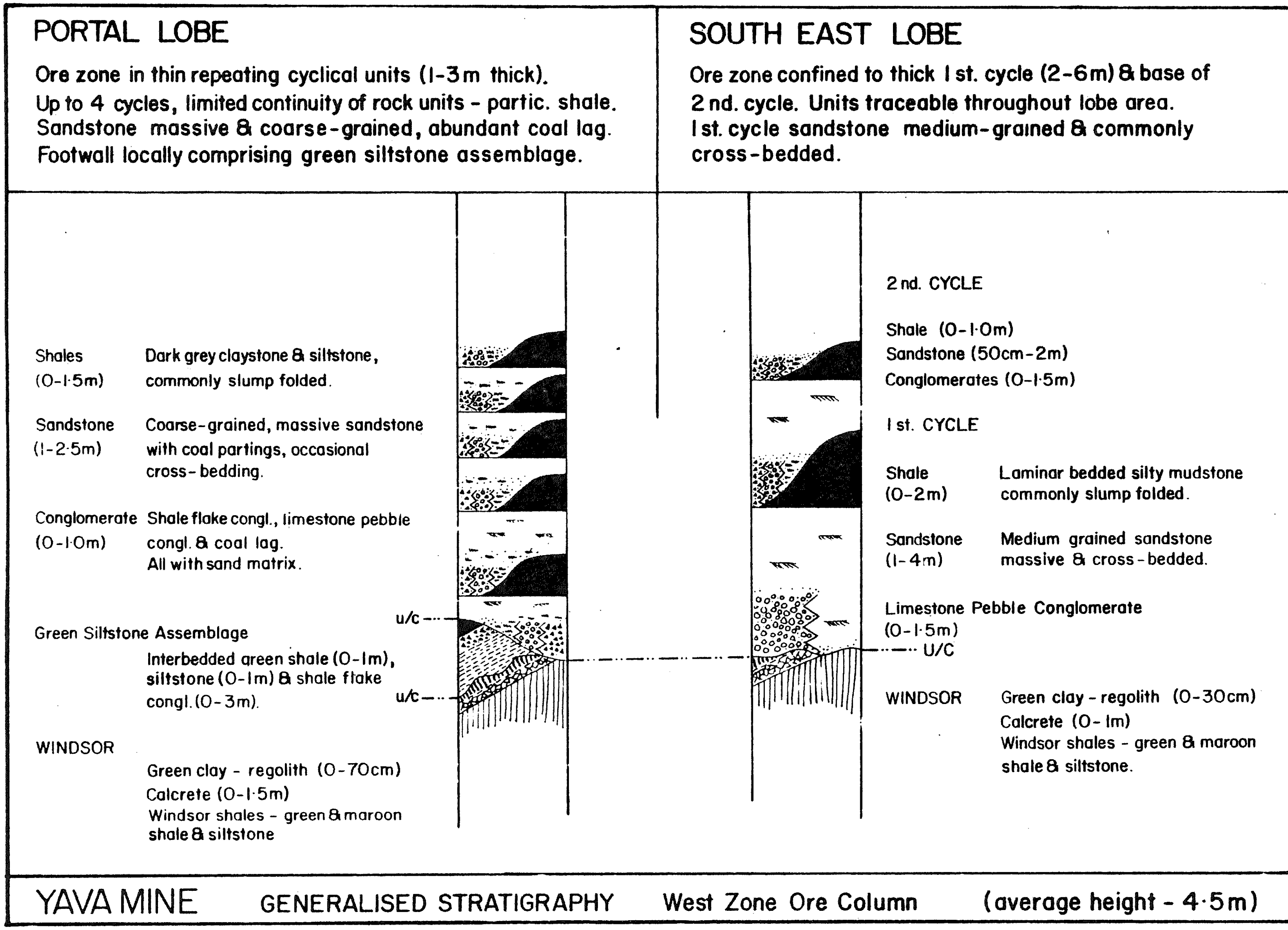

PORTAL LOBE
Ore zone in thin repeating cyclical units (1-3m thick).
Up to 4 cycles, limited continuity of rock units - partic. shale.
Sandstone massive & coarse-grained, abundant coal lag.
Footwall locally comprising green siltstone assemblage.
SOUTH EAST LOBE
Ore zone confined to thick 1st. cycle (2-6m) & base of 2nd. cycle. Units traceable throughout lobe area.
1st. cycle sandstone medium-grained & commonly cross-bedded.
Shales (0-1·5m) Dark grey claystone & siltstone, commonly slump folded.
Sandstone (1-2·5m) Coarse-grained, massive sandstone with coal partings, occasional cross-bedding.
Conglomerate (0-1·0m) Shale flake congl., limestone pebble congl. & coal lag. All with sand matrix.
Green Siltstone Assemblage
Interbedded green shale (0-1m), siltstone (0-1m) & shale flake congl. (0-3m).
u/c
u/c
WINDSOR
Green clay - regolith (0-70cm)
Calcrete (0-1·5m)
Windsor shales - green & maroon shale & siltstone
2nd. CYCLE
Shale (0-1·0m)
Sandstone (50cm-2m)
Conglomerates (0-1·5m)
1st. CYCLE
Shale (0-2m) Laminar bedded silty mudstone commonly slump folded.
Sandstone (1-4m) Medium grained sandstone massive & cross-bedded.
Limestone Pebble Conglomerate (0-1·5m)
U/C
WINDSOR Green clay - regolith (0-30cm)
Calcrete (0-1m)
Windsor shales - green & maroon shale & siltstone.
YAVA MINE GENERALISED STRATIGRAPHY West Zone Ore Column (average height - 4·5m)

Figure IV. A. 4.

varying composition, up to 50 cm thick; this in turn is overlain by sandstone and shale so to repeat the cyclical sequence.

The same overall sequence can be observed for the Portal Lobe. However, up to four cycles are represented here, and these average 1 to 3 m in thickness.

The thick basal cycle of the South East Lobe pinches out to the west, where it is overstepped by thinner cycles of the Portal Lobe further west. These Portal Lobe cycles could not be traced back, using drill core, above the South East Lobe.

Proportions and distributions of host litho-types

In addition to the more detailed stratigraphy of the ore horizon, it was important to establish the volumetric proportions of the various lithotypes in the sandstone. To do this, the basal 15 m of the sandstone sequence in 108 holes covering the West Zone were tabulated, to show the presence or absence of each of the five main lithotypes. And, where present, the total vertical thickness of intersection for each unit was recorded. From these data, the proportional importance of each lithotype (as a percentage of the total rock profile) was calculated; mean figures to cover the entire zone were then determined. Furthermore, the frequency of occurrence of each lithotype in the drill holes was computed, to ascertain the distribution pattern of each category (given in this case as an overall occurrence percentage).

The results of these two exercises are presented in Table IV.A.2.

From this study, the following observations can be made:

1. The host assemblage consists of 88.6% sandstone/conglomerate (lateral accretion sedimentation) and only 11.4% shale (vertical accretion sedimentation).

2. Sandstones are ubiquitous, and make up 74.4% of the profile, while limestone pebble conglomerate (extra formational conglomerate) and shale are widespread, and comprise most of the remainder of the profile.

3. Shale flake conglomerate and coal lag (intraformational) are locally distributed, and together make up only 4.5% of the total profile.

These proportions and distribution patterns are considered to be representative of the lower 150 m of the Canso section. It is only in the upper 100 m of the basal sandstone, intersected in the reconnaissance drilling down-dip of the orebody, that beds become more massive and uniform (Watson 1963).

IV.A.4. Palaeocurrent Analysis

As part of the overall investigation of host rock geology, an attempt was made to determine palaeocurrent directions within the sandstone sequence. As this is not possible from drill core, foreset readings could only be taken underground. During the mapping period, 142[a] foreset orientations were collected from eight different areas of the Mine. These were measured as dip and strike readings on the

LITHOLOGICAL DISTRIBUTION: YAVA WEST ZONE

Distribution in section (intersection percentage): 108 holes

Sandstone:	comprises	74.4%	of profile
Shale	comprises	11.4%	of profile
Lst. peb. congl.:	comprises	9.7%	of profile
Sh. flk. congl.:	comprises	3.3%	of profile
Coal lag:	comprises	1.2%	of profile

Distribution in space (occurrence frequency): 108 holes

Sandstone:	present in	100%	of holes
Shale	present in	88%	of holes
Lst. peb. congl.:	present in	93%	of holes
Sh. flk. congl.:	present in	33%	of holes
Coal lag:	present in	27%	of holes

Vertical and lateral distribution of lithotypes through the basal 15 m of sandstone section in 108 drill holes covering the West Ore Zone, Yava Mine.

TABLE IV.A.2

foreset surface, of a visibly cross- stratified set. Readings were taken from different sedimentary cycles within the basal 4 m of the Canso Group sequence. Tectonic dip in the area of the Mine (as determined by Phelps Dodge Corp.), following their overall analysis of the deposit (Mudford 1964 and Watson 1963, 1964) is 14-15° along a strike of N50°E. Therefore, all readings must be adjusted to allow for post-depositional tilt. This was achieved by stereographic projection on a Wulff net, using the procedure outlined by Ragan (1973). Individual rose diagrams of palaeocurrent directions for the eight sample areas, and a composite rose for the whole Mine area, are shown in Figure IV.A.5 (back pocket). Also shown on this Figure (as an inset) is the rose for the uncorrected readings.

This study indicates a predominant unimodal current direction towards the east, consisting of a strong mode in the 80° to 100° sector, with supporting figures over a 115° range on either side (30°-145°). A small subordinate mode, in an opposing west and south-west direction, is also present. This direction is mostly derived from the readings of the separate population, collected to the west side of the mine.

This suggests that fluvial transportation in the area of the South East Lobe was from the western quadrant, and that to the south-west, in the area of the Portal Lobe, transportation was in the opposite direction. This probably indicates a general flow south, with local redirection east and west, to either side of the intervening basement high.

The regional understanding of this area would suggest that

Canso Group sedimentation commenced by covering a peneplain (floored by Windsor Group lithologies but interrupted by upstanding crystalline basement highs, one of which was in the vicinity of the Yava Mine). With this topographic configuration, it would be expected that fluvial transportation might originate within the area of the high (to the southeast of the study area) and flow north-west onto the peneplain. The palaeocurrent analysis as presented, indicates the opposite, with a strong easterly, and lesser westerly, flow direction; this infers flow from peneplain towards palaeo-high.

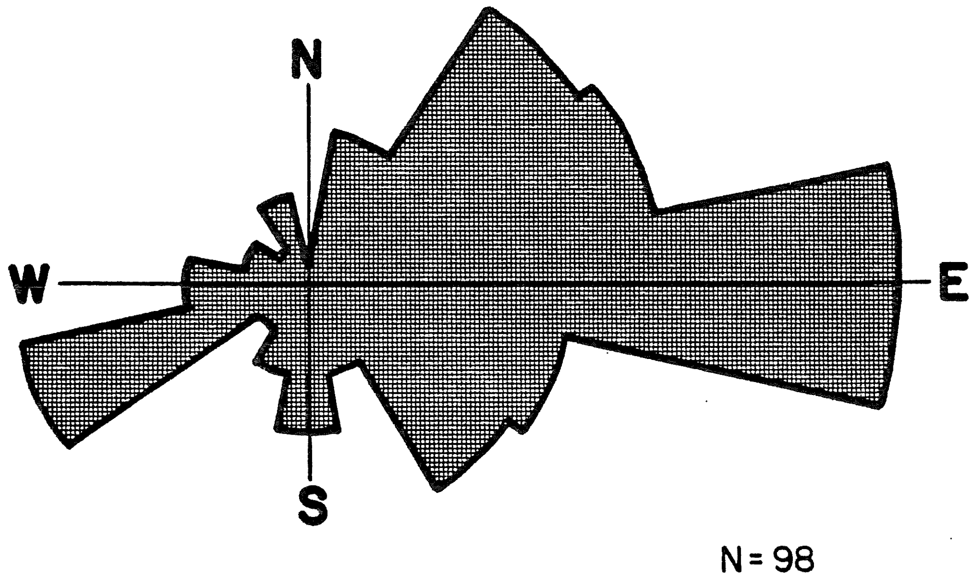
Two possible explanations for this can be proposed. Firstly, it is possible that the lobe areas (as valleys within the palaeo-high) may have been flow-through or spillway points from north-west across the high into an area of sedimentation to the south-east. Or secondly, sedimentation at this level above the disconformity (i.e. the basal 4 m) was strongly influenced by local irregularities on the surface of the disconformity, and hence flow directions were locally variable.

On the inset rose of Figure IV.A.5, which shows the uncorrected foreset dip and strike reading, it is apparent that many readings fall in the direction of tectonic tilt. As many of these are at a shallower angle than the tilt angle, the removal of tilt has the effect of translating the foreset direction to the opposite quadrant (i.e. from north-west to south-east). Also, the resulting angle of repose for some of these foresets, after correction, can be quite shallow (0-10°).

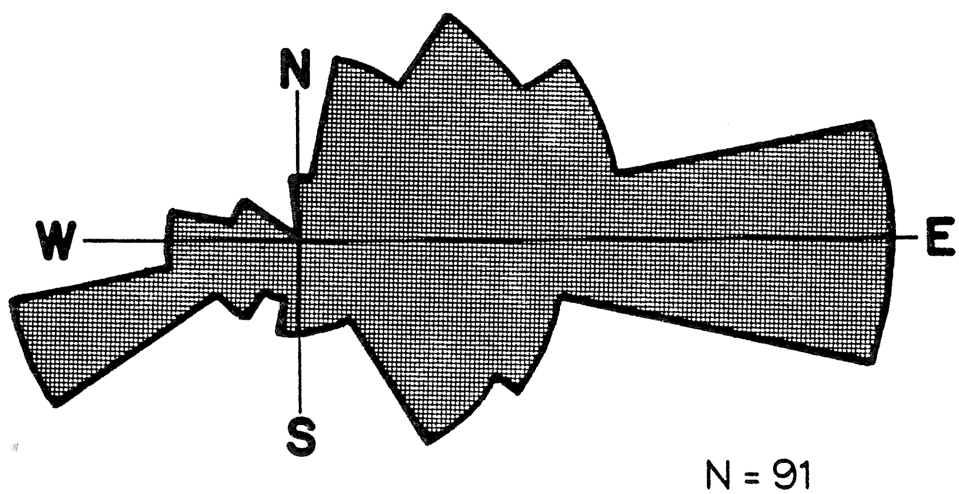
In order to try and refine this analysis, and eliminate spurious readings which might influence the resulting flow pattern, two replots of the rose diagram have been prepared. Replot 1 (Figure IV.A.6a) uses only those foreset readings which indicate (after correction) an angle of repose (σ), after correction, between 10° and 25°. This accommodates the normal range for angles of repose for foresets in undeformed rocks, 18° to 25° (Potter and Pettijohn 1977). It also allows for the trough-stratified nature of the foresets. The second replot (Figure IV.A.6b) is a further refinement of replot 1; in this case, those foreset readings which indicated a pre-correction dip and strike approaching the tectonic plane (14°NW on N50°E) were also eliminated. The range taken for elimination was strike N30-70°E and dip 5-25°NW.

After replot 1, 44 out of the 142 readings were eliminated, but the resulting rose plot shows no appreciable difference in the directional flow pattern. Following replot 2, only an additional 7 readings were lost; the resulting directional flow pattern also remained unchanged.

In conclusion, palaeocurrent analysis of sandstone foresets from within the basal 4 metres of the Canso Group of the South East Lobe, indicate fluvial transportation from west to east. Flow is in the opposite direction in a different topographic depression, to the west side. It is felt that these flow patterns, which cover a small area (350 x 200 m) are local patterns, strongly influenced by the underlying palaeolandscape; they do not represent regional transportation direction for the Canso Group.



A. Foreset palaeocurrent directions - Yava West Zone
N50°E, 14°NW removed & resulting Θ 10°-25° selected.



B. Foreset Palaeocurrent directions, Yava West Zone
N50°E, 14°NW removed, resulting Θ 10-25° selected, and uncorrected readings with strikes 30-70° & dips 5-25° omitted.

Figure IV.A.6

Environmental Analysis

An environmental analysis for the basal section of the Canso Group (that part of the section hosting the mineralisation at Yava) will be discussed under the five facies-defining parameters proposed by Selley (1972); and with reference to Cant and Walker (1976) and Walker (1979).

Geometry: the study is too limited in extent to determine any overall shape to the sedimentary facies; however the sediments do occur as an extensive blanket, infilling depressions in the underlying palaeo-landscape.

Lithology: the predominant lithology is sandstone, classified as well-sorted litharenite-feldspathic litharenite, containing clay silicate, and, more locally, carbonate cement. Sandstones make up 75% of the sedimentary pile. Conglomerates are of varying clastic composition; extraformational limestone pebble conglomerates, intraformational shale flake conglomerates, and coal lag. These conglomerates all have a sandy matrix, and occur as laterally variable coarse cycle bases. They make up 14% of the pile. Shale occurring as dark, laminar-bedded shale, and heterolithic siltstone-shale couplets, makes up the remaining 11% of the sequence.

Sedimentary Structures: Pre-depositional sedimentary structures are observed along erosional cycle bases; these include erosional channels, flute marks, and ridge- and furrow-features (on the surface of eroded mudstone). Syn-depositional structures include large-scale trough and planar cross-stratification, and small-scale trough cross-laminations with associated asymmetric ripple marks. Post-depositional slump folding and gravity thrusting can also be observed in some mudstone sections.

Palaeocurrent analysis: the analysis of palaeocurrents indicates uni-directional flow in two opposing directions into two different negative areas in the palaeolandscape.

Fossils: Coaly matter originating from plant debris (transported as waterlogged bed load) is abundant throughout the section. Palynomorphs are common in mudstone. No other fossil material can be discerned.

Sequences and Cycles: Sedimentation has progressed in a series of systematic fining-upward cyclothems, with three distinct subfacies: conglomerate, sandstone and shale, representing an autocyclic ABC ABC design. Complete cycles, however, are generally not preserved. It is proposed that this sedimentation took place in a continental, sandy, fluvial environment. The abundance of plant debris, absence of marine fauna, and absence of intercalations of marine sedimentation would indicate continental conditions. Deposition in distinct fining-upward cycles, sedimentary structures, and palaeocurrent directions, indicate river transportation.

Within this environment, conditions of sedimentation can range from low-sinuosity braided stream conditions, to high-sinuosity meandering river conditions. Coarse to fine sediment ratios of 8:1

would indicate braided stream; while the lateral extent of cyclical units, and the nature of the vertical accretionary deposits, would indicate meandering river. It is proposed that sedimentation took place in upper meandering river conditions, where sediment load was coarser than normal.

Diagenetic Aspects

At Yava diagenesis of the Canso Group sandstone is closely interrelated with stages in the sulphide mineralisation; it is thus considering in detail in section B of this chapter which examines sulphide mineralisation. To summarise here, petrographic examination would suggest the following sequence of events:

1. Deposition of sediment as clean detrital gravel, sand and mud.
2. Early carbonate cementation in localised areas under low compaction conditions, to seal porosity in these areas.
3. Introduction of clay silicate cement in areas not already cemented with carbonate. This only partially reduces porosity.
4. Precipitation of first interstitial sulphides; framboidal pyrite and sphalerite, associated with biogenic activity.
5. Quartz overgrowth, caused by compaction and pressure solution cementation of silica. This results in slight corrosion along intergranular boundaries (to develop an interlocking texture) and the authigenic overgrowth of quartz grains.
6. The main introduction of sulphides at Yava follows quartz overgrowth; this mineralisation represents the last visible diagenetic

change.

The original porosity of these sediments (that of a moderately sorted fine to medium grained sand) can be taken at 35% (Beckman 1976); while the present porosity of Yava sandstone is known to be 9-10% (following lab testing for porosity conducted by the Ontario Research Foundation). This would indicate a reduction in porosity during diagenesis (and mineralisation) from 35 to 10%. Present day porosity can be seen in thin sections of sandstone impregnated with coloured resin, and as pits and cavities on polished sections.

SECTION B

IV. B. Sulphide Mineralisation

In Chapter III the general features of the Yava mineralisation were discussed. This section will consider the mineralisation of the West Zone in detail.

IV. B. 1. General feature of mineralisation

In the West Zone, as in the other zones at Yava, the mineralised horizon is characterised by having a low-grade or unmineralised footwall, a high-grade basal section (of varying thickness) followed by a lower-grade upper section (marking a gradational loss of mineralisation into barren or weakly mineralised ground in the hanging wall). Within this overall pattern, lithologic aspects of the host rocks have a secondary, but important, effect on mineralisation. In the West Zone, the ore footwall is marked by the Windsor disconformity, except in some isolated drill hole intersections on the north-west margin (where the base of mineralisation is at a higher level).

IV. B. 2. Mineral Styles

An important aspect of the galena mineralisation at Yava and at other deposits of this type, is the often remarkable congruence between sedimentary structures and mineralisation. This has lead to considerable discussion in the literature (Samama, 1976, Rickard et al., 1979, Ncube and Amstutz, 1981, and Rickard et al. 1981). In order to facilitate a descriptive account of the large-scale features of the mineralisation at Yava, an informal classification of mineral styles (modelled after the classification of Rickard et al. (1979) for Laisvall) has been drawn up, and is presented in Figure IV.B.1. A classification for Yava styles was attempted by Scott (1980); it is inadequate and incomplete, being based on only limited drill hole observations.

1. Concordant - following microfeatures

These styles (which are distinguishable at the scale of the hand specimen) include all mineralisation concordant to the sedimentary texture. Massive homogenous sandstone (where mineralised) contains galena, either in the form of disseminated dustings or as blebs or eyes (up to 1 cm in diameter). Also, in massive sandstone containing isolated clastic fragments, galena will often occur as a halo surrounding

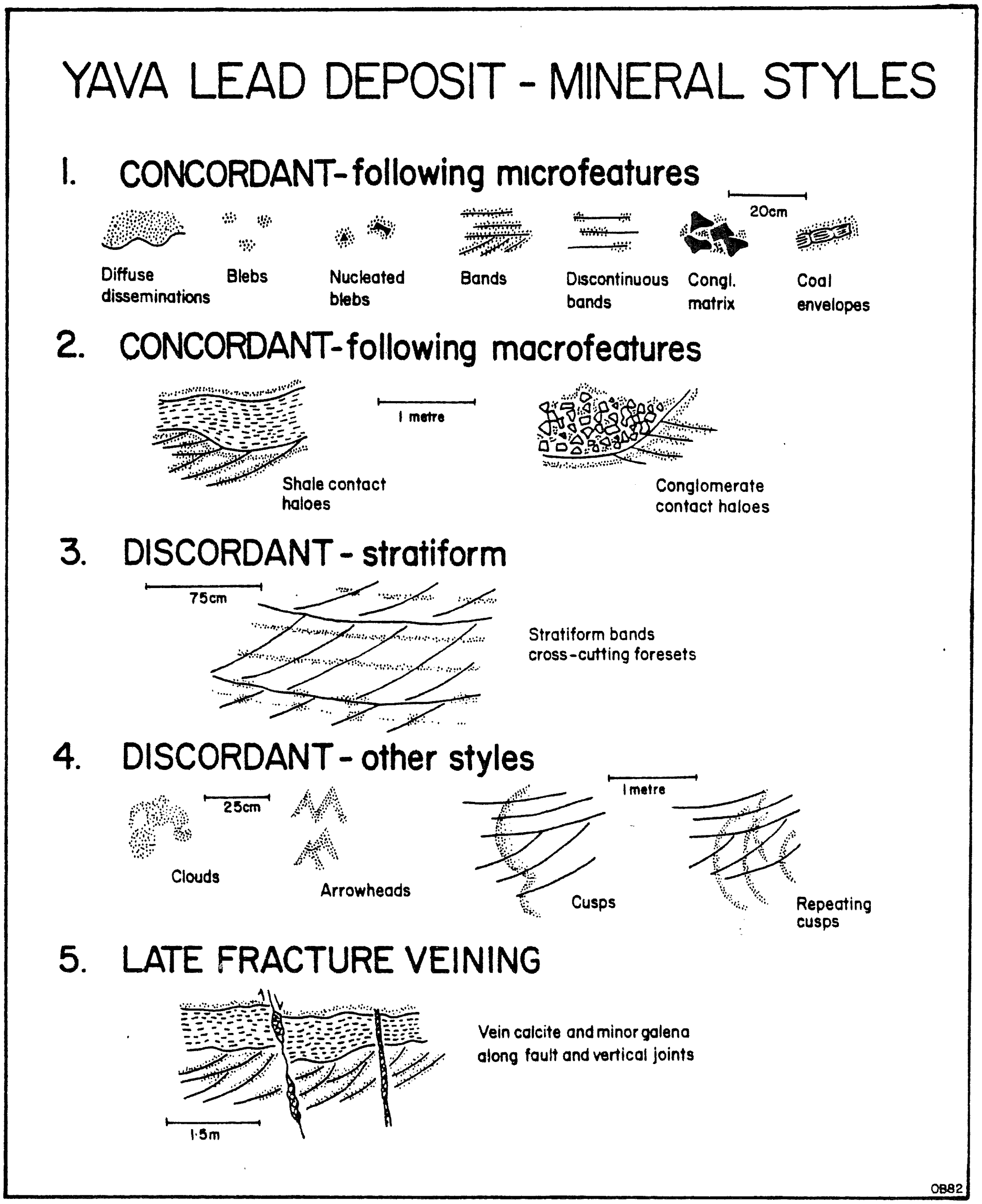

YAVA LEAD DEPOSIT - MINERAL STYLES
1. CONCORDANT-following microfeatures
20cm
Diffuse disseminations
Blebs
Nucleated blebs
Bands
Discontinuous bands
Congl. matrix
Coal envelopes
2. CONCORDANT-following macrofeatures
1 metre
Shale contact haloes
Conglomerate contact haloes
3. DISCORDANT - stratiform
75cm
Stratiform bands cross-cutting foresets
4. DISCORDANT - other styles
25cm
Clouds
Arrowheads
1 metre
Cusps
Repeating cusps
5. LATE FRACTURE VEINING
Vein calcite and minor galena along fault and vertical joints
1·5m
OB82

Figure IV.B.1

the fragment.

Where internal sedimentary partings are present, as foresets or bedding planes, galena occurs as bands marking the partings. These bands are either continuous, completely mirroring the sedimentary texture, or discontinuous, following partings in a patchy incomplete manner (Plate IV.B.1).

In addition to sandstone mineralisation, disseminated galena is also abundant within the sandy matrix of conglomerate units. This mineralisation is characteristically present as centralised interstitial patches, reflecting the interstitial area in shape, but with an unmineralised zone bordering the clastic fragment (Plate IV.B.2).

Where mineralisation occurs in association with coal fragments, pyrite and sphalerite are commonly present along with galena. This assemblage occurs within coal, and as a zoned halo in surrounding sandstone. Pyrite forms the inner rind around the coal, followed by sphalerite, with galena in the outer area.

2. Concordant - following macrofeatures

On a larger scale, in walls underground, additional features can be observed, following macro-sedimentary features. These are in the form of galena haloes, (bands of disseminated galena, 1-4 cm thick), which follow the top and bottom contacts of shale horizons. They are located up to 10 cm away from the particular contact, in the surrounding sandstone. A noticeable feature of this style, is that halo

PLATE IV.B.1. Cross-bedded sandstone with typical concordant galena bands. (safety glasses = 14 cm) bands will cross-cut sedimentary banding within the sandstone (a minor feature), in order to follow the lithologic change (a major feature). The same halo patterns are observed in mineralisation around conglomeratic horizons (Plate IV.B.2).

3. Discordant - Stratiform

Throughout the mine, bands and streaks of galena occur discordant to the sedimentary fabric. In one area discordant galena was observed as horizontally oriented parallel and sub-parallel bands cross-cutting foreset bedding. This banding was mostly continuous but locally it consisted of a series of short galena streaks following foreset parting which together formed a discordant band (Plate IV.B.3).

4. Other Discordant Styles

Small scale discordant features include: clouds, arrowheads, cusps, and repeating cusps. The clouds are irregular patches of disseminated galena (up to 30 cm across) in otherwise unmineralised or weakly mineralised sandstone. The features are often, but not always, centred on a clastic fragment (Plate IV.B.4).

In a drill hole intersection through the eastern margin of the ore zone (hole 340), curious discordant arrowhead features were observed. These appear as overlapping, cone-shaped concentrations of disseminated galena, up to 10 cm long and inferred to be some 6 cm wide at base. The apices of the cones, which point upwards, contain the higher amount of galena. These arrowhead features, although observed in one instance

PLATE IV.B.2. Galena halo in sandstone parallelling conglomerate contact, also shows galena "patches" in sandy conglomerate matrix. (hammer shaft = 30 cm)

PLATE IV.B.3. "Stratified" galena banding in sandstone discordant to the primary sedimentary stratification.
(hammer head = 20 cm)

PLATE IV.B.4. Galena "clouds" in coarse grained sandstone with thin coaly partings. (silva = 6cm across)

PLATE IV.B.5. Discordant cusp and discontinuous bands of galena in finely bedded sandstone.

only, are documented because of the remarkable similarity between these and galena arrowheads, described by Caia (1969). The latter are associated with sandstone-hosted Pb-Zn-Cu mineralisation in the Cretaceous of the High Atlas in Morocco.

Cusps and repeating cusps of galena are sporadic; these consist of cusp features, up to 1 m long, which cross-cut sedimentary bedding at a high angle. Characteristically, the most intense mineralisation occurs along the sharper convex side, while grade trails off from the concave side (Plate IV.B.5).

5. Late Fracture Veining

Vein mineralisation is also observable underground; this is associated with a single high angle (75°) normal fault, which trends 074° E, down-thrown to the north. It cuts through the central part of the mined area. Euhedral galena, pyrite and calcite occur in open vugs along this fault gash, and in associated tension cracks, parallel to the fault. This mineralisation, confined to features of brittle deformation, has no association with the disseminated mineralisation in surrounding sandstones and does not influence ore grade in any noticeable way. It is considered to be a late remobilisation phase, unrelated to the main mineralising episode.

Apart from the fracture mineralisation, the styles described are the end member of what is a continuum, ranging from wholly concordant, to wholly discordant features. But it should be emphasised that most of the ore is concordant, represented by the styles of Type 1 and Type 2. Lower grade mineralisatison in marginal areas, is observed to reflect less intensive mineralisation, over the same range of styles. The only significant mineralisation recognised in the sandstone, outside the mineralised horizons in the three zones, are isolated galena-pyrite assemblages associated with coaly matter.

IV. B. 3. Ore Mineralogy and Ore Textures

Scott (1980), in his thesis on geochemistry and petrography of the Yava deposit, has described the ore mineralogy and ore textures, seen in a section through the West Zone, in some detail. However, he does not specifically relate mineralisation features observed, to the various host-rock lithotypes or macroscopic mineral styles. The objective for this study, is to characterise the mineralisation for the ore zone as a whole, by considering the ore mineralogy of each rock type in turn, and examining, in more detail, some of the main mineralisation styles already described. Oytenbogaardt and Burke (1971) and Ramdohr (1980) were the main references for this study.

The sulphide assemblage, in the Canso Group at Yava, consists of galena, sphalerite and pyrite, with rare chalcopyrite. Galena is the dominant sulphide present, and is widespread in distribution, while sphalerite and pyrite occur in a localised association. Chalcopyrite and marcasite are present as rare isolated crystals (0.10 mm), associated with other sulphide mineralisation.

Sandstone Mineralisation

Sandstone mineralisation will be considered first, because sandstone is the dominant lithotype present, and because it carries most of the mineralisation at Yava. In sandstone, galena characteristically occurs as anhedral crystals in the interstitial spaces between clastic grains (Plate IV.B.6) Galena is generally in straight-edge contact with clay-silicate matrix and granular clastic rock fragments. The interstitial crystals range in size from 0.09 to 0.30 mm but are generally 0.20 mm in diameter, exhibiting triangular cleavage pits, in single crystal alignment. Crystal shapes are characteristically triangular to irregular in outline, with acute re-entrant angles mirroring the intergranular space (Plate IV.B.7). Where grain configuration provides an interconnection of interstitial areas, galena will follow this system, to form irregular interconnected crystalline fill. In this typical interstitial style, clastic grains remain in original point contact, and galena is present as isolated occurrences separated by sandstone, with normal interstitial clay-silicate as cement. Interstitial galena generally contains inclusions. Most commonly, these consist of small, rounded bodies or islands of clay silicate material. Less frequently, clear anhedral sphalerite patches, up to 0.20 mm, may be included, along with remnant zoned pyrite-sphalerite (in pyrite-rich areas). These inclusions are considered to be remnants of pre-existing loose interstitial cement and early sulphide phases, later replaced by galena.

