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GEOLOGY OF THE
CIRQUE BARITE-ZINC-LEAD-SILVER DEPOSITS
NORTHEASTERN BRITISH COLUMBIA, CANADA

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CYPRUS ANVIL MINING CORPORATION

600-1281 W. GEORGIA STREET

VANCOUVER, BRITISH COLUMBIA

V6E 3K3

CANADA

32.2 million tonnes 7.9% Zn 2.1% Pb = 10% Zn+Pb
47.7 gm/tonne Ag.

= 2.92 x 10^6 tonnes (Pb+Zn) metal

ABSTRACT

The stratiform barite-sulphides Cirque and South Cirque deposits in the Akie District are part of a Devonian-Mississippian marine sequence of basinal shales and submarine fan deposits of chert pebble conglomerate. This sequence occurs in a northwest-trending, second order depositional trough within the Kechika Trough, a southeast extension of Selwyn Basin. The second order trough was bounded on the northeast by Early to Middle Devonian platform reefs. Major eastward transgression beyond this margin in Middle Devonian was probably caused by a eustatic rise in sea level. The southwest margin has been structurally removed by later Laramide deformation. This trough was greater than 50 kilometres long and at least 8 kilometres wide. Chert pebble conglomerates have not been noted within the immediate vicinity of the deposits; nearby they are stratigraphically above the mineralized horizon.

The deposits occur within earliest Late Devonian (Frasnian) shales of the Earn Group. The background depositional unit is a soft grey shale. Enveloping the deposits are diagenetically silicified, carbonaceous, thick bedded shales and ribbon porcellanites. Contacts between sulphide bodies and enclosing fine clastics are sharp. Stockworks, alteration halos, or disturbed bedding zones have not been found adjacent to the deposits.

Both deposits consist of barite, pyrite, sphalerite, and galena. Baritic, pyritic, and laminar banded pyrite facies have been recognized

although proportions of barite and sulphides range continuously from nearly pure barite to nearly pure sulphides. The deposits consist predominantly of baritic and pyritic facies with only minor shale interbeds. Laminar banded pyrite is a marginal facies which contains numerous fine, black, siliceous shale interbeds.

The Cirque deposit is an asymmetric, east-tapering, wedge-shaped lens 1000 metres long, 300 metres wide, and 2 to 60 metres thick. The axis of thickest barite and sulphides is near the western margin of the deposit and trends northerly. Highest Zn:Pb ratios also occur along the western margin. Pyritic facies predominates in the northern part of the lens with baritic facies increasing in proportion to the south. Laminar banded pyrite occurs dominantly along the eastern margin and above the deposit.

The deposits appear to be related to isolated sub-basins within the second order depositional trough. Genetically they are considered to result from exhalative activity from vent areas associated with regional growth faults.

INTRODUCTION:

The Selwyn Basin[1] of the northern Canadian Cordillera is a major Pb-Zn-Ag province (Carne and Cathro 1982). The Anvil and Howards Pass Districts within Selwyn Basin (figure 1) contain several mineral deposits in Early Paleozoic basinal sediments. Exploration within Devonian-Mississippian successor troughs in the Selwyn Basin area has led to the discovery of the Macmillan Pass and Akie Districts (figure 1). In total some twenty deposits and occurrences have been recognized within these four districts.

The major deposits in these districts are bedded, sulphide-rich bodies belonging to the group of mineral deposits classified as sediment-hosted, stratiform deposits (Gustafson and Williams 1981). Other similar deposits within this same class are Meggen, Rammelsberg, Sullivan, and Mount Isa (Gustafson and Williams 1981; Large 1983).

In the Akie District of northeastern British Columbia, exploration in Devonian-Mississippian carbonaceous shales was initiated in the early 1970's. The first major discovery (in 1974) consisted of several barite-sulphide occurrences in the Driftpile Creek area (MacIntyre 1980; Carne and Cathro 1982). Since that time several additional deposits and

[1]Selwyn Basin (Gabrielse 1967) refers to the marine basin immediately southwest of the carbonate/orthoquartzite Mackenzie Platform. It existed as a depositional basin from Early Cambrian through Middle Devonian (Gordey et al. 1981). Kechika Trough is the southeastern extension of Selwyn Basin.

occurrences have been discovered in northeastern British Columbia (MacIntyre 1982, 1983). The most significant of these at present is the Cirque deposit (figure 2). The Cirque claims were staked in 1977 by Cyprus Anvil Mining Corporation and Hudson's Bay Oil and Gas Company Ltd. Detailed geologic mapping and diamond drilling during 1978-1982 on Cirque have outlined two significant barite-Pb-Zn-Ag stratiform mineral deposits within black shales of the Devonian-Mississippian Earn Group.

The Cirque deposit (figure 3) is a barite-sulphide lens 1000 metres long, 300 metres wide, and 2 to 60 metres thick. A conservative estimate of drill indicated reserves is 32.2 million tonnes with an overall grade of 7.9% Zn, 2.1% Pb, and 47.7 grams/tonne Ag. The South Cirque deposit is a blind deposit located approximately 1 kilometre southeast of the Cirque deposit. Several widely spaced diamond drill intersections through South Cirque indicate a significant resource which has not been fully explored.

This paper represents a progress report on the stratigraphy of the Earn Group in the vicinity of the Cirque claims. It is based on detailed property mapping for Cirque (1979-1982), Fluke (1979-1981), and Elf (1979-1981) and selected traverses in adjacent areas (1982). Jefferson et al. (1983) recently described the ore facies within the Cirque deposits and presented a brief overview of Earn Group stratigraphy. This paper complements that earlier presentation by describing a more regional view of the deposits within their stratigraphic setting.

REGIONAL GEOLOGY

Regional geology in the vicinity of Cirque has been outlined by Cecile and Norford (1979), Fritz (1979), Gabrielse (1975, 1981), Gabrielse et al. (1977), MacIntyre (1980, 1981, 1982, 1983), and Taylor et al. (1979). These different studies have been largely stratigraphic in nature. Ages and correlations of units (particularly in the Devonian-Mississippian) are imprecise because of rapid facies changes, sparse paleontologic control, and structural complications.

Strata range in age from Cambrian through Triassic. Table 1 and figure 4 outline relevant stratigraphic units in the vicinity of Cirque. Many of these units have been only informally recognized. Figure 4 also contrasts nomenclature of this paper with that of MacIntyre (1983).

Ordovician-Silurian strata consist of a thick (up to 1500m) sequence of calcareous, graptolitic, black shales containing regionally mappable units of limestone, siltstone, sandstone, orthoquartzite, chert, and mafic volcanics (Cecile and Norford 1979). Gabrielse (1975) correlated this sequence with the type Road River Formation (Jackson and Lenz 1962) in northern Yukon. Because the Road River Formation is readily subdividable, it is here informally given group status (see also Gordey et al 1982). Road River group strata were deposited in a northwest-trending stable marine shale basin whose northeast boundary is at a facies transition to platformal carbonates 25 kilometres northeast of the Cirque Claims (Cecile and Norford 1979).

In contrast Devonian-Mississippian strata feature rapid facies changes. Previously the Devonian-Mississippian clastic rocks containing the Cirque mineral deposits have been informally called "Black Clastics" (Taylor et al. 1979). Recently Gordey et al. (1982) described facies relationships for similar strata of the same age along the eastern margin of Selwyn Basin and adopted the term Earn Group after Campbell (1967), a convention used here.

Structurally the Cirque area is within the Rocky Mountain Fold and Thrust belt. The dominant structural style consists of tight, asymmetric, northeast-verging folds and northeast-directed reverse faults (Gabrielse 1981). Deformation is broadly restricted to the interval between Late Jurassic and Early Tertiary and is considered to be an integral part of the 'thin-skinned tectonics' traditionally associated with the entire Rocky Mountain Fold and Thrust belt. (Thompson 1979).

The Akie District contains several northwest-trending belts of Earn Group preserved in synclinal fold keels and thrust plates (figure 2). Two of these belts are within the Cirque area and will be discussed in this paper (figure 3). Facies changes within these two belts delineate the Devonian-Mississippian depositional trough containing the Cirque mineral deposits.

The western Cirque belt (figure 3) has a maximum exposed width of 1200 metres. It is bounded on the west by the 'A' thrust which structurally places Road River group over Earn Group. Diamond drilling indicates a minimum displacement of 1.5 kilometres along the 'A' thrust. The eastern boundary of the Cirque belt is the depositional contact between Earn Group and the underlying Road River group. Within this belt Earn Group has been structurally thickened by repetition along three reverse faults. Informal names have been given to the different structural panels of Earn Group (figure 3, figures 5-7). The Cirque deposits occur in the uppermost or Gossan panel.

The eastern Elf belt of Earn Group (see figure 3) has an exposed width of about 800 metres. Structurally this belt is a syncline which has been partially imbricated by reverse faults. Near Cirque both margins of the belt have been interpreted as depositional contacts between Earn Group and underlying strata. Reverse faults have not been recognized in this area although they do occur along strike to the southeast.

Thompson (1981) has presented a palinspastic reconstruction of the eastern portion of the Rocky Mountain Fold and Thrust belt along cross-sections both north and south of the Cirque area. Although not strictly comparable because of scale considerations, his ratio between deformed length and restored, undeformed length provides an indication of the degree of deformation at Cirque. For each of his sections, the ratio between deformed and undeformed lengths is approximately 0.6. From figure 3 the deformed width of exposed Earn Group is roughly 4.5 kilometres. Using the ratio from Thompson, the undeformed reconstructed width at Cirque is approximately 7.5 kilometres. Although crude, this distance does give a general indication of the original distance between the northeast margin of exposed Earn Group (Elf belt) and the Cirque mineral deposits.

CIRQUE - STRUCTURE

Two coaxial phases of deformation (D1 and D2) have been recognized at Cirque. The D_1 deformation is pervasive, and the later D_2 deformation is only locally developed.

D_1 macroscopic structures consist of northwest-trending, tight, asymmetric folds. These D_1 folds verge northeast with long, gently southwest-dipping, upright limbs and short, steep to overturned limbs. The steep limbs commonly are attenuated or removed by high-angle reverse faults which are subparallel to axial planes of the D_1 folds. These reverse faults shallow with depth and are rooted in northeast-directed thrust faults with large scale displacements. Fold amplitudes and fault displacements range in scale from 10's of metres to 100's of metres.

All stratigraphic units contain a pervasive, southwest-dipping S_1 cleavage which is axial planar to D_1 macroscopic folds. In shales S_1 is a slaty cleavage; in siltstones, limestones, and porcellanites it typically is a closely spaced fracture cleavage.

The D_2 deformation is delineated by a locally developed S_2 crenulation cleavage that is axial planar to northwest-trending, open to tight, upright D_2 folds with northeast vergence. D_2 folds, when developed, deform bedding and the pervasive S_1 slaty cleavage. In places S_2 is so intensely developed that it becomes the dominant cleavage. Macroscopic D_2 folds with an amplitude of up to 30 metres have been mapped southeast of Cirque, but none have been recognized on the property.

Three types of faults in addition to the reverse faults have been interpreted at Cirque. Steep, near vertical tear faults are restricted to individual thrust panels. They generally trend northerly and exhibit right-lateral, strike-slip displacement of 50 metres or less. Listric normal faults are subparallel to the high angle reverse faults. These faults shallow rapidly with depth and appear to be rooted in the reverse faults and thrust faults (figure 11). Displacements along listric normal faults are commonly up to 100's of metres. Numerous arrays of steep to vertical, planar, late normal faults cross-cut all stratigraphic units and macroscopic structures. The most prominant arrays trend northerly and northwesterly. Displacements are generally less than 50 metres with the west sides being downthrown.

Structural panels consisting dominantly of competent Road River group are highly imbricated with numerous tight isoclinal folds, listric normal faults, and high angle reverse faults (figure 11). In contrast, structural panels consisting dominantly of Earn Group are generally upright and dip moderately to the southwest. D_1 folds with overturned limbs are only locally developed.

CIRQUE - STRATIGRAPHY

Strata at Cirque range in age from Ordovician through Mississippian. (Table 1 and figure 4). Figure 8 illustrates facies relations for Devonian-Mississippian units on a stratigraphic cross-section through Cirque claims. Locations of the different columns in figure 8 are indicated in figures 5 through 7. Unit thicknesses in figure 8 are calculated from the geologic maps. The horizontal datum for figure 8 is arbitrarily chosen as the top of the lower, major siliceous clastic sequence in the Earn Group. More detailed lithologic correlations of Earn Group facies for the Gossan panel in the immediate vicinity of the mineral deposits are shown in figures 10 and 11.

Road River Group

The oldest strata exposed in the area are a thick (greater than 700 metres) sequence of Early Ordovician to Late Silurian graptolitic, calcareous, black shales containing limestone, chert, siltstone, and volcanic interbeds (Table 1).

The Ospika volcanics consist of calcareous pillow basalts, tuffs, breccias, and minor gabbro intrusions occurring within graptolitic shales low in the Road River group (see figure 3). Typically the tuffs and breccias weather bright orange. Regionally the Ospika volcanics are exposed in a 10 kilometre wide belt which trends northwesterly through the Cirque claims (Gabrielse 1981; MacIntyre 1980). Although much older than the Cirque deposits, the limited paleogeographic extent of the volcanics does suggest a previous and extensive history of faulting (related to rifting?) in the geographic vicinity of the deposits.

The uppermost unit (450-485m thick) of the Road River group consists of a resistant, medium-grey, tan-weathering, bioturbated, thick bedded, dolomitic siltstone (Jefferson et al. 1983). This unit (Silurian siltstone) corresponds to unit SD of Cecile and Norford (1979) (see Table 1). The Silurian siltstone (S_{ss}) includes interbeds of finely laminated, argillaceous siltstone which weathers recessively to thin platy scree and minor orthoquartzite, rhythmically laminated limestone, and black silty shale.

The transitional lower contact of the Silurian siltstone with underlying Road River shales occurs through a 70-115 metre interval. Two informal units have been recognized within this transition (Table 1): a ribbon-bedded, streaky white-striped porcellanite with dolomitic siltstone interbeds (Silurian chert) and a limestone consisting of grey, rhythmically bedded,flaggy, limestone turbidites with graptolitic black shale interbeds

Silurian limestone). Although apparently conformable, regionally recognized unconformities separate these two units from the overlying siltstone and underlying graptolitic shale (see Table 1) (Cecile and Norford 1979).

The upper contact of Silurian siltstone with overlying Earn Group or Paul River formation has been observed both in drill core and outcrop. The contact is normally sharp although locally it consists of a breccia containing angular to subrounded siltstone clasts in a shale to siltstone matrix. This breccia grades upward into the overlying shale units. The contact with Kwadacha reef is sharp. MacIntyre (1982, 1983) reports that the upper Silurian siltstone is often pink to red immediately beneath the limestone. In one location southeast of Cirque the uppermost 3 metres of siltstone beneath the Kwadacha reef is silicified. These different contact relations, as well as the presence of different rock types immediately overlying the siltstone suggest that the upper contact is a major unconformity with possible subaerial exposure and oxidation.

Kwadacha Reef

On the northeast margin of the Elf belt of Earn Group (figures 3, 5), the Silurian siltstone is unconformably overlain by a fossiliferous, medium-grey, massive to thick-bedded limestone (Table 1). The Kwadacha reef is not included within the Earn Group or the Road River group because it lithologically contrasts with both of these sequences. Fossils include stromatoporoids, corals, and crinoids with some of these being in growth positions; they indicate an Early Devonian (Emsian) to Middle Devonian age (Gabrielse 1981). Both upper and lower contacts are sharp. The limestone is not present along the western margin of the Elf belt.

The Kwadacha reef is thickest along its southwestern limit of exposure, and it thins gradually to the northeast. The maximum thickness exposed in the Cirque area is about 150 metres. Its exposed thickness varies dramatically along strike to the northwest and southeast from less than 10 metres to greater than 250 metres. The southwest limit of exposure is remarkably linear, trends northwest, and delineates the southwest limit of Early to Middle Devonian shallow water carbonate build-up (Gabrielse 1981).