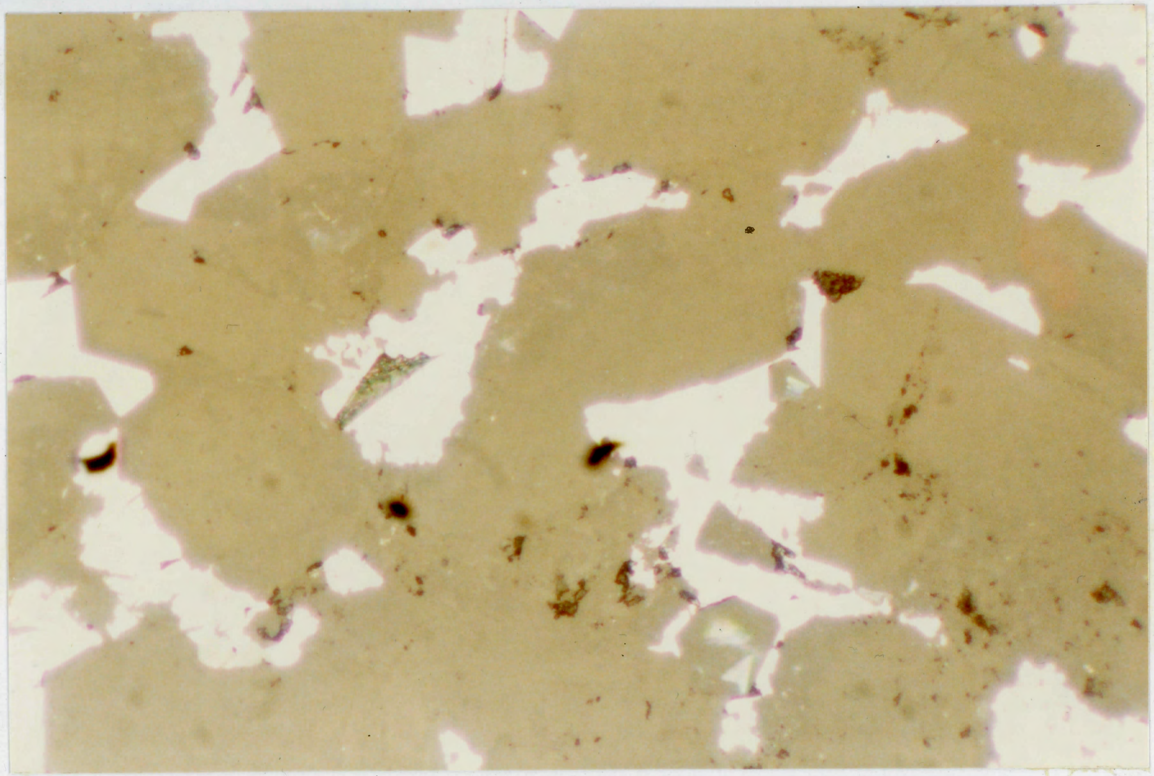


PLATE IV.B.6. Thin section typical interstitial galena in sandstone, - note straight-edged contacts between quartz and galena.
(reflected light 175x)

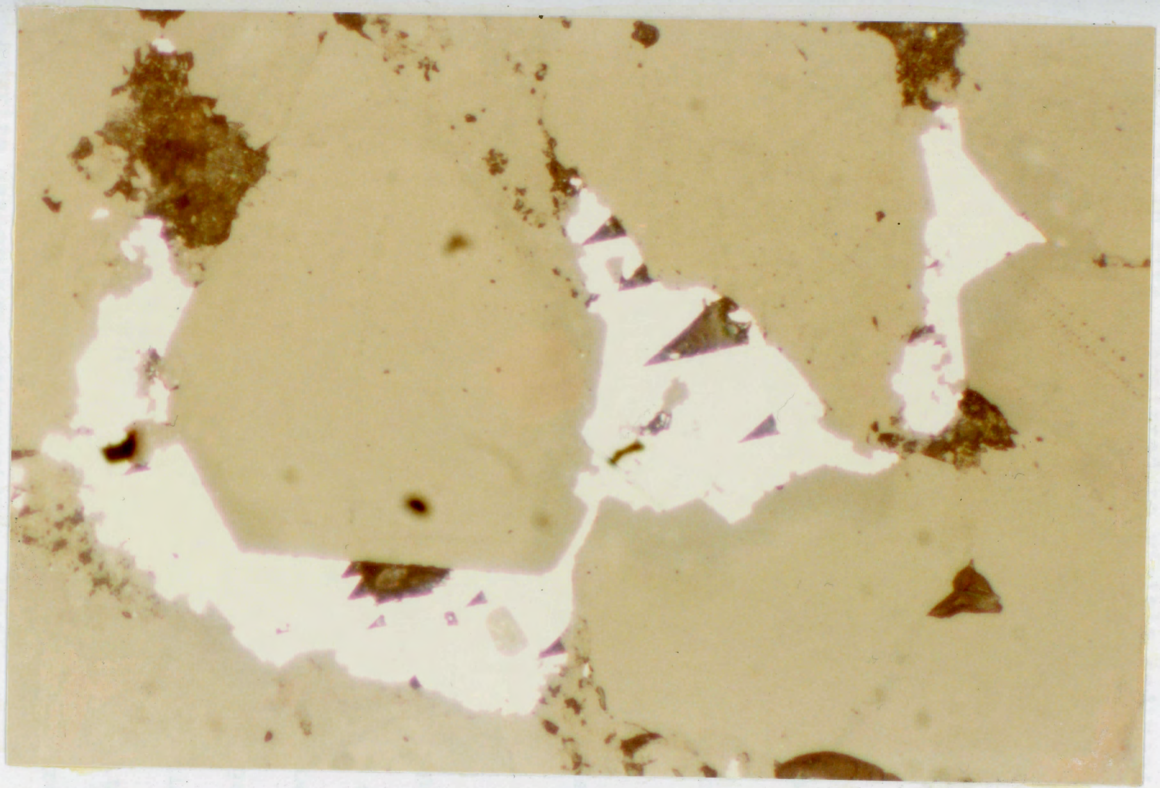


PLATE IV.B.7. Thin section - detail of typical interstitial galena, to show relationship between quartz overgrowth and sulphide fill.
(reflected light 275x)

In sandstone, pyrite is generally localised. It occurs in the following situations:

- as occasional macroscopic blebs and streaks in sandstone, up to 3 mm in size, unrelated to visible sedimentary features
- in richly-mineralised partings, associated with sharply-defined heavy mineral banding in sandstones
- throughout most sandstones, as infrequent and small isolated clusters and remnants in interstitial areas
- in sandstones with calcareous matrix cement
- in sandstones adjacent to mineralised coaly material

In areas of pyrite, mineralisation is characteristically more intensive. The interstitial areas are totally infilled, and often, clastic fragments have been replaced, leaving remnant clasts as islands supported in a pyrite matrix.

In one isolated pyrite bleb examined, amorphous granular pyrite forms the central core area (4 mm across), and acts as a matrix, supporting remnant clastic grains. The grains have corroded margins, and are cut by fractures containing pyrite. Sphalerite generally occurs in association with this pyrite; it forms in similar habit as a zone surrounding the pyrite core. However, with sphalerite, fewer grains are replaced, and the mineralisation is more interstitial. This sphalerite-pyrite assemblage shows evidence of later galena replacement, which affects the outer sphalerites, the core pyrite and remaining clastic grains. Away from blebs, pyrite is absent in the sandstone; galena is the only sulphide present, occurring as characteristic interstitial mineralisation.

Heavy mineral bands (containing mostly zircons) in bedded sandstone are also a site of pyrite in sandstone. Here again, pyrite, with associated sphalerite, also occurs as an intensive interstitial phase, supporting clasts in a sulphide matrix.

At Yava, pyrite is typically local in distribution. Away from these localities, it occurs only as small clusters or rosettes and remnant crystals in interstitial galena. Pyrite clusters consist of compact, ill-defined rosettes of pyrite needles up to 0.10 mm, across, which occasionally have an outer hexagonal rim. These occur as isolated features in an otherwise unmineralised matrix; or they can be seen as remnants, or half remnants, in interstices (later filled by sphalerite or galena). It is important to note that these features can occur both within and outside quartz overgrowth rims. This would suggest that these pyrite clusters, as well as other remnant pyrites within the interstitial galena, represent an early diagenetic sulphide growth, synchronous with framboidal pyrite and sphalerite growth elsewhere.

In sandstones, with a carbonate matrix cement, pyrite is present, exclusive of all other sulphides, except some minor sphalerite inclusions. It occurs as small euhedral cubes, hexagons and starlets, with sharp, well-defined crystal edges, dispersed throughout the rock. These grains are the result of pervasive growth, penetrating matrix and clastic grains alike.

Sphalerite in sandstones occurs in several styles. It is present in association with pyrite, as a groundmass surrounding framboids of pyrite, and as zoned layers in euhedral pyrite-sphalerite crystals (0.02 - 0.10 mm size). It also forms as clear anhedral patches of varying size (0.05 - 0.15 mm); sphalerite patches surround pyrite concentrations and are present elsewhere as small remnant inclusions in interstitial galenas.

On occasion, clear sphalerite can be seen to occur in contact with quartz overgrowth. In some instances it grows against the straight quartz edge, while elsewhere it intrudes into the overgrowth ring. (This is either the effect of sphalerite replacing quartz, or quartz overgrowth around pre-existing sphalerite). The relationship is not clear, but it may suggest that this sphalerite phase, like galena, post-dates quartz overgrowth.

In summary, galena forms the dominant sulphide phase in sandstone. It occurs as interstitial mineralisation post-dating the quartz overgrowth, and it also shows evidence of replacement of earlier interstitial silicate and sulphide phases. Pyrite mineralisation is localised in distribution, but where present, it is pervasive, replacing all except isolated clastic remnants. Sphalerite occurs in zoned association with pyrite, and also in a less associated form, surrounding pyrite areas and dispersed throughout the sandstone, as remnant inclusions in interstitial galenas.

Mineralisation in coarse-grained gritty sandstone was not observed to be different to that in other sandstone, except that the size of interstitial areas (and hence the size of galena crystals) is greater. In two such samples examined, however, 70% of interstitial galena was found to contain sphalerite inclusions, and 45% contained clay silicate inclusions, a higher frequency of inclusions than in fine-grained sandstone.

Shale Mineralisation

Shales characteristically are unmineralised. In thin section, they show only small, widely dispersed grains of pyrite and galena, .03 mm in diameter. Pyrite grains are generally euhedral, while galenas are irregular and anhedral. Coarser horizons within shales were observed to contain more pyrite grains.

Conglomerate Mineralisation

Except where conglomerate clasts are composed of coaly material, mineralisation in conglomerates is generally confined to the sandy matrix.

In limestone pebble conglomerate clasts, small widely-dispersed hexagonal rings of pyrite, (.01 mm in diameter), are normally the only sulphide present. Clasts in shale flake conglomerates, being derived from formational shale beds, contain the same weak mineralisation as does shale.

Mineralisation in the matrix of these conglomerates depends on the composition of the intergranular cement, and on the detrital coal content. One limestone pebble conglomerate, collected from directly above the Windsor contact, exhibited a marked change in sulphide mineralisation as cement composition changed. The lower portion, with calcareous cement, contains only pyrite occurring as small euhedral grains. In the upper portion of the same conglomerate, the matrix is predominantly of clay-silicate composition, and the dominant sulphide is galena, occurring as typical interstitial fill. Most noticeable is that no euhedral pyrite is present in the upper portion, and there is no evidence of quartz overgrowth in the zone of carbonate cement at the base.

In summary, except in areas of carbonate cement, conglomerate matrix mineralisation is consistent with the styles described for normal sandstone. However, as basal thalweg deposits, these conglomerates commonly contain detrital coaly matter which is mineralised in the manner described below. An examination of the unmineralised rims, bordering conglomerate clasts, revealed no reason for a lack of mineralisation; simply, less is present.

Mineralisation associated with coaly material

Mineralisation in coaly material, and in the sandstone enveloping coaly matter, provide the more spectacular ore textures seen at Yava. While these textures may provide evidence of steps in the paragenetic sequence, this mineralisation has received attention which is well out of proportion to its volumetric importance. (Over a 10 month period, during the mining of the West Zone, coal lag horizons were only recorded in 15% of working faces, and the mean grade for coal lag was 9.18% Pb, against a mean of 6.7% Pb in sandstone, which occurred in 100% of working faces.)

To consider mineralisation within coalified plant remains first: coal material may or may not be mineralised. If it is unmineralised, it is either because the material is too dense and compact to accommodate sulpides, or it is because open cellular spaces have been filled and sealed by silicate cement before the mineralising episode (Plate IV.B.8).

Mineralisation within coal ranges from incomplete open cellular fill, to intensive multiphase mineralisation, with chaotic cataclastic textures and fracturing, indicating collapse and replacement of the coal host. With cellular fill, either pyrite alone, or associated pyrite and sphalerite, fill cellular cavities in plant tissue; while galena occurs as a later phase confined to the cell walls, and locally replaces pre-existing sulphide within cells.

At the other extreme, coal material is altogether crushed and fractured, leaving only contorted remnants of coal. Here the fracture spaces are filled with galena containing sphalerite inclusions. Coal cells contain open fill pyrite (commonly framboidal), set in a groundmass of clear sphalerite, while cell walls, and margins of the cavity fill are replaced by galena.

This is the same overall sulphide paragenesis in (cataclastic

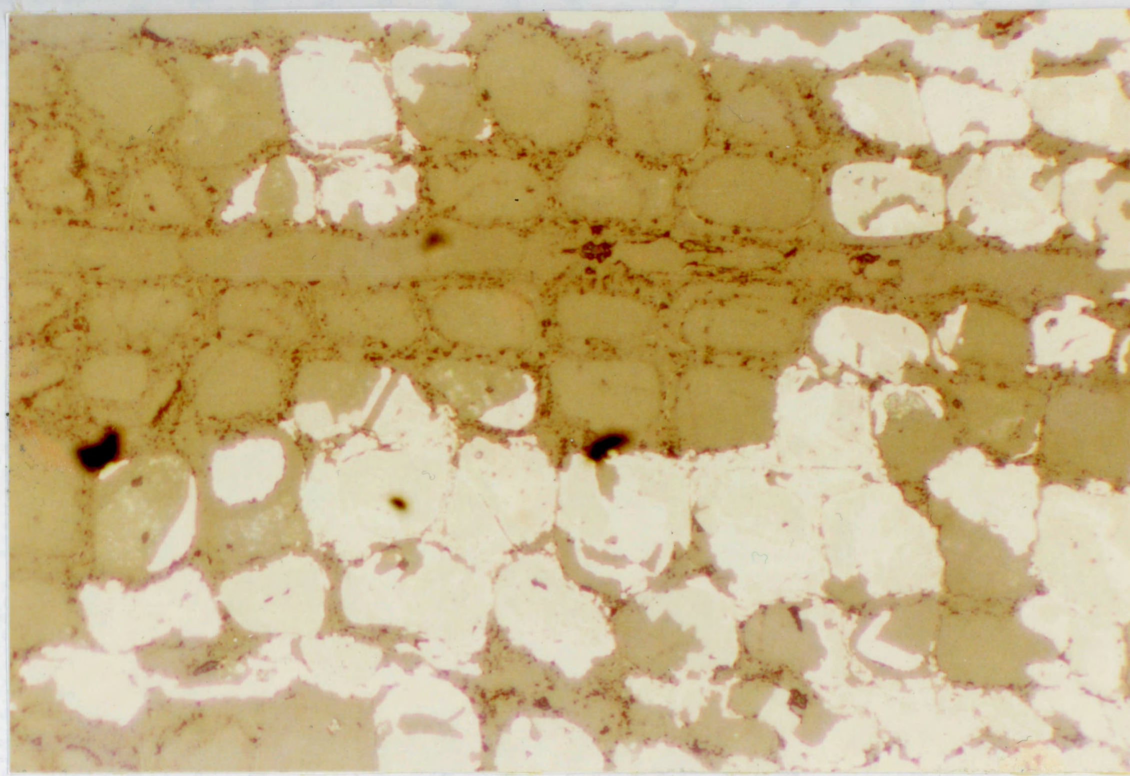


PLATE IV.B.8. Galena, sphalerite and pyrite mineralization in cellular plant material.
(reflected light 150x - pyrite:yellow, sphalerite:pale grey, galena:white, silicate:dark grey/green)

coal) as observed in open fill coal mineralisation. Early pyrite and sphalerite is introduced into the coal before brittle deformation, while galena, perhaps preceeded by a sphalerite phase, is introduced during, or after, collapse of the coaly material.

Coal envelope mineralisation characteristically consists of an inner pyrite zone (< 1 cm wide) bordering the coal fragment, an intermediate sphalerite zone (< .5 cm wide), and an outer zone of interstitial galena mineralisation (up to 2 cm wide). Galena is also characteristically present throughout the inner zone as a later replacement phase (Plate IV.B.9). This mineralisation has many features in common with the localised pyrite mineralisation described in sandstone.

Pyrite occurs in an amorphous granular form, providing a matrix in which remnant clastic grains are preserved as islands. While pyrite is the dominant sulphide present, it occurs in close association with sphalerite, as framboidal pyrite in a sphalerite groundmass (Plate IV.B.10), and as euhedral zoned pyrite-sphalerite crystals. Away from the coal margin, sphalerite predominates over pyrite in the same crystal association, giving rise to large areas of amorphous sphalerite. Further away, galena becomes predominant, but it shows no crystal association with either pyrite or sphalerite. This same galena phase is pervasive through the inner zones, replacing pyrite and sphalerite around the edges of remnant clasts, and frequently replacing clastic grains themselves.

Outside coal envelopes, galena mineralisation gradually becomes

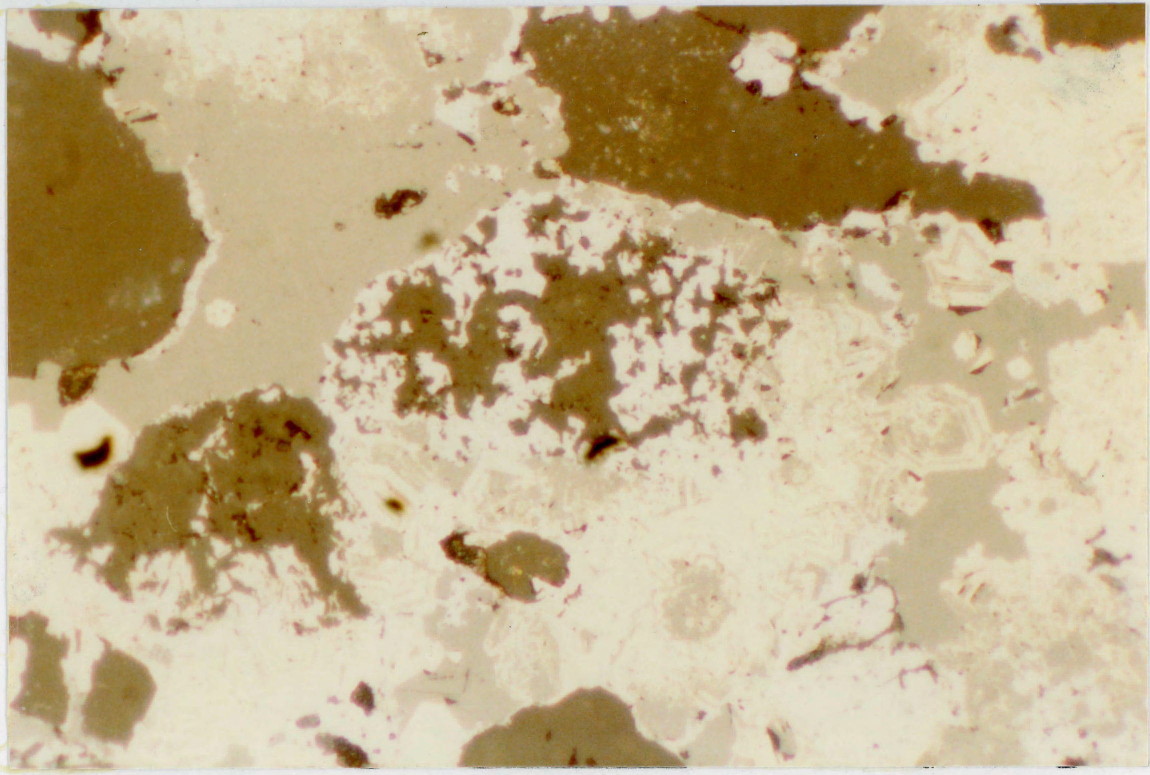


PLATE IV.B.9. Sulphide assemblage adjacent to coal material, showing zoned pyrite and sphalerite, and later galena mineralization.
(reflected light 275x - pyrite:yellow, sphalerite : pale grey, galena : white, silicate host rock : dark grey/green)

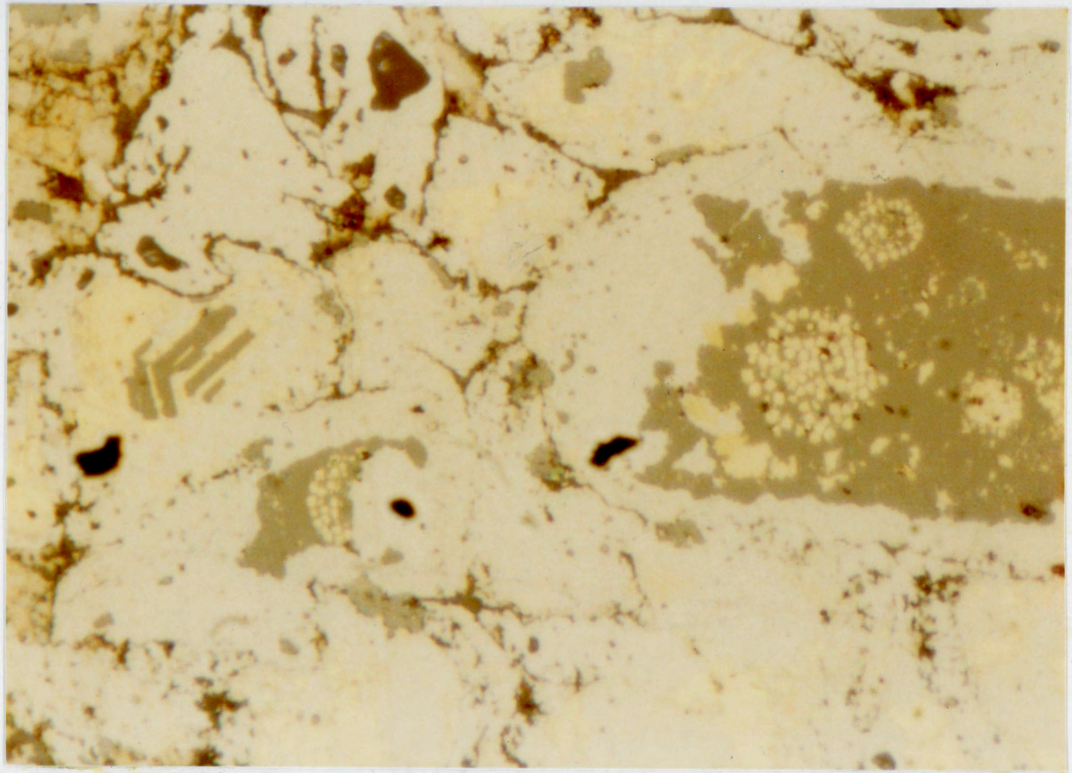


PLATE IV.B.10. Framboidal pyrite in a sphalerite groundmass, infilling plant cells, surrounded and replaced by later galena.
(reflected light 275x - pyrite : yellow, sphalerite : grey/green, galena : white)

more "passive", until it occurs as typical interstitial fill, in straight edge contact with quartz overgrowth, and in more uneven ragged contact with clay-silicate cement and granular rock fragments.

Macroscopic Mineral Styles

In addition to the study of sulphide mineralisation in the various lithotypes, some of the macroscopic mineral styles were examined more closely.

A cusp-shaped "front" of galena, cross-cutting sedimentary banding, was cut and examined in thin section. No visible petrographic change marks this feature, apart from an increase in the abundance of interstitial galena. Ahead of the feature, galena is present in 5% of interstitial space; over a distance of 2 mm at the front, galena content increases to fill 45% of spaces. This intensive mineralisation continues for 1 cm, before dropping off gradually to a 10% level behind the feature. At no stage does galena mineralisation become pervasive. Even in the richest zone, sand grains remain in point contact, and the galena occurs as isolated interstitial fill, in straight edge contact with quartz overgrowth.

Arrowhead textures show the same mineralisation pattern as cusps; there is no apparent petrographic change to mark the margin of the feature, other than the sudden increase in the proportion of interstitial area occupied by galena, within the feature, as opposed to outside. Most noticeable in this case, is the visible porosity in the sandstone outside the feature, which is almost completely filled by galena within the arrowhead.

The same is true of all bands and streaks of galena. Mineralisation is not related to any visible internal changes in the sandstone; simply a higher proportion of interstitial areas are infilled with galena, while away from these features, interstices are less frequently mineralised.

In addition to disseminated mineralisation within the sandstone assemblage, sulphides are also present in cross-cutting veins of calcite, spatially related to a late cross fault. Within these veins, galena is the predominant sulphide; it occurs as cubes (3 mm) or as remnant patches cut by irregular interdigitations of calcite. Smaller anhedral sphalerites also occur within the calcite. Emanating from these main calcite veins, are short discontinuous cracks in the sandstone, infilled with galena. Some replacement of the host silicate by galena along the margins of these features can be seen.

IV. B. 4. Sulphide Assemblages

Based on textural character and intergrowth relationships, several distinct sulphide assemblages can be recognised in the Yava mineralisation, and distribution of each assemblage is quite different.

Pyrite-sphalerite assemblage: Pyrite and sphalerite occur as a cogenetic pair. The assemblage consists of framboidal pyrite rosettes occurring in a groundmass of sphalerite, and zoned euhedral crystals comprising interlayered pyrite and sphalerite. Characteristically, both framboids and zoned crystals nucleate within the intergranular area; they do not grow outwards from the edge of clastic grains. This assemblage has a local distribution; it is the earliest recognisable sulphide phase, and it is confined to areas within, and adjacent to, coaly matter.

Pyrite: The delicate pyrite-sphalerite assemblage can become predominated by pyrite, to a varying degree. Characteristically, when pyrite becomes predominant, extreme interstitial and grain mineralisation takes place to leave remnant clasts, as islands held in a supporting matrix of amorphous pyrite. This pyrite enrichment is common along heavy mineral bands in sandstones, in areas rich in coaly matter, and as isolated blebs within sandstone. It is also, therefore, local in distribution. Isolated clusters of pyrite and zoned crystals of euhedral pyrite occur in interstitial areas throughout the sandy sediment.

Sphalerite: Likewise, the delicate pyrite-sphalerite assemblage can become predominated by sphalerite. This generally occurs in the outer areas of coal envelope mineralisation, to produce similar textures to pyrite. In this case sphalerite would tend to post-date, but not replace, pyrite (while it does partially replace remnant clastic grain surrounded by pyrite). This phase has a distribution pattern similar to pyrite. Sphalerite is also characteristically present as clear inclusions, of varying size, in interstitial galena mineralisation and therefore occurs through the mineralised zone, but at a low abundance level.

Galena: Galena occurs in two forms: as a late replacement phase, localised in areas rich in pyrite and sphalerite, and as widespread interstitial mineralisation throughout the sandy sediment, where cements are clay-silicate in composition. As a late phase in pyrite and sphalerite areas, galena is most prominent "outside" sphalerites; but it does occur in a penetrating habit, along the edges of, and replacing, remnant clasts. Bordering these areas, galena occurs as intrusive interstitial growth, where replacement of clasts is evident and grains are occasionally left, supported in a matrix of galena. Adjacent to these areas, galena gradually changes to a more passive habit, occurring as interstitial mineralisation.

This passive habit is characteristic of the dominant and widespread galena mineralisation, It is characterised by interstitial growth of euhedral crystals, with acute re-entrant angles, straight edge contact with clay-silicate and granular rock fragments. Late galenas, associated with pyrite-sphalerite areas, and this interstitial galena, are considered to represent the same mineralising episode.

IV. B. 5. Summary (with paragenetic sequence)

Each of the lithotypes within the sandstone assemblage tend to contain different sulphide assemblage, and hence are mineralised to a different extent and in a different manner.

To summarise:

Sandstones (overall): predominantly interstitial galena, with common sphalerite inclusions, rare euhedral pyrites present in isolated matrix areas.

Sandstones (locally): pervasive pyrite-sphalerite and associated galena in localised blebs and along heavy mineral bands; distribution is occasional and local.

Shale: generally unmineralised (small and rare pyrite and galena).

Conglomerates: mineralisation confined to sandy matrix within clay-silicate cement, widespread interstitial galena except in unmineralised zones bordering clasts.

Coaly matter: co-genetic, pyrite-sphalerite (generally pyrite dominant), and late galena. This assemblage is confined to coal and sediment envelopes surrounding coal.

Paragenesis

On the basis of ore mineralogy, a paragenesis for the mineralisation can be proposed:

1. Early sulphides

   Within area of carbonate cement

   - early isolated anhedral sphalerite followed by euhedral pyrite overgrowth, additional pyrite growth elsewhere.

   Within areas of clay-silicate cement, particularly where coal rich

- framboidal pyrite
- sphalerite encircling pyrite to form groundmass
- growth of zoned euhedral pyrite-sphalerite
- becoming pyrite-dominant - local amorphous pyrite (pervasive replacement)
- becoming sphalerite-dominant - amorphous sphalerite (additional replacement)

It is not clear whether initial sulphide mineralisation, in carbonate and clay silicate cemented areas, took place simultaneously or not. Clearly the styles are different: one is co-genetic and the other shows evidence of early sphalerite followed by pyrite. Characteristically, this mineralisation is localised in isolated areas, concentrating where organic material, or other local phenomena, form nucleating centres.

2. Quartz overgrowth

Quartz overgrowth on clastic grains, and the infilling of tissue cells in coal, along with subsequent brittle collapse of coal, clearly pre-date galena mineralisation. Quartz overgrowth, in contrast, post-dates introduction of carbonate cement, because grains in these areas show no evidence of overgrowth.

3. Galena (and sphalerite)

(subsequent to quartz overgrowth and outside of areas with carbonate cement)

- pervasive galena, localised in areas of earlier sulphide mineralisation, replacing remnant clasts and pre-existing sulphides
- passive interstitial galena infilling intergranular areas between clastic grains, in straight-edge contact with quartz overgrowth, and in more irregular contact with clay-silicates and granular rock fragments (pore filling mineralisation with some replacement at margins)

This is a widespread and dominant phase: the presence of sphalerite inclusions, in much of this galena, indicates that a sphalerite phase of similar character may have preceded the galena mineralisation.

4. Vein sulphides
   - galena, sphalerite, pyrite and sporadic chalcopyrite in calcite-filled tension joints related to post lithification faulting.

SECTION C

IV. C. Distribution of Lead Mineralisation

IV. C. 1. Early Understanding

Laisvall in Sweden and L'Argentiere in France, the two most extensively studied and described deposits of lead-zinc in sandstone, show directly opposing relationships between mineralisation and host rock geology. At Laisvall, the ore zone is not congruent to bedding; it occurs close to the base of the host sandstone up-dip, and passes through the bedding, to occur at the top of the sandstone section down-dip. In this way, an oblique baseline through the sandstone is formed, below which ore-grade mineralisatison does not occur (Rickard et al 1979). In contrast, at L'Argentiere, lead is concentrated along four "preferential beds" within the stratigraphic sequence (Samama 1976). This contrast between stratiform and stratabound mineralisation (sensu stricto), has not only influenced the understanding of mineralisation controls for these deposits; but it has also, it is felt, profoundly influenced the choice of metallogenic models for each deposit, which are quite different. On this basis, it was considered of fundamental importance to consider this situation at Yava, and demonstrate clearly the relationship between geology and mineralisation.

Extensive underground mapping and core logging indicate that the sandstone assemblage consists of laterally discontinuous and incomplete fining-upwards cyclothems of conglomerate, sandstone and shale, directly overlying footwall of variable composition. Consideration of macroscopic mineral styles and ore mineralogy, shows that galena is the most prominent and widespread sulphide, while pyrite and sphalerite mineralisation is localised and of little overall importance. Galena occurs as a cement infilling intergranular areas in sandstone and sandy matrix of conglomerates, in the form of bands and patches concordant and discordant to internal sedimentary structures.

IV. C. 2. Underground Mapping

Certain features of the lead distribution became apparent during the mapping period. Most obviously, levels of mineralisation reflect lithologic composition; sandstones can be extensively mineralised, as can the matrix of conglomerates, while shales are unmineralised.

In the South-east Lobe, the first cycle in the sequence is an extensive unit which can be traced throughout the area, comprising a sandstone 3 m thick. Locally, as a result of intra-formational erosion, it is reduced to 1 m in thickness. Visual observations indicated that the extent of mineralisation of this sandstone changes laterally, while grade appears the same for different sandstone thicknesses.

The presence of shale interbeds, an important influence on grade concentration in the sandstones at Laisvall, (Rickard et al, 1979) are not seen to have an influence at Yava, apart from the common occurrence of a thin halo-band of galena in sandstone mirroring the shale contact. Mineralisation does not increase in areas surrounding shale occurrences, or at sandstone pinchout points into shales.

Mapping of the No. 2 decline, an oblique section across the entire West Zone, indicates an overstep of sedimentary cycles against the Windsor unconformity, in a southerly direction. And as the decline was driven in ore, i.e. to follow the mineralised horizon, it clearly demonstrates that at Yava, the mineralisation is discordant with respect to host rock stratigraphy (this relationship is illustrated in

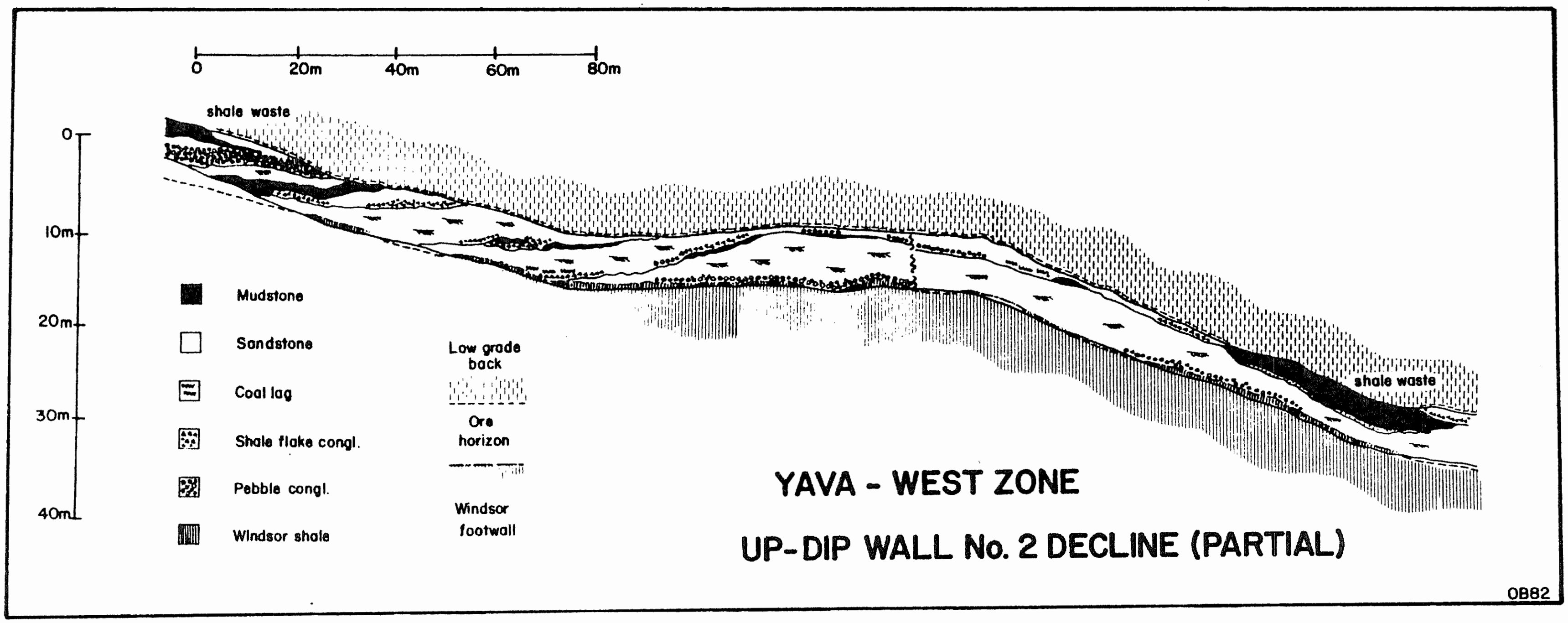

0
20m
40m
60m
80m
shale waste
shale waste
0
10m
20m
30m
40m
Mudstone
Sandstone
Coal lag
Shale flake congl.
Pebble congl.
Windsor shale
Low grade back
Ore horizon
Windsor footwall
YAVA - WEST ZONE
UP-DIP WALL No. 2 DECLINE (PARTIAL)
OB82

Figure IV.C.I

Figure IV. C. 1). This observation, that mineralisation transects host rock stratigraphy in order to follow the footwall contact, suggested that aspects of the unconformity might have more influence on grade distribution than the hosting sediments.