Paul River Formation

The Paul River formation flanks the southwest margin of the Kwadacha reef (figures 3, 5). It is a fine-grained, carbonaceous shale characterized by the presence of limestone debris flow interbeds up to 3 metres thick; these consist of subrounded to angular clasts of fossiliferous Kwadacha reef lithologies and black porcellanite in a dark grey to black calcareous shale to porcellanite matrix. Locally the debris flows are intraformational shale chip breccias containing abundant shale and pyritic, quartzose siltstone clasts, and rare limestone clasts in a carbonaceous shale matrix.

Northeast of Cirque the background unit containing the carbonate debris flows is a black, ribbon-bedded porcellanite. Bedding is on a scale of 3 to 10 centimetres with thin carbonaceous shale partings separating individual beds. Maximum exposed thickness is approximately 150 metres. Although porcellanites within this unit are lithologically identical to those within the Earn Group, Paul River formation has not been included in the Earn Group because of its close genetic association with the Kwadacha reef.

The Paul River formation has not been intersected in drill core at Cirque. Along strike further to the southeast, drill intersections at Elf and Fluke indicate that this unit interfingers with rocks typical of the Earn Group. The intimate association with the Kwadacha reef and the presence of fossiliferous reef clasts indicate a maximum age of Early to Middle Devonian. The formation represents a regionally restricted, proximal, slope transition facies between shallow water carbonate sedimentation (Kwadacha reef) and deeper water marine shale basin sedimentation (Earn Group).

Southeast of Cirque MacIntyre (1983) has mapped fossiliferous limestone debris flows stratigraphically underlying the Kwadacha reef as Paul River formation. Shales interbedded with these debris flows contain Pragian graptolites (Norford 1979). This unit is not correlative with the

Paul River formation in the Cirque area as described in this paper (see figure 4).

Earn Group

The Earn Group in the Cirque area has been informally divided into the Akie, Gunsteel, and Warneford formations (Jefferson et al 1983). Table 1 briefly describes the different lithologic units comprising these formations. Clastic rocks of Earn Group contain rapid three dimensional facies changes which are most pronounced perpendicular to the northwest trend of the structural belts. The rapidity of the facies changes is attributed partly to telescoping of facies by the northeast-directed folds and reverse faults and partly to rapid changes in depositional environment.

Paleontologic control for the Earn Group is sparse. Interfingering relations with Paul River formation indicate an age at least as old as Early to Middle Devonian. A Ponticeras ammonite from a barite horizon stratigraphically beneath the Cirque deposit has an earliest Late Devonian age (Frasnian) (Jefferson et al. 1983). In Selwyn Basin Gordey et al. (1982) have shown that the lower contact of Earn Group is diachronous and locally is at least older than Early Devonian (Lockhovian). They bracketed the upper Earn Group contact in Selwyn Basin as between Early Mississippian (Osagean) and Late Mississippian (Visean). Earn Group bedded barite horizons in Selwyn Basin have been dated using conodont assemblages as

Middle Devonian (late Eifelian to mid Givetian), Late Devonian (mid Frasnian), and Mississippian (Osagean) (Dawson and Orchard 1982). Sulphide-barite deposits in the Macmillan Pass area are largely correlated with Frasnian baritic horizons; a similar correlation is reasonable for Cirque mineralization.

Gunsteel Formation

The Gunsteel formation contains all carbonaceous, siliceous, fine clastic rocks within the Earn Group. It is a laterally extensive unit that forms the lower part of Earn Group and hosts the stratiform barite-sulphide deposits in the Akie District. Thickness ranges from zero to more than 200 metres, and changes in thickness are locally abrupt. The Gunsteel formation is similar to the Lower Earn Group in the Macmillan Pass area, Yukon, both in lithology and stratigraphic position (Gordey et al. 1982).

The Gunsteel formation is subdivided into three main facies (Table 1): ribbon-bedded porcellanite (DG_C), siliceous shale (DG_{PR}), and ore facies (DB). The ore facies is discussed later. The most siliceous facies (DG_C) is a ribbon-bedded, black porcellanite with thin carbonaceous shale partings at 1-10 centimetre intervals. Fine planar bedding laminations and clastic textures within the porcellanites indicate they are diagenetically silicified fine clastic rocks. Thin quartzose siltstone laminae contain variably preserved, locally abundant radiolarians. The porcellanite (DG_C) typically weathers to blocky, dark bluish grey, resistant outcrops. Scree consists of elongate rhombs formed by the intersection of bedding and cleavage surfaces.

Porcellanite members of the Gunsteel formation range from less than 1 metre to greater than 20 metres in thickness. They occur mainly at the top and/or bottom of the major Gunsteel unit (figure 8). The porcellanites are discontinuous in a northeast-southwest direction, and seem to develop their greatest thickness immediately northeast of the Cirque mineral deposits in the Gossan panel. In the Elf belt (figure 8) this facies is the southwest lateral facies equivalent of the Paul River formation.

Locally the porcellanite members contain one or more blebby to laminated barite horizons with associated pyrite. Baritic horizons range from a few centimetres to greater than 3 metres in thickness. Several of these baritic horizons are illustrated schematically in figure 8. Northeast of the Cirque deposits baritic horizons occur both stratigraphically above and below the mineral deposits.

In the Tuff panel, the lowermost porcellanite also contains a thin, soft, speckled, silty, tan-weathering felsic tuff. The tuff contains angular quartz grains, altered micas, and relict feldspars. Although not thick (less than 1 metre), the tuff does indicate some volcanic activity during Earn Group deposition. It is problematic why this tuff is not more extensive in distribution.

The Warneford panel, Tuff panel, and Elf belt contain a procellanite member higher in the Earn Group. This porcellanite has been termed DG_{C*} to indicate that it is a separate, regionally mappable unit. Typically this member contains medium grey, ovoid carbonate concretions up to 2 metres in diameter. On the Fluke claims to the southeast it also contains a baritic horizon, although barite was not observed near Cirque at this stratigraphic level.

The other major Gunsteel facies is a noncalcareous, thick-bedded, black, siliceous shale. This unit has been informally called the "Pregnant Shale" (DG_{PR}) because it is the immediate host for the barite-sulphides deposits. Bedding is generally on a scale of 30 to 50 centimetres; locally fine laminations on a scale of 1 to 3 centimetres are also visible. Fine, streaky, discontinuous pyrite laminae are common. The siliceous shale (DG_{PR}) forms resistant slaty cleaved outcrops which weather pale blue grey. Pyritic members typically weather to a deep rusty brown to orange-brown. Scree slopes consist of small, smooth S_1 cleavage flakes that may expose bedding laminations.

Th siliceous shale (DG_{PR}) contains numerous irregular to spherical nodules and concretions of pyrite, calcite, barite, and/or quartz which are less than 20 centimetres in diameter. Thin blebbly barite horizons occur at intervals throughout. Medium grey, slightly calcareous, pyritic, graded quartzose siltstone laminae are common and locally abundant. Thin interbeds of thick-bedded to homogeneous, dark grey to black porcellanite up to 2 metres thick are also present. Intraformational shale chip breccias occur rarely. In the Barren panel this facies also contains the same thin felsic tuff unit noted in the lower porcellanite facies (DG_C) farther to the northeast.

The Gunsteel siliceous shale facies (DG_{PR}) occurs dominantly in the lower part of the Earn Group. Regionally it is unmineralized, but locally adjacent to the Cirque deposits and other showings it is anomalous in lead and zinc. This geochemical anomaly is caused by thin beds of framboidal pyrite with minor interstitial sphalerite and galena.

The ribbon bedded porcellanites and siliceous shales of the Gunsteel formation are similar to the Mesozoic and Cenozoic marine bedded cherts and siliceous muds recovered from the deep-sea drilling program (Von Rad and Rosch 1974; Pisciotto 1981; Nisbet and Price 1974). In these cases silicification of the muds is caused by the diagenetic alteration of tests of siliceous organisms. The presence of locally abundant, well preserved radiolarians in the Gunsteel suggests a similar origin. Conversely the Gunsteel does not contain the distinctive lithologic characteristics such as extensive veining, high Mn content, and thick bedding of inorganic hydrothermal cherts described in the Franciscan Formation (Crerar et al 1982). The siliceous nature of the Gunsteel formation, therefore, is most likely biogenic in origin.

The high organic carbon content (up to 7 weight percent), siliceous nature, and fine grain size of the Gunsteel suggest a sub-wave base, euxinic, starved marine shale basin sedimentation pattern. Graded siltstone laminae indicate periodic, distal turbiditic influx of slightly coarser clastics.

Akie Formation

The Akie formation contains all nonsiliceous shales within the Earn Group. Akie shales are planar laminated, medium grey, and soft to extremely soft. Exposures are recessive and weather tan or deep rusty brown. Akie shales are similar to the Upper Earn Group as described by Gordey et al. (1982) for the Macmillan Pass area both in terms of lithology and stratigraphic position. Several facies for the Akie shale are described in Table 1.

The dominant facies within the Akie formation is a homogeneous to thick-bedded, medium grey, aluminous shale. This unit has been informally called the "phyllitic shale" (DA_p) because of its softness and phyllitic sheen on the S_1 cleavage surface. Locally this shale has a faint planar colour lamination (3-5 centimetres) in shades of grey. Thin siltstone laminae are generally rare but may be abundant locally. Intraformational shale breccias occur rarely. Pyrite occurs infrequently as irregular diffuse concentrations of fine disseminated grains. Barite and/or calcite locally form radiating rosettes up to 5 cm in diameter.

The phyllitic shale (DA_p) weathers to recessive, tan to rusty brown outcrops. Rusty brown surfaces are irridescent. Scree slopes consist of irregular brown, waxy chips. Lenses of pyritic siltstone locally weather out as bright orange chips.

In places the Akie shale has a distinctive pinstriped appearance because of regularly spaced interbeds of fine grey siltstone (3-5 centimetres). In the vicinity of Cirque this pinstriped shale (DA_{PS}) occurs only as very minor interbeds within the phyllitic shale (DA_p). To the southeast on the Fluke and Elf claims, the pinstriped shale (DA_{PS}) forms a separate thick unit of Akie shale within the upper part of the Earn Group.

From figure 8 the phyllitic shale (DA_p) generally overlies the Gunsteel formation, although in detail it is also interbedded with it. In the Gossan and Barren panels, the Akie formation (DA_p) also forms a thin tongue in the lower part of the Earn Group; this tongue pinches out to the northeast. In the Barren, Warneford, and Tuff panels phyllitic shale (DA_p) above the Gunsteel formation is intimately interbedded with coarse clastics of the Warneford formation.

The phyllitic shale (DA_p) represents background, sub-wave base, marine shale basin sedimentation for the Earn Group. The general absence of siltstone laminae suggests a monotonous depositional environment lacking episodic turbiditic influxes.

In the immediate vicinity of the Cirque deposits, Akie and Gunsteel formations are intercalated with siltstone which is included in the Akie formation (DA_S) (Figures 10, 11). The siltstone also occurs as thin interbeds within the mineral deposits. It is soft, variably calcareous, speckled, planar to irregularly laminated, and burrow mottled. Clastic grains are mainly carbonate with minor quartz. The siltstone (DA_S) is variably brecciated and silicified adjacent to and within the mineral deposits. Intraformational breccias are common and generally consist of siltstone clasts in a shale-siltstone matrix.

Northeast of the Barren panel, the Gunsteel sequence contains interbeds of a medium to dark grey, thick-bedded, moderately soft, silty shale (DA_{SS}) of the Akie formation. The proportion of Akie silty shale steadily increases to the northeast at the expense of Gunsteel siliceous shale (DG_{PR}). Because these two units are intimately intercalated, they are not consistently differentiated as separate units in figures 5 through 8. Regionally the Gunsteel siliceous shale (DG_{PR})/Akie silty shale (DA_{SS}) sequence typically forms the lowermost Earn Group units overlying the Kwadacha reef.

The Akie silty shale (DA_{SS}) is massive to indistinctly laminated. Bedding typically is in the order of 30 to 50 centimetres although thin-bedded variants also occur. It is characterized by a distinctive, irregular, subconchoidal S_1 slaty cleavage surface and a silty appearance. Typically it weathers to a dull medium or light grey. Concretions and nodules are uncommon. Locally one or more blebby to laminated barite horizons up to 3 metres thick are present. The baritic horizons are siliceous and weather pale bluish grey.

Warneford Formation

Earn Group shales containing beds and lenses of sandstone or conglomerate are included within the Warneford formation. Warneford strata generally overlie the Gunsteel formation and are interbedded with the Akie formation. Thickness ranges from zero to greater than 150 metres.

The dominant facies within the Warneford formation consists of soft to moderately hard, grey to black shale with lenses to discontinuous laminae of pyritic, quartzose siltstone to fine sandstone (DM_{WBX}). Siltstone laminae have wavy irregular margins; typically they are ungraded. Irregular carbonate nodules are uncommon but do occur locally. This unit weathers to a bluish grey colour. It typically forms resistant, somewhat blocky outcrops. Scree slopes consist of small irregular shale chips and lenticles of dark grey to black, quartzose sandstone.

Large composite lenses of coarse sandstone and chert pebble conglomerate are also present within this Warneford unit (DM_{WBX}). Chert clasts are black, grey, white, and rarely pink or green. The coarse conglomerate facies may range up to 10 metres in thickness; generally the conglomerates cannot be traced laterally.

The Warneford (DM_{WBX}) also is characterized by thick interbeds of intraformational breccia. Angular to subangular clasts of shale, siltstone, sandstone, and chert pebble conglomerate occur within a shale to siltstone matrix. These breccia interbeds are locally more than 30 metres thick.

The Warneford (DM_{WBX}) forms a thick wedge in the Barren, Tuff, and Warneford panels (figure 8). This wedge tapers out both to the northeast and southwest. Where present, it is intimately interbedded with the Akie formation (DA_p). Conglomerate and sandstone lenses within the Warneford (DM_{WBX}) are interpreted as channel deposits within a submarine fan complex. The generally thin and very discontinuous nature of the coarse clastics suggests a more distal facies. The common intraformational breccia suggests that much of this unit was deposited as slump or debris flows. The large amounts of chert pebble conglomerate north of Mt. Alcock in Kwadacha Park suggest a northwesterly provenance for the coarse clastics at Cirque.

Similar chert pebble conglomerates at Macmillan Pass form massive debris flow units ranging up to 240 metres thick (Carne 1979). Current indicators and facies distribution there indicate a western source provenance formed by active erosion of uplifted blocks of Road River cherts within Selwyn Basin (Carne 1979; Gordey et al. 1982). Similar Road

River cherts may also have been the source of chert clasts in the Akie District.

The uppermost Warneford (and Earn Group) exposed at Cirque is a thick-bedded, soft, grey, silty shale containing numerous planar beds of cross-laminated, quartzose, pyritic siltstone to sandstone (DM_{WR}). The shale weathers dark rusty brown, and the coarse siliciclastics weather beige to tan. Locally the Warneford rusty shale (DM_{WR}) has a thin-bedded, pinstriped appearance because of abundant argillaceous siltstone interlaminae. This unit is very similar to the Akie phyllitic shale (DA_P); it is characterized by its stratigraphic position above the upper Gunsteel porcellanite (DG_{C*}) and the ubiquitous presence of numerous rusty-weathering, pyritic, quartzose siltstone to sandstone interbeds.

The Warneford rusty shale (DM_{WR}) represents marine shale sedimentation with periodic influx of sandy turbidites. At present it is preserved only in the Warneford and Tuff panels. Its distal turbidite nature suggests a much greater primary distribution before structural truncation and erosion.

CIRQUE - MINERAL DEPOSITS

Cirque and South Cirque mineral deposits are restricted to the uppermost Gossan structural panel in the Cirque belt (figure 3). The immediate host for the deposits is the Gunsteel siliceous shale (DG_{PR}). All units within the Gossan panel dip uniformly and moderately to the southwest.

The Cirque deposit is a lensoid, stratiform barite-sulphides body 1,000 metres long, 300 metres wide, and 2 to 60 metres thick (figure 9). The northeastern margin of the deposit is exposed at surface. The southern fringe is not yet drill defined. Figure 10 is a cross-section through the deposit.

Located about 1 kilometre southeast of the Cirque deposit, the South Cirque deposit is a stratiform tabular, barite-sulphides body which is not exposed at surface. Isopachs are shown in figure 9, and a representative cross-section is illustrated in figure 11. The deposit remains open to the east, south, and north. Widely spaced drillhole intersections do not adequately constrain the overall shape of the deposit.

Both deposits consist of bedded barite and sulphides with a continuum of facies between nearly 100% barite to nearly 100% sulphides. Major minerals in decreasing order of abundance are barite, pyrite, sphalerite, and galena. Sphalerite contains less than 0.2 weight percent Fe. Trace amounts of tetrahedrite/tennantite have been observed within galena (K. McClay, personal communication 1982). Quartz, calcite, and complex barium-calcium carbonates also occur in minor amounts. Except for the sulphosalts, copper minerals have not been observed.

CIRQUE DEPOSIT

Contacts between the surrounding Gunsteel clastic rocks and the barite-sulphides of the Cirque deposit are depositional and visually abrupt. Gradational contacts occur where siltstone intraformational breccias within the deposit consist of siltstone clasts in a sulphide-rich matrix. Sulphide clasts are absent from these breccias. Thin interbeds of siliceous, carbonaceous shale (DG_{PR}) and siliceous siltstone (DA_S) locally range up to several metres in thickness; these interbeds constitute less than 10% of the deposit. Locally these interbeds can be correlated among closely spaced drill intersections. Stockworks, disturbed bedding zones, or alteration halos have not been recognized within the surrounding Gunsteel formation.

Mineral Facies

The Cirque deposit is comprised of three major ore facies: baritic facies (DB_{BS}), pyritic facies (DB_{SB}, DB_{MS}), and laminar banded pyrite facies (DG_{LB}). Table 1 briefly describes these facies, and Table II presents partial analyses of a composite sample for each facies type. The baritic and pyritic facies constitute most of the deposit; laminar banded pyrite occurs dominantly as a fringe facies within the Gunsteel siliceous shale (DG_{PR}) both above and northeast of the deposit.

The baritic facies (DB_{BS}) consists of pale grey to white, diffusely laminated, fine to medium grained barite with less than 40 percent sulphides. Sulphides occur as discontinuous, 1-5 millimetre thick, lenticular laminations of pyrite, sphalerite, and minor galena. A small proportion of the baritic facies is intraformational breccia consisting of barite and siltstone clasts in a shale, barite, and sulphides matrix.

The pyritic facies (DB_{SB}, DB_{MS}) is distinguished from the baritic facies by its greater sulphide content (greater than 40 percent). It ranges from diffusely interbedded sulphides and barite to nearly 100% sulphides. Mineralogy consists of pyrite, barite, sphalerite, and galena with lesser quartz and carbonate. Cross-cutting, sharp-edged veins to diffuse pods of coarsely crystalline barite with patches of coarse galena are restricted to the pyritic facies.

The laminar banded pyrite facies (DG_{LB}) consists of 0.1 to 20 centimetre laminae to beds of framboidal pyrite in siliceous black shale. Generally the siliceous shale interbeds constitute 50 to 90% of the unit. Sphalerite, galena, and barite occur as sparse, disseminated grains within the pyritic layers. This facies is responsible for the strong lead and zinc geochemical anomalies associated with the siliceous shale (DG_{PR}) unit up-dip from the deposit.

The overall facies distribution within the deposit is shown in figure 12. In plan the pyritic facies predominates in the north, and the baritic facies predominates in the south. In cross-section the baritic facies forms an envelope partially surrounding the pyritic facies. Laminar banded pyrite occurs as a fringe facies and minor constituent of the deposit. This facies is located primarily to the east and immediately above the deposit (figure 10). A portion of the laminar banded pyrite beds east of the deposit are interpreted as lateral stratigraphic equivalents of most, if not all, of the barite-sulphide lens forming the main deposit.

Mineral Textures

K. McClay (personal communication 1982; 1983) has completed a preliminary textural study of sulphide-rich facies within the Cirque deposit. All facies exhibit a combination of depositional-diagenetic and deformational features. Since pyrite is the main sulphide phase present, pyrite textures dominate the sulphide-rich facies. The following discussion considers first the primary growth textures and then the deformation overprint textures. Ores have been divided into massive and laminated types for this discussion.

In the massive ores pyrite typically occurs as colloform aggregates ranging from $10\mu m$ to $400\mu m$ in diameter. Locally the pyrite grains are euhedral; commonly they display concentric growth zoning patterns. Colloform pyrite primarily contains $10\text{-}40\,\mu m$ concentric sphalerite interlaminae. The interlaminae often display radial growth features. Galena occurs as interlaminae in the pyrite aggregates in only minor amounts.

Galena, sphalerite, and barite occur predominantly in the massive ores as coarse, irregular to subhedral, interstitial grains. Concentric growth zoning is common in sphalerite and rare in galena. Grain size ranges up to 600μm although typically grains are about 100μm in diameter.

In contrast, pyrite in the laminated ores typically consists of 10-40 μm spheroidal framboidal clusters of 1-2μm euhedral pyrite crystallites. Locally the clusters are partly to completely enclosed by concentric or radiating pyrite shells. Small colloform aggregates (up to 100μm) of pyrite occur in lesser amounts. Minor galena occurs as 1-5μm inclusions in the pyrite framboidal structures.

Sphalerite, galena, and barite in the laminated ores also dominantly occur as large (20-100μm) irregular to subhedral grains or aggregates of grains forming a matrix for the framboidal pyrite. Sphalerite grains commonly display concentric growth zoning.

Both massive and laminated ores display deformation and recrystallization textures (K. McClay 1983); the S_1 cleavage can be recognized in all samples. Massive and colloform pyrite aggregates in the massive ores typically display cataclastic textures; pyrite grains are fragmented with the fractures being infilled by remobilized, fine-grained galena. These features define the S_1 cleavage.

Sphalerite, galena, and barite interstitial grains in the massive ores are partly to completely recrystallized and commonly display lobate grain boundaries and triple point junctions. Primary growth zoning is partly to completely destroyed during recrystallization.

In the laminated ores the S_1 cleavage is typically delineated by spaced pressure solution striping. Pressure solution overgrowths and truncation of pyrite framboids is common. Both barite and sphalerite are partly to totally recrystallized. Primary growth zoning in sphalerite is partly to completely obliterated. Grain aggregates of sphalerite and barite are typically elongate in the plane of the S_1 cleavage.

Coarse grained colloform and massive pyrite aggregates (i.e. massive ores) are restricted to the pyritic and baritic mineral facies. Framboidal pyrite occurs in all of the three facies types. Pyrite within the baritic facies consists dominantly of framboidal aggregates in a barite and quartz matrix.

Trend Maps

Trend maps and isopach maps for the deposit were calculated using 42 diamond drill intersections. For each intersection an overall weighted average was calculated using the true thickness as calculated from the apparent thickness in drill core. This average value was then plotted at the centre of the intersection in plan projection. Normal faulting was not taken into consideration in construction of the diagrams. The margin of the deposit was taken as the 2 metre isopach.

Figure 13A illustrates isopachs for the barite and sulphides. The axis of maximum thickness trends northerly and is near the western margin of the deposit. The deposit lens is asymmetric with thickness decreasing more rapidly to the west.

Figure 13B illustrates trends for overall (Pb + Zn) combined grade. The axis of highest grade material lies just east of the thickest portion of the deposit and is rotated slightly counterclockwise with respect to it. The axes of best grade and greatest thickness coincide in the northern end of the deposit where grades are uniformly high. Zinc:lead ratios for the deposit show a zinc-rich western margin with the ratios decreasing away from the southwest corner (figure 13C). The highest grades and thickest portions of the deposit have a zinc:lead ratio between 2 and 4. Silver content correlates directly with the highest (Pb + Zn) grades (figure 13D).

SOUTH CIRQUE DEPOSIT

South Cirque is similar in many respects to the Cirque deposit. Both deposits are hosted in the same siliceous shale (DG_{PR}) of the Gunsteel formation. The deposits belong to the same barite-sulphides continuum with the same facies subdivisions. Both have a fringe laminar banded pyrite facies which occurs dominantly to the northeast and above the deposits.

Differences between the deposits consist of facies variations within and adjacent to them. In South Cirque the pyritic facies is commonly calcareous. Porcellanite, (DG_C) which occurs above and below the Cirque, is only present above the South Cirque. The South Cirque is underlain by an extensive siltstone breccia (DA_S); this breccia is thin and discontinuous beneath the Cirque deposit. Southwest of the South Cirque, the siltstones contain high grade lenses of sphalerite and pyrite; this feature cannot be compared to siltstones down-dip of the Cirque deposit due to insufficient drilling.

GOSSAN PANEL TREND MAPS

Drillhole intersections within the Gossan panel give indications of the thicknesses of different facies within the Earn Group in areas immediately adjacent to the mineral deposits. Much of this information can be displayed as a series of isopach maps (figures 14-16).

Cross-sections for both Cirque and South Cirque deposits (figures 10, 11) show that the Gunsteel formation is a broadly uniform sequence which dips moderately to the southwest. The Gunsteel also thins in the downdip direction. Figure 14 shows isopachs of the aggregate thickness of the Gunsteel formation. Although information is sparse immediately southeast of the Cirque deposit, the isopachs clearly illustrate the thinning of the Gunsteel formation to the southwest.

Deposit descriptions have mentioned the presence of Akie siltstones and siltstone breccias (DA_S) adjacent to the deposits and as thin interbeds within the deposits. Figure 15 illustrates isopachs for the aggregate thickness of DA_S within the Earn Group. For the Cirque deposit the Akie siltstones form a rapidly thickening wedge on the west and northwest margins of the deposit. The presence of sedimentary breccias forming a clastic wedge suggests proximal growth fault(s) to the west of the deposit. For South Cirque the siltstone (DA_S) consists largely of intraformational breccia forming a sheet of fairly uniform thickness beneath the ore horizon.

Figure 16 illustrates isopachs for the aggregate thickness of Earn Group between the base of the mineral deposits and the top of the Silurian siltstone. Control for the isopachs is better in the immediate vicinity of the deposits. Coincident with the outline of the Cirque deposit, the isopach map indicates a decrease in thickness of Earn Group which is roughly equivalent to the thickness of the deposit. This pattern indicates that the deposit is a barite-sulphide lens with a crudely flat top and a convex downward base.

Figure 16 also illustrates a southwest-trending, linear decrease in Earn Group thickness within the outline of the Cirque deposit. This linear feature is oblique to the main depositional axis of the deposit, and it coincides with a thinning of the Cirque barite-sulphide lens (see figure 9). These patterns suggest that depositional thinning occurred along a paleohigh before and during deposition of the barite-sulphides. The exact form and trend of the paleshigh is not tightly constrained because several diamond drillholes in this area were stopped short of the Silurian siltstone.

In the vicinity of South Cirque, figure 16 delineates a northward thickening of Earn Group strata beneath the mineralized horizon. Because the South Cirque deposit has a relatively uniform thickness, this northward thickening is not related to the shape and thickness of the deposit. Assuming that the bottom of the mineral deposit corresponds roughly to a time line, this thickening wedge of Earn Group may have onlapped unconformably toward the south on to the surface of the Silurian siltstone. The trend of the isopachs is transverse to the Mesozoic structural grain and is therefore probably not related to Mesozoic deformation.

The greatest thickness of Earn Group beneath the mineral deposits in figure 16 trends westerly through the area between Cirque and South Cirque deposits. The Gunsteel formation in this area does not reflect this rapid increase in Earn Group isopachs immediately south of the Cirque deposit (figure 14). Isolated diamond drillholes which have penetrated the upper portion of this thick Earn Group succession beneath the Gunsteel formation intersected the Akie formation (DA_p). These different features suggest that the zone of greatly thickened Earn Group represents a syndepositional sub-basin, possibly related to transverse growth faults. This possible sub-basin is not directly related to the mineral deposits. At the very least, the top of the Silurian siltstone is an onlap unconformity with a rapidly varying topography.

DISCUSSION AND CONCLUSIONS

Recently much interest has been generated in depositional and genetic models for stratiform, sediment-hosted, massive sulphide deposits The Cirque deposits are clearly of this class. Overviews of deposits and models have been presented by Gustafson and Williams (1981) and Large (1983). Geochemical modelling of these deposits has been attempted by Lydon (1983). These deposits are considered to be syngenetic to diagenetic, bedded, exhalative deposits. They are thought to be associated with deep fault structures that provide conduits for metal-bearing solutions. Solutions were dense saline brines with metals being transported as chloride complexes. Deposition resulted largely from a decrease in temperature and possible mixing with seawater when the brines emerged on the sea floor.

MacIntyre (1982, 1983) and Jefferson et al (1983) have presented genetic models for mineral occurrences in the Akie District. The above descriptions of the Cirque and South Cirque deposits and enclosing Earn Group strata allow several constraints to be placed on such models.

Underlying this discussion of the Cirque deposits is the assumption that they are syngenetic to diagenetic. The stratiform, strata-bound nature of the deposits, the colloform and framboidal pyrite textures, and the interlayering of barite-sulphides with fine clastic rocks on all scales all support this assumption. The presence of only minor shale interlaminae within the deposits indicates that sulphide-barite deposition was at least an order of magnitude faster than that of the enclosing clastic units. Ammonoid fossils from a baritic horizon slightly below the stratigraphic level of the mineral deposits indicate an earliest Late Devonian (Frasnian) age for deposition of the barite-sulphides. (Jefferson et al. 1983). This age is consistent with barite-sulphides mineralization in eastern Selwyn Basin (Dawson and Orchard 1982).

Earn Group Deposition

Figure 17 illustrates schematically the facies variations for Devonian-Mississippian strata in the Cirque area. Early to Middle Devonian Earn Group strata were deposited in a second order, northwest-trending, successor depositional trough within the first order Kechika Trough. The northeast margin of the trough is delineated by the Early to Middle Devonian Kwadacha reef shallow platform carbonates. Southwest of the platform Early to Middle Devonian sediments undergo a rapid facies transition through proximal carbonate debris flow sediments of the Paul River formation to marine shale basin sediments of the Earn Group. The southwest margin of the depositional trough has been removed by thrusting and subsequent erosion. Palinspastic reconstruction indicates the trough was at least 8 kilometres wide in the Cirque area.

Earn Group strata in the Cirque area are broadly divided into two overlapping stratigraphic sequences. The lower sequence consists predominantly of black siliceous shales and thin bedded porcellanites (Gunsteel formation). Quiet water, euxinic, marine, starved basin sedimentation is inferred. Deposition of the siliceous package continued at least into Late Devonian. During Early and Middle Devonian the basin containing this sequence was flanked to the northeast by the Kwadacha reef. By Late Devonian the Kwadacha reef was submerged because DA_{SS}/DG_{PR} sedimentation lapped over the limestone. This transgressien can be readily correlated with major eustatic sea-level rises in Middle to Late Devonian time (Lenz 1982). Overall this sequence received less silica through (dilution) or nondeposition of radiolaria to the northeast and southwest.

The siliceous package was broadly overlain by a sequence of soft grey shale (Akie formation) and coarse clastic rocks (Warneford formation). The Akie shale resulted from background marine shale basin sedimentation. The Warneford coarse clastics (DM_{WBX}) were distributed by a distal submarine fan complex and reworked by slumping. Renewed background marine shale basin sedimentation with periodic turbiditic influxes of silt and sand was recorded by the uppermost Warneford rusty shale unit

(DM_{WR}).

Interfingering of the siliceous sequence and the nonsiliceous sequence both laterally and vertically on large and small scales suggests smaller sub-basins within the overall depositional trough. Paleontologic control is needed to delineate facies distributions through time.