IV. C. 3. Drill Hole Study

Procedure

On the basis of these observations, it was decided to consider in a quantitative way, aspects of the grade distribution and geology for the entire West Zone, using the regularly spaced surface drill holes as a data base.

There are several advantages to using the drill holes:

1. Drilling extended well outside the orebody into the weakly mineralised and unmineralised margins, thereby providing full coverage of the problem.
2. So much local variation in geology and mineralisation was indicated in underground mapping and mine channel sampling, that the drill holes provide a manageable set of regularly distributed random intersections of the ore zone.
3. All the drill holes have surveyed surface locations and collar elevations, hence allowing for accurate isopleth and structure contour plans to be drawn. Also, except for seven angle holes, all holes were drilled vertically.
4. 20% of the drill holes had been logged by the author and the

rest had detailed standard diamond drill logs, prepared by earlier workers.

5. All cores through the ore zone and overlying beds had been split and assayed for lead, and more locally for zinc and silver. An additional advantage was that all core splitting after 1970 (70% of holes), was on a lithological basis (i.e. bed-by-bed splitting rather than over set 5 ft. intervals as before).

6. Underground operations in the upper part of this area meant that detailed follow-up was possible to check out features, indicated in this drill hole study.

As a data base, a core card was drawn up for each drill hole. Each card contains: the vital statistics of the hole (number, location, collar elevation, total depth, angle, etc.), the thickness and lithotype of each stratigraphic unit (through the entire footwall intersection and the basal 15 m of the sandstone sequence) and the thickness and assay value for each split interval. This thickness information for grade and lithology is recorded in sequence, above and below a reference line, taken at the elevation of the Windsor unconformity. In this manner, the real three dimensional location of data points can be readily derived. An example of two core cards is shown in Figure IV.C.2.

With knowledge of the range of lithotypes present in the sandstone assemblage and the footwall sequence, a limited classification system

DDH: *325* *(-90^{o})* TD: *220'*

OB: *30'*

<u>Units:</u>

5/9.0, 7/2.0 | *1/13.7, 2/4.3, 1/2.5, 4a/1.5, 1/11.6, 2/1.4,*

- 1/15.5, 3/4.5, 4b/4.0, 1/15.0

<u>Assays:</u> 7.10/3.7,8.15/5.0,6.22/5.0,2.35/4.6,3.00/3.9,

- 3.05/5.0,0.65/5.0,1.90/5.0,2.90/5.0,2.95/5.0,

- 2.60/5.0,0.49/5.0

<u>Elev:</u> *4772.1' (1454.9m)*

feet

DDH: *57* *(-90^{o})* TD: *312'*

OB: *42'*

<u>Units:</u>

Bx/5.4, 5/73.2, -
- 7/2.5 | *1/7.3, 2/4.5, 1/1.1, 4a/0.4, 1/13.5, 2/1.2, 1/15.1,*

- 3/1.0, 1/11.7, 2/5.0

<u>Assays:</u> 6.75/5.0,4.27/5.0,3.45/5.0,1.51/5.0,1.90/5.0

- 0.75/5.0,0.36/5.0,0.62/5.0,1.30/5.0,

- 0.20/5.0,0.57/5.0

<u>Elev:</u> *4751.6'* *(1448.7m)*

feet

FIGURE IV.C.2. Examples of DDH core cards. [TD: total depth, OB: overburden, *1/7.3*: lithology /thickness (ft), 6.75/5.0: lead grade (%)/thickness (ft), *4751.6'*: datum elevation of footwall Windsor contact.]

of lithotypes was established. For this, numbers were used to represent each of eleven major lithotypes. Intersected units were then "pigeon-holed" by number, on the basis of lithologic descriptions.

Drill Sites, Isograd and Isopach plans

Figure IV. C. 3 shows the location of the drill holes covering the West Zone study area. Angle holes are marked at the site of Windsor contact intersection, not the surface collar site.

As a background to the study, standard isograd and isopach maps of the West Zone are included as Figures IV. C. 4 and 5. The grade contour plan shows total lead grade to a 3.5% grade cut-off. In areas with greater than 3.7 m thickness of mineralisation, total grade over the full thickness is given; while lead grade over 3.7 m is given in low grade areas outside. This provides a comprehensive impression of lead distribution in one plan; marginal grade holes are marked with black circles; ore holes are left as open circles. On the isopach plan, the true vertical thickness of mineralisation, to a 3.5% cut-off, is shown. Many of the marginal holes did not intersect any significant mineralisation, and are therefore marked zero. The most important observation from these plots, one which was mentioned in the introduction, is that most intensive mineralisation corresponds with greatest thickness distribution.

The figure of 3.5% lead, as a designated grade between ore and waste is of course, an arbitrary figure; figures of 5% or 1% could have

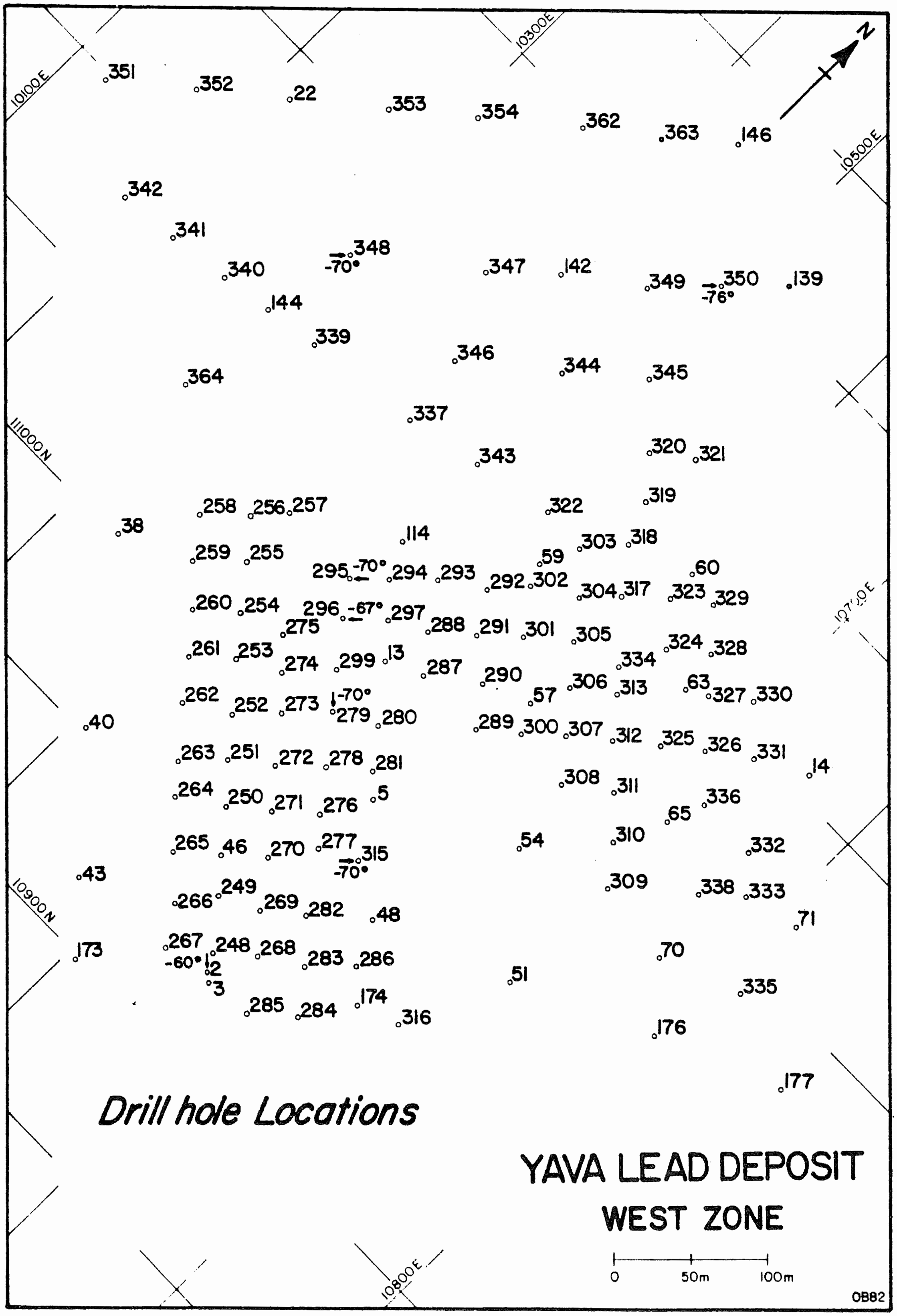

10100E
10300E
10500E
10700E
10800E
11000N
10900N
N
351 352 22 353 354 362 363 146
342
341
348 -70°
340 347 142 349 350 -76° 139
144
339 346 344 345
364
337
343 320 321
319
258 256 257 322
38 114 303 318
259 255 59
295 -70° 294 293 292 302 60
304 317 323 329
260 254 296 -67° 297 288 291 301
275 305
261 253 324 328
274 299 13 287 334
290 306 313 63
262 252 273 -70° 57 327 330
279 280
40 289 300 307 312 325 326 331
263 251 272 278 281 14
264 250 271 276 5 308 311
336
65
265 46 270 277 315 54 310 332
-70°
43 309
249 338 333
266 269 282 48
71
267 248 268 283 286 70
173 -60° 2 51
3 335
285 284 174 316
176
177
Drill hole Locations
YAVA LEAD DEPOSIT
WEST ZONE
0 50m 100m
OB82

Figure IV.C.3.

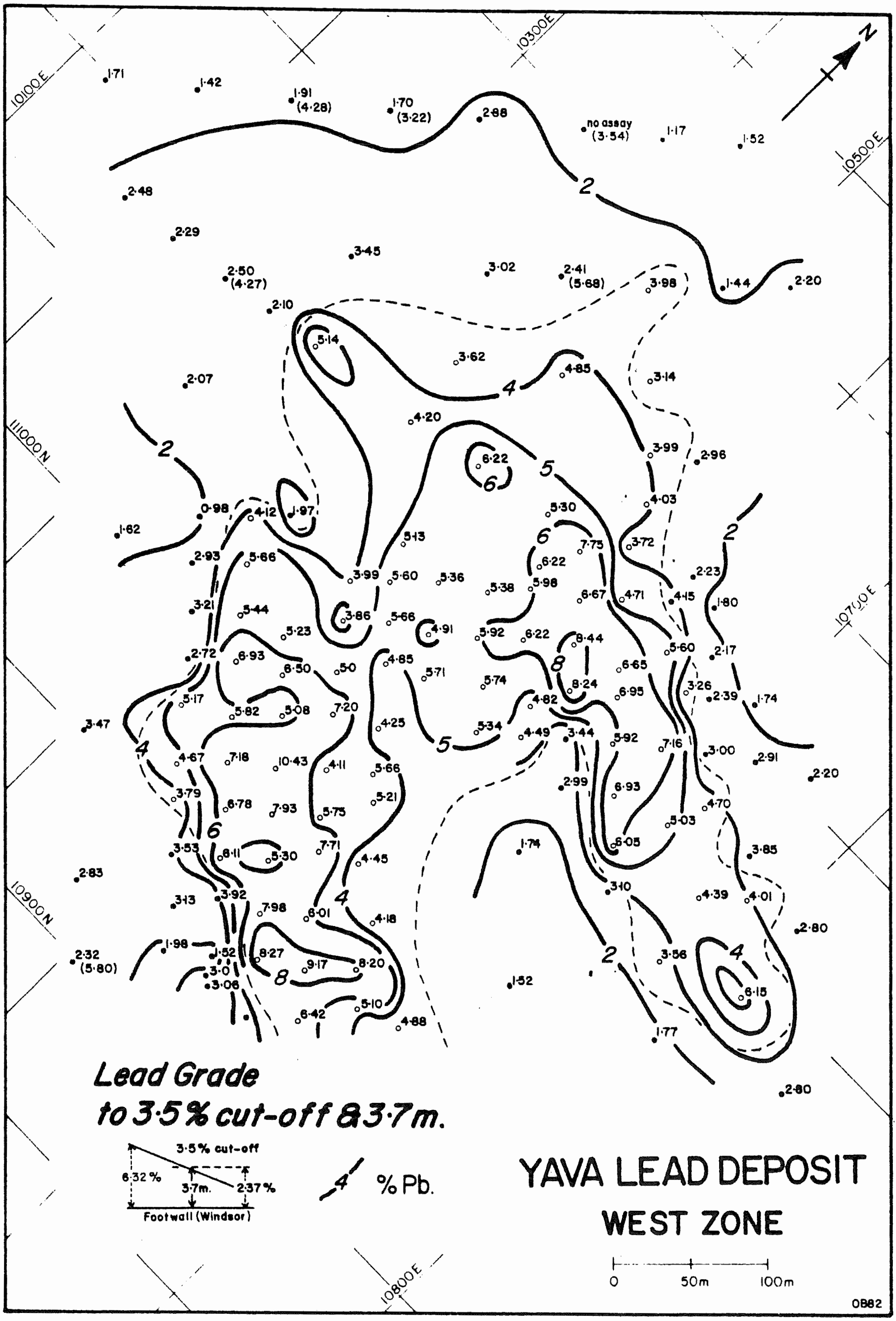

YAVA LEAD DEPOSIT
WEST ZONE
Lead Grade
to 3·5% cut-off & 3·7m.
3·5% cut-off
6·32%
3·7m.
2·37%
Footwall (Windsor)
% Pb.
0
50m
100m
10100E
10300E
10500E
10700E
10800E
11000N
10900N
N
0882

Figure IV.C.4.

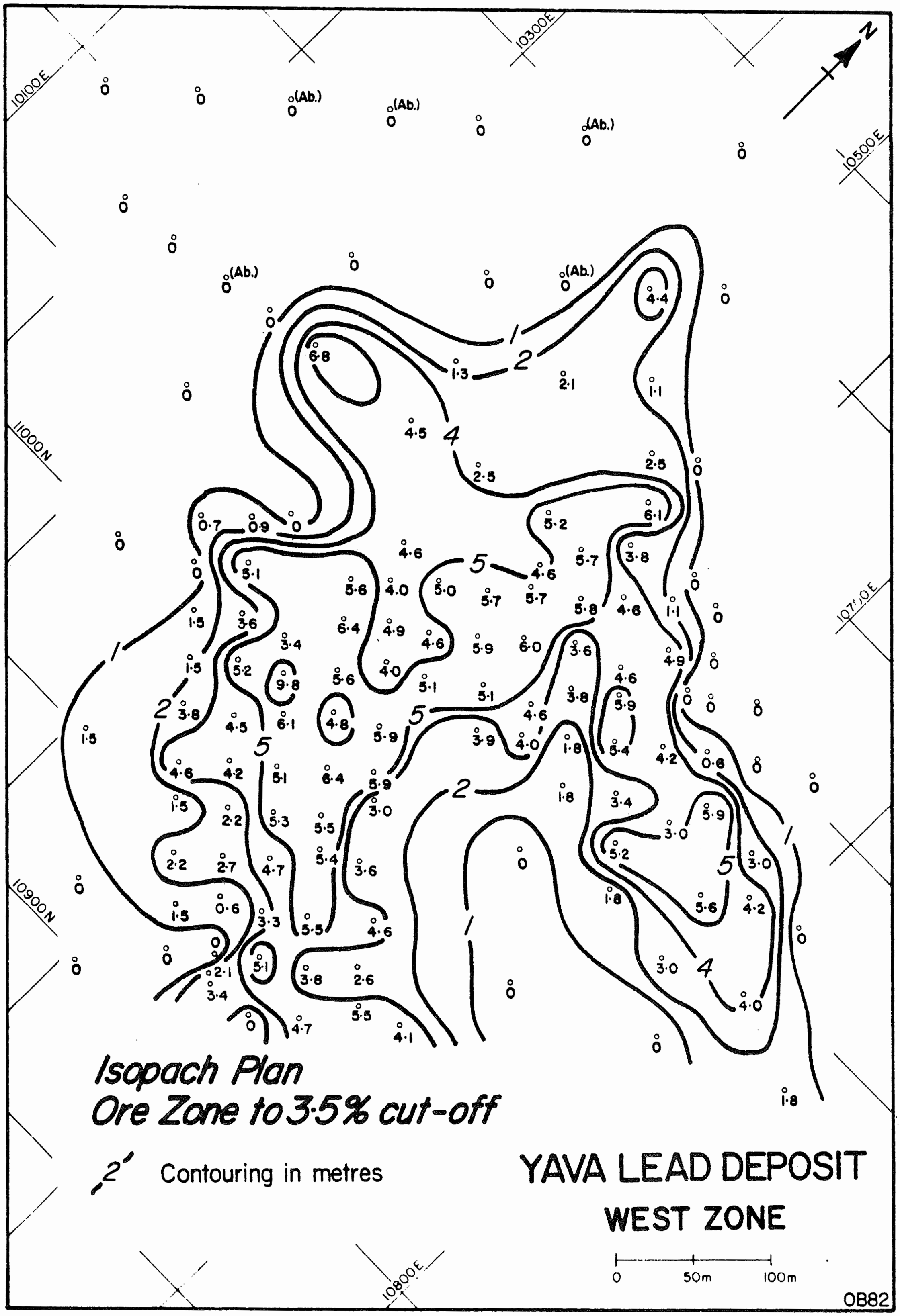

Isopach Plan
Ore Zone to 3·5% cut-off
2 Contouring in metres
YAVA LEAD DEPOSIT
WEST ZONE
0 50m 100m
OB82
10100E
10300E
10500E
10700E
10800E
11000N
10900N
N

Figure IV.C.5

been used. However, 3.5% was the figure used as an economic cut-off, delineating ore during most of the underground mining phase. It has been retained to delimit ore for this study, for the following reasons:

1. All indications are that the Yava mineralisation consists of limited centres of higher grade lead enrichment (averaging 5.5% Pb), surrounded by extensive areas of weak mineralisation (averaging 1.5% Pb). And as the contacts between these areas are gradational, it is most probable that observed distribution patterns will hold at different delineation levels.
2. For the study area, using a 3.5% cut-off, approximately 50% of the area is ore and 50% is waste, thus providing a proper balance. To consider a lower grade would mean extending the area and therefore the number of drillholes; with this, coverage in the marginal areas would be poor to inadequate. To consider a higher cut-off level would limit the area considerably, and introduce influence from secondary local variables.
3. By choosing 3.5%, the same as that used for the Mine, the horizon of study would be the same as the mining horizon, thus allowing for direct underground follow-up. Also, by using a common cut-off figure, direct comparisons could be made with other studies of ore reserves and mining procedures.

First Cycle Sandstone

Given the observed lateral change in lead grade in the sandstone of one continuous cycle in the south-east lobe, it was decided to consider lead distribution of an equivalent unit, throughtout the West Zone. Figure IV. C. 6 shows the thickness and lead grade (weighted average over the same thickness) for the first sandstone interval occurring above the Windsor contact. In a few cases, this interval is unusually thick and contains weak mineralisation with no distinct top; here the grade over the basal 3.7 m is taken.

The grade contouring of this data shows two well-defined and well-supported anomalies, with centres of >7%, a surrounding halo of 5-6%, and a marginal area of 3-5%, linking these anomalies and remaining open in a northwesterly direction. Figure IV. C. 7 is an isopach of the same first sandstone interval (same figures); this shows that while overall isopach trends are in the same direction as the grade distribution, changes in sandstone thickness bear little relationship to the level of mineralisation. This suggests that there is no diffusion of grade in thick sandstone, and no concentration in thinner sandstone. In the South-East Lobe anomaly, sandstones of 5-6% Pb range in thickness from 0.4 m to 5.7 m; likewise at 8-9% Pb, the range is from 0.3 m to 3.1 m.

First Cycle Shale Distribution

In a further attempt to ascertain any influence of rock type on grade, in a spatial sense, the distribution of shale directly overlying the first sandstone interval, discussed above, was plotted.

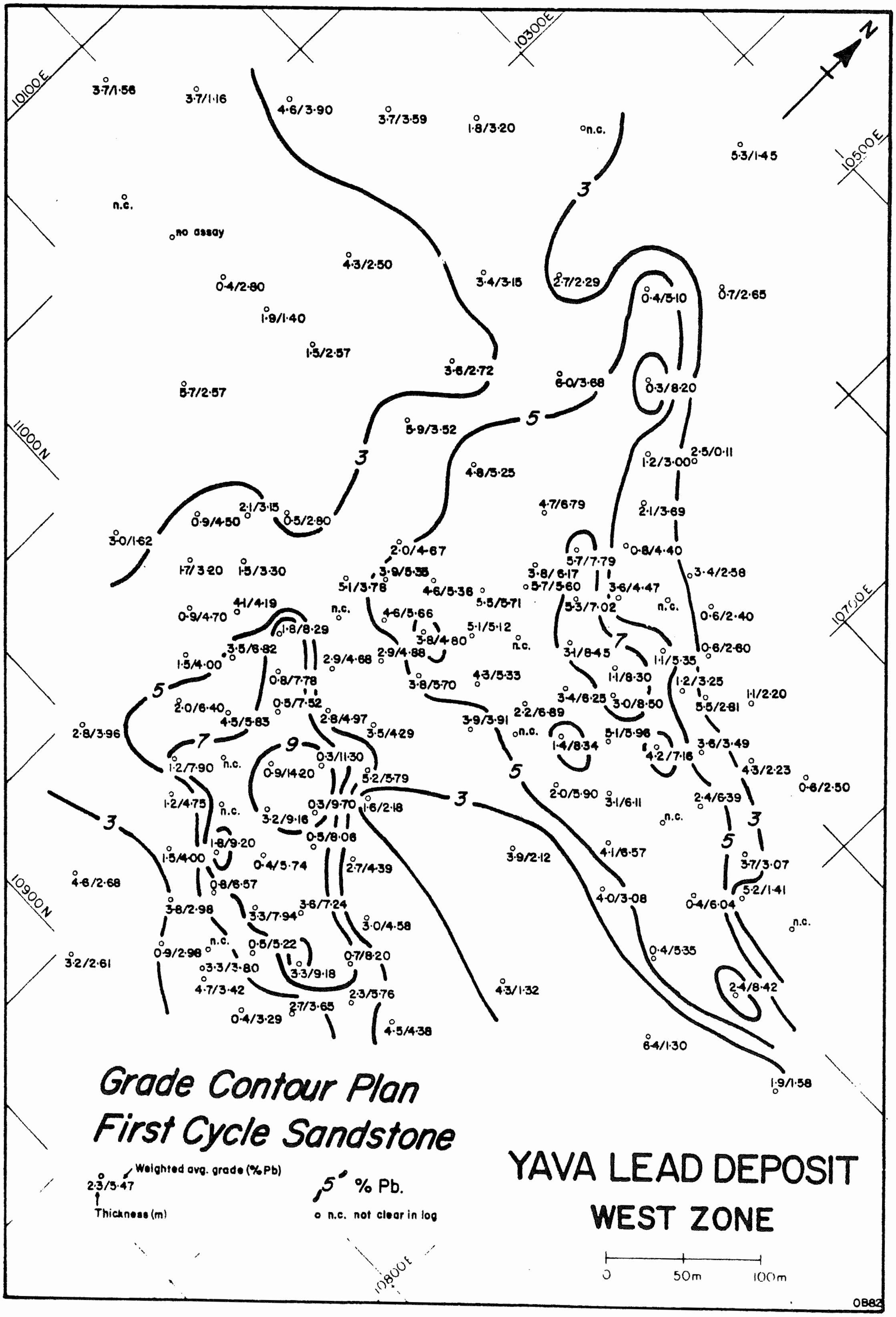

Grade Contour Plan
First Cycle Sandstone
YAVA LEAD DEPOSIT
WEST ZONE
Weighted avg. grade (%Pb)
2·3/5·47
Thickness (m)
5 % Pb.
o n.c. not clear in log
0 50m 100m
10100E
10300E
10500E
10700E
10800E
11000N
10900N
N
0B82

Figure IV.C.6

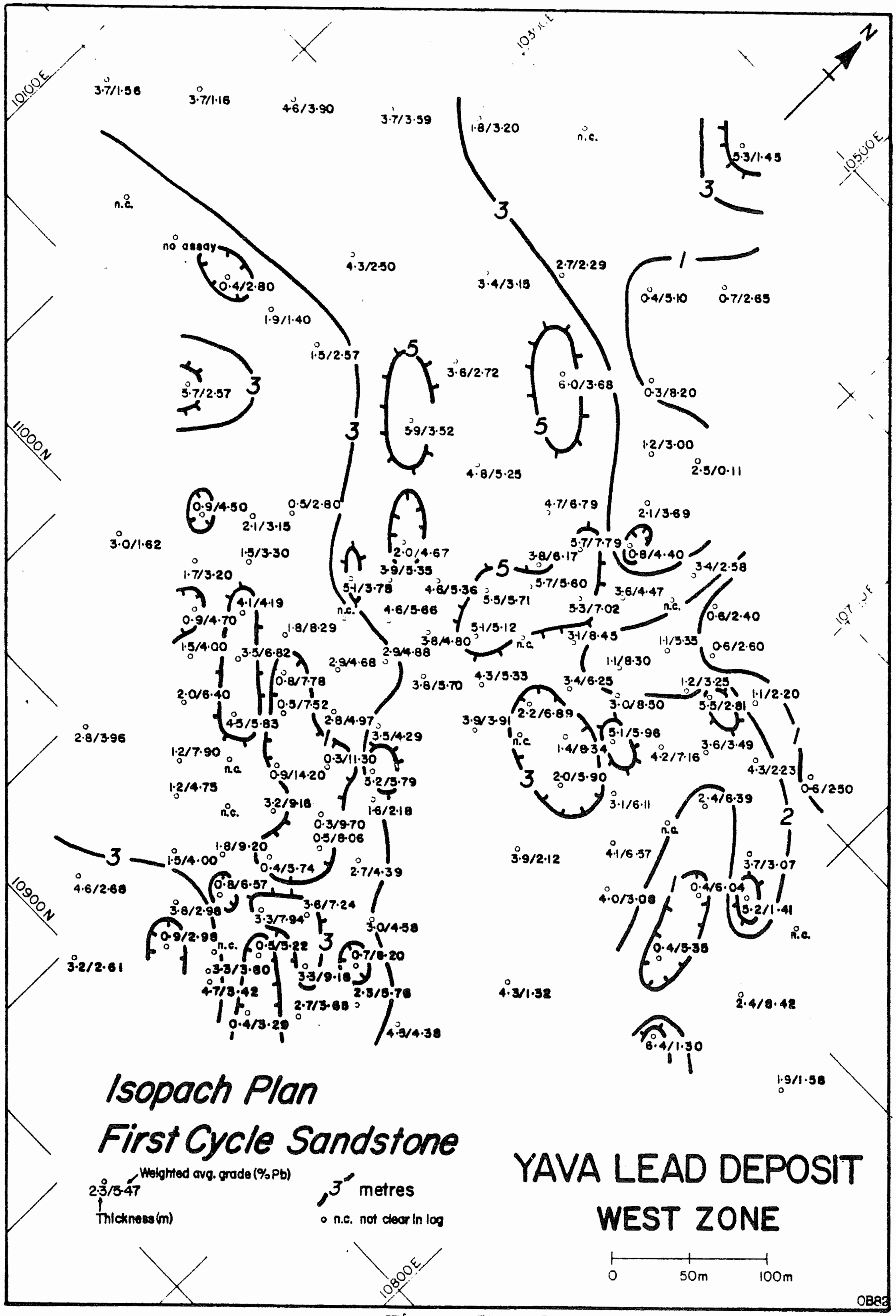

Isopach Plan
First Cycle Sandstone
Weighted avg. grade (%Pb)
2·3/5·47
Thickness (m)
3 metres
n.c. not clear in log
YAVA LEAD DEPOSIT
WEST ZONE
0
50m
100m
OB82

Figure IV.C.7

Figure IV.C.8 gives the thickness and grade of the first shale horizon above the Windsor unconformity; where the shale was not intersected, holes are marked as solid black circles. Areas of shale are outlined, each area is correlated to represent the top of a single cycle, while different areas may represent the same, or different cycle tops. Most noticeable in this plot is the patchy distribution of shale and the generally low level of mineralisation.

A comparison between this plot and figure IV. C. 5 indicates that mineralisation is not influenced by shale distribution (i.e. the anomalies develop regardless of the distribution of overlying shale). Comparison with Figure IV. C. 4 (overall lead distribution) indicates the same lack of influence.

Cycles Numbers

Underground mapping through the upper part of the West Zone had illustrated: a discordant relationship between the mineralised horizon and the stratigraphic cycles; and that the ore column occurs within several thin cycles in the Portal Lobe, and within two thicker cycles in the South East Lobe. In order to qualify this observation and establish a pattern for the entire zone, a plot was made of the distribution of cycles within the ore zone (3.5%) - Figure IV. C. 9. For each site, the number of cycles (and portion thereof) and the overall ore thickness are given. The plot shows that in the South East Lobe, the ore occurs within two cycles (1.3-1.6 cycles); while in the Portal Lobe, 2 to 2.6 cycles are common, and up to 4 cycles are present. The

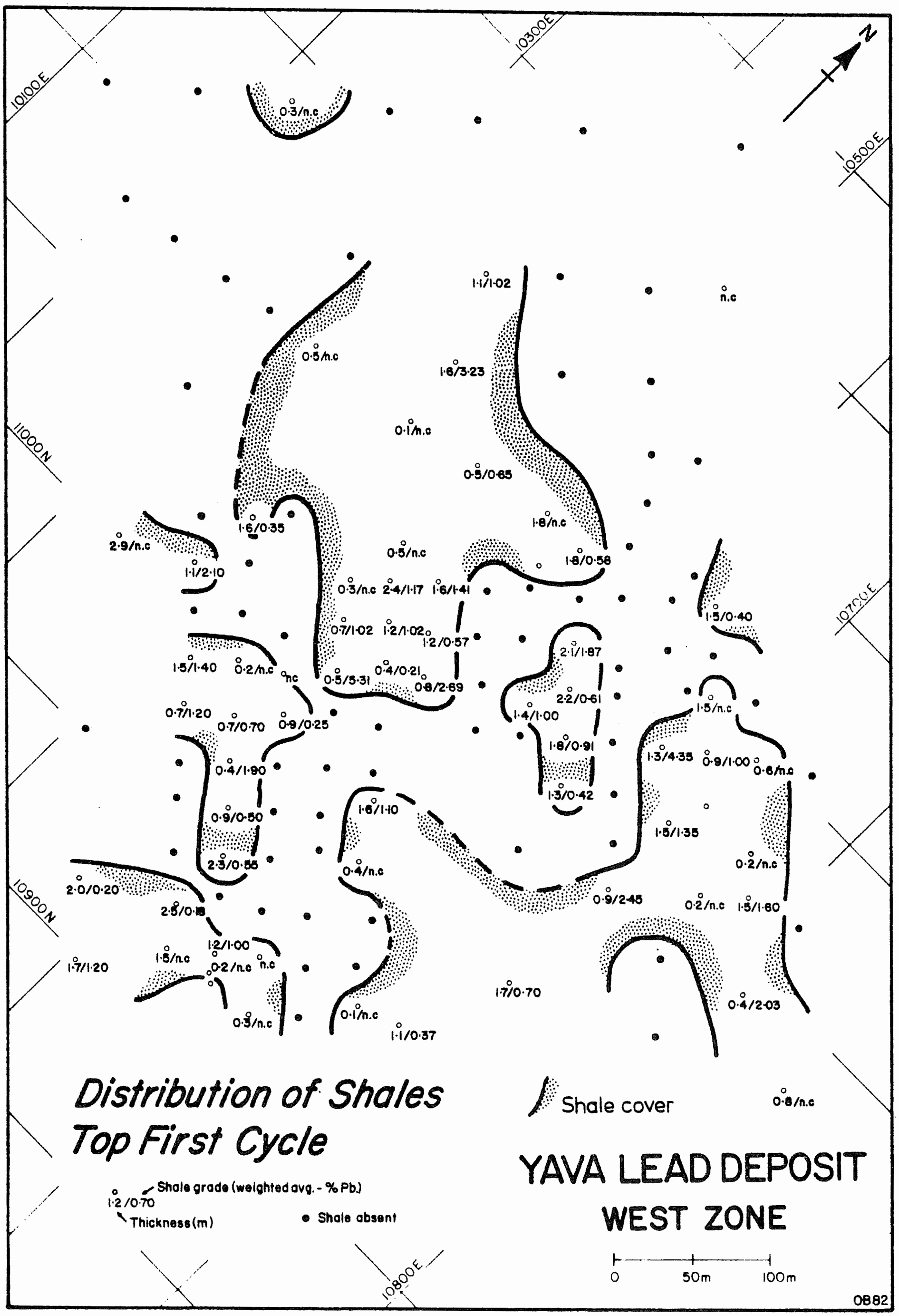

Distribution of Shales
Top First Cycle
Shale cover
YAVA LEAD DEPOSIT
WEST ZONE
1·2/0·70
Shale grade (weighted avg. - % Pb.)
Thickness (m)
Shale absent
0
50m
100m
N
10100E
10300E
10500E
10700E
10800E
11000N
10900N
0882

Figure IV.C.8

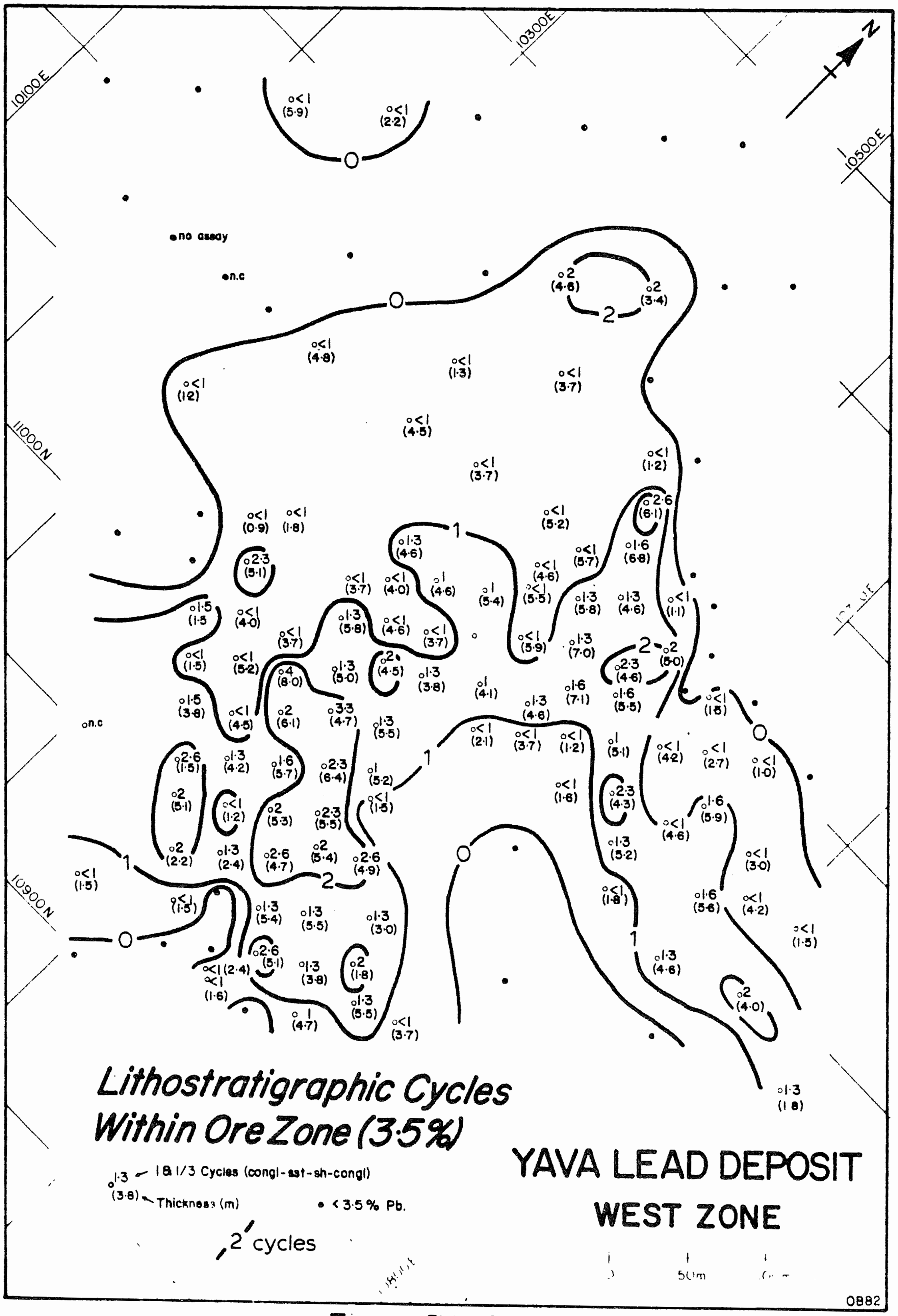

Lithostratigraphic Cycles
Within Ore Zone (3·5%)
YAVA LEAD DEPOSIT
WEST ZONE
1·3 ← 1 & 1/3 Cycles (congl-sst-sh-congl)
(3·8) ← Thickness (m)
• < 3·5 % Pb.
2 cycles
• no assay
10100 E
10300 E
10500 E
11000 N
10900 N
N
50m
0882

Figure IVC.9

thickness in the two lobes is comparable. In the marginal areas less than 1 cycle is mineralised.

Footwall Lithotypes

Given the indicated lack of influence of host rock geology on grade distribution, possible influence by lithologies exposed on the surface of the Windsor unconformity were considered. Figure IV. C. 10 shows the spatial distribution of footwall lithotypes. Rather than trying to create a geological map for this surface, patches of different lithotypes are outlined by marking lines of contact. The sequential order of the lithotypes is given in the legend. It shows that to the extreme east, outside the orebody, the sandstone lies directly on basement; but close by, to the West, where hole 335 intersects 6.15% Pb over 4 m, the sandstone lies on talus breccia. Elsewhere, along the extreme margins, sandstone lies on Windsor shales. Under the main portion of the orebody, footwall is composed of either calcrete or regolith (regolith generally overlies calcrete); within this area, there is a tendency for calcrete to underlie the central section and regolith to underlie the margins. This spatial correlation between calcrete/regolith and ore may be significant, or it may be concidental, reflecting erosion levels on the Windsor landscape. Of particular note is the abrupt rise in the level of mineralisation at the point of exposure of the talus breccia. Further examination of footwall lithotypes for all three zones is presented below.

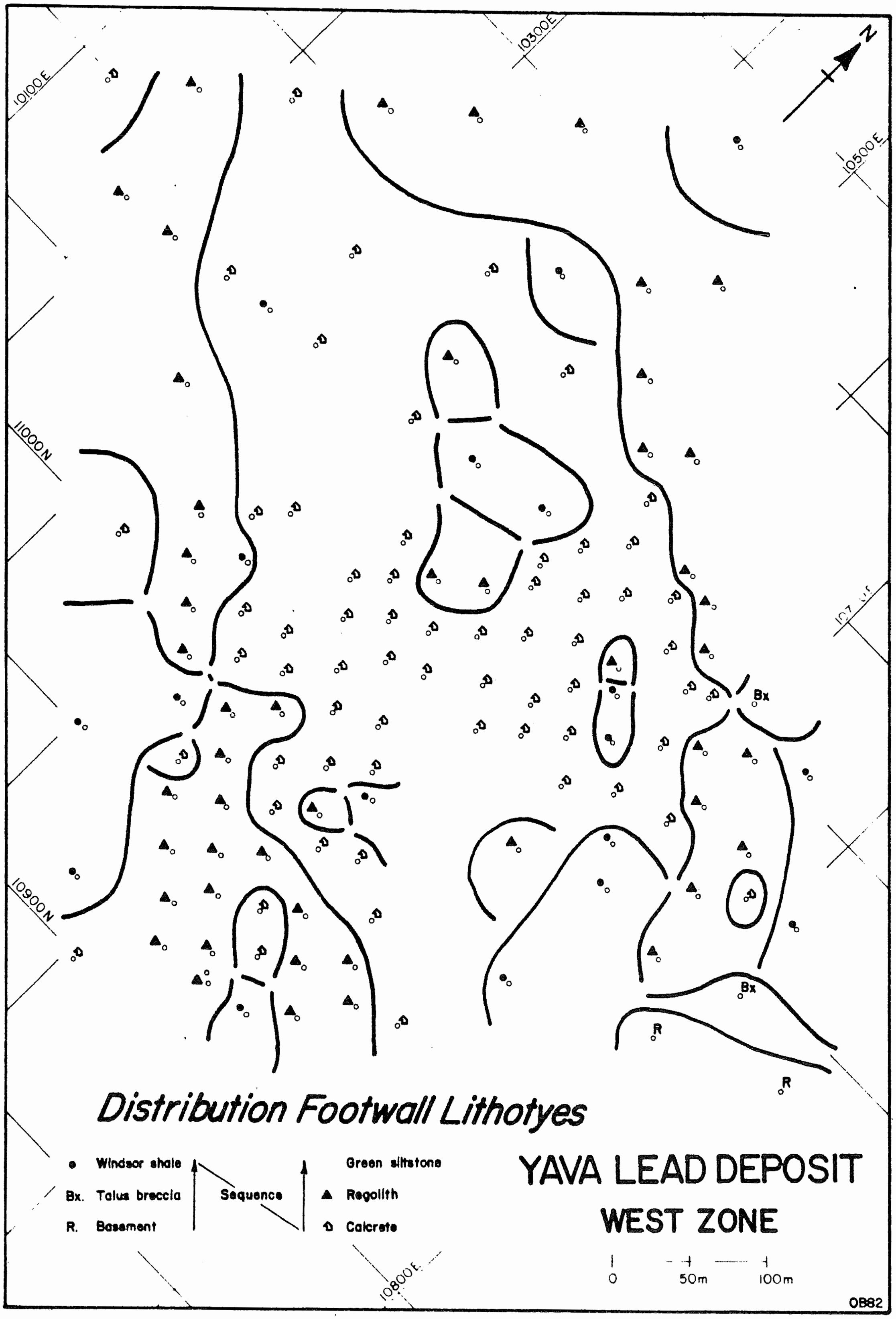


Figure IV.C.10

Structure Contour and Palaeotopographic Reconstruction

The regional correlation between lead concentration and the location of palaeodepressions, in the basement landscape along the strike of the Yava deposit, has long been appreciated (Mudford, 1964). However, details of this relationship have not been examined thus far; nor has the third dimension (the down-dip dimension) to the spatial distribution of the ore been considered.

Figure IV.C.11 is a structure contour on the Windsor contact in the study area over the West Zone. It shows the steady drop in elevation, 150 m over some 600 m, corresponding with the dip to the northwest. Irregularities in the contour separation spacing, and along the line of contour, indicate that the surface of the contact is not planar. Most noticeable is the spur in the centre of the up-dip portion, flanked by two open re-entrants. Also the increase in contour spacing in the down-dip portion indicates a decrease in overall gradient. A comparison between this surface and grade distribution shows the two ore lobes correspond spatially to the re-entrant features.

Given this situation, an attempt was made to remove the tectonic tilt and examine relationships between mineral distribution and the topography of the Windsor unconformity. Some difficulty arose in deciding on the angle of tectonic tilt. Phelps Dodge, following their assessment of a phase of extensive drilling in the 1960's, established a strike and dip for the Canso sandstone in the area of the Mine, at

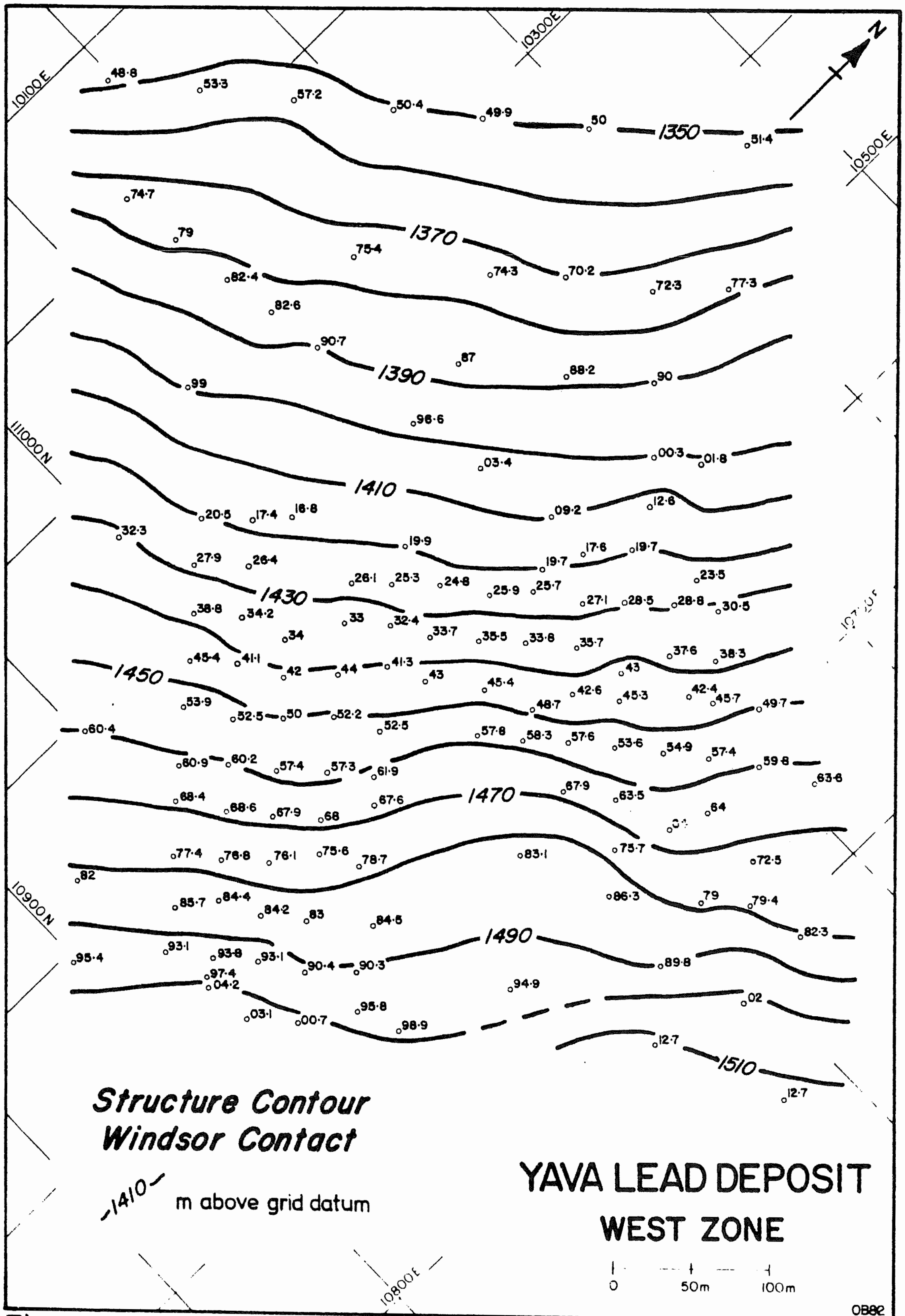


Figure IV.C.11 [Note - Elevations of Windsor/Canso contact shown in metres - last three digits only]

N50°E, 14-15°NW. Mining operations in the West Zone, using this figure as an average gradient, encountered difficulties when it became apparent that the gradient was steeper. A recalculation for the West Zone was conducted by the author, using the weighted average of dips on cross-section between all available drill holes. The results indicated an overall dip for the upper portion of the West Zone at 17°NW, with extremes ranging from 10° to 22°. On this basis, it was decided to plot the Windsor unconformity with reference to three planes all aligned N50°E: one at 14°NW, one at 17°NW and an intermediate plane at 15.5° NW. There was no reason to change the strike azimuth, because contours on the structure contour plan of the contact showed a sub-parallel alignment in this direction.

An alternative method to restore palaeorelief is to plot interval distances between a shale marker in the sequence (assumed to be deposited as a horizontal blanket) and the unconformity. This was not possible in this case, because of the absence of reliably correlatable shale markers within the sandstone, due to the nature of the depositional environment.

To explain briefly the procedure used: grid paper was aligned at 50° over the drill plan, and a reference line was drawn normal to the strike through an arbitrary central drill hole. Using this hole as an origin, a gradient scale, of -25% (for -14°), showing the anticipated elevation of the Windsor contact, was then marked on the reference line. In this way, the actual intersected elevation for each drill site could then be added to the anticipated elevation (a negative figure) to give positive and negative values representing residual ridges and depressions on the surface of the unconformity. To consider other dip values, the gradient scale is simply adjusted.

Figure IV.C.12, 13, and 14 are plots of the palaeorelief of the Windsor unconformity with 14°, 17° and 15.5°NW removed, respectively.

In all three cases, the effect of this exercise is to reveal a considerable topographic relief on the surface of the unconformity. To consider the two extreme cases first: with 14° removed, the surface comprises a closed depression in the lower central portion, extending to the south-east into two re-entrants, separated by a central spur, and flanked by positive features on the outer flanks. The central depression is open to the north. The re-entrant to the east is fully closed at its head, while the one to the west becomes constricted, and then opens into an opposing negative feature, open to the south-east.

At -17°, the effect is to pitch the surface in the opposite direction. The central depression is lost, a positive ridge lies to the north-west, and two re-entrants lie either side of a spur, open to the south-east.

The intermediate plot at -15.5° generates a surface with no overall slope. The central depression and re-entrants separated by a central spur, as described earlier, are present, and the area is confined by positive features to the north-west and on either flank. The

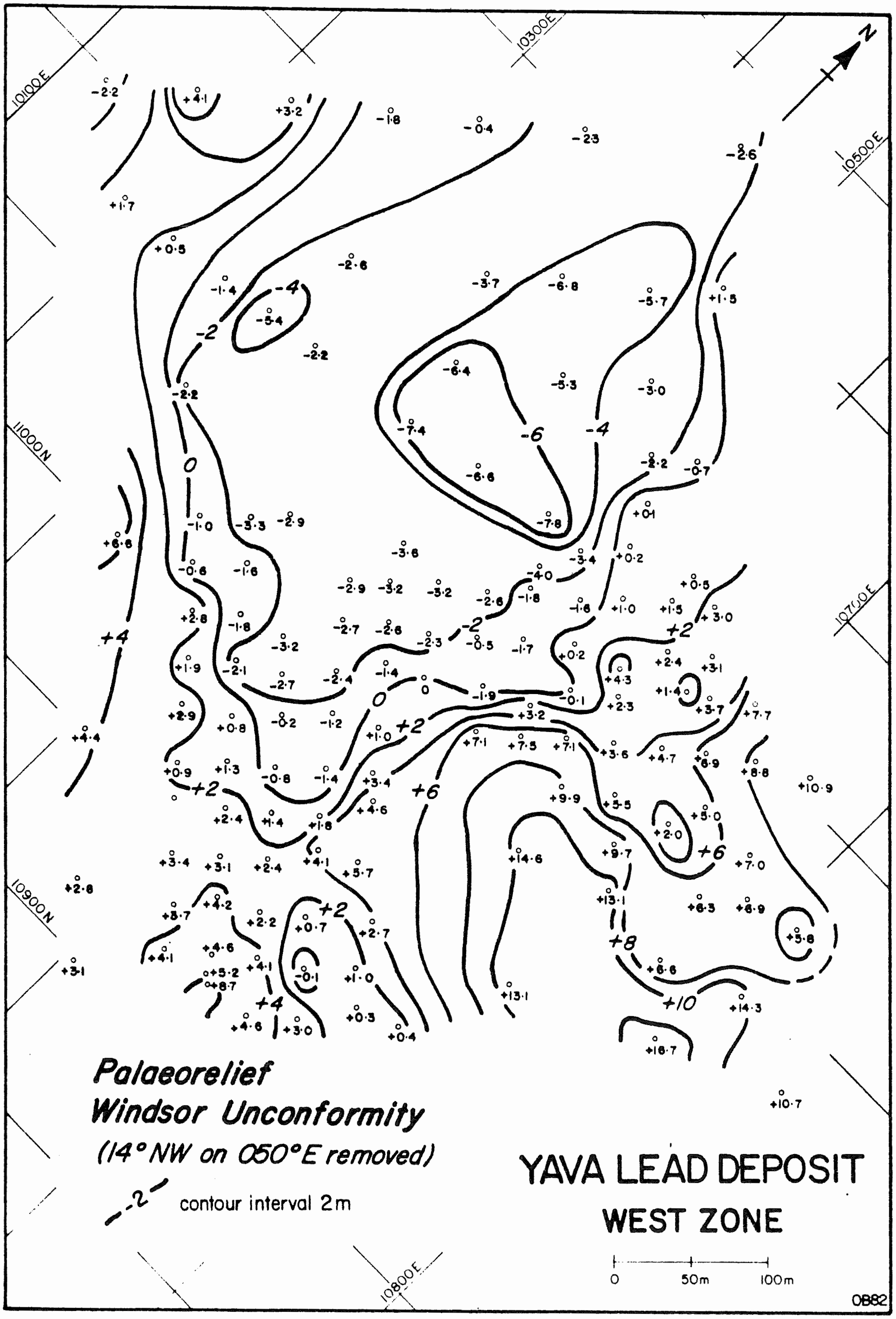


Figure IV.C.12

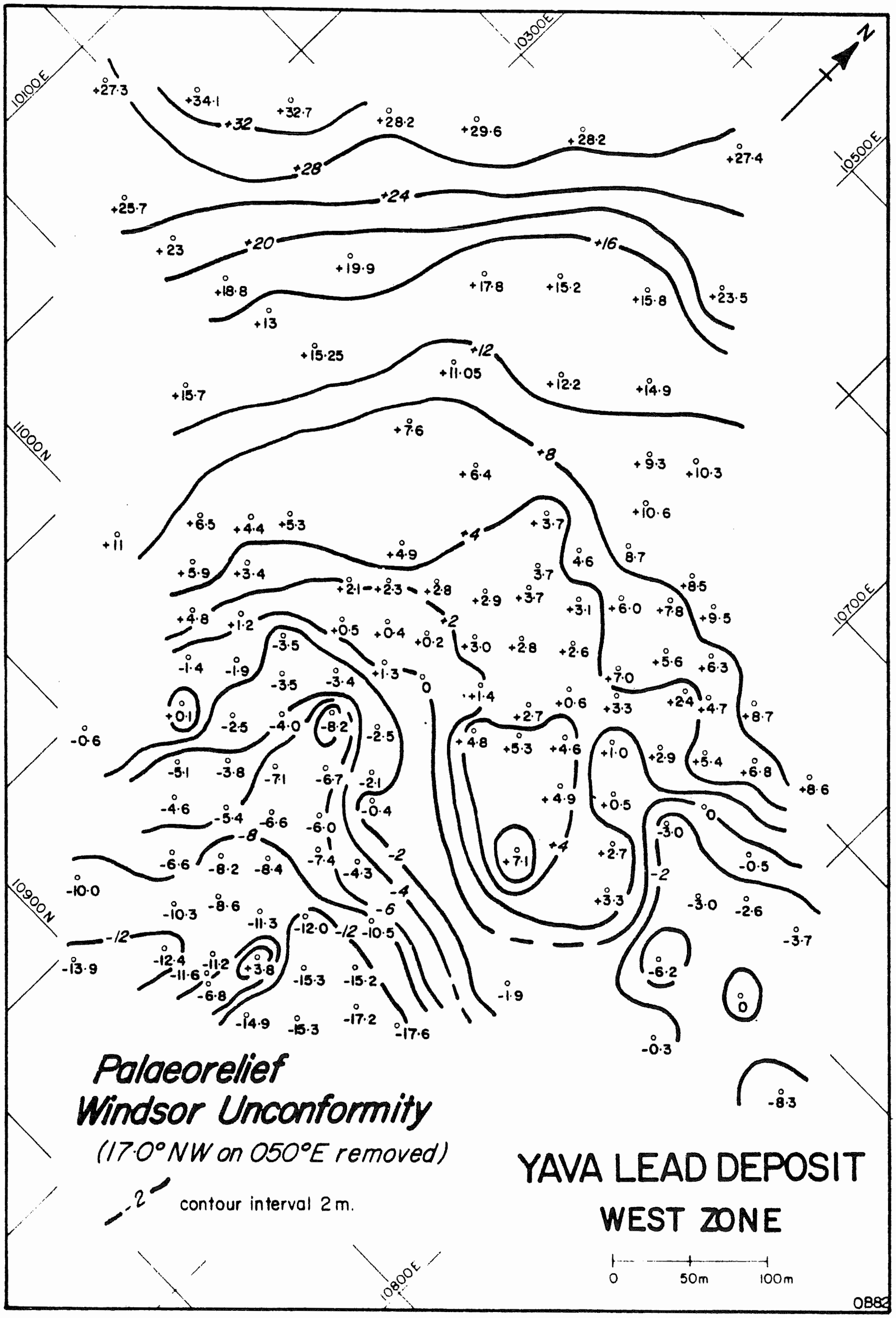


Figure IV.C.13

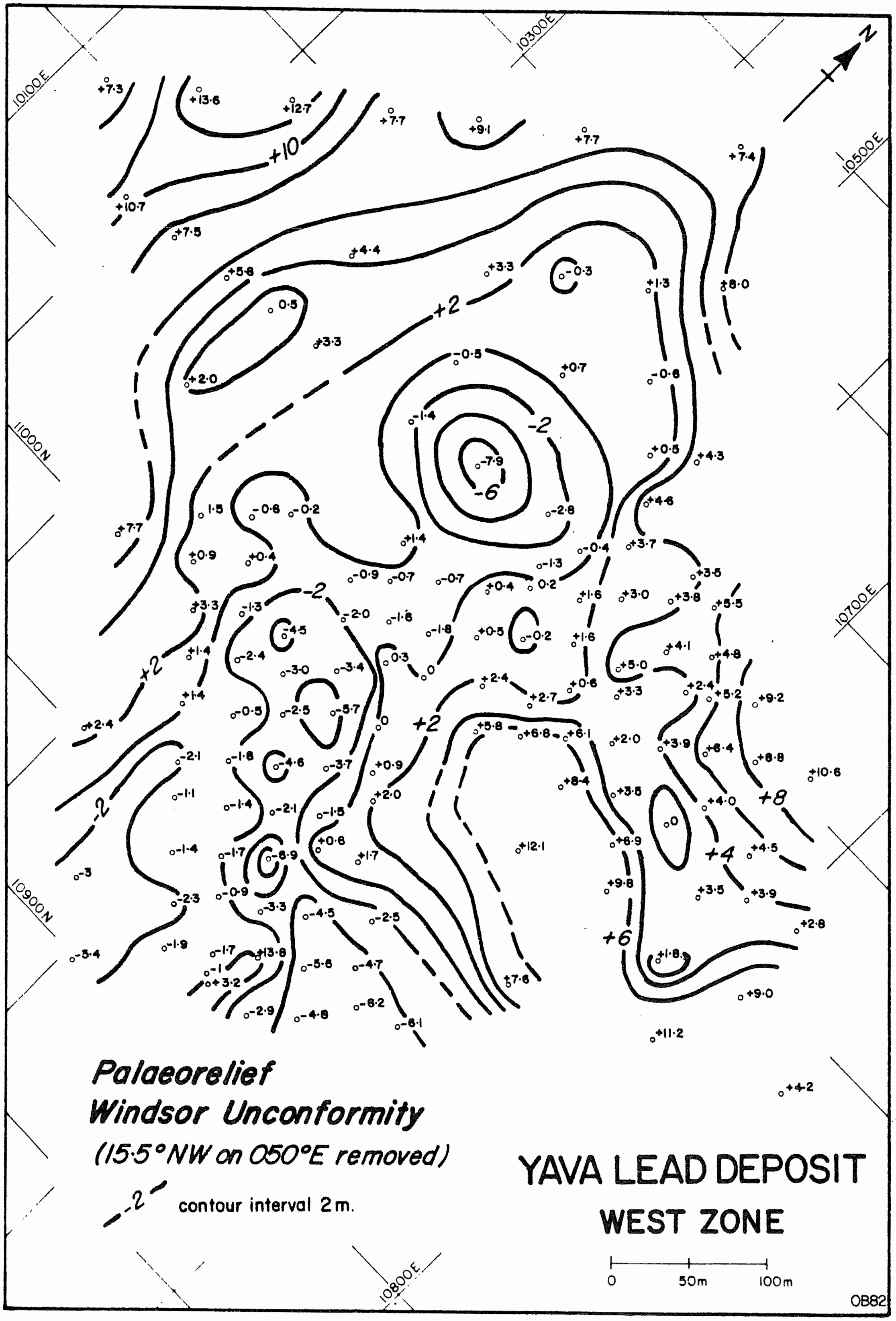


Figure IV.C.14

re-entrant to the east is open south-east, while the one to the west is open north-west.

Lead distribution and ore thickness can then be considered in relation to these surfaces. Comparison between grade distribution (Figure IV.C.4) and the -17° surface (Figure IV.C.13) shows a broad correlation between mineralisation (both thickness and grade) and the location of negative features on the restored surface. Mineralisation is concentrated in the re-entrant features and around the "back" of the central spur.

In contrast, comparison with the surface, after removing 14° only, shows a closer correlation between negative features and mineral concentration. Thickest and best grade mineralisation are concentrated in the re-entrant features and the central depression. Corresponding to changes in the palaeorelief, mineralisation discontinues to the south-east in the re-entrant to the east side, at the head of the feature; while it continues south-east in the other re-entrant which is open in that direction. The relationship with ore thickness is similar.

Comparison between mineralisation and the location of negative features on the intermediate -15.5° surface , shows a striking correlation: areas of thickness and grade are confined to depressions. The termination of ore in the re-entrant on the south-east side, the location of ore in the central depression, the small satellite depression to the west, the distribution of ore in the other re-entrant (closed to the north-west and open to the south-east) are all reflections of relief changes. Other features of note are: the narrow col towards the centre of the area, and the positive feature across the north-west flank. Both appear to influence mineralisation.

In conclusion, the assumption is made that the rocks on this side of the outlier have been subjected to tectonic tilting to the north-west 14°-17°. All three plots of pre-tilt surfaces indicate a positive correlation between spatial concentrations of lead mineralisation and the locations of palaeodepressions. The intermediate plot at -15.5°, where there is no overall slope, shows the closest relationship.

Therefore it is proposed that palaeorelief of the Windsor unconformity had a direct influence on mineralisation. This implies that mineralisation most probably was a pre-tectonic event.

IV. C. 4. Underground Followup

Cycle 1. Sandstone

In order to examine more closely some of the grade distribution features indicated in the drill hole study, follow-up was conducted underground. As outlined in the description of ore column stratigraphy, a single thick cycle is traceable throughout the South East Lobe, but is pinched out by over-stepping cycles to the south-west. Plots of grade and thickness distribution of the first sandstone above the unconformity show a systematic enrichment of lead within this unit, while thickness varies in less regular manner. Figure IV.C.15 shows the underground distribution of cycle one sandstone, throughout the

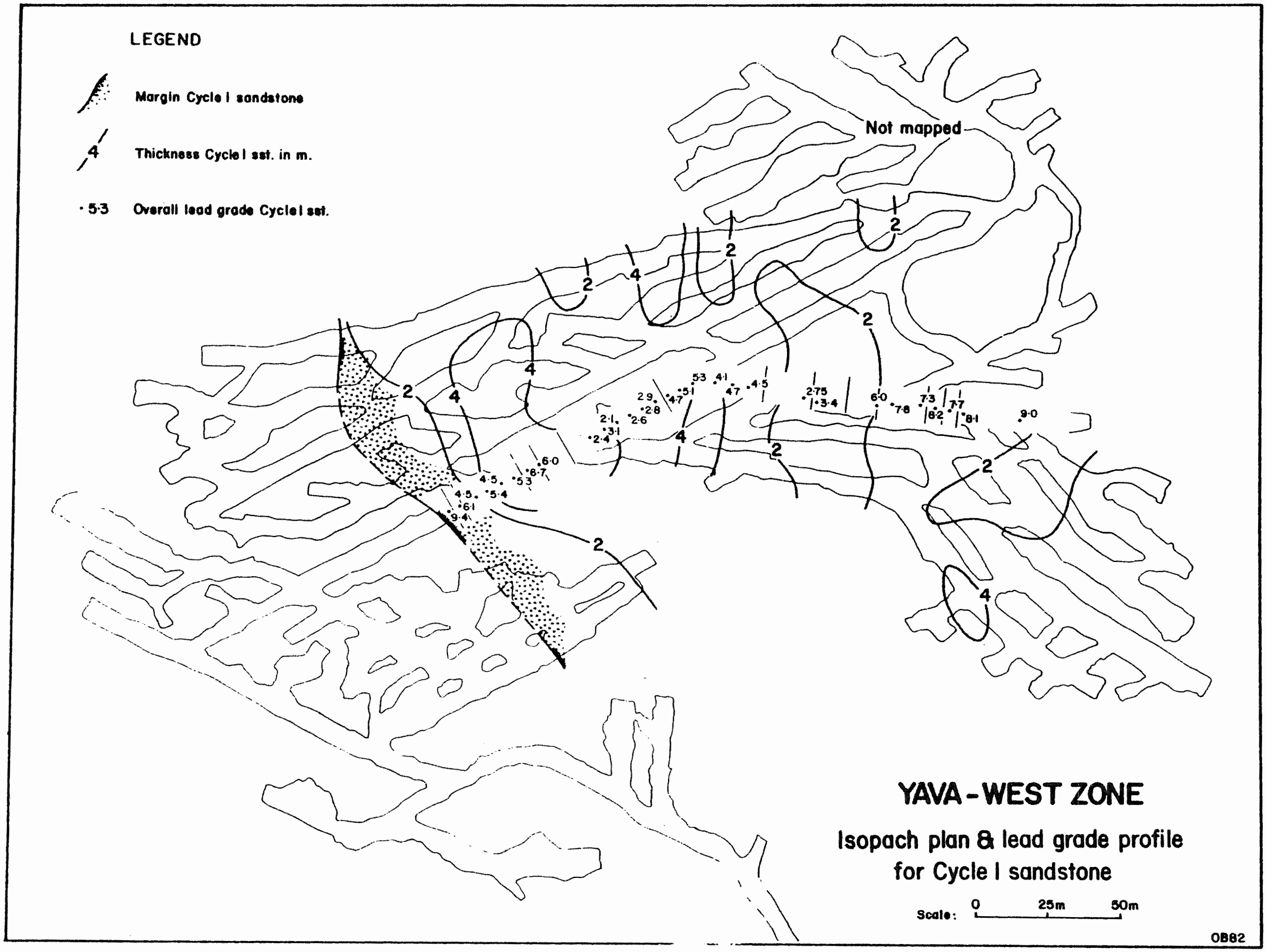


Figure IV.C.15

South East Lobe, and to the point of pinch out to the south. The thickness is shown throughout the area in 2 m isopachs; grade, for the same unit, is shown in percent lead for a profile along part of the No. 2 decline and the 2-5 N drift. Each point represents a single wall channel site; most are 5 m apart.

The isopachs confirm an overall orientation of sand bodies in a west and north-west orientation, with indications of local cross-cutting features. The grade profile shows a rise in grade at both ends (above the 6% level) corresponding with the drill indicated anomalies, while grade drops to 2.75% in the central section. There is a minor high of 5.0% in the middle of this central section.

While a close match between the actual situation underground and drill indication cannot be expected with such a change in detail, underground follow up, in this case, confirms the distribution patterns derived in the drill hole study.

Shale distribution

A follow-up plot of shale units within the ore zone was constructed from underground wall maps, to illustrate in more detail their distribution and lateral correlation. Figure IV.C.16 shows the mapped distribution of individually traced shale units. Each unit represents a single cycle top; their sequential order is shown in the legend. It should be noted that margins are shown, either as visible or inferred pinch out points, or as exposure lost into back or walls.