Barite-Sulphides Deposition

Empirically the mineral deposits are associated with the Gunsteel formation. The siliceous nature of the Gunsteel is biogenic in origin, and by itself does not appear to indicate abnormal depositional conditions. Although highly variable in thickness, the Gunsteel formation is regionally widespread and also occurs where no mineral occurrences have been discovered. The high silica content of the Gunsteel may possibly be related to mass kills, organic blooms, preferential deposition, or preferential preservation due to silica-rich bottom waters (Jefferson et al. 1983).

At least three separate baritic horizons distinct from the mineral deposits have been recognized, indicating intermittent exhalative activity through most of the time of Gunsteel deposition.

In the immediate vicinity of the deposits, the isopach map of Earn Group below the base of the deposits suggests that the top of the Silurian siltstone is an onlap unconformity. Overall topography associated with this unconformity is over 150 metres. Isopachs (figure 16) also suggest a sub-Gunsteel depositional trough/basin trending westerly between the Cirque and South Cirque deposits. These features suggest the presence of sub-basins in the general vicinity of the deposits; the sub-basins, however, cannot be directly correlated with the geometry of the mineral deposits.

The mineral deposits are intimately associated with siltstone and siltstone breccia. These siltstones and breccias thicken rapidly west of the Cirque deposit. The presence of a clastic wedge containing abundant sedimentary breccias suggests proximal growth fault(s) to the west of the mineral deposits. Individual movements of the growth fault(s) could have generated the siltstone interbeds within the deposits. Further, growth fault(s) would provide conduit systems for upwelling metalliferous saline brines.

The Cirque deposit contains a systematic internal zonation in distribution of mineral facies and metal ratios. This regular zonation suggests that the deposit is related to a single exhalative vent. Large (1983) has noted that similar deposits typically show the element zonation Cu-Pb-Zn-(Ba) laterally away from the source or vent area. Fe may be concentrated near the source area (e.g. Sullivan-Hamilton et al. 1983) or distally away from the source area (e.g. Tynagh-Large 1983). Using this model the metal ratio zonation at Cirque indicates a vent area away from the southwest margin of the deposit. When combined with the distribution of pyritic and baritic facies, a vent on the north end of the deposit is suggested. Both barite and zinc content generally increase away from this proposed vent area. A reasonable depositional model requires the development of a shallow sub-basin which is filled by dense saline brines with rate of subsidence being roughly equivalent to rate of accumulation of barite and sulphides.

The metalliferous brine pool(s) collected in an axial trough formed at the base of the siltstone clastic wedge located west of the deposit. This particular configuration is shown schematically in figure 18. Perhaps it is not coincidence that the greatest thickness of siltstone is developed in the same general location as the proposed vent area. Barite-sulphide deposition for the South Cirque deposit is inferred to be associated with a separate hydrothermal vent.

Intermixing of barite and sulphide minerals in the Cirque deposits contrasts with the separation of sulphide minerals and barite in other deposits such as Meggen (Krebs 1981) and Tom (Carne 1979). Similarly Fe (pyrite) at Cirque occurs both as a proximal (massive sulphides) and distal (laminar banded pyrite) facies. Models for deposition of sulphides and barite at Cirque must consider both of these aspects of the deposit.

The absence of copper minerals, the preservation of pyrite framboids, and the absence of a visible hydrothermal alteration halo all suggest a low temperature for mineralization (Large 1983). Recently Gustafson and

Williams (1981) have noted that detailed studies have revealed subtle alteration zoning patterns in deposits previously considered unaltered. Additional detailed petrographic and geochemical work is required to provide tighter constraints on temperature and fluid compositions for the Cirque deposits.

Deformation

All strata in the Cirque area contain both primary depositional features (bedding, pyrite framboids, graded beds) and deformation features (slaty cleavage, minor folds, remobilized galena in pyrite fractures). Previously it was noted that facies variations in a southwest-northeast direction have been telescoped by folding and faulting during the Laramide deformation. Because of the structural complications in the Cirque area, it is necessary to consider the extent to which depositional features such as unit thickness, isopachs, and zoning trends may have been subsequently modified during deformation.

Detailed surface mapping and diamond drilling at Cirque indicate that in the immediate vicinity of the mineral deposits Earn Group strata have been structurally thickened primarily by repetition along northeast-directed thrust faults. Large scale macroscopic folds have not been recognized within the separate structural panels. Although the dominant mesoscopic structural feature is the pervasive slaty cleavage, bedding is generally visible and typically intersects the slaty cleavage at a moderate to acute angle.

Recent textural studies of deformed shales and sandstones indicate that slaty cleavage typically forms during flattening of buckle folds (Wood 1974; Onasch 1983). At low sub greenschist facies temperatures the dominant mechanism of cleavage formation is pressure dissolution although intracrystalline deformation and extension also occur (Wright and Platt 1982; Onasch 1983). Shortening normal to the cleavage commonly ranges up to 75%; this shortening is accommodated by both volume loss and extension in the cleavage plane (Wood 1974; Onasch 1983).

Preservation of delicate primary features such as framboidal pyrite laminae and the continued divergence of bedding and cleavage indicates that deformation has not strongly disrupted units on a mesoscopic and microscopic scale. The volume loss and extension associated with slaty cleavage development, however, does mean that measured thicknesses of Earn Group strata are not depositional. Nevertheless isopach maps and trend diagrams for the different clastic facies are most likely reasonable because deformation was relatively homogenous.

In the Cirque mineral deposits both brittle and ductile deformation textures are evident (McClay 1983). Framboidal pyrite shows strong pressure dissolution, and massive pyrite contains spectacular brittle blow apart textures with fractures infilled by galena. Galena, barite, and locally sphalerite contain extensive remobilization and recrystallization textures. These different features all indicate extensive deformation of the barite-sulphides bodies with probable internal folding and selective remobilization of ore minerals. Consequently trend maps, isopachs, and zoning diagrams for the mineral deposits must be considered tentative. Primary depositional patterns have most probably been significantly modified by subsequent deformation.

Exploration Parameters

In summary, the Cirque deposits appear to be related to isolated sub-basins within a larger, northwest-trending depositional trough. Indirect evidence suggests that at least part of the sub-basin development was related to growth faults with contemporaneous clastic submarine fan development. The siliceous Gunsteel formation is spatially related to the barite-sulphides deposits. A discrete hydrothermal vent is inferred for each deposit. Zonation patterns for the Cirque deposit suggest a vent at the north end of the deposit. Sulphides-barite accumulation was probably by precipitation from dense saline brine pools.

Application of these descriptive and genetic characteristics results in a useful exploration model for similar stratiform, sediment-hosted deposits within the Akie District. On a large scale the deposits are associated with the siliceous Gunsteel formation; thick accumulations of Gunsteel sequences provide excellent primary targets. Further the laminar banded pyrite facies is a distal ore facies with both the Cirque and South Cirque deposits. This pyritic facies typically has a strong geochemical lead and zinc signature in subcrop. In the Cirque area it occurs dominantly northeast of the mineral deposits; this asymmetry may not be significant away from the Cirque area. Finally, the mineral deposits are intimately associated with a thick to thin sequence of Akie siltstones and siltstone breccias. This common association with Akie siltstones is a subtle feature which is most noticeable in diamond drill intersection; it is present only in the immediate vicinity of the deposits.

ACKNOWLEDGEMENTS

Unravelling of the Cirque geology has been a team effort by D. Kilby, C. Jefferson, L. Pigage, and W. Roberts. We have spent many long hours discussing the implications of a particular geologic interpretation. G. Gorzynski, D. Perkins, V. Sterenberg, and B. Youngman have contributed to our knowledge of the Cirque area. Reviews by D. Kilby, C. Jefferson, S. Gordey, and two reviewers have improved the manuscript. Because I have had the opportunity to 'final filter' the geologic information, flawed interpretations and ideas presented in this paper must remain my responsibility.

The Yukon chapter of CIM is acknowledged for making possible the presentation of this information. J. Morin has patiently expressed an interest in receiving a completed manuscript. Cyprus Anvil Mining Corporation and Dome Petroleum are thanked for permitting the publication of this paper. V. VanderPutt has typed and retyped the many versions of the manuscript.

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TABLE I

STRATIGRAPHY, CIRQUE AREA

DEVONIAN-MISSISSIPPIAN

EARN GROUP

WARNEFORD FORMATION

DM_{WR}	Rusty Shale	- Shale with sandstone interbeds: shale is soft, grey, silty, thick bedded, laminated, weathers rusty brown; sandstones are pyritic quartzarenites, laminated and ripple cross-laminated, rusty and orange weathering.
DM_{WBX}		- Shale: dark grey to black, blue grey to rusty weathering, hard, graphitic, common intraformational breccia and/or chert and quartz sand to pebble conglomerate lenses.

AKIE FORMATION

DA_{PS}	Pinstriped Shale	- Shale: dark brown-grey, light grey to rusty brown weathering, silty, distinctly laminated.
DA_{S}	Siltstone	- Siltstone: light to dark grey, speckled, variably calcareous, planar to irregularly laminated + burrow mottled; locally intraformational breccia.
DA_{P}	Phyllitic Shale	- Shale: light to medium grey, rusty brown weathering, faintly laminated, soft; locally contains thin pyritic siltstone lenses and beds which weather bright orange.
DA_{SS}	Silty Shale	- Silty shale: dark brown-grey, rusty brown weathering, medium hard to soft, thick bedded, massive to indistinctly laminated, with spruce-bark flaky cleavage, grades laterally into DG_{PR}.

GUNSTEEL FORMATION

DG_{C*}		- Porcellanite: ribbon bedded black chert overlying DM_{WBX}, locally contains large limestone concretions, also contains a thin laminated /blebby barite horizon.
DG_C		- Porcellanite: dark grey to black, silvery grey weathering, ribbon bedded with graphitic shale partings and interbeds, contains thin laminated/blebby barite horizons.
DG_{PR}	Pregnant Shale	- Shale to porcellanite: dark grey to black, silvery-grey to rusty weathering, silty; bedding thicker than 30 cm, massive to laminated, planar slaty cleavage in outcrop, nodules and laminae of barite, pyrite and calcite.

ORE FACIES

DB_{MS}	Pyritic	- Pyrite, sphalerite $\pm$ galena: massive, medium to coarsely crystalline, $\pm$ minor barite.
DB_{SB}	Pyritic	- High grade sphalerite, galena and pyrite with $20\% <$ barite $< 60\%$: crudely laminated, crystalline.
DB_{BS}	Baritic	- Barite with $< 40\%$ pyrite and $< 10\%$ (PB + Zn): finely crystalline, irregularly to discontinuously interlaminated.
DG_{LB}	Laminar banded pyrite	- Pyrite $> 10\%$: very fine grained, very finely laminated, interlaminated with siliceous + calcareous shale and siltstone in beds 1 to 20 cm thick, can have visible galena and sphalerite.

EARLY - MIDDLE DEVONIAN

PAUL RIVER FORMATION

D_{PL}		- Porcellanite: ribbon bedded, with fossiliferous limestone breccia beds. Shale: black, intraformational breccia with shale, siltstone, limestone clasts.
D_{KR}	Kwadacha Reef	- Limestone: grey, thick, massive bedded, fossiliferous - stromatoporoid, coral, crinoid debris with some fossils in growth position.

UNCONFORMITY

ORDOVICIAN - SILURIAN

ROAD RIVER GROUP

S_{ss}	Silurian Siltstone	- Siltstone: light orange-weathering, dolomitic, with common burrows, feeding fans and burrow mottling, can be distinctly planar laminated.
		- Limestone: grey weathering, laminated or burrow mottled, silty, there may be several horizons within Silurian siltstone.
		- Siltstone: shaly, recessive, laminated, variably calcareous, includes black chert lenticles, occurs at top, middle and bottom of Silurian silstone.

LOCAL UNCONFORMITY

	Silurian Chert	- Porcellanite: streaky white-stiped, ribbon bedded, with black calcareous graptolitic shale partings, some dolomitic siltstone and large limestone concretions.

Silurian Limestone

- Limestone: grey, rhythmic, flaggy to blocky bedded, calcisiltite and fine calcarenite turbidites with graptolitic shale interbeds.

LOCAL UNCONFORMITY

ORDOVICIAN SHALE

O_{RR}

- Shale: black, silvery-grey to black weathering, variably calcareous, graptolitic, minor chert, local barite horizons, thickness ranges from zero to 100 meters.

- Silty shale to siltstone: dark grey, tan to pink weathering, laminated, graptolitic, variably calcareous, contains the Ospika Volcanics (O_V).

OSPIKA VOLCANICS

O_V

- Mafic to andesitic flows, locally amygdaloidal and phyllitic, massive flows to variolitic pillows.

- Mixed volcanic and shale intraclast breccia and conglomerate.

- Tuff and breccia: orange-weathering, flattened, siliceous to highly calcareous.

TABLE II

Grades of mineral facies, Cirque deposit, from assay of three composite samples. Composite samples were made by blending of material from 29 drill intersections. Specific gravities (S.G.) were determined for selected typical samples. Table from Jefferson et al (1983).

FACIES	PB(%)	Zn(%)	Ba(%)	Fe(%)	Ag(g/t)	S.G.
Baritic	1.3	6.2	40.7	6.2	33	4.2-4.4
Pyritic	3.3	11.1	19.4	17.9	73	4.4-4.7
Laminar	0.6	4.0	2.0	--	24	2.7-3.1

Figure 1. Location of major stratiform zinc-lead districts within Selwyn Basin and Kechika Trough in northwestern Canada.

Figure 2. Location of stratiform barite-sulphides occurrences in the Akie District. Size of circle is roughly proportional to economic importance. Location of figure 3 approximately corresponds to the circle for Cirque.

Figure 3. Simplified geology map and cross-section for Cirque and Elf belts of Earn Group strata, Cirque area. Different structural panels are labelled. Deposits are shown projected vertically to surface. Projected position of South Cirque deposit on cross-section X-Y is shown in black. Locations of detailed geology maps (figures 5-7) and cross-sections (figures 10-11) are shown.

Figure 4. Stratigraphy, Cirque area. Mineral deposits are shown in black. Symbol f indicates position of dated ammonoid samples. Nomenclature from MacIntyre (1983) is shown for comparison.

Figure 5. Geology map, Elf belt of Earn Group strata. Locations of stratigraphic columns A and B (figure 8) are shown. For legend and explanation of symbols see Table I and figure 8.

Figure 6. Geology map of Warneford and Tuff structural panels, Cirque belt of Earn Group strata. Locations of stratigraphic columns C, D, E, and F (figure 8) are shown. For legend and explanation of symbols see Table I and figure 8.

Figure 7. Geology map of Gossan and Barren structural panels, Cirque belt of Earn Group strata. Locations of stratigraphic columns G, H, and J (figure 8) are shown. Shaded area in Gossan panel is subcrop exposure of Cirque deposit.

Figure 8. Stratigraphic cross-section of Devonian-Mississippian rocks for Cirque area. Locations of stratigraphic columns are indicated in figures 5-7. For explanation of legend see Table I. The horizontal datum is chosen as the top of the lower Gunsteel sequence.

Figure 9. Isopach map of the baritic and pyrite facies, Cirque and South Cirque deposits. Contours at 2, 10, 30, and 50 metres. All data points are drill intersections. Cirque deposit is an asymmetric lens which subcrops along its northeast margin. South Cirque is a blind deposit whose margins have not yet been drill defined. Locations of cross-sections 283+00 (figure 11) and 297+50 (figure 10) are shown.

Figure 10. Vertical section 297 + 50 N through Cirque deposit unfaulted interpretation. See Table 1 for explanation of legend.

Figure 11. Vertical section 283 + 00 N through South Cirque deposit. See Table 1 for explanation of legend.

Figure 12. Distribution of baritic and pyritic facies, Cirque deposit. Viewer's perspective is from the south; cross-sections trend 050°. Pyritic facies dominates in north end of deposit. Baritic facies forms partial envelope around pyritic facies. Diagram from Jefferson et al. (1983).

Figure 13. Trend maps for Cirque deposit. All data points are weighted averages of drill intersections.

A. Isopachs of baritic and pyritic facies. Contours at 2, 20, 40, and 60 metres. Deposit margin taken as 2m. isopach. Location of section 297+50 (figure 10) is shown.