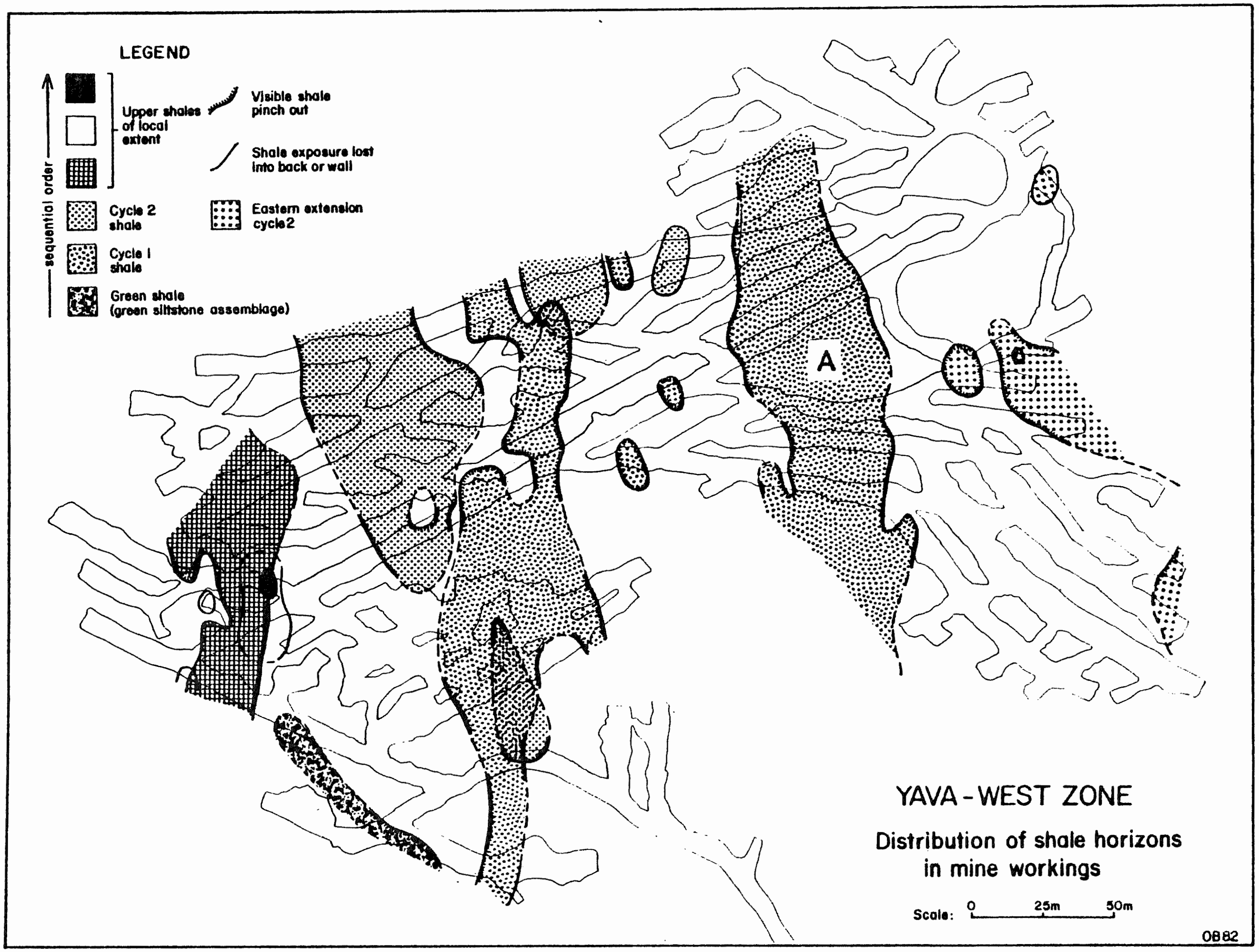


Figure IV.C.16

Up to six shale units were recognised underground. The most extensive unit (shown in random dots) marks the top of cycle one; while the overlying shale (shown in grid dots) marks the top of cycle two. To the south, in the Portal Lobe, up to three shales are preserved in the same location. The plot illustrates the patchy distribution of shale and indicates a strong north-west/south-east orientation. The cycle one shale marked A, is known to represent vertical accretionary fill in an abandoned channelway; at A the unit reaches 2 m in thickness. Elsewhere, shales are generally less than 1 m thick, and are interpreted to be overbank accumulations.

Comparison between Figures IV.C.8 and IV.C.16 shows that the distribution does not compare closely. This is expected, as there is no attempt to distinguish between cycles in the drill hole study. Nevertheless, the patchy distribution and strong north-west/south-east orientation, which the drill holes indicate, is confirmed. With respect to grade distribution (Figures IV.C.4 and 6) the observation that mineralisation trends are not influenced by shale distribution, still holds.

IV. C. 5. Unit Grade Study

As part of investigations into mining dilution and grade control procedures at the Mine, a study was conducted by the author into the distribution of lead grade in the different lithotypes of the sandstone assemblage. While this study was primarily directed towards mine dilution, it does have application to this project. To summarise the study briefly: as part of grade control procedures, face checks were taken on a routine daily basis, at all working headings. These included a sketch map and a channel sample of each lithological unit of the working face; thus providing information on the grade, and disposition of lithologic units, throughout the Mine. The assumption is made that sediments were deposited as a series of fining-upward cycles (conglomerate-sandstone-shale-conglomerate...) and that, even though single cycles may not be laterally continuous, any profile will consist of a cyclical sequence, with the lowermost cycle lying in contact with the basal unconformity. This permits a schematic correlation of profiles and relative cycles across the Mine; thus the grade of respective units can be compared.

199 face checks, covering a 10 month mining period, were examined. Lead grades within the cyclical profile were compared, and the frequency and mean grade of each unit were calculated on a monthly and an overall basis. The overall figures are presented in Table IV.C.1.

The results can be summarised as follows:

- Windsor footwall is effectively unmineralised.
- Basal conglomerate is present in only 20% of faces, and the average grade is 3.62%. Monthly figures for this unit in fact ranged from 1.74% to 9.05%. This wide range and the relatively low grade of this unit, is attributed to

	Frequency of Occurrence	Assay Grade % Pb
No. of complete face checks	199*	
Footwall (Windsor)	108	0.40%
Basal Congl. (Limestone pebble)	54	3.62%
1st. Sandstone	194	6.70%
1st. Shale	43	1.07%
2nd. Conglomerate		
Coal lag	29	9.18%
Limestone pebble conglomerate	66	5.47%
Shale flake conglomerate	50	5.42%
2nd. Sandstone	158	4.40%
2nd. Shale	25	1.15%
Upper conglomerate	60	5.12%
Upper sandstone	46	2.64%
Overall face grades	194	5.02%

* The cyclical sequences of 5 faces were ambiguous and could not be fitted into the profile scheme objectively; these were omitted.

TABLE IV.C.1. Yava West Zone, Mean Lead Grades of Lithologic Units Exposed in Working Faces August 1980 - May 1981.

the known presence of calcareous cement, common at this level, inhibiting mineralisation.

- The first sandstone in the profile is present in all faces; it contains above average mineralisation (6.70% Pb).
- The overlying shale is local in distribution (22% presence) and is consistently low grade (1.07% Pb).
- Conglomerates of the second cycle are also local in distribution. Coal lags contain higher than average mineralisation (9.18% Pb), which is expected, but occurrence is limited (15%). Shale flake and limestone pebble conglomerates are equally limited in distribution; they contain the same average lead content 5.45% Pb. (With mineralisation confined to the matrix, only a mean grade approaching half that of the underlying sandstone might be anticipated. The higher level actually recorded is attributed to the influence of coal matter common in these conglomerates).
- The second sandstone is also widespread in occurrence, but mineralisation has dropped off 30%, in comparison to the lower sandstone, to a mean of 4.40% Pb. Furthermore, the upper sandstone (above), where present, is even lower in grade (2.64% Pb).
- Overall mean face grades (weighted grades by lithotype surface area) of all faces is 5.02% Pb.

On a simple numerical basis, this study illustrates that frequency of occurrence of the different lithotypes within the ore zone is markedly different. When these figures are compared with the volumetric calculation for lithotypes present in Section A, the importance of sandstone as the primary host rock can be fully appreciated. Conglomerates, particularly coal lag, are also an important host, but their distribution and overall volume is limited. Shales are poorly mineralised and are a minor rock component.

Another feature emphasised by this study is the grade profile within the ore horizon. Higher than average grades occur in the lower half of faces while lower than average grade occurs in the upper half. A comparison of the three sandstone units, dropping from 6.70% Pb, through 4.40% Pb, down to 2.64% Pb, from the bottom to the top of faces, illustrates this point.

IV. C. 6. Drill Hole Follow Up: Footwall Geology

In presenting the plot of footwall lithotype distribution in the drill hole study, the observation was made that mineralisation increases abruptly with the change in footwall, (i.e. from solid basement to talus breccia). This suggested a possible spatial relationship between talus breccia and mineralisation, perhaps implying some aspect of control. An hypothesis was considered that the talus breccia might provide a conduit up which mineralising solutions could pass, exiting at the point of sub-outcrop into the porous sandstone cover rocks.

To consider this, the sub-sandstone geology for the three ore zones was determined, using drill hole information and available surface mapping. Figure IV.C.17 shows the surface and sub-sandstone exposure of the three main footwall lithotypes, the extent of sandstone cover, and the distribution of lead mineralisation therein. The figure also contains a strike section across the deposit (A-A').

As shown, mineralisation is clearly concentrated between areas of basement sub-outcrop; the basement forms topographic highs or spurs extending north-west. Two main basement features are present separating the three ore zones.

Grade contouring indicates that while mineralisation appears to drop off gradually to the north-west, it is truncated abruptly to the southeast (open contours) at the edge of the sandstone exposure. This would suggest that erosion of much of the southeast (up-dip) portion of the three ore zones has occurred since the time of tectonism in the area.

There is a general spatial relationship between talus breccia and mineralisation across the deposit. The western margin of the East Zone in particular, corresponds closely with talus breccia suboutcrop; while on the opposite side of the basement feature, where breccia is not exposed, there is no mineralisation. This feature may be of significance; however it may be that relief change, associated with this geological contact, is the overriding control. Erosion of the mineralised horizon to the south-east prohibits a full assessment of this

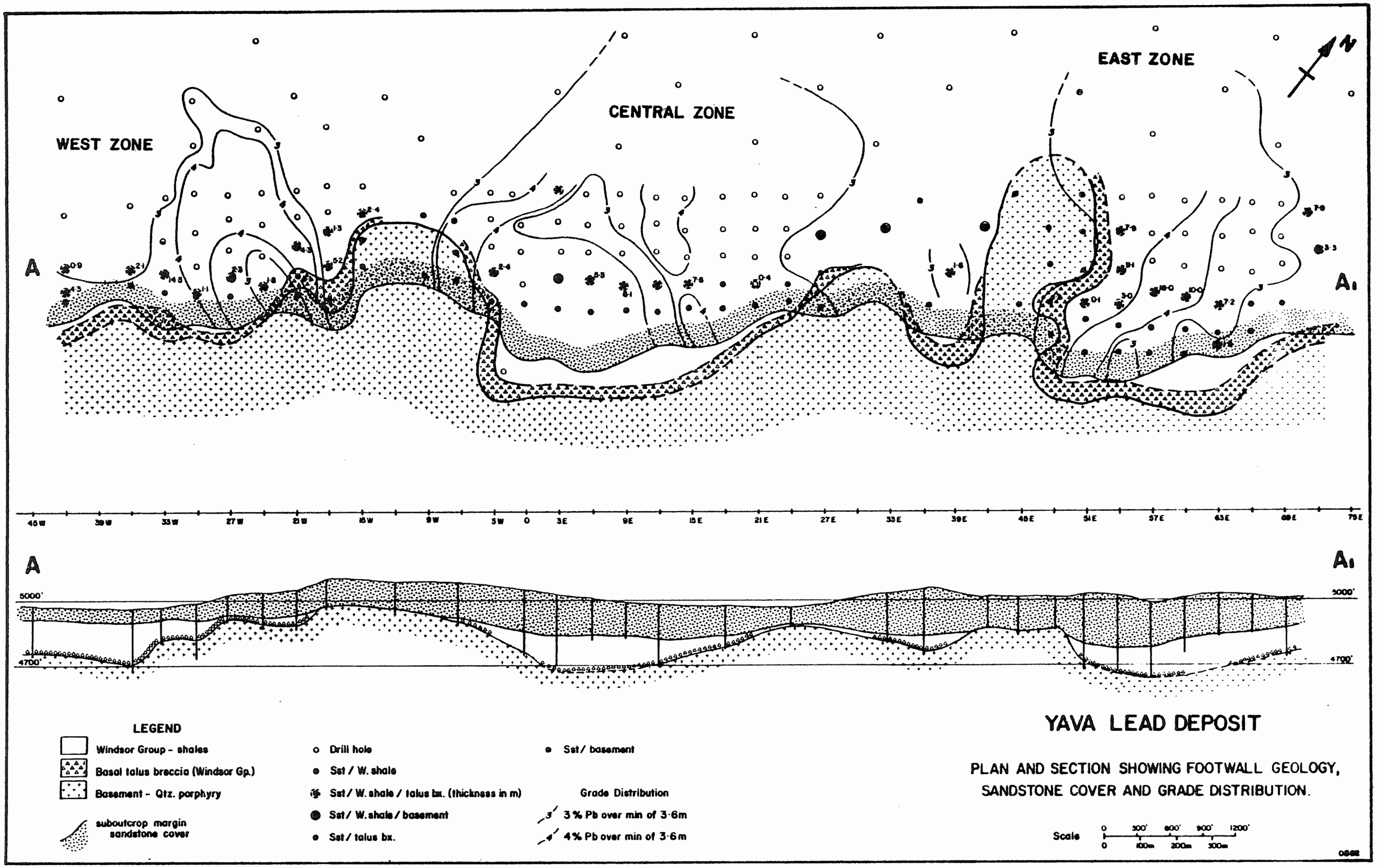


Figure IV.C.17

horizon, which is discordant to the stratigraphy. Up-dip mineralisation is confined to the Lower Sandstone, while down-dip it is limited to the Upper Sandstone, thus forming a roughly horizontal horizon, passing obliquely through the sediments, which dip to the north-west at 3°. Rickard et al. (1979) state that

> "a base line below which there is no ore grade mineralisation can be drawn below the whole deposit. This base line drops less than 20 m in a 2000 m north-west - south-east traverse across the deposit, while the sandstone, dipping steadily at about 3°, drops over 100 m in the same section."
>
> (Rickard et al., 1979, p. 1262)

At L'Argentiere, mineralisation of the Horizon Superieur is stratabound occurring in sandstone/conglomerate intercalations, 3-5 m thick, between mudstone horizons of similar thickness, while mineralisation of the Horizon Inferieur bears some resemblance to Yava; it appears as an horizon of mineralisation confined to the basal 10 m of a 27 m coarse clastic interval, directly above the Carboniferous/Permian-Triassic unconformity.

Detailed spatial plots of grade and thickness of ore have not been published for any comparable deposits. One plot presented by Christofferson et al. (1979) for Vassbo, outlines the spatial distribution of lead greater than 2.0%, lead 1-2% and zinc greater than .5%. This shows broadly that lower grade lead mineralisation "haloes" higher grade central areas, while zinc is spatially displaced and adjacent. Another plot of basement contours and quartz sandstone thickness for Gutussjo, which includes an outline of the orebody, indicates that ore relationship.

IV. C. 7. Summary

To summarize the salient observations on grade distribution for the West Zone:

1. Mineralisation is discordant with respect to host rock stratigraphy - passing laterally through the overstepping sedimentary sequence in order to follow the basal unconformity.
2. The spatial configuration of both ore thickness and ore grade indicate that central areas of thick and high grade ore are surrounded by a marginal halo of thinner, low grade ore.
3. Within a single mappable sandstone unit, lead grade changes laterally in a systematic manner, and is not affected by thickness changes in the same unit.
4. Trends in grade distribution within sandstone alone, or in the complete host rock assemblage, are not influenced by the distribution of intervening shale horizons.
5. Within the ore zone, mineralisation occurs in 1.3-1.6 sedimentary cycles in one lobe area, and in 2-2.6 cycles in the other. The overall ore thickness in both lobes remains the same.
6. There is a broad correlation between footwall lithotype and lead distribution. Grade tends to occur over areas where footwall is composed of calcrete, and to a lesser extent, regolith. Marginal and unmineralised areas are underlain by regolith, Windsor shale

and basement rock. However, this may be a coincidental relationship.

7. Restoration of palaeotopography of the disconformity surface, by removal of tectonic tilt, shows a striking correlation between the location of palaeodepressions and lead concentration, (both thickness and grade). This relationship is seen most clearly on the -15.5° NW plot, where there is no overall slope to the restored surface.

8. Quantitative evaluation of the distribution of lithotypes and respective lead grades, within the ore zone, indicates that:
   - sandstone is the most dominant rock type; conglomerates and mudstones are common, but local in occurrence.
   - mineralisation is closely related to lithology: sandstone contains ubiquitous mineralisation; conglomerates are well-mineralised, particularly where rich in coaly matter; while shale and footwall lithotypes are unmineralised.
   - there is a clear mineralisation profile, with highest grades occurring in the basal beds, and a steady drop in grade upwards, through the ore zone, to the mine back and above.

9. Examination of footwall distribution for the entire deposit indicates:
   - there is an antipathetic spatial relationship between basement suboutcrop (positive palaeorelief), and the three ore zones, with mineralisation being confined to the intervening areas.
   - a relationship between basal Windsor talus breccia suboutcrop and

ore margin is exhibited.

- also, the open configuration of grade contours at the limit of sandstone cover, suggests that much of the south-eastern portion of the deposit has been removed by erosion.

CHAPTER V

GEOCHEMISTRY

In order to characterise the geochemical composition of rock units at, and adjacent to, the Yava mineralisation, and to check for obvious elemental associations, a pilot study involving whole rock and trace element analysis was conducted.

V. 1. Major and Trace Element Composition of Selected Sample Suite

A selected suite of 13 samples, representing all rock types and all types of mineralisation associated with the Yava mineralisation, were analysed for major elements, using the microprobe energy dispersal system, and for trace elements, using atomic absorption and spectrographic methods.

For major element analysis, sample pulps were fused onto metallic strips, and prepared for analysis following the method of McKay (1981). Samples were mounted on both tantalum and molybdenum strips; a flux was used when necessary. In the resulting analysis, samples containing sulphide mineralisation (high sulphur) had to be considered unreliable, because of the possible line interference by heavy metal elements from outside the energy system spectrum; also samples fused on molybdenum strip showed less error than those fused on tantalum.

Major element analysis for typical lithologies from the Mine area are presented in Table V.1.

Trace element analysis (Table V.2), which could be completed for the entire suite, (including sulphide-rich samples) includes some overlap analysis with the whole rock determination, i.e. those for Fe, Ca, Mg and Mn. This provides a check where trace element levels are elevated to within the detection limit of the microprobe. In general, there is a good correlation between the two analyses.

The diversity of lithology and mineralisation styles is too great in this sample set, to apply statistical correlation analysis to examine association. Some comments can, however, be made.

These results show that basement porphyry from the Mine area compares well with a potassic granite in major element composition (Table V.3), and it contains 20 ppm Pb, 34 ppm Zn, 36 ppm Ba and 29 ppm Sr. According to Wedepohl (1974), granites, on average, contain 23 ppm Pb, 30-70 ppm Zn, 730-1600 ppm Ba and 147 ppm Sr. Therefore, indications are that basement rock in the Mine area contains average background levels of lead and zinc; it is not magmatically enriched in base metals. Furthermore, there is a depletion in barium and strontium compared to normal granites. Weathered porphyry shows an enrichment of Pb by 9 times to 180 ppm; similar enrichments in Ba, Sr and also Cu (1 to 14 ppm) are noteworthy. Zinc levels remain the same. While these are single-sample determinations for this unit, and must be treated as such, they do indicate a marked enrichment in base metals, which may be

Sample No.	OB53	OB52	OB1031	OB57	OB41	OB28	OB1029
Lithology	Fresh Quartz Porphyry	Weathered Quartz Porphyry	Windsor Shale	Calcrete	Green Siltstone	Shale (within ore zone)	Regolith Clay
SiO_2	75.00	74.97	54.95	31.11	73.33	62.72	76.26
Al_2O_3	13.76	15.94	19.98	6.67	9.18	22.97	14.99
FeO_{total}	1.53	1.12	7.75	3.83	2.54	5.50	2.11
MnO	0.10	0.07	0.69	1.52	0.53	0.10	0.11
MgO	0.13	0.32	5.00	1.72	1.23	2.09	1.70
CaO	0.12	0.13	5.29	52.51	10.60	0.38	0.67
Na_2O	4.31	1.68	0.23	0.23	0.31	0.31	0.25
K_2O	5.02	5.56	5.39	1.54	1.21	4.13	3.05
TiO_2	0.09	0.26	0.52	0.19	0.76	0.93	0.80
	100.06	100.04	99.8	99.32	99.59	97.04	99.94
	n = 6	n = 6	n = 4	n = 4	n = 6	n = 4	n = 6

TABLE V.1. Yava West Zone, Microprobe Whole Rock Analysis of Selected Sulfide-free Sample Suite.

Sample No.	Sample Type	Rock-type	Pb%	Fe%	Ca%	Mg%	Agppm	Cdppm	Cuppm	Znppm	Mnppm	Bappm	Srppm	Bippm	Sbppm	Remarks
OB 7438	core	sst.	.002	2.73	0.34	0.69	1	.5-	24	218	608		no analyses			60m above ore
OB 7568	core	sst.	.027	2.03	1.63	1.34	1	35	16	3660	2850		no analyses			4m above ore
OB 21	u/g	sst.+Pbs	7.24	0.99	0.23	0.25	5	3	4	622	247	5400	185	0.06	10 -	
OB 24	u/g	coal+PbS	29.4	4.52	0.17	0.22	56	72	100	14600	202	400	15	0.08	10 -	
OB 50	u/g	Vein PbS	9.5	2.31	18.4	0.18	5	466	76	12000	32600	320	220	0.06	10 -	
OB 33	u/g	Calc. Con.	.038	1.73	10.4	0.33	1	.5 -	17	138	58	310	155	0.06	10 -	
OB 28	u/g	Shale	.116	4.08	0.28	0.10	1	.5 -	61	608	524	570	170	0.20	10 -	
OB 48	u/g	Lst.Congl	0.03	1.71	17.8	0.37	1	.5 -	34	72	7620	10400	430	0.05	10 -	
OB 41	u/g	Grn. Slt.	4.04	1.69	4.88	0.52	8	1	164	376	170	390	108	0.09	10 -	
OB 1029	u/g	Rglth.	.064	0.80	0.32	0.32	5	.5 -	10	70	276		no analyses			
OB 57	u/g	Calcrete	.057	1.96	16.9	0.63	1	.5 -	56	180	8230	58900	1100	0.03	10 -	
OB 1031	u/g	W. Shl.	.004	3.74	2.74	0.18	4	.5 -	5	82	4920		no analyses			
OB 55	u/g	T.bx.+Pb	.065	0.96	0.19	0.44	1 -	.5 -	560	128	166	340	68	1.1	10 -	
OB 52	u/g	Qtz.P(w)	.018	0.42	0.94	0.99	1	.5 -	14	46	29	270	200	0.07	10 -	
OB 53	u/g	Qtz.P	.002	1.06	0.08	.019	1 -	.5 -	1	34	59	36	29	0.06	10 -	

TABLE V.2. Trace Element Analysis of Composite Sample Suite, Yava Mine.

	Yava Quartz Porphyry	Potassic Granite (Dartmoor)	Potassic Granite (Finland)
SiO_2	75.00	73.66	77.04
Al_2O_3	13.76	13.81	12.39
Fe_2O_3	1.53	0.21	0.15
FeO		1.51	0.27
MgO	0.13	0.45	0.17
CaO	0.12	0.67	0.22
Na_2O	4.31	2.89	1.96
K_2O	5.02	5.02	6.91
H_2O	Not determined	1.66	Not determined
TiO_2	0.09	0.16	0.05
Rest	-	-	-
		Hatch, Wells and Wells (1972)	Carmichael Turner and Verhoogen (1974)

TABLE V.3. Comparative Analysis of Potassic Granites.

important to the ore-forming process. Further sampling and analysis would be required to clarify this feature.

Compared to shales quoted in Wedepohl (1974), the Windsor shale forming the footwall at Yava is elevated in lead (40 ppm against 22 ppm) and silver (4 ppm against 0.19 ppm), while copper is depleted seven fold in comparison to average shales. In addition, manganese is one order higher than normal (4920 ppm against 850 ppm), but zinc content is comparable to average shales.

Both calcrete and regolith represent what is interpreted to be a period of arid weathering, when processes of surficial enrichment occur. Most noticeable is calcrete, which shows elevated values for Pb, Zn, Cu, Mn, Ba and Sr. Barium at 5.9% is most noticeable in this case; it may be present as either witherite or barite; if so, it represents 8.5% $BaCO_3$ or 10.2% $BaSO_4$ respectively. Neither minerals were recognised in the one thin section of calcrete. Preparation of additional thin sections, and analysis using wavelength measurement on the microprobe, are required to further examine this occurrence. Also noteworthy here, is the regolith, which is anomalously rich in Pb at 640 ppm. With regard to base metal levels, it should be remembered that both these samples were collected directly below ore mineralisation, therefore the likelihood of contamination is very great.

Barium is again high at 1.04% (along with calcium and manganese) in limestone pebble conglomerate from within the ore zone; note that the sample contained only 30 ppm Pb, a reflection of the antipathy between carbonate and galena at Yava.

In comparison to both Windsor shales and average shales, mudstone/shale from within the ore zone is anomalous for all base metals. Despite being anomalous, base metal levels are remarkably low, considering the situation of this lithotype, amid sulphide mineralisation.

Unmineralised sandstone from well above the mineralised horizon at Yava contains lead, copper and iron well within the range for normal sandstone (Wedepohl, 1974). Only manganese shows evidence of enrichment: 608 ppm Mn against normal 200 ppm. Meanwhile, sandstone from close to the ore horizon, containing 270 ppm Pb, is further enriched in manganese and zinc.

Galena/sphalerite mineralisation, from a calcite vein cross-cutting ore mineralisatison, was also analysed. Most notable here, is the elevated cadmium value; cadmium, in this case, is most probably associated with the high zinc. A strong positive association for this pair is also indicated in Section V.2, below.

V.2. Trace Element Distribution in Drill Profiles

In order to test for any obvious elemental zonation, and associations related to the mineralisation, chip samples were collected from cores intersecting, and marginal to, the West Zone orebody. Four holes were chosen: 322, 325, 331 and 362. The first two are ore holes, while 331 is a waste hole on the east flank of the orebody, and 362 is a waste hole down-dip. Sampling had been completed throughout the cores at 10 ft. intervals; a limited number of these samples were selected (mostly sandstone) to represent a section from the unmineralised hanging wall through to the base of mineralisation.

The resulting determinations, using aqua regia and atomic absorption for Pb, Fe, Ca, Mg, Ag, Cd, Cu, Zn and Mn for each of the four drill holes, are presented in Tables V.4, 5, 6 and 7.

In hole 325, (an ore hole which intersected 4.2m at 7.16%), the drop in lead to 270 ppm above the ore zone from 3.0% at the top of mineralisation, in less than 5 m, is most significant. Hole 322 includes a sample of footwall Windsor shale; here lead is low (100 ppm) compared to the ore grade in the ore zone just above; likewise, lead drops abruptly to background levels above the mineralisatison. The sandstone directly under the ore in hole 331 is calcareous; this is reflected in the analysis, which returned Ca at 21.5% and Pb at only 1000 ppm. The high cadmium of 136 ppm corresponds to the elevated zinc of 9200 ppm. The analysis of sandstone from down-dip of the West Zone, compares in trace element content to sandstones overlying ore in the other holes. An exception is the mean manganese value for hole 362, at 3450 ppm, compared to means of 1840-1030 ppm for the other holes; this might indicate a manganese enrichment down-dip of the ore. This feature merits further investigation.

On the basic premise that increase in lead content represents intensity of galena mineralisation, and given that all except two of

Sample No.	Depth from Surface (m)	Rock-type	Pb%	Fe%	Ca%	Mg%	Ag ppm	Cd ppm	Cu ppm	Zn ppm	Mn ppm	Remarks
7568	47.2	sst.	0.027	2.03	1.63	1.34	1 -	35	16	3660	2850	
7571	51.8	sst.	3.0	1.74	0.49	0.47	16	.5 -	10	456	708	
7575	57.9	sst.	4.94	1.19	0.55	0.56	22	2.5	12	396	1400	
7578	62.5	sst.	5.7	1.96	0.38	0.18	11	17	51	3200	245	

TABLE V.4. DDH:325 Trace Element Analyses.

Sample No.	Depth from Surface (m)	Rock-type	Pb%	Fe%	Ca%	Mg%	Ag ppm	Cd ppm	Cu ppm	Zn ppm	Mn ppm	Remarks
7438	30.5	sst.	.002	2.73	0.34	0.69	1-	.5 -	24	218	608	
7421	76.2	sst.	.98	2.34	0.31	0.57	1-	.5 -	6	1180	541	
7410	93.0	sst.	2.62	1.35	2.06	0.56	3	.5 -	10	212	3420	
7406	99.1	sst.	7.6	1.15	.006	.001	5	2	6	494	1440	
7401	106.7	W. shale	.01	2.68	4.56	2.08	1	.5 -	49	128	3180	Geological footwall

TABLE V.5. DDH:322 Trace Element Analyses.

Sample No.	Depth from Surface (m)	Rock-type	Pb%	Fe%	Ca%	Mg%	Ag ppm	Cd ppm	Cu ppm	Zn ppm	Mn ppm	Remarks
7526	27.4	sst.	.015	2.67	.47	.61	1.0-	.5 -	7.0	104	848	
7537	45.7	sst.	1.54	2.46	1.31	1.24	1.0	4.5	11.0	2020	2330	
7542	53.3	sst.	2.44	1.89	.34	.5	3.0	.5 -	33.0	554	611	
7546	59.4	sst.	5.24	3.87	8.93	.38	13.0	136.0	48.0	9200	3400	
7547	61.0	sst.	.10	1.43	21.5	.35	1.0	.5 -	79.0	134	624	Calcareous sst.

TABLE V.6. DDH:331 Trace Element Analyses

Sample No.	Depth from Surface (m)	Rock-type	Pb%	Fe%	Ca%	Mg%	Ag ppm	Cd ppm	Cu ppm	Zn ppm	Mn ppm	Remarks
7583	18.0	sst.	0.22	4.19	0.36	0.94	10	.5-	26	172	1280	
7588	34.0	sst.	0.01	3.59	0.15	0.7	6	.5-	40	88	728	
8559	129.6	lst. congl.	0.016	4.01	4.89	1.17	7	66	13	8000	6790	
8569	144.8	sst.	1.88	2.47	3.92	2.71	5	.5-	24	328	8400	
8572	149.4	sst.	0.81	2.15	0.38	0.58	11	.5-	10	230	687	
8573	150.9	sst.	2.98	1.93	2.76	0.44	8	.5-	14	436	2830	

TABLE V.7. DDH:362 Trace Element Analyses these samples are of the same lithology, simple statistical analysis was applied to this population using the Minitab program.

Table V.8 is a composite table of all 20 analyses ordered according to lead content. Table V.9 shows the normal correlation co-efficients between elements, and correlation co-efficients using the log of concentration.

Both straight and log values have been used to calculate two sets of correlation co-efficients for each pair, because values for many of the elements show log normal distribution. Exceptions to this are iron (which is bimodal) and zinc and cadmium (which are erratic with almost all values at a single low level and a few higher values).

As indicated by Brooks (1972), pairs in a population of 20 cases show significant correlation, with a correlation co-efficient ± .45 and high significance at ± .68. Despite a bi-modal distribution for iron, the Pb:Fe co-efficient is -.496, indicating an antipathetic relationship. The same relationship is evident in Table V.8: Fe levels in unmineralised and weakly mineralised sandstone are 2.5% (one population), while Fe drops off to less than 2%, when lead content is greater than 2% (a second population). One exception is where Fe is 3.87%; this sample is also anomalous for Ca, Cd and Zn, along with high Pb (5.34%). Figure V.1.A, a log plot of Pb against Fe, shows this relationship; here, however, values do tend to cluster into two groups in a broad negative band. Silver also shows a relationship with lead; in this case, the association is sympathetic (.539). Lead against

Sample No.	Lithology	Pb%	Fe%	Ca%	Mg%	Agppm	Cdppm	Cuppm	Znppm	Mnppm
7438	1	.002	2.73	.34	.69	1	.5	24	218	608
7401	5	.01	2.68	4.56	2.08	1	.5	49	128	3180
7588	1	.01	3.59	.15	.70	6	.5	40	88	728
7526	1	.015	2.67	.47	.61	1	.5	7	104	848
8559	3	.016	4.01	4.89	1.17	7	66.0	13	8000	6790
7568	1	.027	2.03	1.63	1.34	1	35.0	16	3660	2850
7547	1	.10	1.43	21.50	.35	1	.5	79	134	624
7583	1	.22	4.19	.36	.94	10	.5	26	172	1280
8572	1	.81	2.15	.38	.58	11	.5	10	230	687
7421	1	.98	2.34	.31	.57	1	.5	6	1180	541
7537	1	1.54	2.46	1.31	1.24	1	4.5	11	2020	2330
8569	1	1.88	2.47	3.92	2.71	5	.5	24	328	8400
7542	1	2.44	1.89	.34	.50	3	.5	33	554	611
7410	1	2.62	1.35	2.06	1.56	3	.5	10	212	3420
8573	1	2.98	1.93	2.76	.44	8	.5	14	436	2830
7571	1	3.00	1.74	.49	.47	16	.5	10	456	708
7575	1	4.94	1.19	.55	.56	22	2.5	12	396	1400
7546	1	5.24	3.87	8.93	.38	13	136.0	48	9200	3400
7578	1	5.70	1.96	.38	.18	11	17.0	51	3200	245
7406	1	7.60	1.15	.006	.001	5	2.0	6	494	1440

Note: Lithology: 1 - sandstone; 3 - Lst. Pebble Congl.; 5 - Windsor Shale

TABLE V.8. Drill Profiles: Composite Table of Element Analyses.

	Pb%	Fe%	Ca%	Mg%	Ag ppm	Cd ppm	Cu ppm	Zn ppm
Fe%	-.426							
Ca%	-.144	-.026						
Mg%	-.417	.186	-.002					
Agppm	.515	-.030	-.160	-.311				
Cdppm	.217	.490	.283	-.091	.226			
Cuppm	-.075	.131	.715	-.052	-.095	.200		
Znppm	.170	.486	.212	-.064	.172	.944	.115	
Mnppm	-.074	.274	.153	.744	-.067	.342	-.108	.399

	LPB	LFE	LCA	LMG	LAG	LCD	LCU	LZN
LFE	-.496x							
LCA	-.148	.229						
LMG	-.364	.444	.668x					
LAG	.539x	-.013	-.149	-.184				
LCD	.093	.245	.234	-.073	.204			
LCU	-.209	.275	.467x	.234	.005	.122		
LZN	.285	.188	.197	-.048	.169	.896x	-.036	
LMN	-.006	.204	.467x	.293	.025	.313	-.097	.258

TABLE V.9. Normal and Log Correlation Co-efficients for Element Pairs, in Composite Population from Drill Profile Analyses.

silver is shown in Figure V.1.B; in this case, the plot is for straight values (.515) because the log plot shows clustered distribution.

Calcium shows no systematic relationship to lead. However, a strong association between calcium and copper (Figure V.2.a) is suggested for straight values at .715 (.467 for log values). This unusual association is not understood. Furthermore, an association between calcium and magnesium (.668), and calcium and manganese (.467), is indicated for log values. The former association is unfounded; firstly, because the co-efficient for straight values is -.002; and secondly, the log plot shows all samples form a cluster (except for one - which is anomalously low for both elements, and is therefore set apart). The association between calcium and manganese, although only .153 using straight values, is considered to be a real association, because calcites from the ore zone analyses on the microprobe were found to contain 1.6 wt% Mn on average, and the distribution for both elements is log normal.

The other correlation to be mentioned in this study is cadmium with zinc; a strong positive association at .896. This is shown in Figure V.2.B.

V.3. Lead - Zinc - Silver Association

For a period in 1980, it was arranged that all cores from the development drilling, which were split for lead assay, would also be checked for zinc and silver. These three-element analyses were also

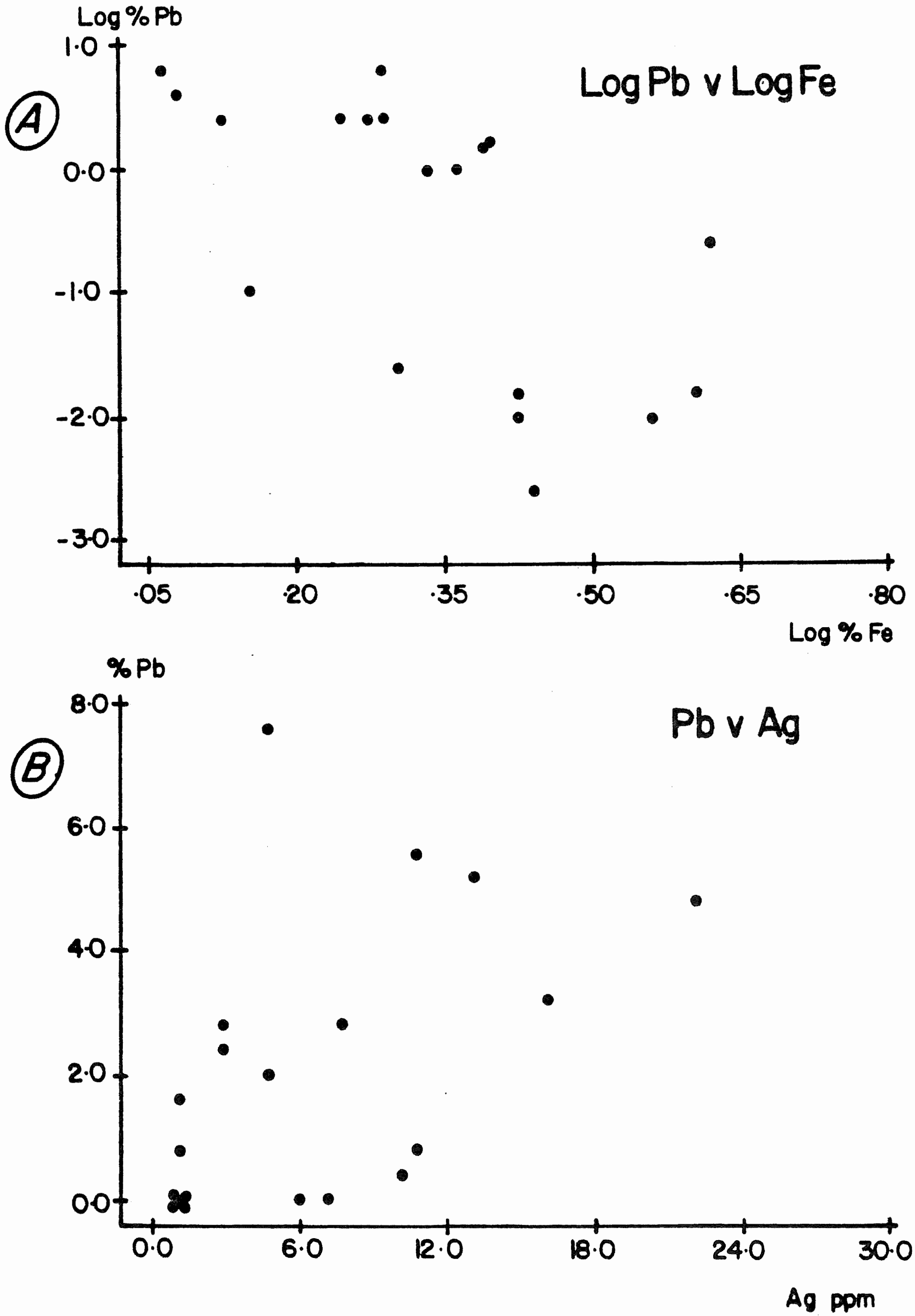


Figure V.1 A: Drill hole profiles Log Pb v Log Fe
B: Drill hole profiles Pb v Ag

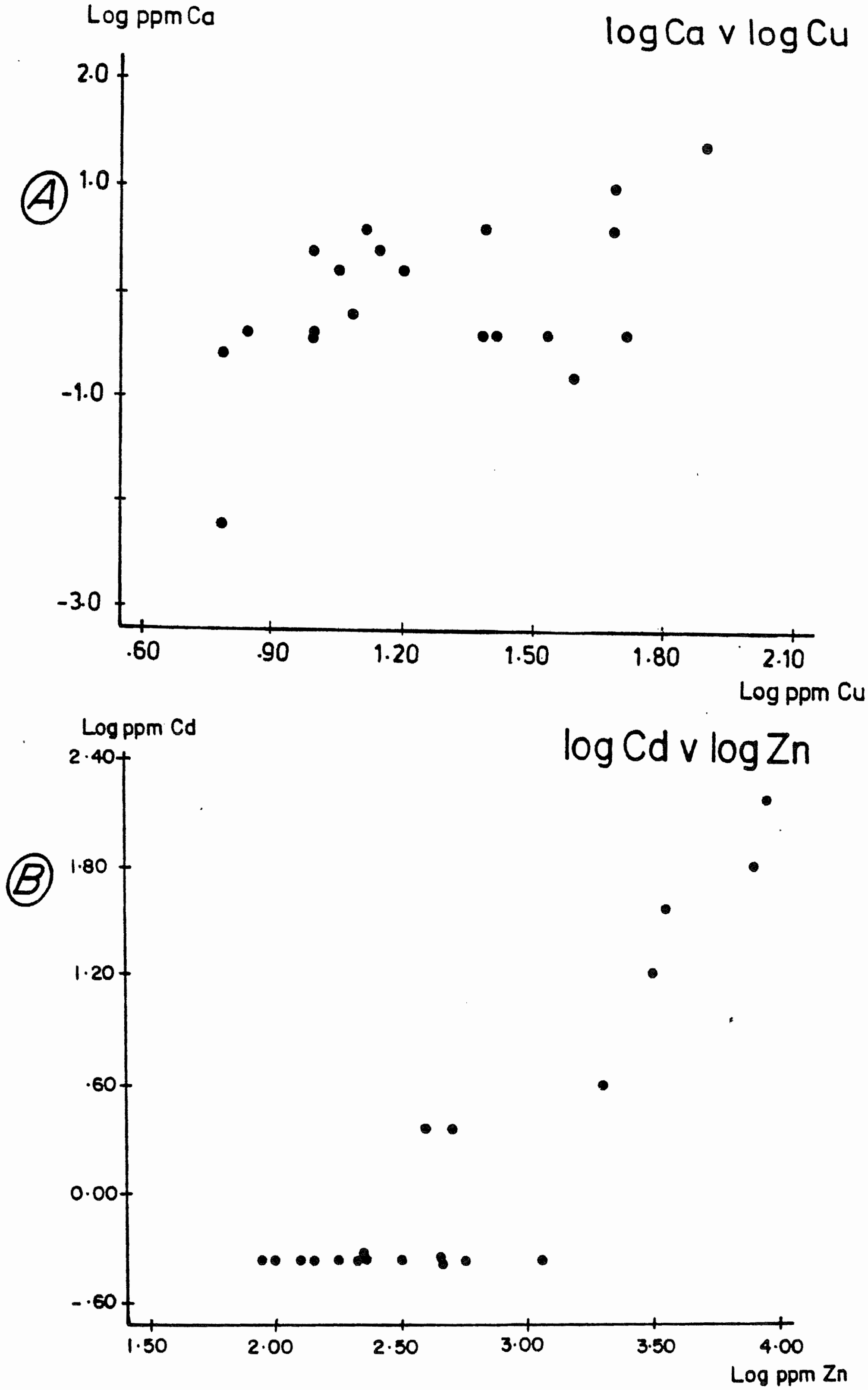


Figure V.2.: A: Drill hole profiles - Log Ca v Log Cu
B Drill hole profiles - Log Cd v Log Zn

used to examine further metal association at Yava and establish metal ratios. During the period, 86 three-element analyses were returned. The samples range in lead content from 400 ppm to 10.75%, and they represent samples from within, above and below the ore horizon; they are from both ore and waste holes. The results of the analysis are presented in Table V.10. Lead is ordered in increasing value in column 1, with corresponding zinc, and silver values shown in columns 2 and 3; columns 4, 5 and 6 give the relative ratios for each element pair.

Most of these samples are mineralised (> 1% Pb), therefore the regional background is not well represented. Nevertheless it is a large and significant population from which some patterns can be discerned. For this large population of 86 paired values, values for r = ±.25 can be taken as significant, and r = ±.35 as highly significant (Brooks, 1972).

Correlation co-efficients of straight concentrations, and log concentrations for each pair, are shown in Table V-11 A. Most striking, for straight concentration, is the good positive correlation between lead and silver (.656). Zinc shows poorer correlation with either lead or silver. Plots of lead against silver and lead against zinc are included in Figure V.3, A and B.

The log concentration correlation shows a quite different picture. In this case, all three elements are indicated to show association. The rise from .365 to .682 for Zn:Ag is most noteworthy. For this exercise, however the correlation of straight values is considered to

TABLE V.10. Assay Values and Relative Ratios for Lead, Zinc and Silver, Typical Yava Drill Core.

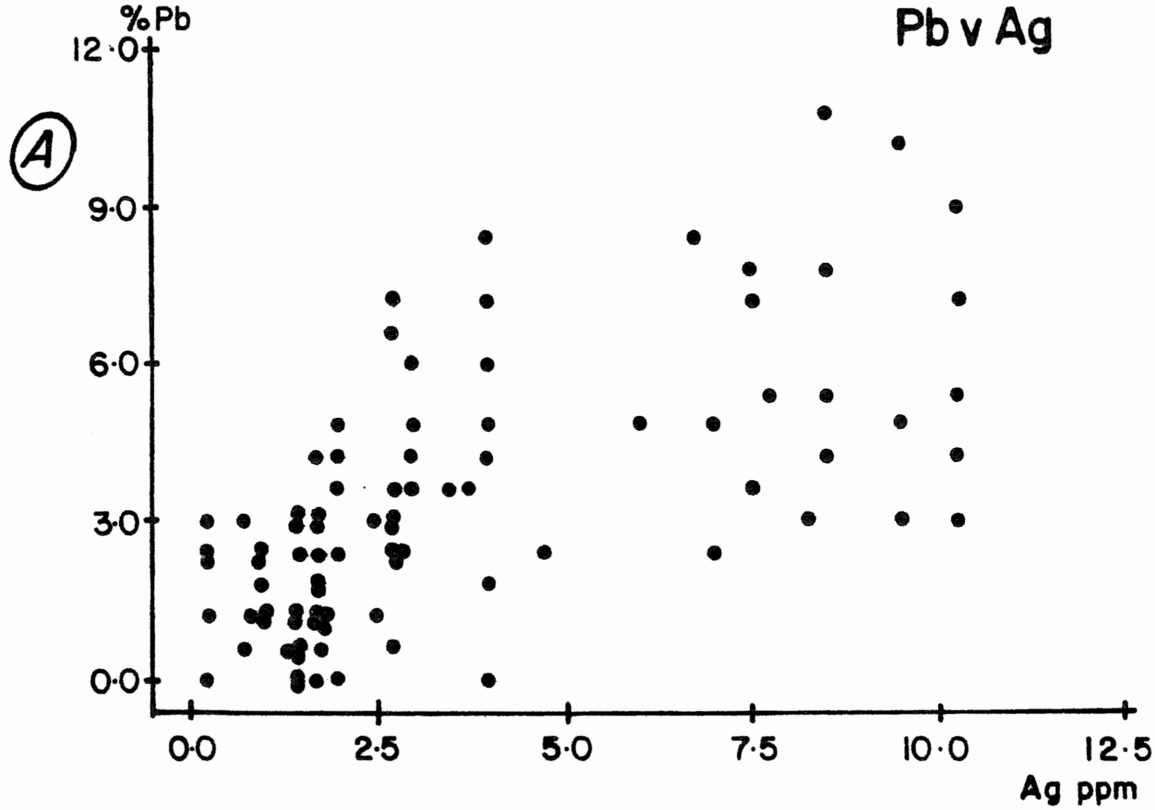
Pb%	Zn%	Agppm	Pb/(Pb+Zn)	Pb/(Pb+Agx1000)	(Zn/(Zn+Agx1000)
.04	.01	1.7	.80	.19	.05
.11	.01	.3	.92	.78	.25
.15	.01	1.4	.94	.52	.07
.22	.03	1.4	.88	.61	.18
.25	.70	2.0	.26	.56	.78
.26	.12	4.1	.68	.39	.22
.38	.03	1.4	.92	.73	.18
.43	.04	1.4	.91	.75	.22
.46	.01	.7	.98	.87	.12
.55	.03	2.7	.95	.67	.10
.58	.03	1.7	.95	.77	.15
.65	.02	1.4	.97	.82	.12
.96	.02	1.0	.98	.90	.17
.97	.01	.3	.99	.97	.25
1.01	.02	1.7	.98	.85	.10
1.04	.01	1.4	.99	.88	.07
1.10	.04	1.4	.96	.89	.22
1.22	.015	2.4	.99	.83	.06
1.25	.03	1.7	.98	.88	.15
1.25	.03	1.7	.98	.88	.15
1.35	.01	1.0	.99	.93	.09
1.42	.01	1.7	.99	.89	.05
1.45	.02	1.0	.99	.93	.17
1.70	.02	1.7	.99	.91	.10
1.76	.04	1.7	.98	.91	.19
1.85	.01	1.0	.99	.95	.09
2.00	.06	4.1	.97	.83	.13
2.10	.01	.3	.99	.98	.25
2.10	.02	1.0	.99	.95	.17
2.10	.01	1.4	.99	.94	.07
2.20	.02	2.7	.99	.89	.07
2.25	.04	1.0	.98	.96	.28
2.28	.03	.3	.99	.99	.50
2.30	.03	2.7	.99	.89	.10
2.30	.07	2.7	.97	.89	.20
2.55	.03	2.0	.99	.93	.13
2.55	.08	1.7	.97	.94	.32
2.55	.40	4.8	.51	.84	.83
2.60	.07	7.1	.97	.78	.09
2.75	.06	2.7	.98	.91	.18

TABLE V.10 (continued)

Pb%	Zn%	Agppm	Pb/(Pb+Zn)	Pb/(Pb+Agx1000)	Zn/(Zn+Agx1000)
2.76	.015	2.4	.99	.92	.06
2.85	.06	1.7	.98	.94	.26
2.85	.03	.7	.99	.98	.30
2.88	.01	.3	.99	.99	.25
2.90	.03	1.7	.99	.94	.15
3.00	.06	1.4	.98	.95	.30
3.03	.06	9.5	.98	.76	.06
3.15	.14	10.2	.96	.75	.12
3.15	.20	8.2	.94	.79	.19
3.22	.03	1.4	.99	.96	.18
3.25	.08	2.7	.97	.92	.23
3.30	.14	3.7	.96	.90	.27
3.45	.02	3.4	.99	.91	.05
3.50	.02	2.0	.99	.94	.09
3.55	.04	2.7	.99	.93	.13
3.65	.05	3.1	.99	.92	.14
3.85	.28	7.5	.93	.84	.27
3.96	.27	4.1	.94	.91	.40
4.15	.07	1.7	.98	.96	.29
4.25	.04	3.1	.99	.93	.11
4.30	2.90	8.5	.60	.83	.77
4.35	.12	10.2	.97	.81	.10
4.40	.01	2.0	.99	.96	.05
4.55	.12	7.1	.97	.86	.14
4.65	2.00	6.1	.70	.88	.77
4.70	.06	4.1	.99	.92	.12
4.76	.07	3.1	.98	.94	.18
4.80	.34	2.0	.93	.96	.63
5.02	.26	9.5	.95	.94	.21
5.45	.06	7.8	.99	.87	.07
5.50	.10	10.2	.98	.84	.09
5.67	.04	8.5	.99	.87	.04
6.00	.17	4.1	.97	.94	.29
6.15	.18	3.1	.97	.95	.37
6.35	.11	2.7	.98	.96	.29
6.93	.12	10.2	.98	.87	.10
7.20	.32	4.1	.96	.95	.44
7.30	.10	2.7	.99	.96	.27
7.30	.08	7.5	.99	.91	.10
7.50	.07	7.5	.99	.91	.08

TABLE V.10 (continued)

Pb%	Zn%	Agppm	Pb/(Pb+Zn)	Pb/(Pb+Agx1000)	Zn/(Zn+Agx1000)
7.60	1.10	8.5	.87	.90	.56
8.40	.10	4.1	.99	.95	.20
8.45	.80	6.8	.91	.92	.54
9.05	.24	10.2	.97	.90	.19
10.20	.85	9.5	.92	.91	.47
10.75	.90	8.5	.92	.93	.51



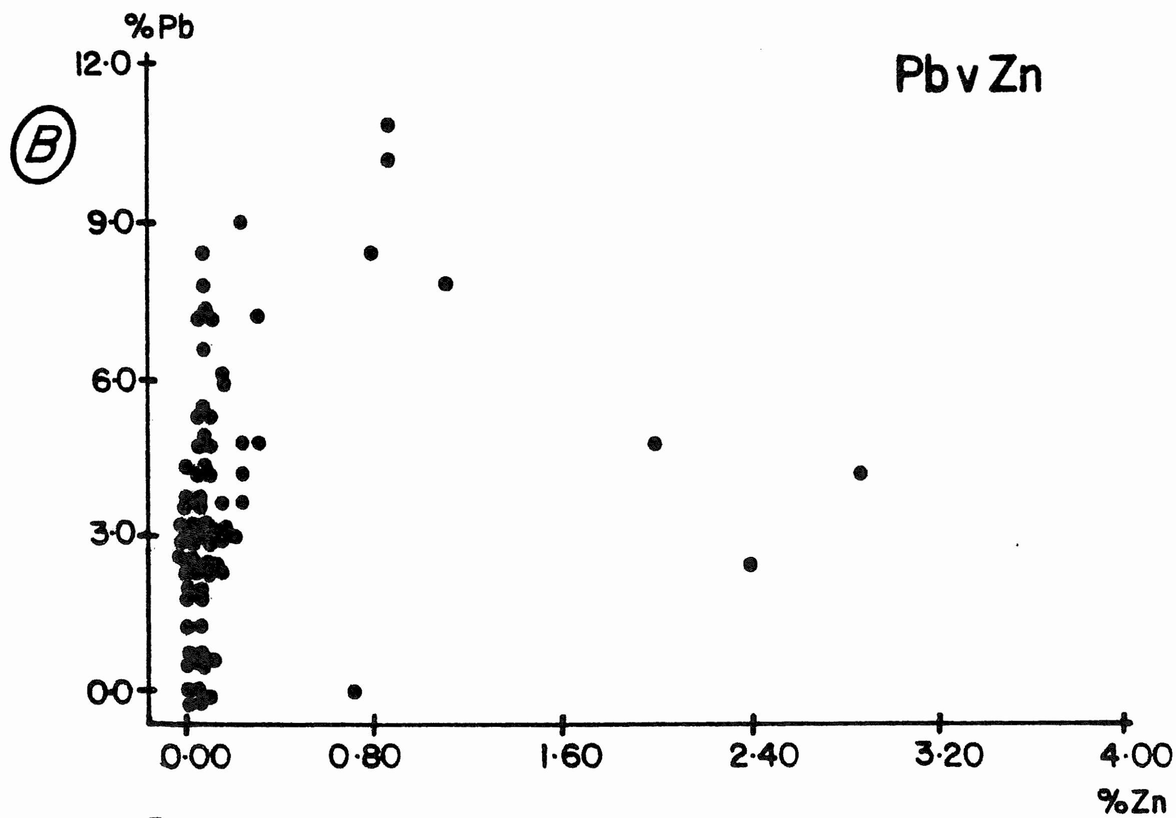


Figure V.3 A: Metal association study - Pb v Ag
B: Metal association study - Pb v Zn

be more reliable than that of log values; because while lead does show a log normal distribution, zinc is mostly close to background 76% (< 400 ppm) and silver is bimodal in distribution. With these varying patterns, using log values does not result in less skewed distribution. The effective rise in the co-efficient for Zn v Ag using log values compared to straight values, is shown graphically in Figure V.4 A and B. Log conversion simply raises the significance of background zinc and thus shows a sympathetic association between zinc and silver. The same is true of zinc and lead.

Metal ratios for typical Yava ore were established, and a check for zonation was conducted by looking at changes in ratios as lead content increases (intensity of galena mineralisation). Mean values of metal concentration, metal ratios and relative metal ratios for three categories of increasing lead content (0-1.0%, 1.0-3.5% and >3.5%) are presented in Table V.11 B.

Typical Yava samples over at 3.5% cut-off, therefore, contains 5.9% Pb, .36% Zn and 5.8 ppm Ag (0.18 oz/ton Ag), representing ratios of Pb:Zn of 16:1, Pb:(Ag X 1000) of 10:1, and (Ag X 1000):Zn of 1.6:1.

Pb/(Pb+Zn) ratios show a drop from ratios of greater than .95 in samples containing greater than 1.0% Pb, down to .86 in samples less than 1.0% Pb. Likewise Pb/(Pb+AgX1000) ratios drop from .90 to .68 over the same range for lead, while Zn/(Zn+AgX1000) ratios show little change. This would suggest that zinc and silver are relatively pre-dominant outside areas of lead mineralisaion, and that zinc and silver

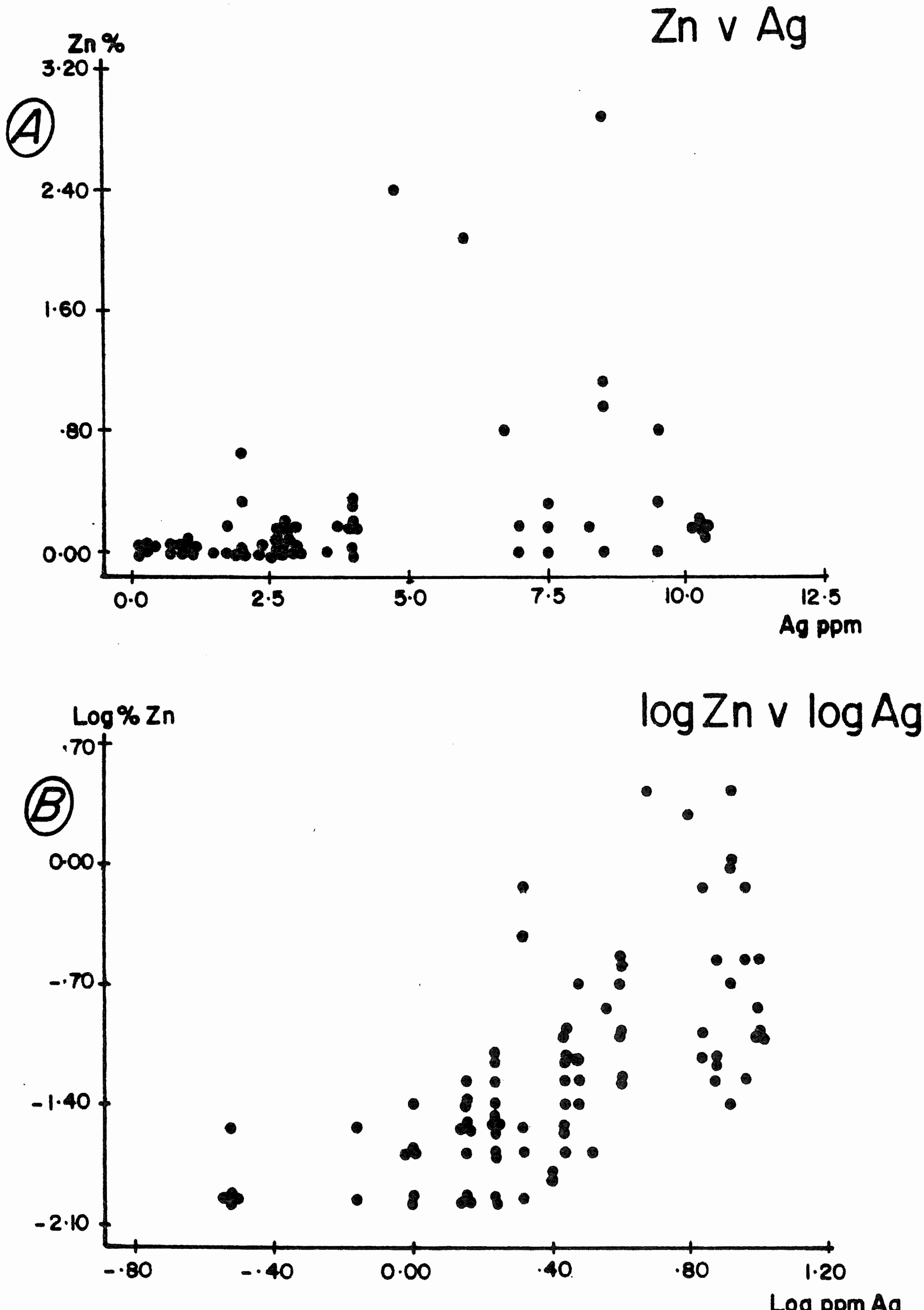


Figure V.4 A : Metal association study Zn v Ag
B : Metal association study Log Zn v Log Ag

	Pb%	Zn%
Zn%	.279	
Agppm	.656	.365
	LGPB	LGZN
LGZn	.495	
LGAg	.543	.682

TABLE V.11.A. Normal and Log Correlation Co-Efficients for Lead:Zinc:Silver, Typical Yava Core

	0-1.0% Pb	1.0-3.5% Pb	3.5% + Pb
Pb%	.42929	2.3080	5.8861
Zn%	.076429	.10200	.36333
Agppm	1.5357	2.5550	5.8424
Agx1000	.15357	.25550	.58424
Pb/Zn	.18(5.6:1)	.04(22:1)	.06(16:1)
Pb/(Agx1000)	.36(2.8:1)	.11(9:1)	.10(10:1)
(Agx1000)/Zn	.50(2:1)	.40(2.5:1)	.62(1.6:1)
Pb/(Pb+Zn)	.86719	.97071	.94863
Pb/(Pb+Agx1000)	.68170	.90405	.90893
Zn/(Zn+Agx1000)	.20487	.18254	.27443

TABLE V.11.B. Lead, Zinc and Silver Grades and Ratios, Typical Yava Core are somewhat independent of lead.

Bjorlykke and Sangster (1981) report for Yava that

> "analyses of samples selected from a 40 m drill hole through the West Zone have shown that the lower half contains a weighted mean zinc content of 670 ppm (mean Pb/Pb+Zn = 0.98) whereas the upper half averages 7,900 ppm zinc (mean Pb/Pb+Zn = 0.40)"
>
> (Bjorlykke and Sangster, 1981, p. 189)

and they go on to suggest that the upward increase in zinc relative to lead, reflects a metal zonation consistent with that in the L'Argentiere, Vassbo and Laisvall deposits.

The present author would disagree with this interpretation. Such lead-zinc zonation, which involves positive zinc enrichment above lead mineralisation, is not confirmed by either the drill profile study or this study. The present studies do confirm, however, that high background zinc (500 - 1000 ppm) is widespread and constant (zinc mineralisation greater than 1.0% is rare); while lead mineralisation is variable and more localised. In this way, zinc is of more relative importance when lead content is low. There is no evidence of zinc enrichment adjacent to lead enrichment from this study. It would appear that while the two elements do behave independently, zinc shows no evidence of more than isolated enrichment.

In summary, from this pilot study, the following observations can be made:

1. Basement porphyry underlying the ore is of alkali-granite

composition.

2. The same basement porphyry does not contain anomalous levels of Pb, Zn, Ba and Sr, compared to normal alkali granites.

3. Weathered porphyry from the Mine area shows an enrichment in Pb, Ba, Sr and Cu. Both Pb and Cu are enriched by an order of magnitude compared to unweathered basement.

4. Calcrete, representing a period of arid weathering prior to sandstone deposition, contains anomalous Pb, Zn, Cu, Mn, Ba and Sr. Most noteworthy is Pb at 570 ppm and Ba at 5.9%. Similarly, regolith is enriched in lead (at 640 ppm), and Ba (at 1.04%).

5. Lead content in sandstone and footwall rocks is localised; outside areas of mineralisation, lead remains at background concentration (100 ppm).

6. There is a suggestion of relative manganese enrichment down-dip of the main mineralisation.

7. Lead and iron show an antipathetic relationship, while lead and silver, calcium and magnesium and zinc and cadmium, all show sympathetic associations.

8. Straight correlations between lead, zinc and silver in a large population of assays show a positive correlation between lead and silver and little significant association between lead and zinc or zinc and silver.

9. Typical Yava ore ($>$3.5% Pb) contains 5.9% Pb, .36% Zn and 5.8 ppm Ag.

10. Metal ratios indicate that zinc and silver predominate over lead in unmineralised samples, in a relative sense.

CHAPTER VI

DISCUSSION

The main characteristics of the Yava mineralisation have been summarized at the end of Chapter VI. How does Yava compare with other deposits of its type? What controls can be proposed? And of these, which are local features peculiar to Yava, and which are fundamental features, perhaps with common application, that are particularly well-illustrated at Yava? Also, what is the nature of the ore entrapment mechanism at Yava? And does it conflict with mechanisms proposed for other deposits? These questions will be considered in this discussion section, leading up to a proposal of controls for the Yava mineralisation.

The chapter ends with a brief discussion of the possible timing and temperature of mineralisation and metallogenic models.

VI.1. Other Comparable Deposits

Yava clearly qualifies as a "lead in sandstone: or "grey-bed lead" type deposit. These deposits have been misfits in the literature; they have been included as red-bed type deposits by Samama (1968, 1976) and as "carbonate-hosted" deposits by Stanton (1972). Recently, Bjorlykke and Sangster (1981) proposed that they form a distinctive deposit type on their own. This is well-justified; however, it is felt that, as a distinct deposit type, the close similarities and analogous relationships with red-bed copper and planar-uranium deposits should not be forgotten. All three are intracratonic clastic aquifer-hosted accumulations, closely linked to the presence of organic matter and reducing conditions within the host rock.

"Lead in sandstone" type deposits are characteristically occurrences of galena in basal quartzitic sandstone, representing continental to shallow marine environments, deposited on sialic basement. They are generally low grade; galena is dominant, sphalerite and pyrite occur in association, and the silver content is normally low. The sulphides occur as a cement, infilling intergranular pore spaces, and appear as concordant and discordant bands, clouds and disseminations.

These deposits are not common in occurrence, and are a minor world source of base-metals; they do, however, form important resources in some countries. Of those described in the literature, five in particular provide the better examples, and will be cited in this discussion. They include, Laisvall and Vassbo in Sweden, L'Argentiere in France, and Bou-Sellam and Zeida in Morocco.

Laisvall is described by Grip, 1967, Rickard et al., 1979, and Willden, 1980a, 1980b. The deposit consists of galena and sphalerite (at a ratio of Pb:Zn 8:1) occurring as a cement, infilling pore spaces in an Eo-Cambrian quartz sandstone. The mineralisation is located in the lower and upper sandstone units of a sandstone interval composed of three units, underlain and overlain by shaley lithologies. The sequence dips to the west at 2°; within this dipping sequence, mineralisation occurs in the lower sandstone up-dip, and in the upper sandstone down-dip, thus forming a flat-lying discordant ore horizon. The deposit is sheet-like and elongated NE-SW (5 km x 2 km), and the maximum thickness of mineralisation is 24 m. The up-dip boundary to the south-east is abrupt; combined grade drops from 15% metal to less than 1%, over a lateral distance of less than 10 m. Down-dip to the west, grade decreases gradually. The sulphides occur predominantly as bands and disseminations, following internal sedimentary structures. A regional zonation of galena and sphalerite is documented, with sphalerite becoming dominant over galena down-dip in the upper sandstone. The deposit is located at the Caledonian front. Where the autochtonous host rocks are covered by two thick east-thrusted allochthonous nappe slices. Evidence indicates that the mineralisation pre-dated this tectonism. Minor thrusting is also present within the ore horizon; this also post-dates mineralisation.

Overall reserves at Laisvall are set at 80 million tons (72.5 million tonnes) of 4% combined lead-zinc; it is a major European lead deposit (Rickard et al. 1979).

Vassbo-Guttusjo, which is also close to the Caledonian front, is located 500 km south-west of Laisvall; it consists of similar mineralisation to Laisvall, in the same stratigraphic interval. This deposit is described by Christofferson et al., (1979). Here also, a sandstone interval is "sandwiched" by shales. The basal part of the sandstone is calcareous and unmineralised, while the upper part is noncalcareous and mineralised. A close correlation between mineral distribution and basement topography is evident for this deposit. The combined Vassbo-Guttusjo deposit contains 8.0 million tons (7.25 tonnes) of 4.8% lead (Christofferson et al. 1979).

L'Argentiere, which is located on the south-eastern border of the Hercynian Massif Central in France, is an occurrence of lead-zinc in basal arkosic sandstone of Triassic age. A high silver content in the ore of 80 g/T is peculiar to this deposit. Mineralisation is related preferentially to some five clastic horizons within a continental sequence. The Triassic sediments consist of a coarse-grained clastic facies, or pediment, which passes basinward into lacustrine sediments. The mineralisation is concentrated at the intermediate position between these two facies. There is a marked zonation in clastic cement composition within the sediment prism; argillaceous cement in the pediment, calcareous cement in the lagoonal sequence, and an intermediate area of silicate cement in-between. It is in this silica fringe that the sulphides are concentrated. The mineralisation occurs as disseminated sulphides cementing the arkoses, lens-type ore clusters and local joint mineralisation. L'Argentiere is described by Bernard and Samama (1976), Foglierini, et al., (1980), and Samama (1968, 1971, 1976). L'Argentiere is a major French lead and silver producer, with reserves of 10 million tonnes of 3.80% Pb, 0.75% Zn and 80 g/T Ag (Foglierini et al., 1980).

At Bou-Sellam in Morocco, described by Caia (1969, 1976), copper and lead mineralisation occurs in basal detrital sediments of the Cretaceous, at separate locations. The host rocks consist of conglomerates, sandstones and siltstones, deposited in a laguno-deltaic environment, at the margin of a sedimentary basin. In detail, the mineralisation surrounds the detrital grains, in white and grey conglomerates and sandstone, and is associated with carbonate cement. Sulphides are found as congruent bands following bedding and cross-bedding, or as non-congruent clouds and arrowheads.

The mineralisation at Zeida was originally decribed by Schmitt and Thiry (1977) in French; it has recently been summarised in English by Bjorlykke and Sangster (1981). Here, continental and marine arkosic sediments of Triassic age contain galena and lesser chalcopyrite. Three mineralised sandstone horizons have been recognised, separated by barren yellow sandstone and red argillite. Indicated reserves in the Zeida area are set at 16.2 million tons (1.47 million tonnes) at some 3.2% Pb (Bjorlykke and Sangster, 1981).