B. Overall (Pb+Zn) grade. Contours at 6, 9, 12 wt % (Pb+Zn).

C. Zind:Lead ratios by weight. Contours at 3, 5, and 7.

D. Overall Ag grade. Contours at 20, 40, and 60 grams/tonne.

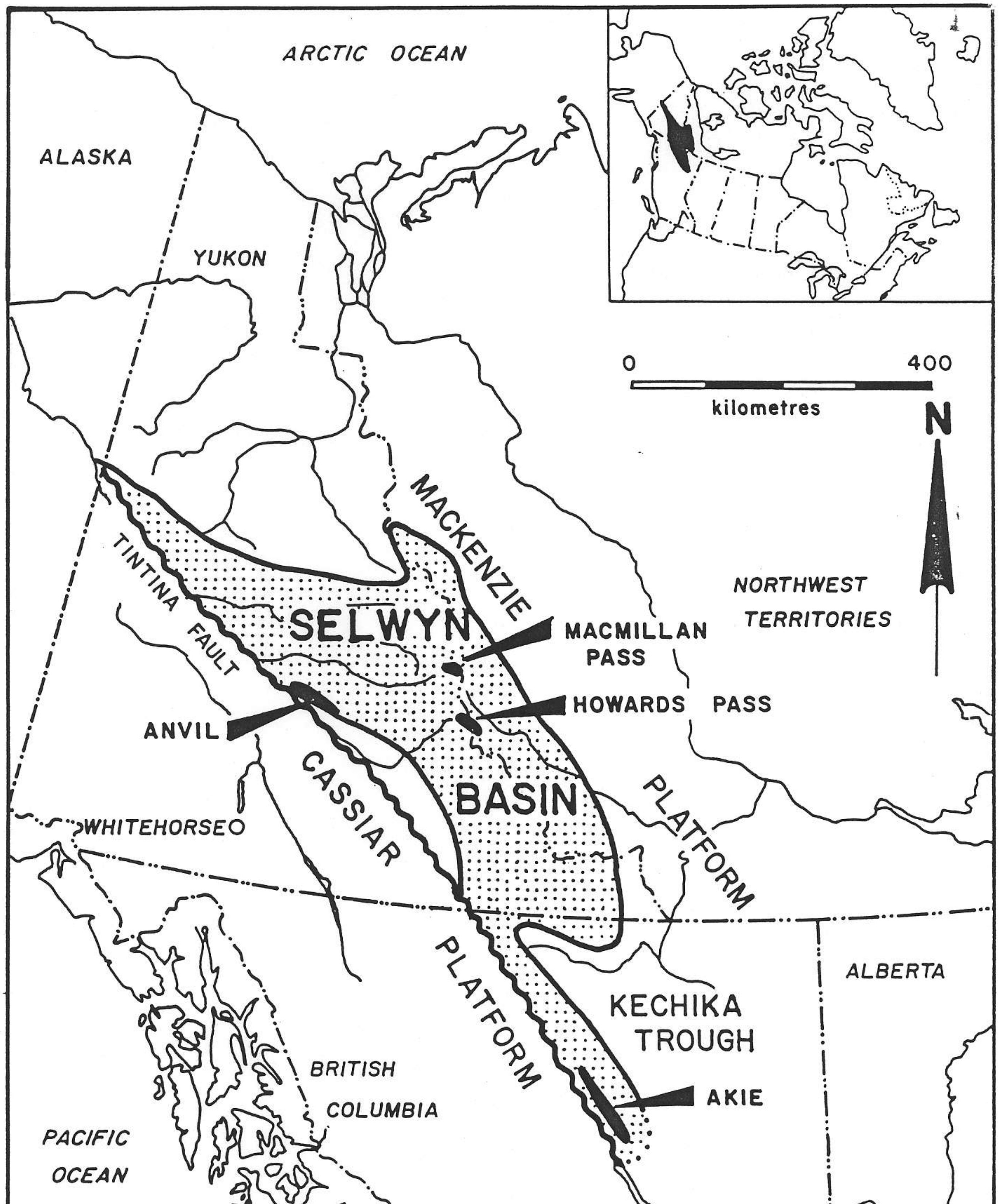
Figure 14. Isopach map, Gunsteel formation, Gossan panel. Contours at 20, 60, 100, 140, 180, and 250 metres. Dotted lines correspond to 2m. isopach outlining Cirque and South Cirque mineral deposits (see Figure 9).

Figure 15. Isopach map, Akie siltstone, Gossan panel. Contours at 1, 10, 30, 50, and 70 metres. Dotted lines correspond to 2m. isopach outlining Cirque and South Cirque mineral deposits.

Figure 16. Isopach map, Earn Group between base of mineral deposits and top of Silurian siltstone. Contours at 10, 20, 40, 60, 80, and 100 metres. Dotted lines correspond to 2m. isopach outlining Cirque and South Cirque mineral deposits.

Figure 17. Schematic facies relations for Devonian-Mississippian sediments containing the Cirque deposits. Diagrammatic time line shows that Kwadacha reef was submerged and probably buried at time of ore deposition (Frasnian). For explanation of legend see Table I and Figure 8.

Figure 18. Schematic block diagram of depositional setting for the Cirque deposits (Frasnian). Growth faults acted as conduits for hydrothermal solutions carrying metals as chloride complexes. Mineral deposits formed by precipitation from dense saline brine pools on the sea floor. Brine pools collected in small sub-basins limited to the southwest by a siltstone clastic wedge (possibly related to a fault scarp).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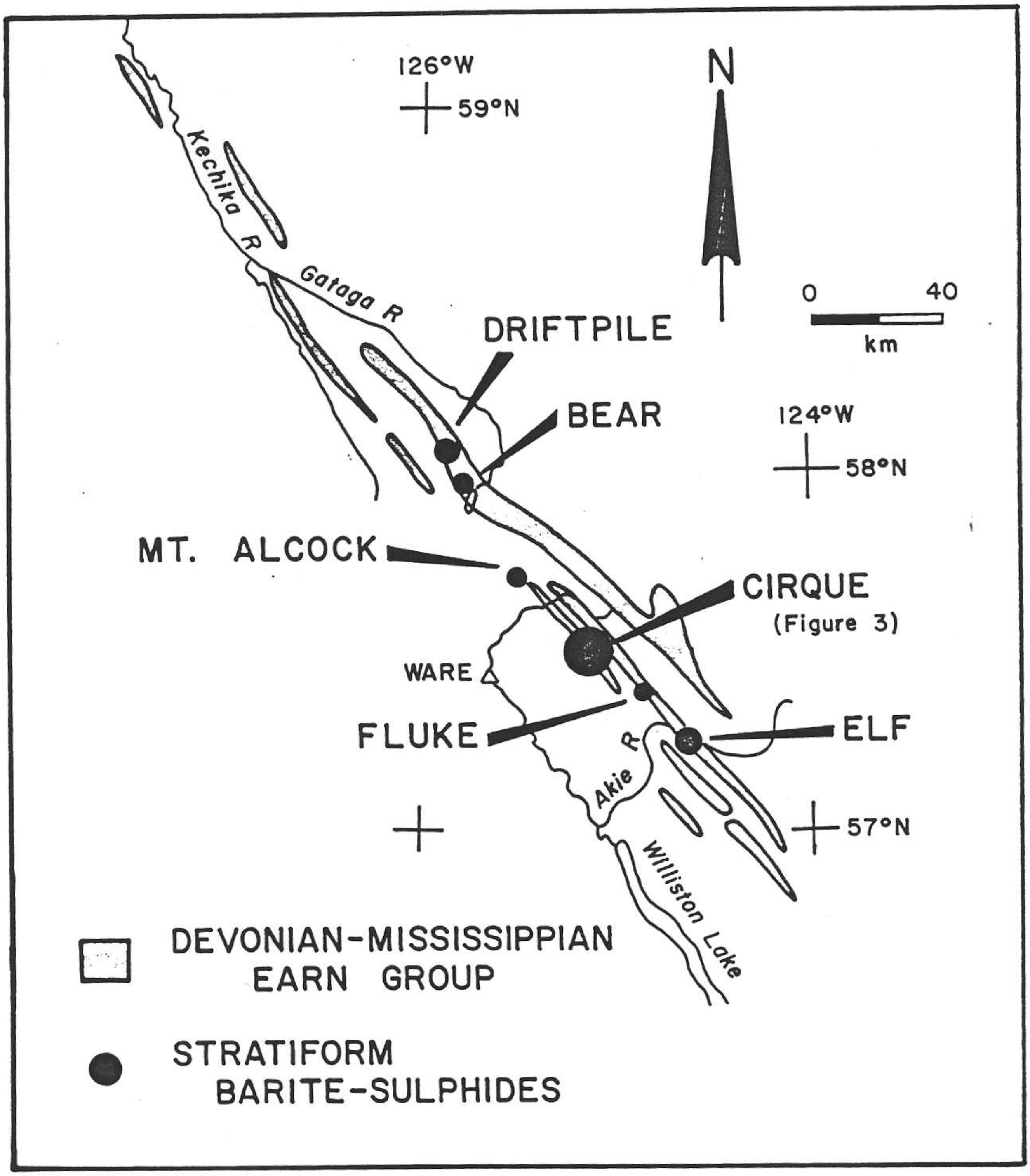

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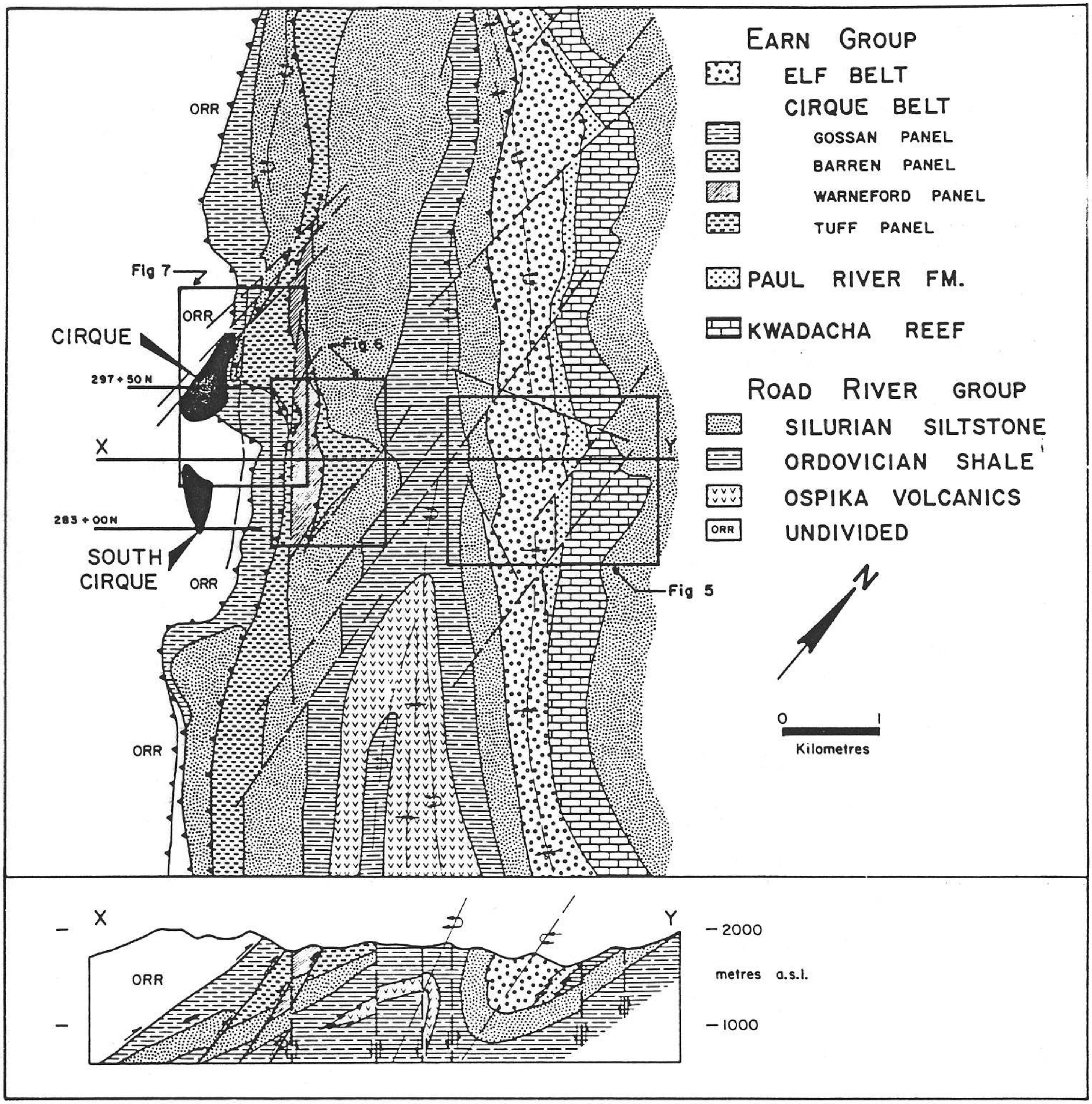

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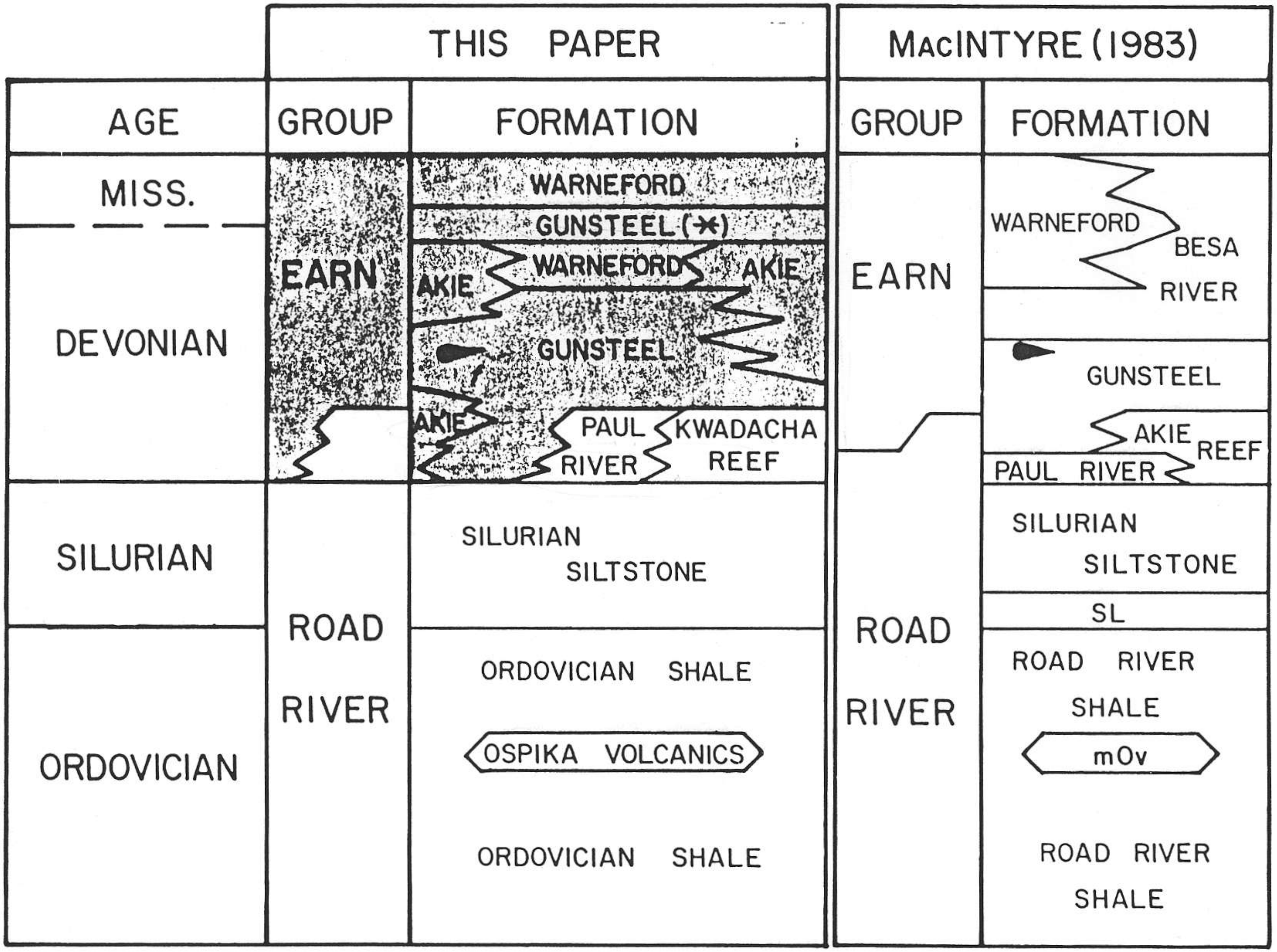