VI.2. General Regional Setting

Despite the very different host rock ages of lead in sandstone deposits from Cambrian (Laisvall) through to Cretaceous (Bou-Sellam), there are common regional features, many of which are recognisable at Yava (Carboniferous). Basement rocks underlying the host sandstones of these deposits are always of sialic composition and often granitic: Laisvall and Vassbo-Guttosjo (Pre-Cambrian crystalline basement), L'Argentiere (Hercynian granites and metamorphic rocks) and Yava (Pre-Cambrian-Cambrian acid intrusives).

Lead mineralisation is, in all cases, located in the lowermost sandstone of a basal intracratonic clastic sequence. (Qualified exceptions are Vassbo-Guttusjo and parts of Yava, where early carbonate cements inhibit mineralisation in the most basal sandstone - a matter of metres).

At Laisvall, Vassbo-Guttusjo, Bou-Sellam and Yava, the host sandstone is an arenite, while at L'Argentiere and Zeida it is arkosic in composition. With the exception of L'Argentiere, the host rock sandstone is invariably white or grey-green in colour (i.e. grey beds) indicating more reducing conditions; while it is not stated clearly, it is inferred that the host rocks at L'Argentiere are red-beds.

VI.3. Host Rock Geology

The geological unit hosting mineralisation at Yava, consists of a 240 m thick sequence of monotonous fluviatile sandstone, with conglomerate and sandstone interbeds, which lie in unconformable contact with Pre-Cambrian-Cambrian basement and Mississippian Windsor Group rocks. The top of the unit is marked by a transition into lacustrine mudstones (160 m thick). Lead mineralisation is confined to the basal 30 m (15%) of this 240 m sandstone sequence.

This situation is in contrast to all other deposits. Typically the sandstone host is a thin clastic interval, or intervals, bracketed by argillaceous sediments (e.g. Laisvall, L'Argentiere, Vassbo and Bou-Sellam). And the thickness of the sandstone is, in those deposits, in the same range as ore thickness (less than 25 m). Mineralisation may occur throughout the sandstone, or at certain levels within it. Therefore, in comparison to other deposits, there is no evidence of any cap rock at Yava to provide a constraint to mineralisation in the upward direction; it is the only deposit without a geological hanging wall.

The environment of sandstone deposition is not unique for these deposits. A palaeoenvironmental study of Laisvall by Willden, 1980, indicates that the ore sandstones were deposited under intertidal nearshore marine conditions; similar conditions are inferred for Vassbo-Guttusjo (Bjorlyyke and Sangster, 1981). Bou-Sellam and Zeida are located in laguno-deltaic sediments (Caia, 1976, Bjorlykke and Sangster, 1981); while L'Argentiere (Samama, 1976) and Yava occur in fluvial sediments. Common to all these depositional regimes is the abundance of well-sorted, medium-to-fine-grained sandstones with clast-supported conglomerates, and limited mudstone interbeds.

The association between this type of mineralisation and carbonaceous components within the host rock, is considerable, particularly in the younger deposits. All the North African deposits and L'Argentiere contain terrestrial organic material, in the form of plant remains in the host rocks (Bjorlykke and Sangster 1981), as does Yava.

At Laisvall, which is in Cambrian sediments, the only evidence for organic association, is the presence of alkanes and bitumen (100 ppm, in sphalerite-rich ore); while lead-rich samples contain only 1 ppm organic matter (Rickard et al., 1979). These organic components are attributed to the ore-forming process, proposed by Rickard et al. for Laisvall, which involves the introduction of fluids of oil field brine composition. The "sister" deposits (red-bed coppers) invariably show a close association between mineralisation and organic carbonaceous matter in the host rock (Gustafson and Williams, 1981). The same is also true of tabular uranium deposits (Nash et al. 1981).

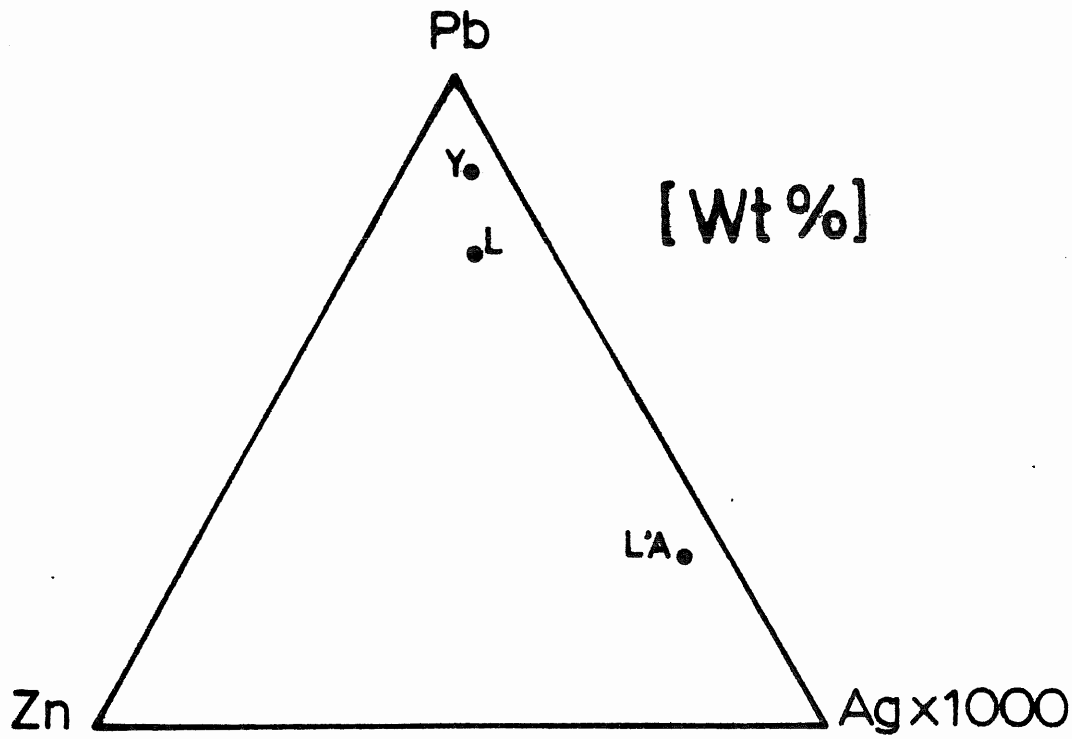
A common feature of all lead sandstone deposits is the reduced condition of the host sandstone, giving a grey-green or white colouration to the rock. This is in contrast to red-bed coppers, where the sandstones are oxidised and red in colour. In order to maintain necessary reducing conditions in high energy terrestrial environments of this type, the water table must have been continuously above the sediment water interface, and decaying organic matter in the sediment must have been abundant. In the extensive exposure underground at Yava, no evidence was encountered to indicate sub-aerial exposure, such as desiccation features or local oxidation.

An important feature at Yava is that the entire sandstone section, from the Windsor disconformity up to the overlying conglomerate (850 m of section), is predominantly grey-green in colour. This would suggest that reducing conditions prevailed through much of this section. Also, reference to drill logs describing intersections through the basal 240 m (at least) of the same section, continue to record the presence of coal lag horizons. Therefore, the combination of reducing conditions and high organic content in the sandstone, is not peculiar to the horizon of mineralisation. Mineralisation occurs in the basal 30 m of a thick sandstone section, which shows no change in present redox state or organic content, either up section or laterally.

VI.4. Sulphide Mineralisation

Lead sandstone deposits are typically low-grade (less than 5% combined Pb+Zn) and Yava is no exception. Their sizes (tonnage) vary considerably, and depend greatly on the cut-off grade, because so much mineralisation is low-grade. A summary of tonnages, metal grades and metal ratios in these typical deposits is presented in Table 1 of Bjorlykke and Sangster, 1981, p.184. It shows that lead is clearly dominant over zinc by an order of magnitude, and Pb/(Pb+Zn) ratios are seldom less than .95. Also, silver content is generally low, averaging 9 and 5 g/T in typical ore from Laisvall and Yava, respectively. The one exception is L'Argentiere, where typical ore contains 80 g/T Ag (Foglierini et al. 1980). A triplot of Pb v. Zn v. Ag x 10000 (in weight percent) for typical ores from Laisvall, Vassbo, L'Argentiere and Yava are presented in Figure VI.1.

Other sulphides in the Yava assemblage are pyrite and chalcopyrite. Pyrite is recorded at both Vassbo and Laisvall, but it is in minor abundance; in typical Laisvall ore, containing 4.7 wt.% galena,



Triplot to show typical Pb-Zn-Ag ratios for Yava and other related deposits.

Y : Yava (Bonham, 1982)
L : Laisvall (Rickard et al., 1979)
L'A: L'Argentiere (Foglierini et al., 1980)

Figure VI.1.

0.2% pyrite is present (Rickard et al. 1979). Chalcopyrite is not present at Laisvall, but does occur at Vassbo as weak impregnations (Christofferson et al. 1979). Pyrite and chalcopyrite are also present at L'Argentiere as associated sulphides (Foglierini et al. 1980). At Bou-Sellam, sphalerite appears to be absent; while galena-cerussite occurs in an ore association confined to palaeochannelways, and chalcopyrite-malachite forms in a separate association confined to interchannel sands.

Without exception, sulphide mineralisation in these deposits is described as a cement phase, infilling intergranular spaces in the clastic host rock. At Yava, the evidence suggests that interstitial galena post-dates quartz overgrowth on detrital sand grains. At Laisvall, Rickard et al. (1979) indicate that galena is situated between sand grains and the silica cement, (except in richer ore areas where galena occupies the entire pore space) suggesting that galena pre-dates silicification. Associations between certain sulphides and different sandstone cements have been noted by various authors. While no common relationships are indicated, some patterns are of importance. At L'Argentiere, zinc dominates over lead mineralisation in areas of sulphate-carbonate cement, with lead being dominant in silicate-cemented sandstones (documented by Samama, 1976, summarised by Bjorlykke and Sangster, 1981). Also, in a broad regional sense, at L'Argentiere, the sulphide mineralisation corresponds spatially with a fringe of silicate cement in the clastic wedge; this fringe separates sediments with argillaceous cement landwards, and carbonate cement basinwards (Samama, 1976).

As Bou-Sellam, the galena-chalcopyrite mineralisations occur in sandstones and conglomerates with carbonate cement (Caia 1976); while at Vassbo-Guttusjo, mineralisation is absent in basal carbonate-cemented sandstones, being confined to the upper quartz-cemented sandstones. Some galena is present at the top of the calcareous sandstone directly underneath intensive mineralisation (Christofferson et al. 1979). At Yava, the pattern is that pyrite and sphalerite are present in the limited calcareous sections in the sandstone, while galena is always absent. And in the non-calcareous areas, pyrite is localised in distribution, while galena and lesser sphalerite are widespread. In this respect, the unexplained, sympathetic relationship between copper and calcium (indicated in the trace element populations for Yava) may be relevant. There may be an association between weak copper concentration and calcareous cement. Two other features of other deposits worth noting at this point are: firstly, the presence of limestone pebble conglomerates in the host sequence at Bou-Sellam (a rare clastic lithology, also present at Yava); and secondly, the concentration of mineralisation at Vassbo-Guttusjo, just above the interface between calcareous-cemented sandstone and quartz sandstone. The presence of a calcareous subsurface (in the form of calcrete or calcareous sandstone) at Yava may be a comparable phenomenon important to sulphide fixation. An examination of drill core for the East Zone at Yava (where much of the ore horizon occurs within the sandstone, removed from the Windsor contact) revealed that, in these areas, sub-ore sandstone is frequently calcareous.

Thin-section textures in the Yava sandstone indicate that the carbonate cement, with associated sulphides, is an early diagenetic event, predating quartz overgrowth (a feature also noted by Scott, 1980) while the main galena mineralisation is evidently a later event, post-dating quartz overgrowth. Amade (1965), quoted by Bjorlykke and Sangster (1981), recounts that the sandstone at the Zeida deposit in Morocco, contains primary carbonate, barite and fluorite cement, followed by a secondary phase of silicification, argillation and ferrugination. For Yava, the present author suggests that when mineralisation was introduced into the sandstone section, access into the calcareous areas was prevented for physical or chemical reasons, by the sealing effect of this early diagenetic cement.

In considering a paragenetic sequence for Yava, it was noted that pyrite formed as an early phase in co-genetic association with sphalerite, while a more massive sphalerite was also present as remnant inclusions in interstitial galena crystals of the late sulphide mineralisation phase; this later episode apparently precipitated sphalerite first, and galena (as a major event) second. A similar paragenesis is suggested for Laisvall (Rickard et al. 1979) to quote:

> "Both galena and sphalerite apparently replace each other, although there is evidence that sphalerite is generally older. For example, it is not uncommon to find a pore space filled with islands of sphalerite surrounded by galena, indicating galena replacement of earlier sphalerite mineralisation. Pyrite, often bravoitic is universally very early ...."
>
> (Rickard et al., 1979, p. 1265-1266)

The mineral styles described for Yava show a range from perfect concordance, to sedimentary structure in the host rock, to complete discordance,(when sulphide bands are discontinuous and can run normal to the sedimentary textures). A similar range of textures (with the exception of cusps, clouds and arrowhead features) have been observed at Laisvall by the author, and are described by Rickard et al. (1979). Peculiar to Laisvall is the abrupt up-dip ore margin, where mineralisation drops from 15% combined metal, over a 10 m thickness, to less than 1% over a similar lateral distance. "Clouds" and "arrowheads" are described by Caia (1976) at the Bou-Sellam deposit. The "clouds" are similar in dimension and character to those at Yava; while the "arrowheads" are well developed at Bou-Sellam, and are reported to occur in parallel sets, pointing upwards towards the top of the bed at an angle of -45°; they are 15-20 cm long and 1.5-5 cm wide. The cusps, repeating cusps, and discordant, stratiform, banding styles, described in Chapter IV, are peculiar to Yava.

Concordant sulphide mineralisation is not unique to lead-in-sandstone deposits. Excellent examples are described from the Zambian Copper Belt (red bed copper deposits, Garlick 1967) where bands of chalcopyrite, bornite and pyrite reflect perfectly the sedimentary textures of the clastic host.

The question of concordance of mineralisation and ore syngenesis, versus discordance of mineralisation and epigenesis of ore, is a much discussed topic (Amstutz, 1967, Bernard, 1971; Samama, 1976; Ncube and

Amstutz (1981), and Rickard et al. (1981). While it is not within the scope of this thesis to solve all the metallogenetic problems of the Yava deposit, a discussion of genetic models and some speculations concerning ore genesis are presented in the concluding remarks; some observations regarding the ore textures are relevant at this point.

The hypothesis that the sulphides of these deposits are detrital in origin, being deposited mechanically as heavy mineral bands within the clastic sequence, must perhaps be considered. There is little evidence to suggest this: firstly, the ore textures indicate that the sulphides are not detrital, but occur as interstitial cement precipitated from solution; secondly, the likelihood of placer sulphides, particularly galena, surviving sub-aerial weathering and high energy transportation, is slight. To quote Samama (1976) discussing this point:

> "On the contrary red-bed ore deposits are characterized by the low chemical and/or mechanical resistance of the economic minerals (sulphides, oxides, carbonates) under conditions prevailing during the period of ore concentration; the economic minerals in this case result from processes of deposition and concentration which involve chemical reactions of precipitation."
>
> (Samama, 1976, p. 1)

This mineralisation is therefore not detrital or placer in origin. It is also unjustified to consider it to be syngenetic: (i.e. "Minerals deposited or formed simultaneously with the enclosing sediment"; Tourtelot and Vine 1976). Field observations strongly suggest that the mineralisation is a post sedimentation, diagenetic event.

Congruence (concordance) of mineralisation at Laisvall is attributed to the local sedimentary control of differential permeability and porosity (Rickard et al. 1979). To quote their explanation:

> "Maximum permeability occurs parallel to parting lineations such as bedding planes, whether they are horizontal or dipping as in crossbedding. In fact, the horizontal component of permeability in crossbedding is considerably reduced. Likewise slumping structures, load casts and convolute bedding also reduce the horizontal component of permeability. Mineralizing solutions tend to follow the fabric discordancies in the sandstone caused by these structures, and the ore minerals are precipitated along those zones of the structure to which there is access and where pore space is available".
>
> (Rickard et al., 1979, p. 1281)

The congruent macroscopic styles and the pore-filling nature of the mineralisation at Yava can only be explained by the same mechanism.

Non-congruent, discordant mineral styles, such as discordant stratiform banding,clouds, cusps and arrowheads, are either a creation of the actual mineralising process in itself, or they result from preferential mineralisation along pre-existing physico-chemical discontinuities resulting from early diagenetic changes. To consider the former explanation, sulphide bands have been created under experimental conditions by passing reactant fluids through sandy sediment. Bubela (1981) describes the generation of sulphide bands in homogeneous glass sand, along the line of diffusion between a flowing sulphide fluid and a flowing metal fluid. The banding develops parallel to the flow direction and normal to the direction of diffusion. Rickard et al.

(1981) demonstrate by similar experimentation, that galena can precipitate in interbedded clays and sands, as concordant and irregular discordant features, as a function of the internal sedimentary geometry and the flow dynamics. For the latter explanation, the analogous tabular uranium deposits of the San Juan basin, New Mexico, are considered. Here, during the diagenetic decomposition of plant matter humates are believed to have been released into the clastic sediment. These components encircle plant remains, settle out as bands, (oblique or parallel to bedding), or migrate through the sediment to accumulate in eddies or irregular streaks and patches. These organic-rich reducing locations attract uranium, vanadium and other metals, and become the sites of mineralisation (Saucier, 1982, pers. comm.). It can be speculated that early diagenetic remobilisation of humates, within the Yava sequence might have created some of the features, later to become preferential sites of galena precipitation.

VI.5. Mineral Distribution

Gross spatial features and detailed stratigraphic relationships at Yava, indicate the lead mineralisation occurs as a single stratiform horizon, passing through the basal beds of the clastic sequence, regardless of stratigraphic configuration, to follow either the Windsor unconformity, or more locally, an interface within the clastic sequence, marking the top of calcareous cementation.

At Laisvall, mineralisation overall occurs as a single stratiform distribution corresponds with greater sandstone thickness and the location of basement palaeo-depressions. In addition, a three dimensional view of Laisvall presented in Rickard et al. (1981), shows that, while Upper Sandstone ore is uniform in thickness, the Lower Sandstone ore is thickest in the centre, thinning towards the margin, akin to the Yava orebodies.

The lead distribution patterns illustrated for the West Zone at Yava show a systematic metal enrichment from less than 2% Pb in the outer areas, through to 4-6% and then 8% in two central patches (Figures IV.C.4 and 6). This suggests that the mineralisation has a distinct spatial focus. The study also indicates that trends in grade distribution in the West Zone, are not influenced by the distribution of intervening mudstone units. The influence of mudstone interbeds on grade distribution trends for other deposits is not clear. Some influence is suggested at L'Argentiere, where mineralisation in the arkosic units does tend to increase and concentrate under argillaceous interbeds, forming a local roof to mineralisation (Foglierini et al. 1980). Mudstone influence at Laisvall is present on a small scale. The Lower Sandstone there contains abundant thin shale interbeds; galena is concentrated at the contacts between these shales and the surrounding sandstones (Rickard et al. 1979). This is probably comparable to the galena banding observed at Yava, following mudstone contacts as a halo feature. The common indirect relationships between lead mineralisation in sandstone, and nearby carbonate cement, has been considered in the discussion on host-rock geology. To reiterate briefly, the drill-hole study indicates that much of the West Zone mineralisation occurs over areas where calcrete is exposed on the surface of the Windsor unconformity; while in the East Zone (where mineralisation is above the unconformity within the sandstone) the sub-ore sandstone is calcareous. A similar calcareous substrate to ore is present at Vassbo-Guttusjo; carbonate-sulphate cements are associated with the ore at L'Argentiere; and the arenites hosting the mineralisation at Bou-Sellam are carbonate-cemented.

The evidence presented for the Yava West Zone indicates that palaeotopography has an influence on the distribution of ore at two levels. Firstly: the three ore zones are spatially located over palaeodepressions in the basement topography; they are separated by basement highs, against which the underlying Windsor pinches out. Secondly: within the West Zone, there is a close relationship between both ore thickness and ore grade distribution, and the detailed surface configuration of the Windsor unconformity. This relationship is most marked on a palaeosurface derived after a 15.5° tectonic correction.

Palaeotopographic controls to mineralisation have been implied for many of the other deposits of this type; however, if scale is taken into account, many of these observations apply only to local concentrations of ore in intraformational channels, 10's of metres in extent (e.g. L'Argentiere, Samama, 1976).

To consider palaeotopographic controls at the deposit level: the Vassbo-Guttusjo deposits are both located over palaeo-depressions in the basement landscape. Preferential weathering of diabase dykes up to 500 m wide, cutting the basement rocks, has resulted in the development of long (6 km), linear and sinuous depressions. Later, during shallow marine sedimentation, somewhat thicker accumulations of quartz sandstone occurred over the depression. A relative increase in sandstone thickness (by up to 4 m) was measured from drill holes for the area of the depression at Guttusjo. The Guttusjo orebody (2.25 million tonnes of 3.5% Pb) is 2,750 m long, 2.5 to 5.0 m thick and 50 to 250 m wide. With this spatial dimension and thickness, the orebody is accommodated by the excess sandstone accumulation infilling the underlying depression. Both Vassbo and Guttusjo are spatially related to underlying diabase, a related palaeodepression and thicker sandstone. Christofferson et al. (1979), in describing these deposits, and in proposing an epigenetic model for mineralisation, conclude that:

> "differential thickness in the sandstone caused differences in fluid pressure in the fluid across the bed. Solutions were thus directed towards these low pressure areas and flowed preferentially along the thickened parts of the quartz sandstones above the basement depressions. The scarcity of mineralisation in equally permeable and porous, but thinner sandstone above basement highs is caused by reduction in solution flow in these areas."
>
> (Christofferson et al., 1979, p. 1248)

At Laisvall, at the up-dip extremity of the orebody, where the ore lies against the geological footwall, grade distribution is influenced by basement topography. The Central ore member is located in a re-entrant in the basement, with the ore pinching out at the head of this feature, to the north-east. A separate lobe of ore, to this ore member, occurs further north in another re-entrant, separated by an intervening high. As a whole, the Laisvall orebody is limited to the east by a regional basement ridge, elongated north-south. Also, an additional smaller basement knoll, located to the north, is considered to form a constraint to ore distribution in that direction (Willden, 1980b).

At Zeida, in Morocco, Schmitt and Thiry (1977) indicate positive correlation between grade of mineralisation and sandstone thickness and a similar correlation between grade distribution and basement palaeo-relief. Mineralisation is concentrated in palaeovalleys and at the confluence points between major palaeovalleys and tributary features (Bjorlykke and Sangster 1981).

Bou-Sellam and L'Argentiere do not exhibit any relationship between mineralisation and palaeorelief, at the scale of the deposit. Local influences are, however, documented. At Bou-Sellam lead (galena-cerrussite) can be seen to concentrate in local palaeochannels, 100-150 m wide and 20 m deep; while associated copper mineralisation (chalcopyrite-malachite) is confined to the interchannel highs (Caia, 1976). Similarly, at L'Argentiere better grade mineralisatison tends to occur in palaeochannelways. From illustrations in Foglierini et al. 1980, it is estimated, however, that these features are only 5-15 m wide, smaller in scale than those at Bou-Sellam. These would compare to palaeochannel features at Yava, containing abundant coal lag (and subsequently well-mineralised).

The spatial correlation between the focal points of mineralisation and palaeodepressions in the footwall for the West Zone at Yava, is striking. Palaeotopographic influence is evident for some of the other deposits; it varies from an overall influence as at Vassbo-Guttusjo, to a limited influence as at Laisvall. At Laisvall it is evident that that portion of the orebody influenced by palaeorelief is the up-dip portion, where the ore occurs against the geological footwall (viz. palaeorelief), while down-dip, the ore horizon becomes removed from the footwall, and is therefore no longer under footwall influence.

This suggests that at Laisvall either: the ore horizon formed as an inclined front, passing through horizontal beds (since tilted to the NW at 3°); or: mineralisation post-dates the tilt, to occur, as it is today, as an horizontal horizon, constrained by the footwall palaeo-relief along its up-dip portion, and by hanging wall shale down-dip.

The study presented in Chapter IV.C.6 on unit grades, indicates that the level of mineralisation achieved is dependent on lithotype and vertical position in the rock profile. Information of this detail is not available for any other deposit; hence no direct comparisons can be made. Some points do, however, require discussion.

The contrast between the grade of footwall samples and those of the overlying ore, emphasise the abrupt increase in mineralisation above the level of the unconformity. The average grade of 3.62% for the basal conglomerate, along with the considerable monthly range (1.74% - 9.05%) emphasises the local inhibiting effect of calcareous cementation on lead mineralisation at Yava. The grade of shale is always low (1% Pb); while conglomerate grades are comparible or higher than adjacent sandstone. This relative increase for conglomerates is attributed to the influence of detrital coaly matter (common in these units) which acts as a focus for sulphide precipitation. Furthermore, hand specimen and thin section examination of conglomerates, indicate that mineralisation is confined to areas of matrix cement, and is absent from clastic fragments. As these are clast-supported lithologies, the original conglomerate porosity might be 40%, with all clasts equidimensional (Beckmann, 1976), and is probably closer to 30% where clast size varies. Therefore, as compared to adjacent sandstone, conglomerates comprise only 30% sandy substrate to contain mineralisation (1/3 that of sandstone), and would be expected to contain 1/3 of the grade. Coaly matter is therefore implied to enhance mineralisation by 2-3 times, compared to adjacent sandstone. It is felt that other factors (such as internal geometry, and higher porosity and permeability in this loose, sandy matrix) may also contribute to this relative increase in grade.

Despite the importance of conglomerates as sites for mineralisation, the study emphasises the local distribution, and limited volumetric importance, of this lithotype. Correspondingly, the volumetric importance of sandstone (as the predominant host to mineralisation) is outlined.

The other aspect of the mineralisation which is clarified, is the existence of a clear grade profile within the ore horizon; there is a distinct drop in grade, from the lower units (which are well mineralised) up section, into lower grade and then weak mineralisation.

VI.6. Mineralisation Controls

The following empirical features are proposed as controls to the localisation and distribution of sulphide mineralisation at the Yava deposit.

Pre-requisites: from comparisons between Yava and other deposits of its type, certain features are proposed as prerequisites for mineralisation at Yava.

1. Host Rock

Well-sorted continental clastic sediments, containing abundant clean sandstone, preferably of arenaceous composition, deposited just above an unconformable contact with weathered basement rock are required. The clastic sediments are typically grey-green or white in colour, and in a reduced chemical state. The presence of organic detritus in the clastic sequence is also an important feature.

2. Basement

Underlying basement rocks of granitic composition, particularly alkali granite containing abundant K-feldspar (considered to be a source rock for lead - Samama, 1976, Bjorlykke and Sangster, 1981).

3. Unconformity

A marked unconformity at the base of the mineralised sequence with evidence of emergence, during which time weathering, and perhaps pedogenic enrichment, has taken place.

Local Controls: Spatially, there are three margins to the Yava ore accumulation: the footwall, the hanging wall and the flanking margins.

4. Footwall

The footwall to ore is considered to be the interface between an impervious floor and overlying porous host rock. Over much of the deposit, this is marked by the Windsor unconformity. But in places, early diagenetic welding, by carbonate cement, has sealed the lowermost beds, raising the impervious floor above the unconformity into the sandstone sequence.

5. Hanging wall

There is no geological hanging wall to the Yava mineralisation. The economic ore back, at 3.5%, is marked by an arbitrary line in the grade profile, above which insufficient mineralisation is present to make grade. Likewise, mineralisation, per se, drops off at a higher level in the profile.

6. Ore Margin

With the indication that the flanking margins to the mineralisation represent a lateral decrease in grade and ore thickness in a host rock of the same physical character throughout, it is implied that the margins mark the convergence of the impervious footwall interface with the assay back surface. In other words, when the footwall rises to approach the surface of the back, grade and thickness decrease to the point of overlap where mineralisation ceases. This represents the influence of footwall relief on grade distribution, seen on a broad scale for the three zones, each located in basement palaeodepressions. At a local scale, within the West Zone, ore is also concentrated in minor depressions in the surface of the Windsor unconformity.

Internal controls: Within the mineralised horizon, grade distribution is controlled by lithology and diagenesis - a reflection of compositional variation and porosity.

7. Lithology

Sandstones are abundant and contain widespread mineralisation throughout, as interstitial pore filling cement. In shale flake and limestone pebble conglomerate, mineralisation is confined to the sandy matrix, while mudstones are either poorly mineralised or unmineralised. Grade in these sediments is generally less than 10% Pb, (11.5% galena); the exception is where coal is present as a clastic component. Here, galena and additional sulphide concentrate to achieve grades of up to 20% Pb (23% galena). Most important, conglomerates, coal lag and mudstones are of limited volumetric significance within the ore horizon.

8. Diagenesis

Superimposed on this lithological control is the influence on grade distribution of diagenetic changes within the sequence. Lead grades less than 3.5% Pb (4% galena) in basal sandstone in the West Zone are rare. Where it does occur, the lack of mineralisation, is related to the presence of early diagenetic calcareous cement, welding the clastic grains. This occurs as concretions and hard bands, which are of limited abundance within the ore zone.

Other features: Several other features, peculiar to the area of the Yava mineralisation have been mentioned; these coincide spatially with the mineralisation, but their influence is unclear.

9. The deposit is located over a regional basement high. It is the only place along the south-eastern flank of the outlier where basement knolls protrude through the Windsor, forming an irregular surface on which the Canso Group sandstone is deposited.

10. There is a spatial coincidence between mineralisation and the distribution in sub-sandstone outcrop of both Talus Breccia and Windsor Calcrete. The former corresponds spatially with the ore margins in several places, while the latter forms the geological footwall for most of the West Zone.

VI.7. Model for Localisation of Mineralisation

In the West Zone, disseminated lead mineralisation is concentrated in the basal 7 m of the sandstone sequence, directly above an unconformity with Windsor shales. The ore horizon has a distinct profile: the base is marked by an abrupt incoming of mineralisation at the unconformity; grade then drops off gradually, in an upward direction above the ore zone, and laterally towards the ore margins. Best ore thickness or ore grade coincides spatially, outlining two distinct lobes of ore overlying depressions in the footwall palaeorelief. The only physical constraint to mineral distribution as a whole, appears to be the impervious interface of the footwall unconformity. There is no geological hanging wall to form a constraint in an upward direction, and the margins of the orebody simply mark the point of overlap between rising footwall and the assay back. This configuration indicates that a relatively planar surface marks the top of the ore, paralleling the general palaeo-horizontal. The position of this top surface will change up and down as different cut-off grades are applied.

It is proposed that, at Yava, mineralisation is concentrated in traps, akin to an inverted oil trap. The impervious footwall forms a floor, below which no mineralisation is present, while the transitional back is the effect of gravity in an otherwise open system (akin to the oil/water interface).

The coincidental spatial configuration of grade distribution, ore thickness and palaeorelief can be explained in two ways; these are diagramatically present in Figure VI.2. The observed situation, as illustrated, demonstrates the overall coincidence of the variables. In Explanation 1, mineralisation occurs as homogeneous concentrations, dropping in grade and thickness from a central thick concentration, to a marginal, thin area of enrichment. Explanation 2 projects the upper grade interface down within the ore zone, with increasing grade. In this way, the thickest and highest grade mineralisation concentrates in the centre of the depression; this is then overlapped by a more

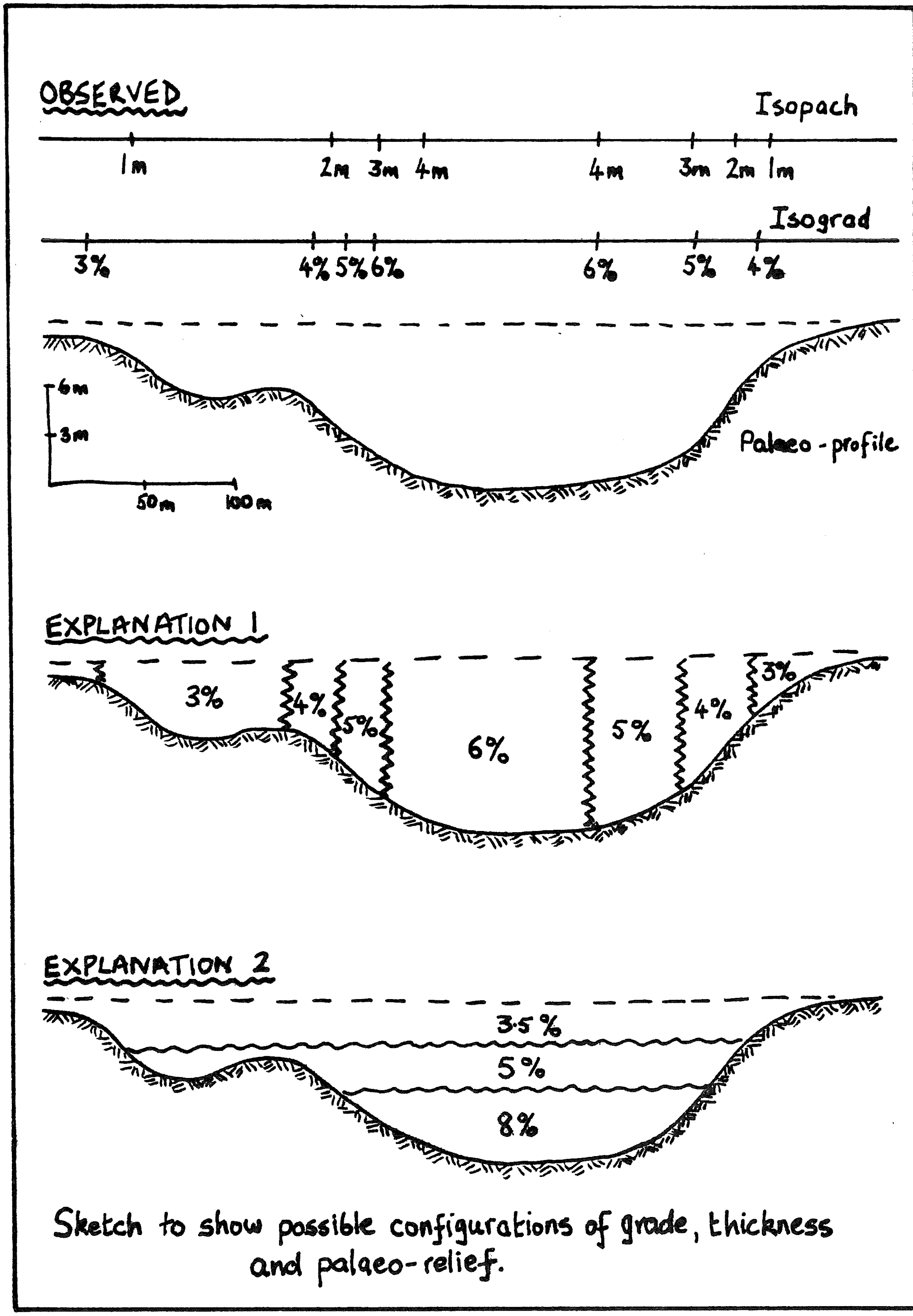

OBSERVED
Isopach
1m
2m 3m 4m
4m
3m 2m 1m
Isograd
3%
4% 5% 6%
6%
5% 4%
6m
3m
50m
100m
Palaeo - profile
EXPLANATION 1
3%
4%
5%
6%
5%
4%
3%
EXPLANATION 2
3.5 %
5 %
8%
Sketch to show possible configurations of grade, thickness and palaeo-relief.

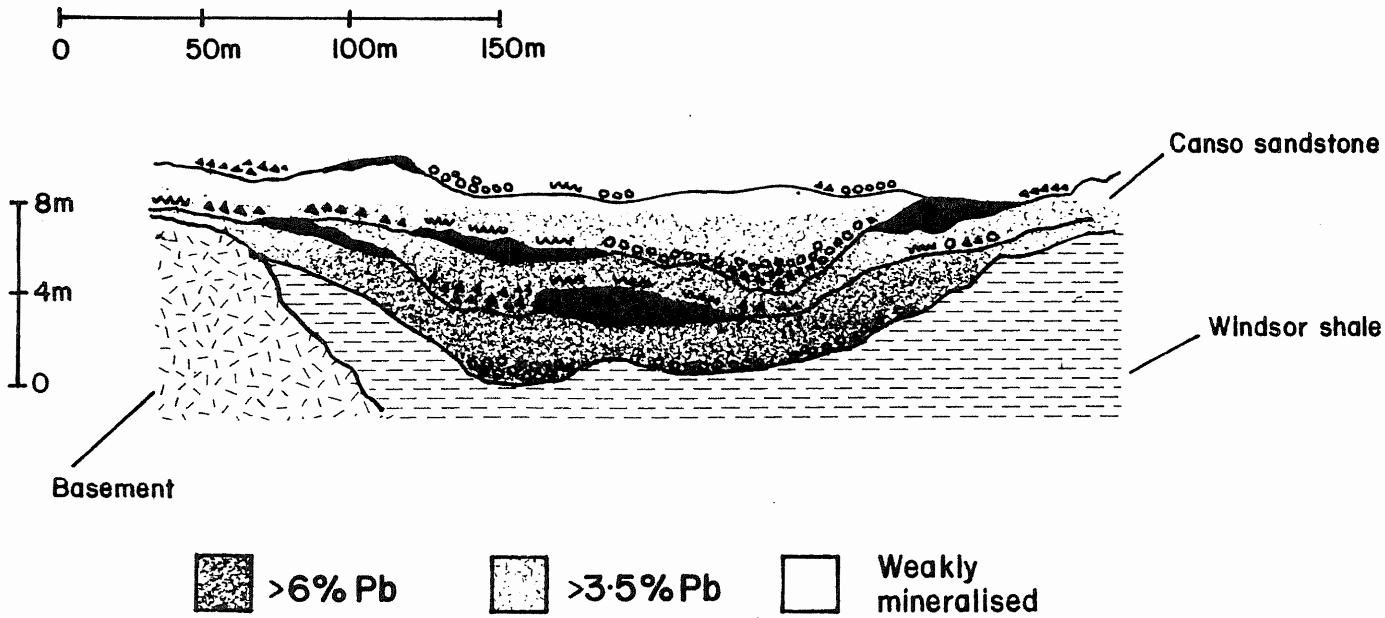
Figure VI.2

extensive lower grade interval above. By calculating weighted averages through the ore zone to the point of cut-off, the same contour configuration will result.

Explanation 2 is preferred for Yava, because: firstly, the profile of lead grade within the ore zone is known to drop steadily from higher grade mineralisation (in the basal section of the ore zone) up to lower grade mineralisation above. And secondly, detailed sampling for grade distribution (in a single continuous sandstone) shows that grade drops from a high level in the centre of a depression, towards the flanks, where grade is lower.

Figure VI.3 is an idealised section across an ore lobe at Yava to illustrate this mechanism for ore localisation. Taking into account all the local variations in mineral styles, lithology and diagenesis, and their effect on internal distribution, it can be postulated that below particular levels in the profile, mineralisation will reach a saturation grade. The internal effects of lithological configuration, and the presence of localised areas of calcareous cementation, are clearly second order features. However their influence on grade distribution, ultimate tonnage and grade is considerable.

The only difference between the Central and East Zones and the West Zone is that, in part, the bases of economic mineralisation for the Central and East Zones are removed from the geological footwall (Windsor unconformity), to lie within the sandstone sequence. While weak galena mineralisation is present in sub-ore sandstone, the



YAVA LEAD DEPOSIT : Idealized section to show ore entrapment

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Figure VI.3

sandstone are generally calcareous in composition and poorly mineralised.

It is proposed that the impervious base to mineralisation in these Zones is either the Windsor contact, or the top of diagenetic carbonate cement (where basal sandstones are calcareous). The same spatial configuration of grade and mineralisation in these zones would suggest that palaeodepressions in this combined lower interface also form the focal points of mineralisation.

On a regional basis, this displacement of footwall by several metres is insignificant; all three ore zones, and the deposit as a whole, are located in palaeodepressions, and have no constraint to mineralisation in an upward direction.

VI.8. Timing of Mineralisation

As indicated in the foregoing discussion, the timing of Yava mineralisation is not clear. The mineralisation at Yava is in fact in such an original state (i.e. with no evidence of post-mineralisation changes) that it could have occurred at any time, from after deposition in the Namurian, until the Pleistocene glaciation, when the deposit was breached.

Timing of mineralisation for some of the other deposits has been more closely examined. Samama (1976) considers that the mineralisation at L'Argentiere is syngenetic; explained by him thus:

> "the age of the Pb concentation distributed along four preferential beds among the whole series, has been determined with great accuracy by sedimentological observation mainly based on the relationships of mineralisation with early features such as soft pebbles, synsedimentary and diagenetic faults, slumps and filling of geodes. The result of these observations is that the primary mineralisation has taken place after the deposition of the siliceous detrital materials (pebbles, gravels and sand grains) but before deposition of the next detrital level. More precisely, this mineralisation originated between the active mechanical sedimentation periods and it appears to be a result from phreatic circulations involving chemical precipitation."
> (Samama, 1976, p. 2-3)

At Laisvall Rickard et al. (1979) propose that the mineralisation occurs after the deposition of sandstones (Eo-Cambrian) and prior to the overthrusting and tectonism of the Caledonian orogeny (Devonian), a time period of 200 my. They go on to suggest that the mineralising episode is a short event (3,500 years duration) which took place after early jointing, and prior to host rock consolidation; they postulate an early Caledonian (Late Silurian) age for mineralisation.

At Yava, textural considerations indicate that the galena mineralisation is a diagenetic event. It post-dates the deposition of sandstone, post-dates early carbonate and sphalerite-pyrite-mineralisation, and post-dates quartz overgrowth. Texturally, galena emplacement is the last recognisable diagenetic change. Some indications are that quartz overgrowth is an early event. To quote from Bjorlykke and Sangster (1981) referring to Blatt (1979 reference not obtained):

> "Recent work by Blatt (1979) has shown that the main portion of silica cement in orthoquartzites is introduced at a very shallow depth (up to but not exceeding,

a few hundred metres) by ground water."
(Bjorlykke and Sangster, 1981, p. 203)

Others (Pettijohn, Potter and Siever, 1972, and Chilingarian and Wolff, 1976) indicate that quartz overgrowth is mostly associated with silica pressure solution which does not occur until conditions of at least intermediate burial (2500 m) have been reached. Whatever the depth of burial, the inference must be that, while galena may be the last recognisable cement phase, it must have been introduced before quartz overgrowth was sufficiently advanced to reduce porosity, and seal available permeability. Also, the spatial coincidence between mineralisation and the location of depressions in the footwall palaeo-relief, must strongly suggest that mineralisation pre-dates tectonism (which at Yava is interpreted to be tilt, in response to movement on Post-Carboniferous normal faults, along the north-west flank of the outlier).

Scott (1980) proposed that the early pyrite-sphalerite mineralisation was an early diagenetic event, while the main galena mineralisation was a later diagenetic or epigenetic event. The author would concur with this broad view.

In addition, it is proposed that the Yava mineralisation post-dates diagenetic changes in the host rocks, while it most probably pre-dates tectonism. This would date the mineralisation as post-middle Namurian and Pre-Triassic (Hercynian). This is comparable to the time frame proposed by Rickard et al. (1979) for Laisvall; however at

Laisvall the discordance of mineralisation with respect to stratigraphy does suggest that there, mineralisation post-dates the tectonic tilt.

VI.9. Temperature of Mineralisation

It is not within the scope of this thesis to investigate the temperature of mineralisation, however some comments on palaeotemperature are necessary.

No direct information is available on the temperature of mineralisation at Yava. Scott (1980) failed to find fluid inclusions in sphalerites large enough to use for temperature determinations, and no sulphur isotope work has been conducted on any Yava sulphides. Rickard et al. (1979) report sphalerite fluid inclusion temperatures of 150°C for the Laisvall mineralisation. (Sulphur isotope geothermometry was unsuccessful because the sulphide phases are in disequilibrium.) The temperature of mineralisation at L'Argentiere is inferred from textural evidence (near surface diagenetic mineralisation) to be low. Likewise the textures at Yava indicate low temperatures for some of the sulphides. The presence of framboidal pyrite, and zoned euhedral sphalerite-pyrite, suggest low temperature anaerobic conditions of precipitation, associated with bacteriological activity. The temperature of galena precipitation is not known.

To derive an indirect temperature of mineralisation, Scott (1980) submitted samples of coaly matter from within and above the ore zone at Yava, for vitrinite reflectivity determination at the Geological Survey of Canada coal laboratory at Bedford.

The results indicate that the coals in the vicinity of the ore zone were up-ranked from a regional country rock value of v8 to v13. One of several possible explanations proposed for this upranking was a local introduction of hydrothermal fluids in the Mine area (possible ore solutions, linking rank changes to the mineralisation event). Scott postulates time and temperature constraints for coalification, using a Karweil diagram. In order to achieve a rank of v13, he deduces that it would take an event of 60 million years at 150°C, or 1 million years at 250°C.

The temperature of mineralisation at Yava is therefore not clear. The textural and sequential timing of mineralisation compares well with other sandstone-hosted sulphide deposits, which in most cases, suggest low temperature diagenetic mineralisation in the presence of organic-rich anoxic conditions.

Yava could provide an excellent case study for more detailed and regionally-extensive vitrinite reflectivity investigations, combined with sulphur isotope geothermometry, fluid inclusions and a study of illite crystallinity. Of particular importance in any such study would be the selection of coal samples for reflectivity, containing no disseminated sulphide mineralisation, Because of the strong reflective properties of all sulphides, splits of all coal samples would have to be taken for trace analysis to check for contamination.

VI.10. Metallogenetic Models

Two main metallogenic models for lead sandstone deposits have been postulated in the literature; these are a hydrothermal (basin brine) model, and a ground water transport model. The latter has been recently split into two versions, one requiring saline, and the other fresh groundwater, for metal transportation (Bjorlykke and Sangster 1981).

Hydrothermal Model

This model, involving the dewatering of a sedimentary basin, was originally proposed for Mississippi Valley type deposits by Jackson and Beales (1967); it has been most recently adopted to explain the mineralisation at Laisvall by Rickard et al. (1979) following an integrated study of that deposit. The model as proposed, is clearly summarized by Bjorlykke and Sangster (1981):

> "The model can be described in terms of three basic steps:
> (1) dewatering of sediments in the basin - this water would have a high salinity and metal content, the latter carried as chloride complexes;
> (2) the metal bearing brines would move outward and upward through the permeable sandstones to the marginal parts of the basin; and
> (3) precipitation of metals as a function of decreasing temperature and pressure and/or by mixing with sulphide bearing groundwater."
>
> (Bjorlykke and Sangster, 1981, p. 202)

Rickard et al. (1979) suggest that the emplacement of overthrusted nappe complexes to the west, may have provided the additional compaction necessary to drive the dewatering process. This model is compatible with the fluid inclusion chemistry, and the discordant nature of the ore horizon at Laisvall.

This is also attractive as a model for the Yava deposit. Firstly, the mineralisation is epigenetic in character, and is discordant to stratigraphy, as it is at Laisvall. Secondly, Yava is located at the margin of an outlier which was originally part of the Sydney depocentre (a major ancient sedimentary basin which must have undergone considerable dewatering at some stage, thus providing a potential source of hydrothermal fluids). Conversely, however, Yava has no caprock under which fluid, emanating in an upward and outward direction from within a basin, might be trapped, as would appear to be the case at Laisvall.

Scott (1980) favours this model to explain the Yava mineralisation. He suggests that the same thermal event that upranked the coal, may have deposited the main stage of mineralisation. He states that mineralisation may have occurred during the Triassic, (inferred from some lead isotope analysis of Yava material, indicating a model lead age of 250 million years BP, given to him by D. Sangster, pers. comm.). Such a coincidence of events and such a recent date both seem unlikely. Firstly, the findings of this study indicate mineralisation to be pre-tectonism; and secondly, Hacquebard and Donaldson (1970) have shown that coalification in the Eastern Canada Basin is a post-tectonic event.

While there is no direct information on the temperature of mineralisation at Yava, indications from other deposits of this type are that temperatures were low, 150°C or less. This suggests that, while dewatering basin brine may provide a mechanism, hydrothermal mineralisation in the strict sense seems unlikely.

Groundwater Model (Saline)

This model proposed by Samama (1976) to explain the L'Argentiere mineralisation, involves the movement of groundwater basinward through the sediment prism. En route, the water becomes saline and enriched in metals from within the sediment prism. Transportation continues until a geochemical barrier is reached at the edge of the basin, where organic-rich reducing conditions prevail, and where sulphide precipitation occurs.

An important feature of this model is the geochemical maturation or weathering of the basement rocks. During maturation, Cu, U and also Zn (derived from the breakdown of ferromagnesian minerals) are leached out, and Pb and Ba (derived from the breakdown of K feldspar) remain to concentrate in the sediment prism and provide enriched source beds for this mechanism. For this process, Samama suggests that long periods of hydrologic stability (arid), when pedogenetic enrichment occurs, must be followed by rapid transport and deposition of this enriched sediment under humid conditions.

Groundwater Model (Fresh)

Bjorlykke and Sangster (1981) in their review paper on sandstone-hosted lead-zinc deposits, point out that all such deposits are sufficiently similar to have been formed from the same metallogenic process. They favour the groundwater model of Samama (1976) over the hydrothermal model of Rickard et al. (1979); they adopt the need for pedogenetic enrichment, as proposed by Samama (1971), during the period of weathering when metals are released, following the breakdown of K feldspars. However they propose that the ground water which transported the metals, was not saline, but remained in a fresh state. They suggested that in shallow, oxidizing, meteoric groundwater, lead can remain in solution (1-2 ppb Pb) as long as dissolved carbonate/sulphate remains low. Later precipitation of galena would then occur in areas of reducing conditions, where ionic lead would combine with "in situ" biogenically derived sulphide. They go on to make the point that, under these conditions, the solubility of galena is six orders of magnitude less than that of sphalerite - hence the preferential precipitation of galena typical of these deposits.

Observations at Yava are also compatible with a groundwater model. There is good evidence there for a prolonged period of arid weathering, marked by the disconformity and calcrete development on the Windsor palaeosurface. This was then followed by an abrupt change to humid clastic deposition, when sandstone sedimentation commenced.

Presently, there is no background information on regional base metal levels in either basement rocks, or the weathering profile, for the Salmon River area. Isolated analyses (conducted for this project to characterise the lithotypes) indicate: basement rock shows no enrichment in base metals; while weathered basement (pre-Carboniferous, weathered) does, however, suggest some enrichment in lead and other metals; also, basement rock is of potassic granite composition, indicating an abundance of K-feldspar, the required primary source for lead. These aspects of regional geochemistry in the Mine district are understood to be presently under investigation (D. Sangster, pers. comm.).

Also, Yava does not have several horizons of mineralisation (each related to a particular period of emergence and sedimentation) as is the case at L'Argentiere. Perhaps the single horizon at Yava is equivalent to the basal horizon at L'Argentiere; and that, while all other conditions for the formation of additional horizons of mineralisation were ideal, no further emergence took place during sandstone sedimentation to allow for repetition of the process.

As proposed for L'Argentiere, this groundwater model infers that mineralisation must have taken place immediately after sedimentation, as an early diagenetic event. Mineralisation at this early stage is not evident for Yava. Precipitation of carbonate, early sulphides, and most importantly, quartz overgrowth, must have occurred prior to the introduction of lead-rich fluids.

Preferred Model

The information presented on controls to the mineralisation, imposes certain limitations on any mineralisation model for Yava.

The nature of ore entrapment in depressions on the original surface of the unconformity, implies that mineralisation controls acted prior to tectonic tilting of the sequence to the north-west. This might indicate that mineralisation must pre-date tectonism. This is not necessarily the case; there are, it is felt, two explanations. One is that mineralisation is indeed a pre-tectonic event, when sulphides pooled in depressions in the footwall relief. The other is that early diagenetic preparation of the ground within the area of the depressions took place prior to tectonism. For instance, humates derived from coaly matter might have migrated to concentrate within depressions, and create localised, highly reducing, sulphur-rich conditions. Lead introduced into this prepared ground at a later date, even after tectonism, would still tend to concentrate in these same features, regardless of their attitude. (The analogy of planar-type uranium mineralisation is being considered here.)

Another condition which this trapping mechanism would imply, is that the system was hydrostatic, as opposed to being hydrodynamic. The evidence indicates that mineralisation has pooled under the influence of gravity, to fill in irregularities in the underlying surface, leaving a transitional top surface, orientated by gravity, close to the palaeohorizontal. The current understanding of the genesis of these deposits is that mineralisation results from hydrodynamic processes, when large volumes of fluid containing low metal concentrations are flushed through the site, over long periods of time. It is hard to explain the present configuration in terms of hydrodynamic flow, unless pre-mineralisation ground preparation were existent, or a flow regime were present, vertically stratified to confine ore fluids to the lowermost channels and eddies in the aquifer.

The location of the mineralisation, hugging the base of an open aquifer, would suggest that any ore fluid must be denser (or colder!) than all other fluids in the hydrologic profile. This is most likely a function of salinity, which would increase fluid density. Therefore, it is proposed that some form of brine most likely transported these metals.

For Yava, the present data is compatible with a model in which mineralisation resulted from the basinward migration of saline ground-water, containing lead and zinc in chloride complexes, along the floor of an open aquifer. Precipitation of galena and lesser sphalerite occurred in eddies and depressions in the aquifer floor, where sulphide-rich reducing conditions were pre-concentrated. The event took place during sandstone diagenesis, and prior to tectonism in the area.

CHAPTER VII

CONCLUSIONS

This close examination of the relationship between the sulphide mineralisation at Yava and its hosting environment, and the comparison with other related deposits, indicate the following features to be pre-requisites and controls to mineralisation:

Pre-requisites

1. a suitable host rock - well sorted, continental clastic sediment, rich in organic detritus, in a reduced state, and containing abundant permeable and porous sandstone of arenaceous composition - to form an aquifer of suitable chemical character.
2. an impervious footwall to form a confining lower margin to the aquifer.
3. underlying basement rock of granitic composition.
4. an unconformity at the base of the mineralised sequence marking a period of emergence and sub-aerial weathering.

Controls 1st order

5. negative topographic features in the pre-tectonic footwall relief to act as loci in which the mineralisation is concentrated, either directly or indirectly, under the influence of gravity; this pooling effect can be shown to determine the limits to ore accumulation in all

three dimensions.

Controls 2nd order

6. internal stratigraphic configuration and original compositional variations in the clastic package: these physical features strongly influence grade distribution within the space of ore accumulation. In addition, chemical conditions favourable to excessive sulphide precipitation occur in localities rich in coaly matter.

Controls 3rd order

7. diagenetic changes to the host sediments prior to mineralisation (particularly the precipitation of early carbonate cements and quartz overgrowth) causing local reduction in porosity and permeability.

Other observed features which may influence the localisation of sulphides at Yava are:

8. the spatial coincidence between mineralisation and the sub-ore distribution of Windsor calcrete and talus breccia
9. the location of the deposit over a regional basement high (i.e. the only situation along the south-east flank of the Salmon River outlier where basement knolls protrude through a reduced Windsor succession, thus forming an irregular basement window on which the host sandstone is directly deposited).

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APPENDIX 1

YAVA MINE - LAB PROCEDURES

Atomic Absorption Spectrophotometry

(used for samples below 10% Pb)

Digestion

(1) Weigh 0.5 g into soap washed 250 ml beakers

(2) Add 10 ml HNO_3 and allow to dissolve on hot plate (near boiling)

(3) Evaporate until center of beaker is becoming dry

(4) Add 5 ml HNO_3, heat, and then dilute to 50 ml using hot water

(5) Cover beakers and boil 5 min. Take off heat

(6) Pour solution into 100 ml flask

(7) Dilute to volume with warm water

(8) Shake well

(This is a 200-fold dilution)

Sample (1) is diluted no further.

(9) Pour solutions from flasks back into rinsed beakers

(10) Rinse out flasks well. Pour in 75 ml of warm water

(11) Pipette 10 ml into each flask

(12) Dilute to 100 ml with warm water. Shake well.

(This is a 2000-fold dilution)

Atomic Absorption

(1) Set the 25 ppm standard to 25 on the scale if possible

(2) Check control sample (should be 19.0 ppm, i.e. 3.80%)

(3) Check 10 ppm

(4) Run samples

Use

(a) 283.3 nm line

(b) oxidizing flame

Standard solutions were prepared from Canlab S-7385-82 1000 ppm standard Pb solution. This is a lead nitrate salt dissolved in dilute HNO_3.

Wet Chemical Analysis

(used for samples above 10% Pb)

Ammonium Molybdate

(1) Weigh 0.5 g concentrate into a 400 ml beaker. (Run control sample - 67.20% Pb each day)

(2) Add 10 ml HNO_3 (conc)

(3) Boil until NO_2 fumes are gone (brown color interferes with end point)

(4) Add 10 ml 1:1 H_2SO_4 (pptes $PbSO_4$)

(5) Evaporate to dryness (or very near - must wash later to acid free conditions)

(6) If organic black colour exists (coal) add a few drops of HNO_3 and fume again

(7) Cool

(8) Wash down beaker sides with about 25 ml of cool water

(9) Heat to near boiling (rids solution of last traces of brown color)

(10) Cool by rotating beaker under tap

(11) Filter through Whatman #1 paper (very fast). (If more than 72% Pb is present, use #42 paper because of fine particles).

(12) Wash precipitate with cold water until acid free (litmus)

(13) Wash precipitate out of filter paper into the original 400 ml beaker. (Keep a small portion of precipitate back in the paper). Place wet filter paper on the side of the beaker above the level of the solution.

(14) Add 25 ml of NH_2Ac solution (25 to 27 ml) and bring up to 75 ml with water (precipitate dissolves)

(15) Heat to boiling (lid on). Take off heat and rinse lid

(16) Titrate with ammonium molybdate:

(a) Run solution in quickly to near the end point.

(b) After the yellow colour is seen with tannic acid indicator (in a spot plate outside the beaker) break up filter paper into the beaker.

(c) Titrate to end point adding 0.2 ml portions near end point

(d) End point is light yellow colour (must reproduce same colour each time).

<u>Solutions for Ammonium Molybdate</u>

Ammonium acetate

Mix 1050 ml H_2O

1050 ml NH_4OH

1200 ml HAc

Ammonium molybdate solution

Make 1 ml = 1% in distilled water to obtain direct read-off

Tannic Acid Solution

Make 1% in distilled water

APPENDIX 2

Sample No.	Pulp No.	COMPARISON OF LABS: Yava Lab (AA) (HNO_3)	COMPARISON OF LABS: X-Ray Assay (XRF)	LEAD ASSAY: Brunswick #12 (AA) ($HCl+HNO_3$)	LEAD ASSAY: Brunswick #12 (AA) (HNO_3)	SELECTED DRILL-CORE PULP: Brunswick #12 (wet) (Molybdate)	SELECTED DRILL-CORE PULP: Brunswick #12 (wet) (Molybdate)	SELECTED DRILL-CORE PULP: Brunswick #12 (wet) (Lead Chromate)
7227	1	3.30	2.48					
7229	2	3.60	3.10	3.22	3.40	3.39	3.32	3.16
7232	3	8.40	7.52	7.51	8.23	8.11	8.08	8.17
7235	4	3.70	2.00					
7241	5	4.60	4.33	4.57	4.80	4.66	4.60	4.49
7243	6	3.05	2.81	2.78	2.80	2.87	2.86	2.70
7255	7	2.25	1.68	1.69		1.39	1.66	1.57
7256	8	0.84	0.74	0.73		0.70	0.67	0.73
7258	9	4.76	4.78	4.57	5.10	4.80	4.81	4.82
7263	10	2.35	1.96	1.97	2.06	2.80	1.93	1.95

APPENDIX 3

CLIM LAB PROCEDURES

The analysis of rocks, ores, etc. for Ag, Cd, Cu, Zn, Mn, Pb, Fe, Ca, Mg by Atomic Absorption (A.A.) Spectrophotometry using Jarrell-Ash 810 and with Aqua Regia Extraction.

Weigh a 1.0 gram* sample and put into 100 ml beaker. Add 30 ml of HCl and 10 ml of HNO_3 and heat on hot plate until less than 20 ml. Add enough distilled H_2O to bring volume up to 50 ml. Heat for a short period and filter into 100 ml flasks using Whatman #4 filter paper. Then determine by A.A. doing Ag and Pb right after filtering.

For Ca and Mg make dilution of 1:10 or 1:100, depending upon the concentration and add enough $LaCl_3$ solution until samples contain .1% La.

Use Acetylene/Nitrous Oxide flame for Ca and Mg. For all other elements use acetylene/air flame.

Use background correction for all elements except Cu, Mg and Ca. Use a Continuum Lamp for the background correction.

* It was found that a .1 gram sample was required for +1% Pb and +50 ppm Ag.

The Analysis of Silicate Rocks for Mo and 8 other Elements by Emission Spectrograph

Analytical Method: QV - 2 (volatiles)

Other Elements: Ag, B, Bi, Ge, In, Sb, Sn and Tl.

Reference: Unpublished method QN-13 (volatiles) of H. Champ. Spectrographic Laboratory, Geological Survey of Canada, Department of Energy, Mines and Resources, Ottawa. With changes to meet our conditions.

This method applies to the listed elements at concentration levels below the sensitivity of the other spectrograph method. The sample is mixed with a buffer of Al_2O_3, $BaCO_3$, and KIO_3. The sample is exposed in the 3.4 meter Ebert Spectrograph, using a controlled D.C. arc and recording the spectra on photographic plates. Conversions from densitometer readings through relative intensities to concentrations by Seidel calculating board and analytical working curves. The method is not applicable to ultrabasic rocks.

Refer to the Procedure for the analysis of rocks, minerals, ores, etc., for TiO_2 by Emission Spectrograph for description of equipment.

The Analysis of Rocks, Minerals, Ores, Etc., for TiO_2 and 15 Other Elements by Emission Spectrograph

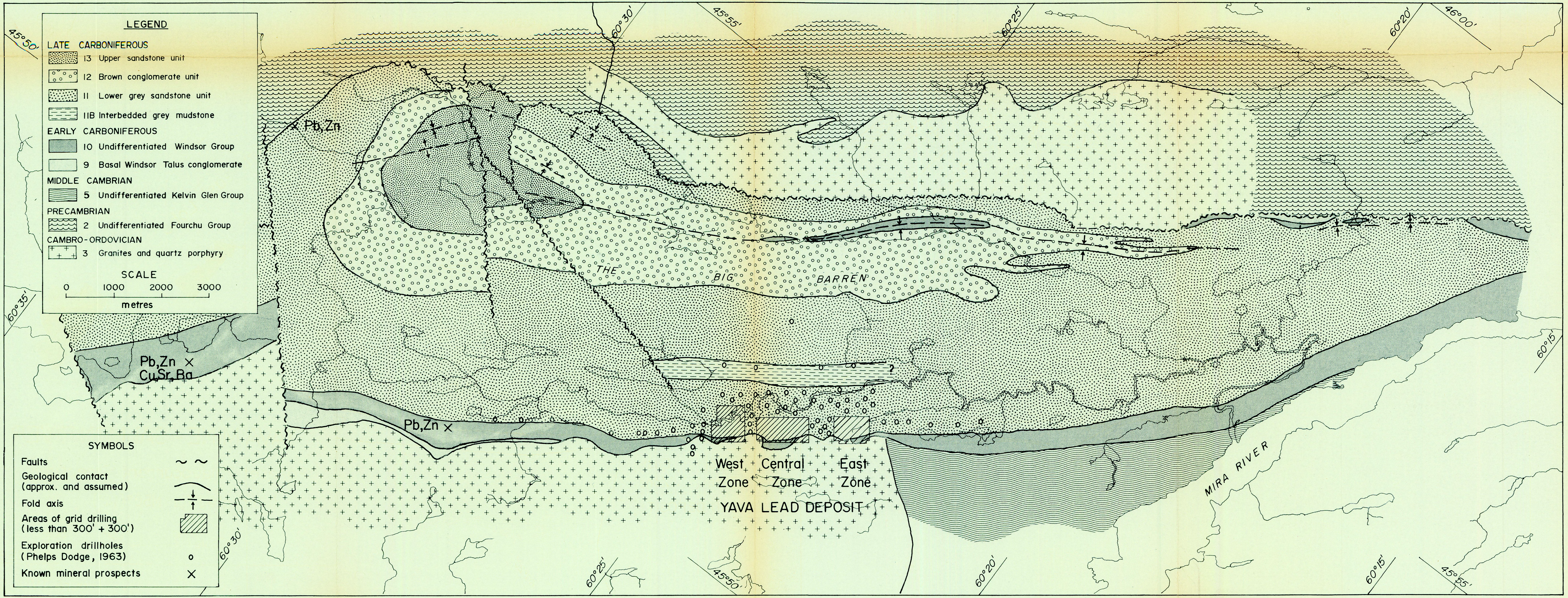
Analytcal Method: QN-3

Other Elements*: B, Ba, Be, Bi, Cr, Ga, La, Mo, Sc, Sn, Sr, V, Y, Yb and Zr

Reference: Unpublished method QN 12b of H. Champ, Spectrographic Laboratory, Geological Survey of Canada, Department of Energy, Mines and Resources, Ottawa. With changes to meet our conditions.

The sample is mixed with graphite and a buffer of lithium, potassium and added as internal standards are Eu and Pd. It is then volatilized and exited in an air-jet controlled D.C. arc. It is dispersed in a 3.4 meter Ebert Spectrograph with the spectra recorded on photographic plates. Conversions from densitometer readings through relative intensities to concentrations by Seidel calculating board and analytical working curves. The concentration ranges for some of the above elements are not quite broad enough and are done by alternative methods.

* 37 elements could be determined by this method, but we find alternative methods to be more suitable.



GEOLOGICAL MAP OF SALMON RIVER OUTLIER (after Phelps Dodge Corporation, 1963)

Figure II.2 (back pocket)

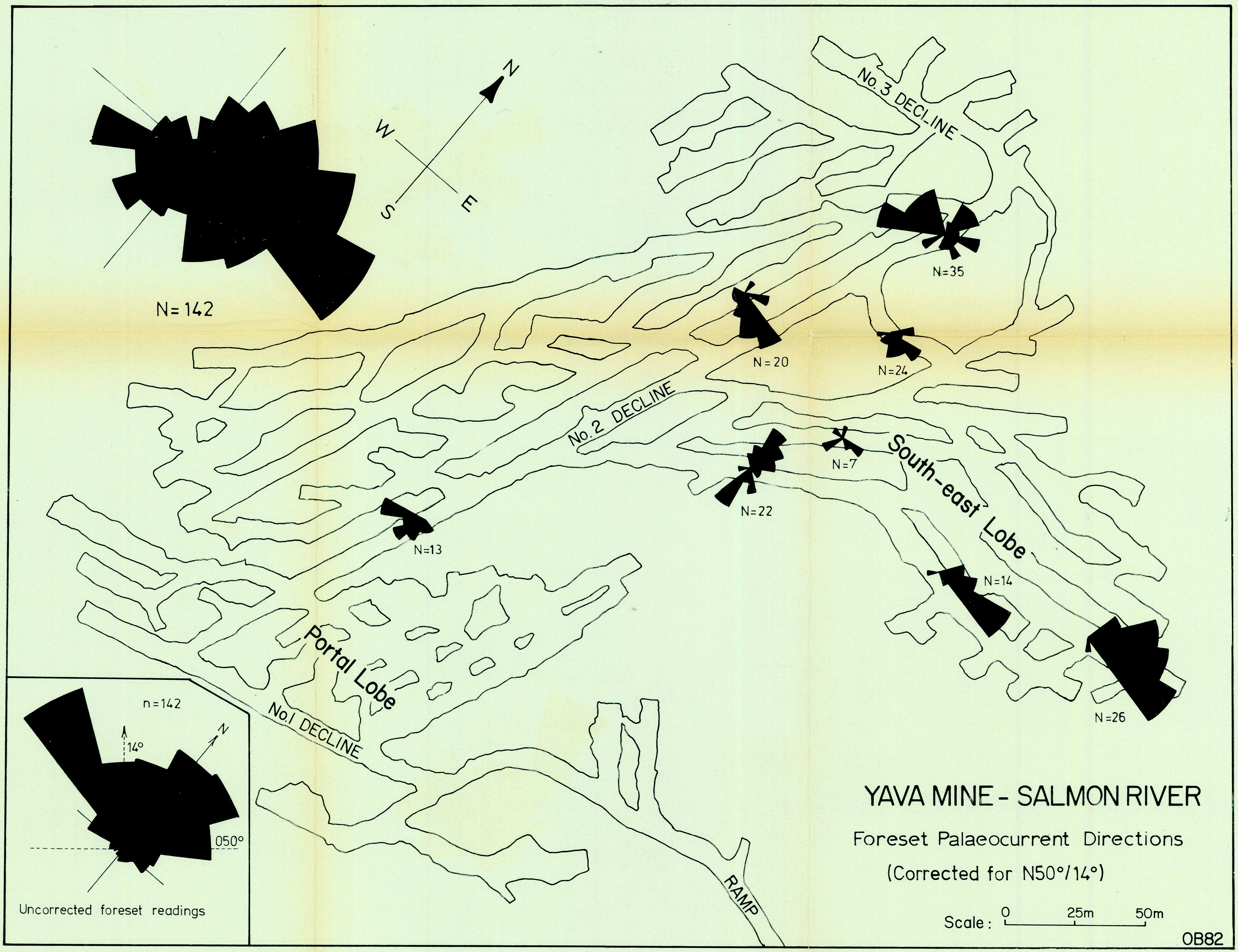


Figure IV. A. 5.
(back pocket)

Figure VI.A.2 (back pocket)

Figure VI.A.3 (back pocket)