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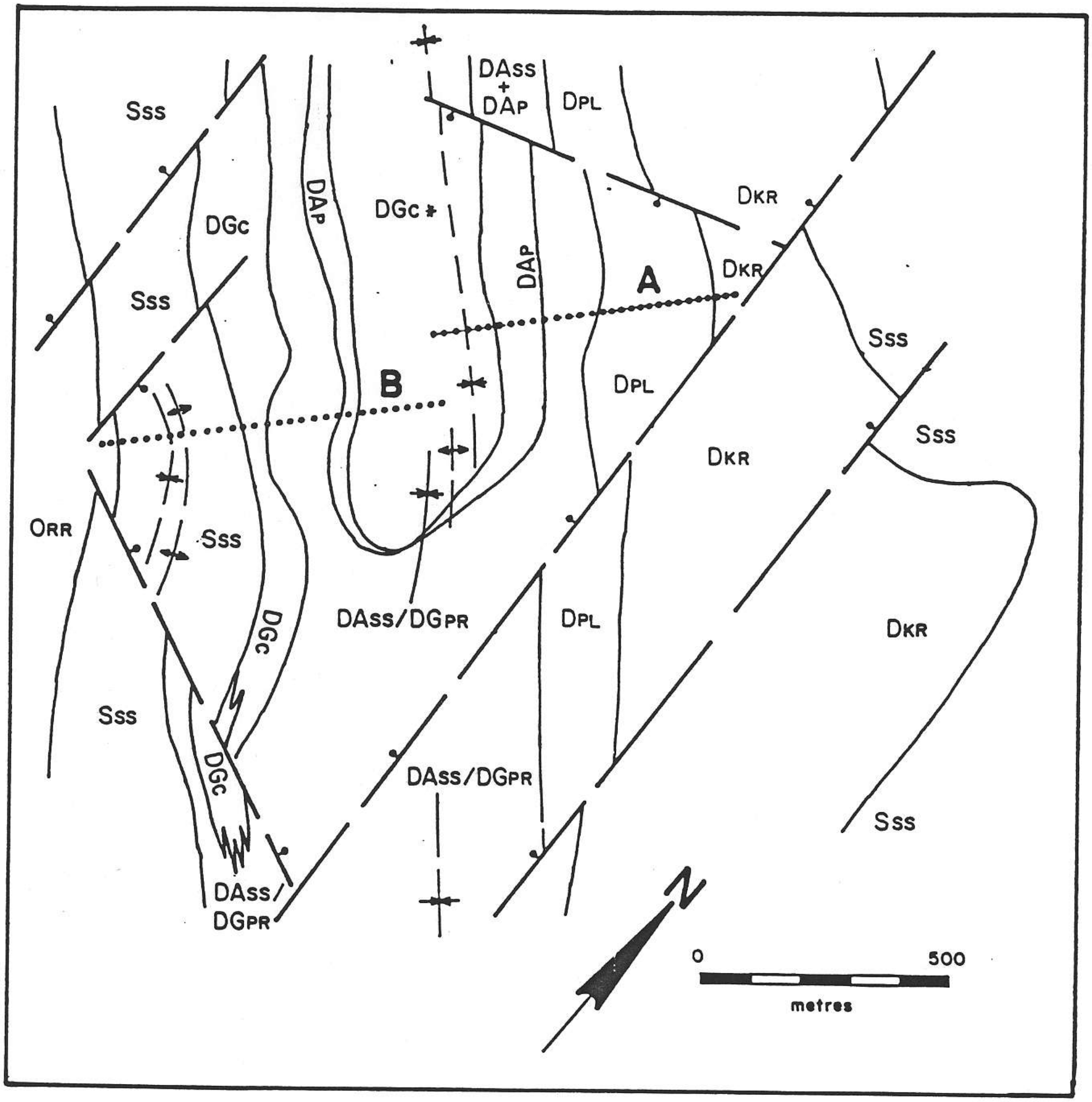

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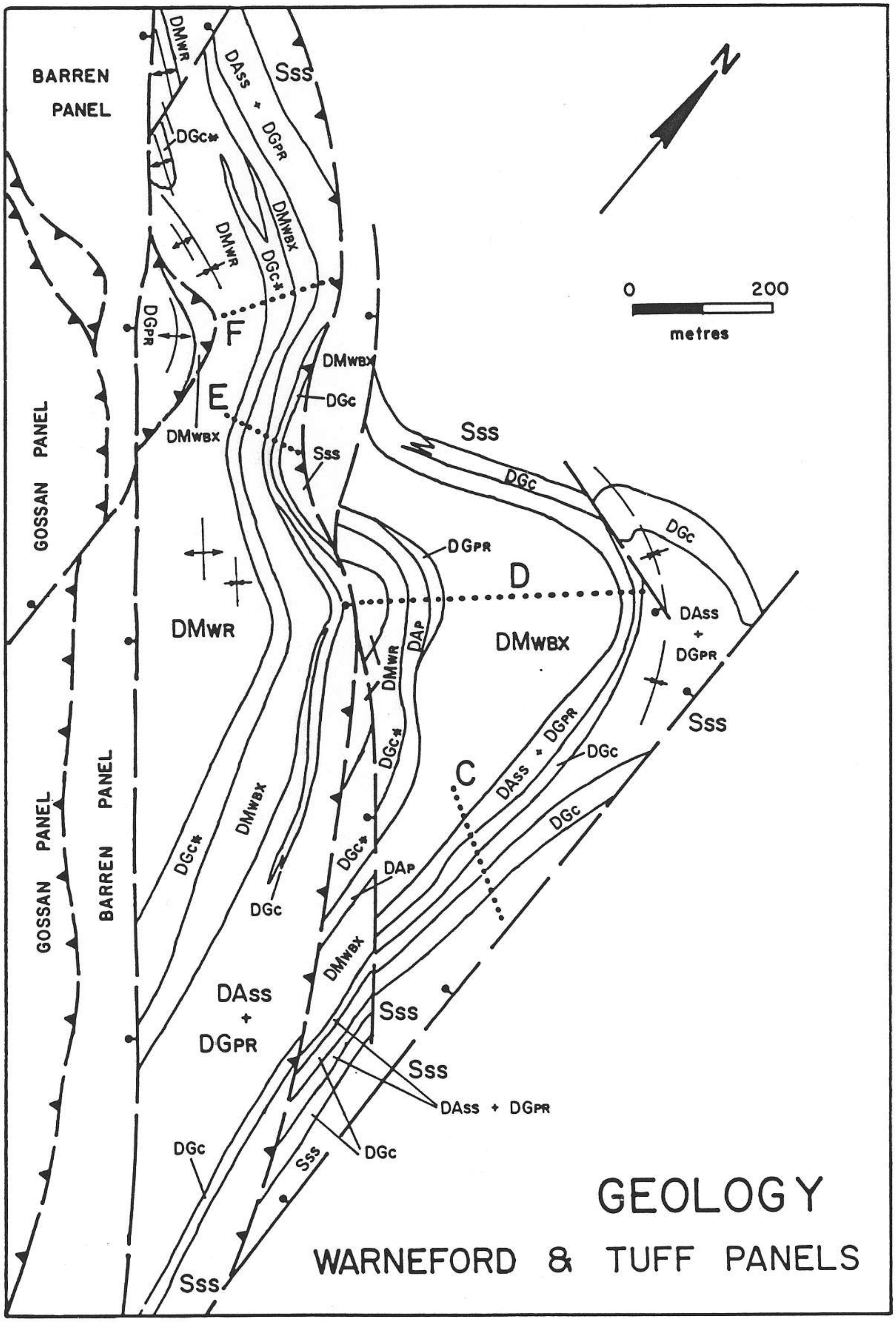
PIGAGE, L.C. Figure 5



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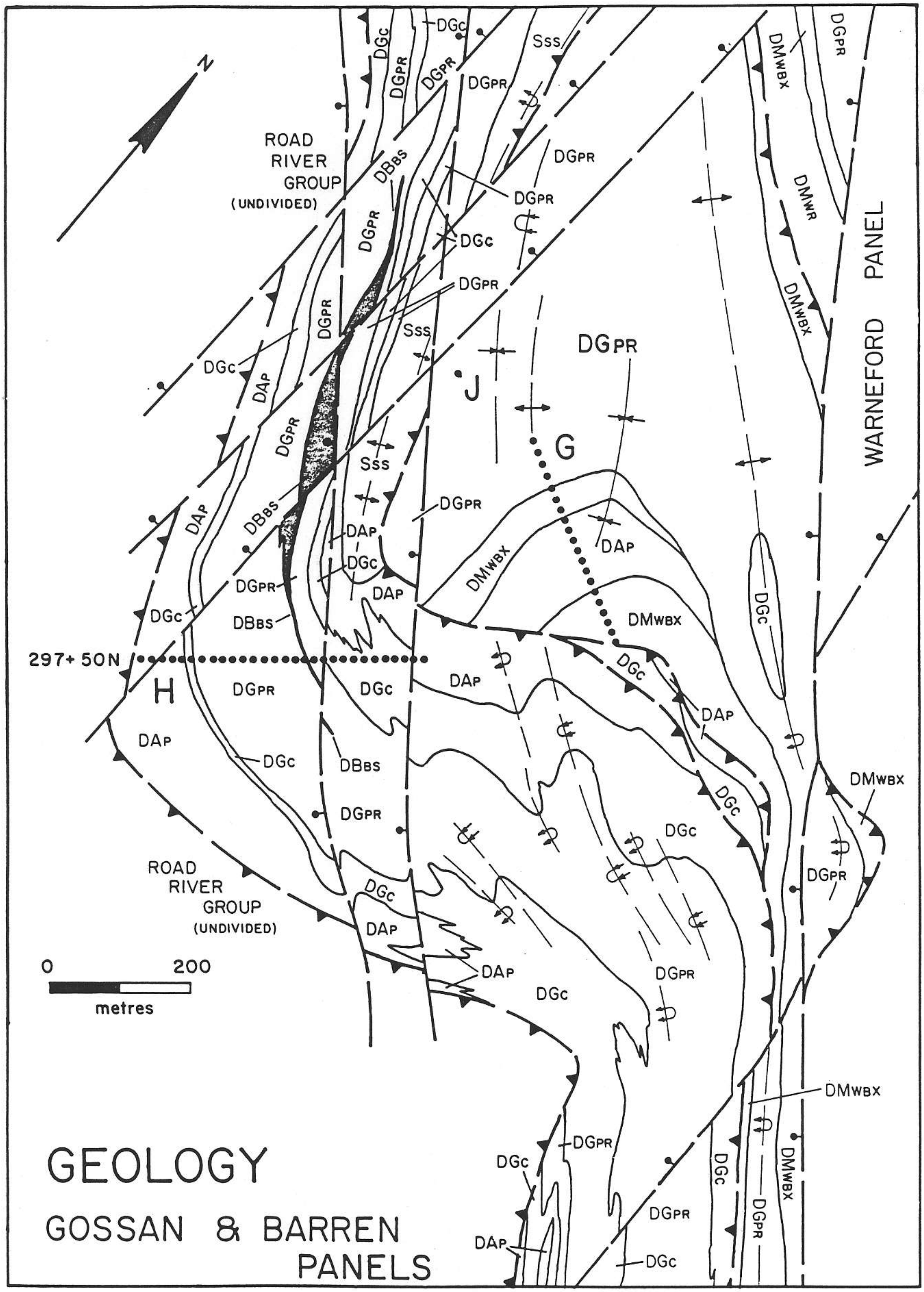
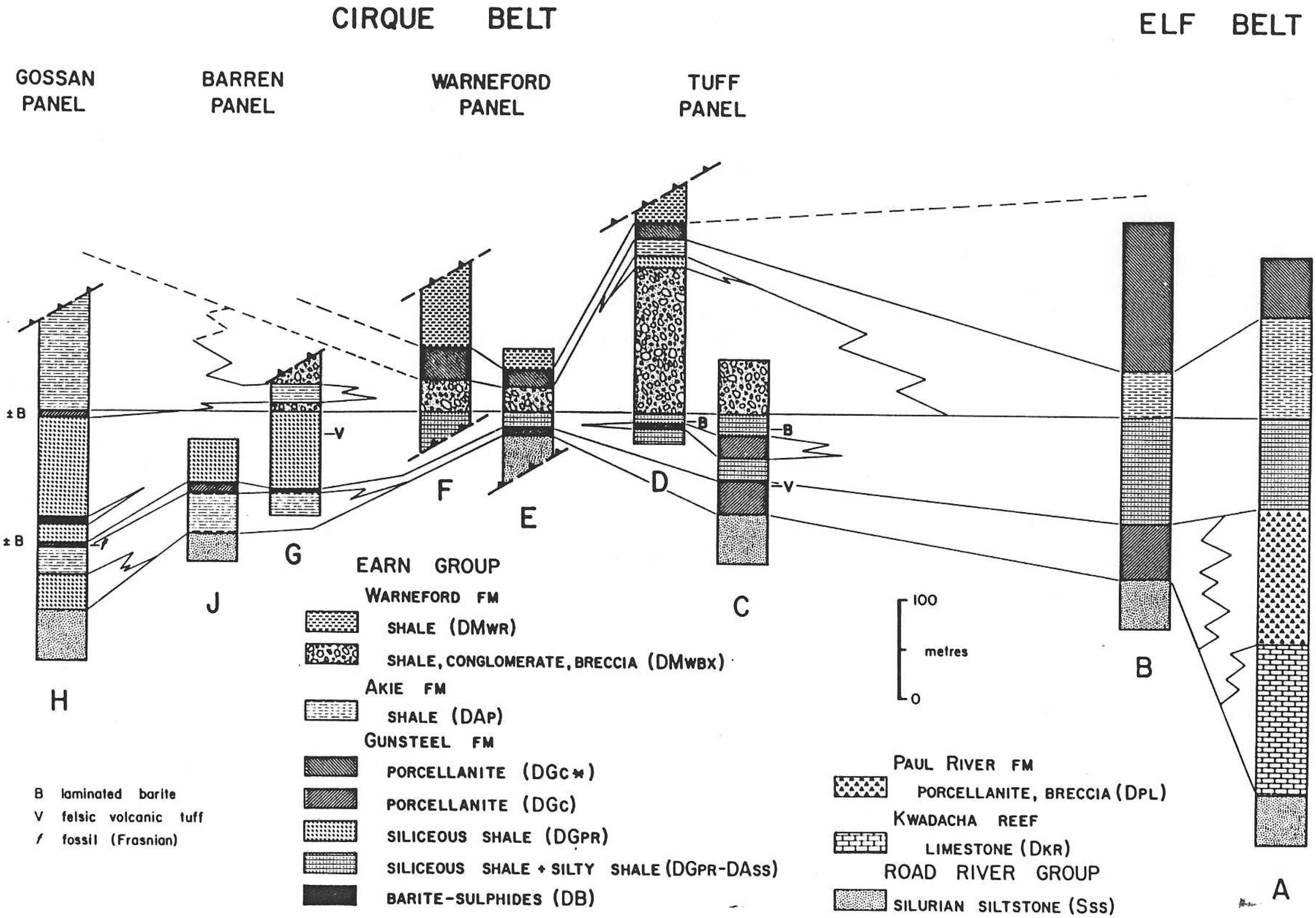
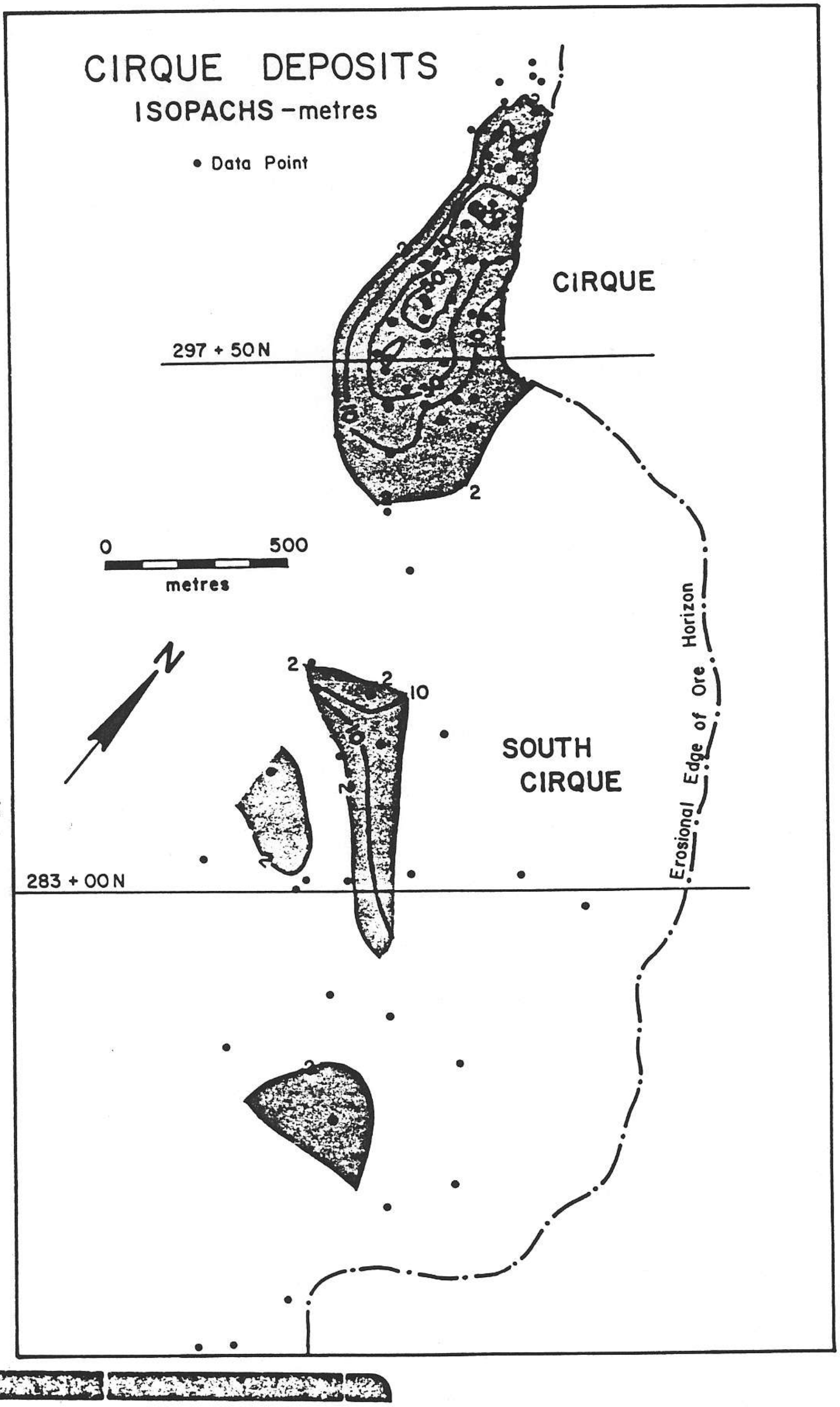


PIGAGE, L.C. Figure 7



PIGAGE, L.C. Figure 8



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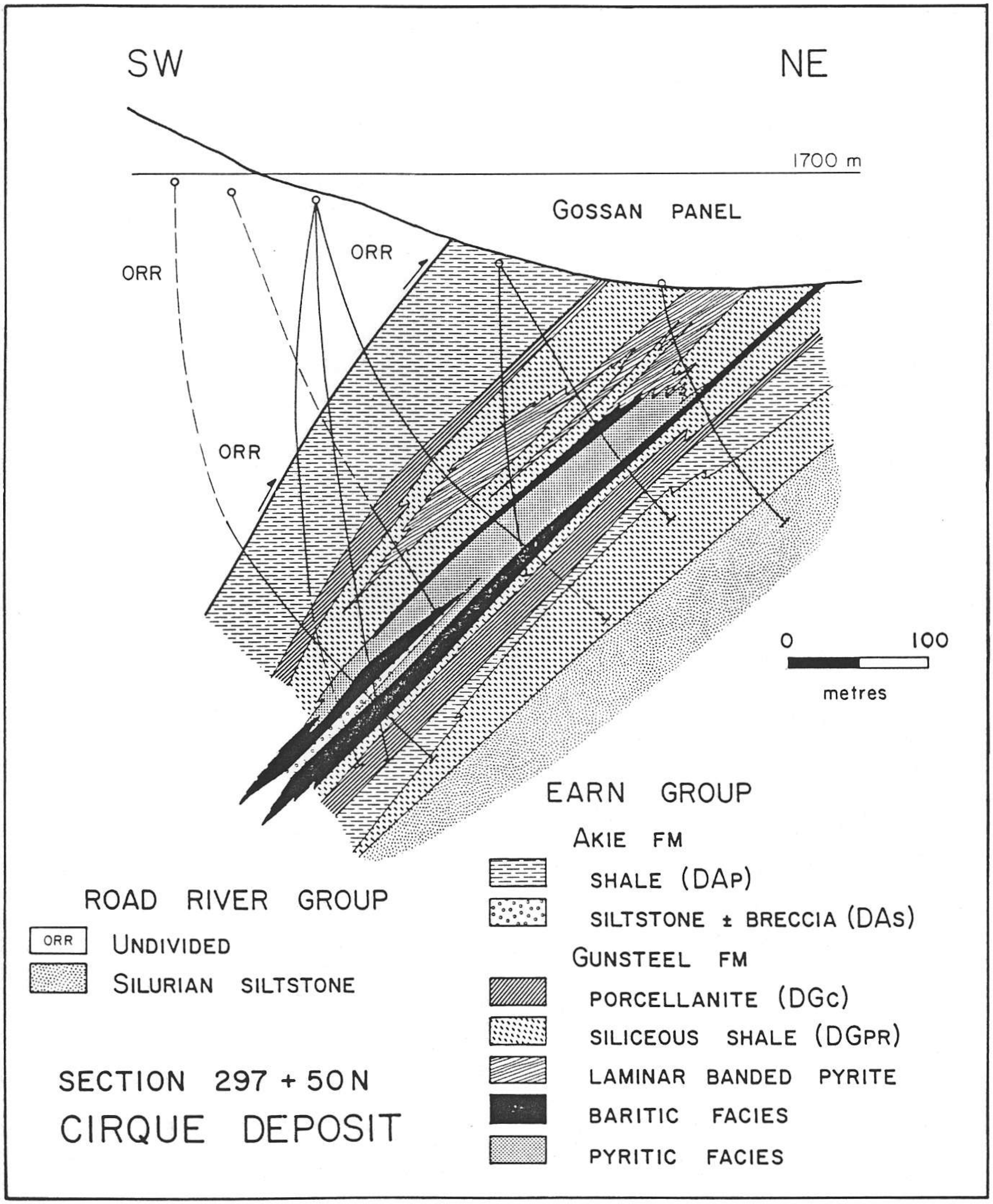

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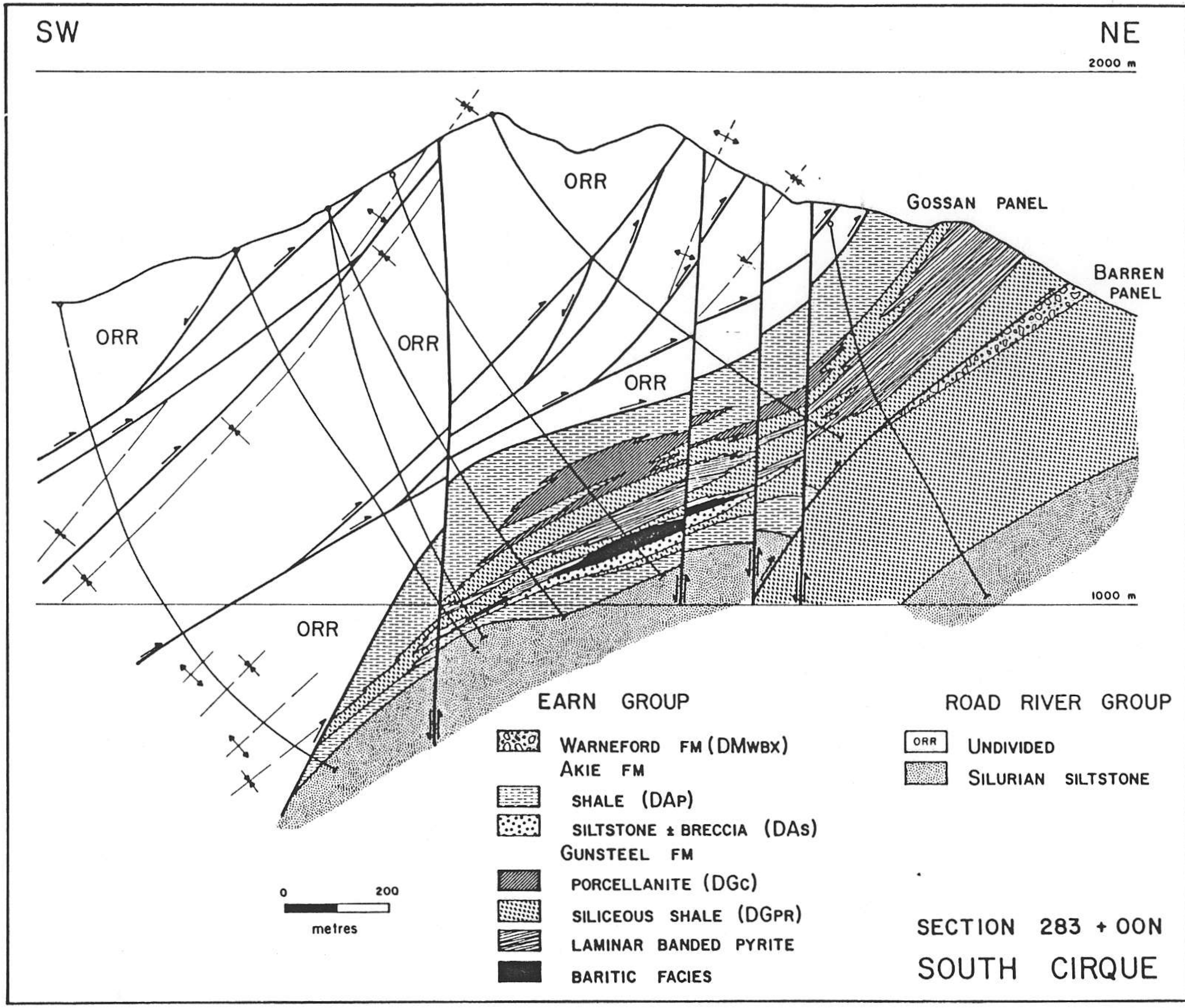

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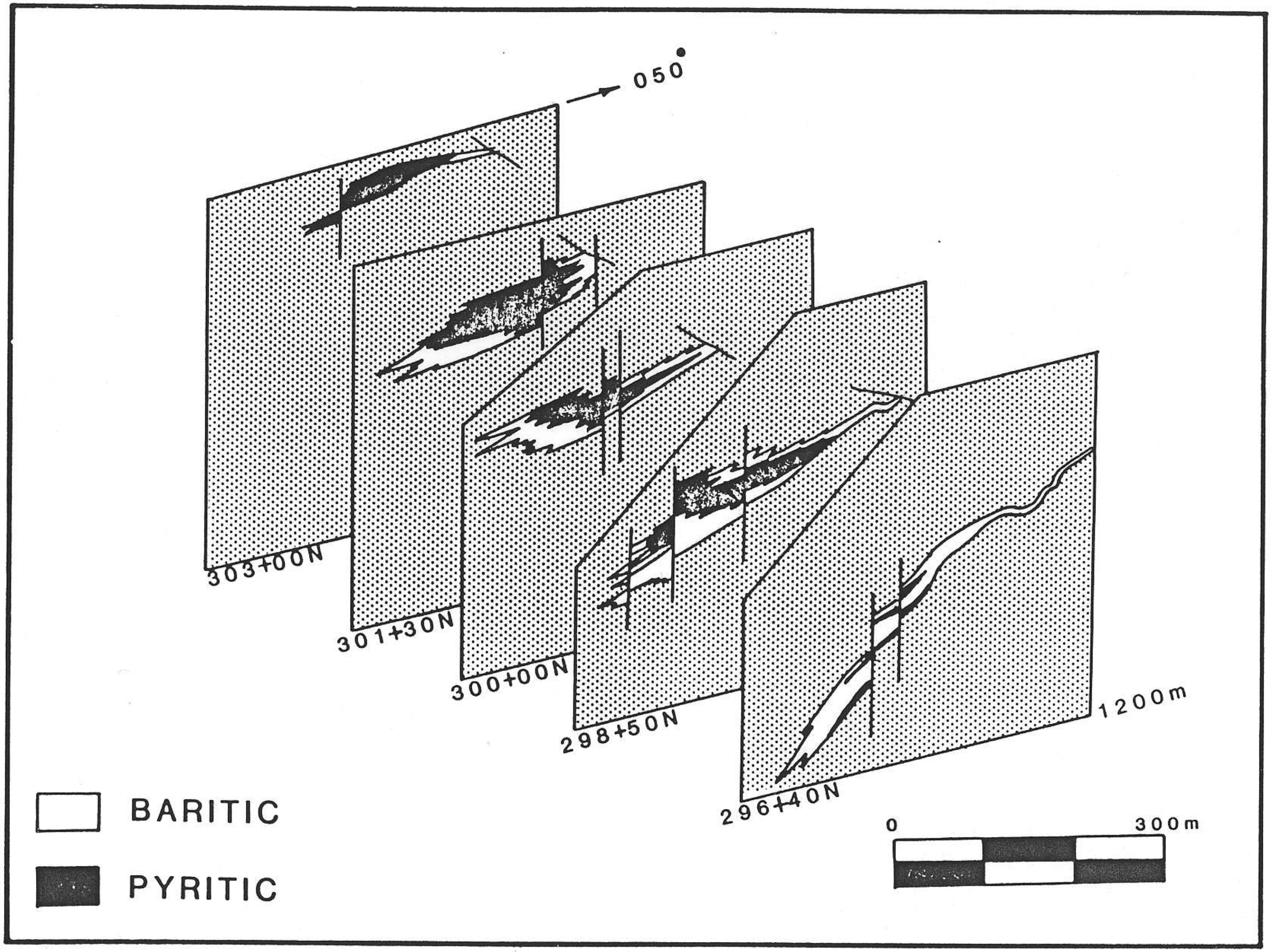

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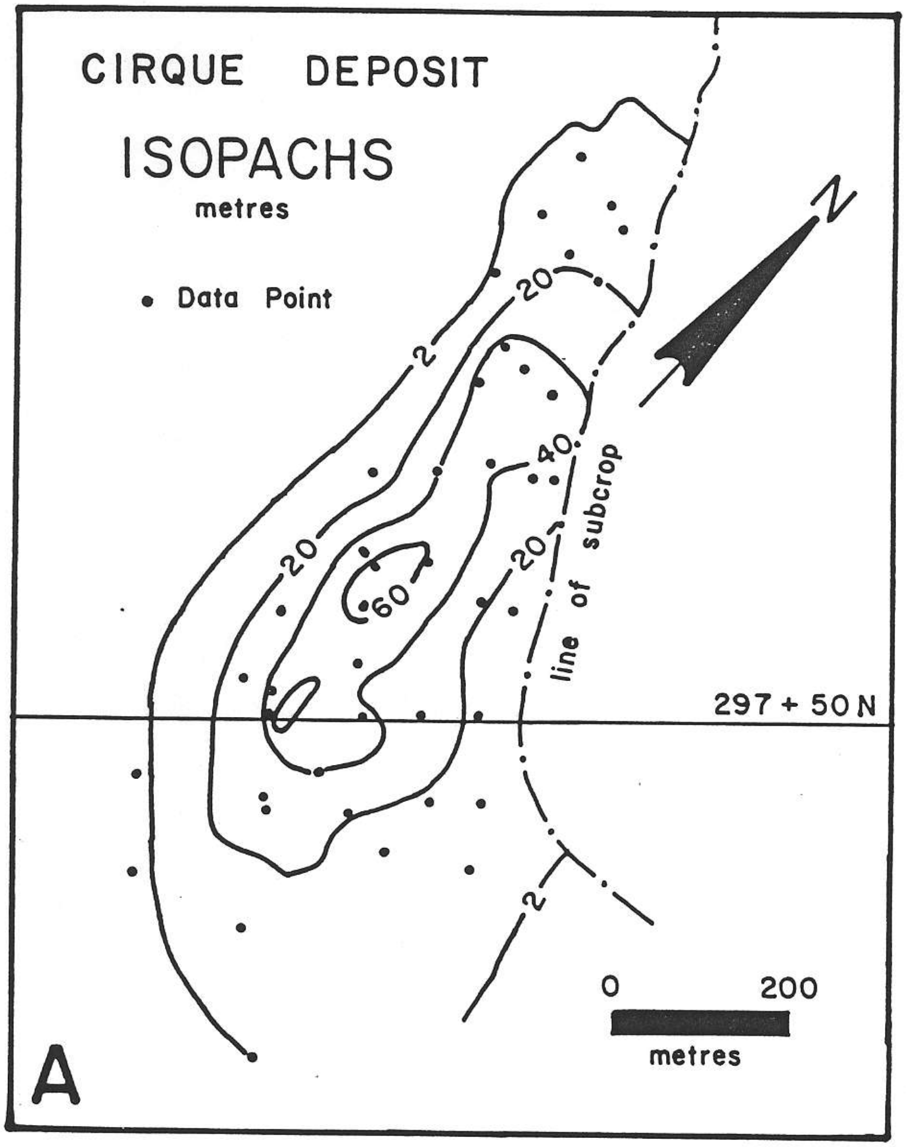
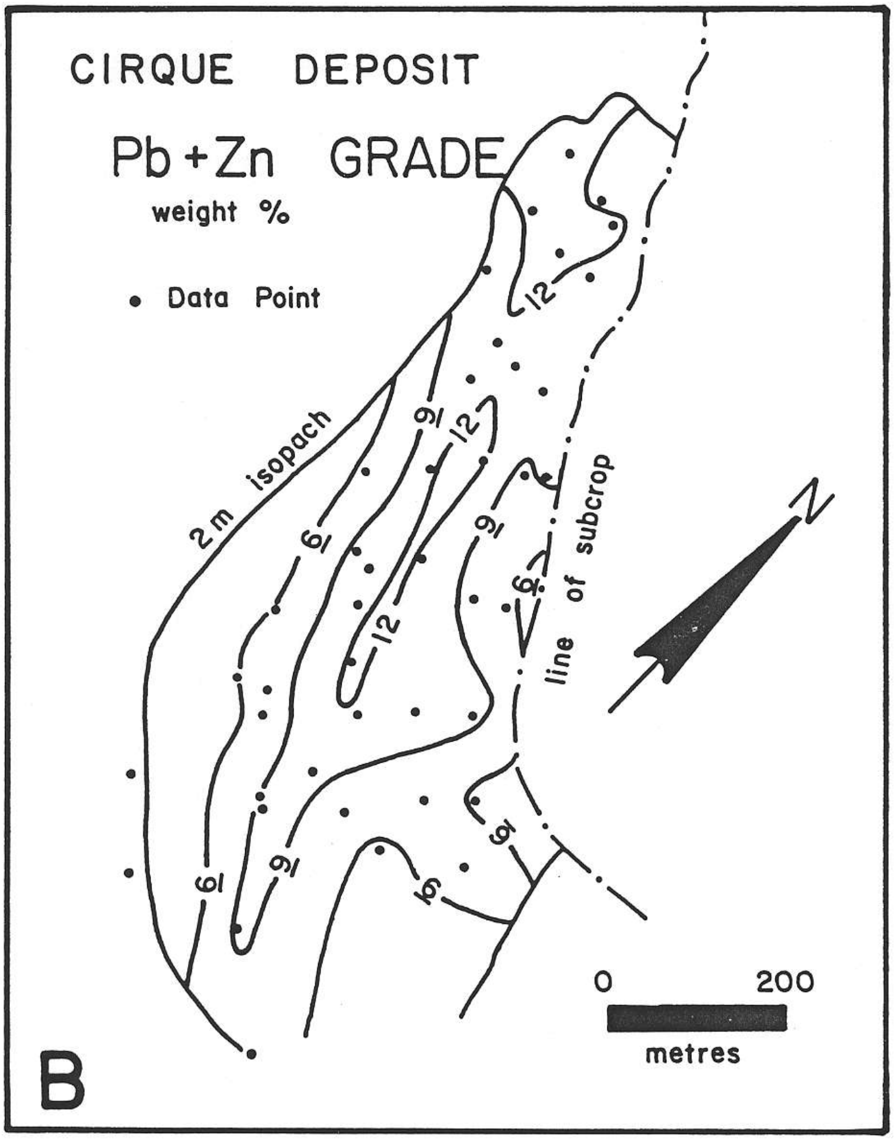
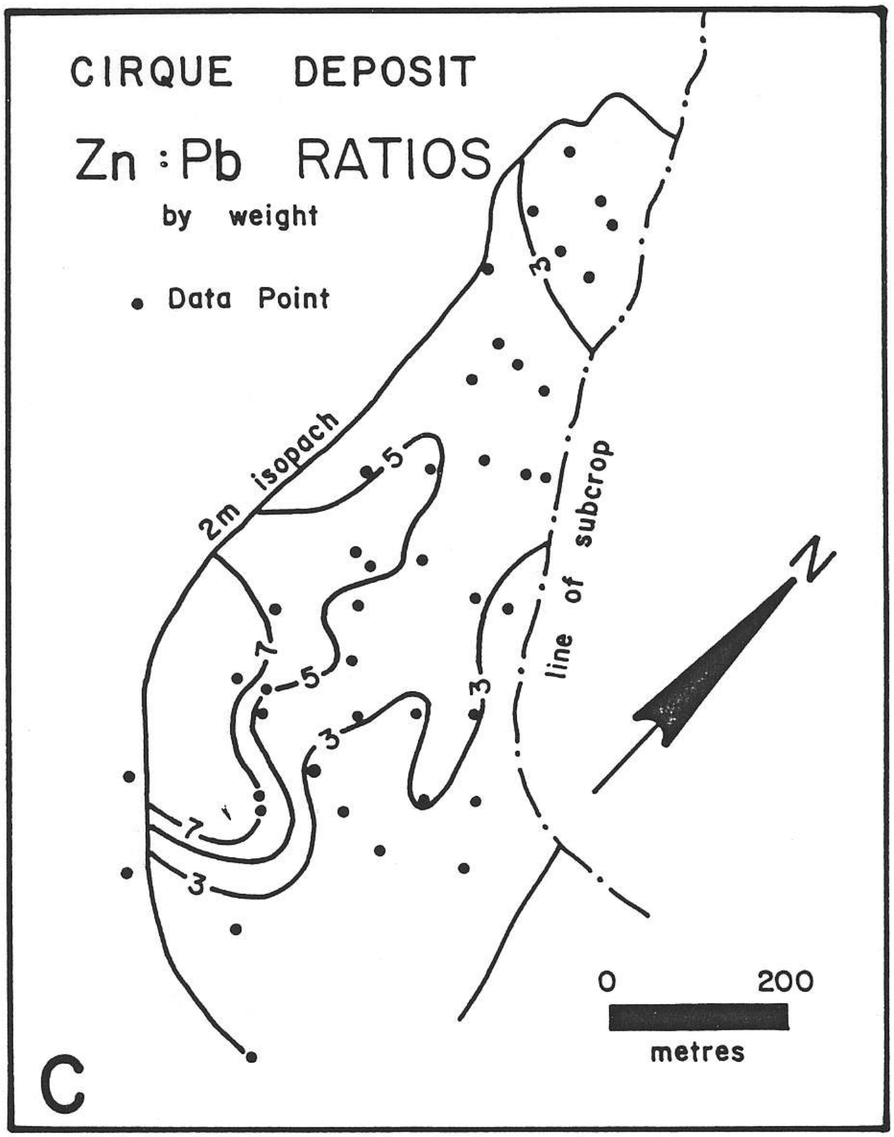


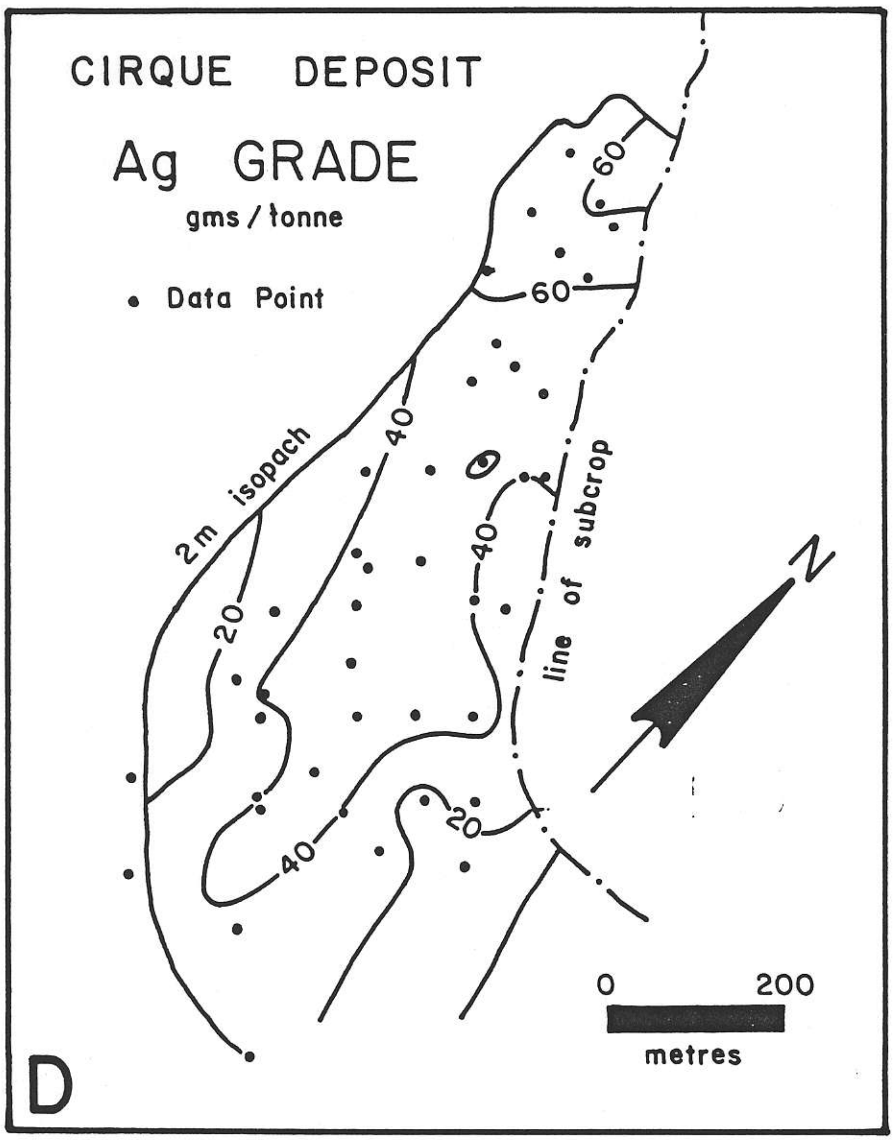
PIGAGE, L.C. Figure 13A



PIGAGE, L.C.   Figure 13B



PIGAGE, L.C. Figure 13C



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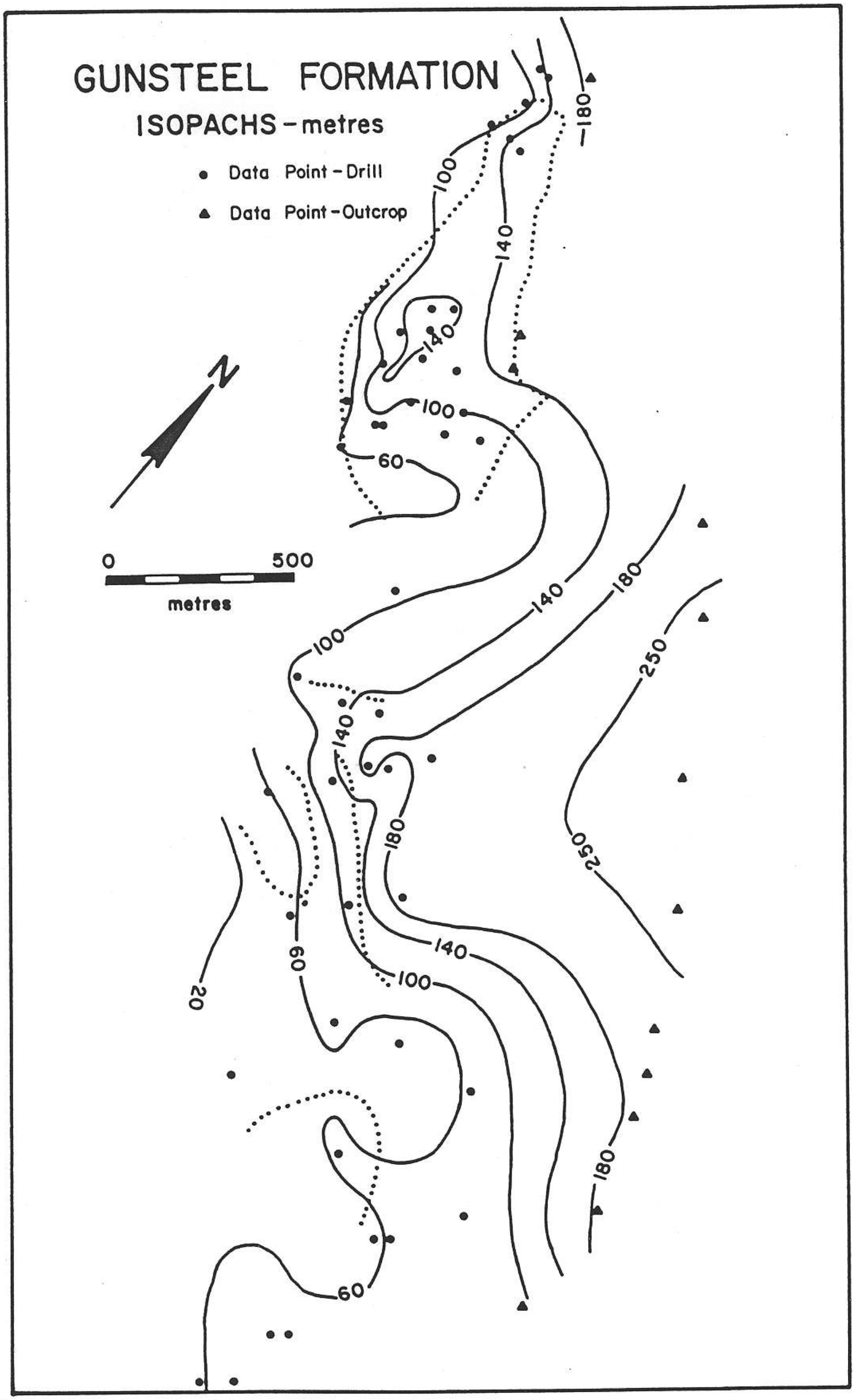

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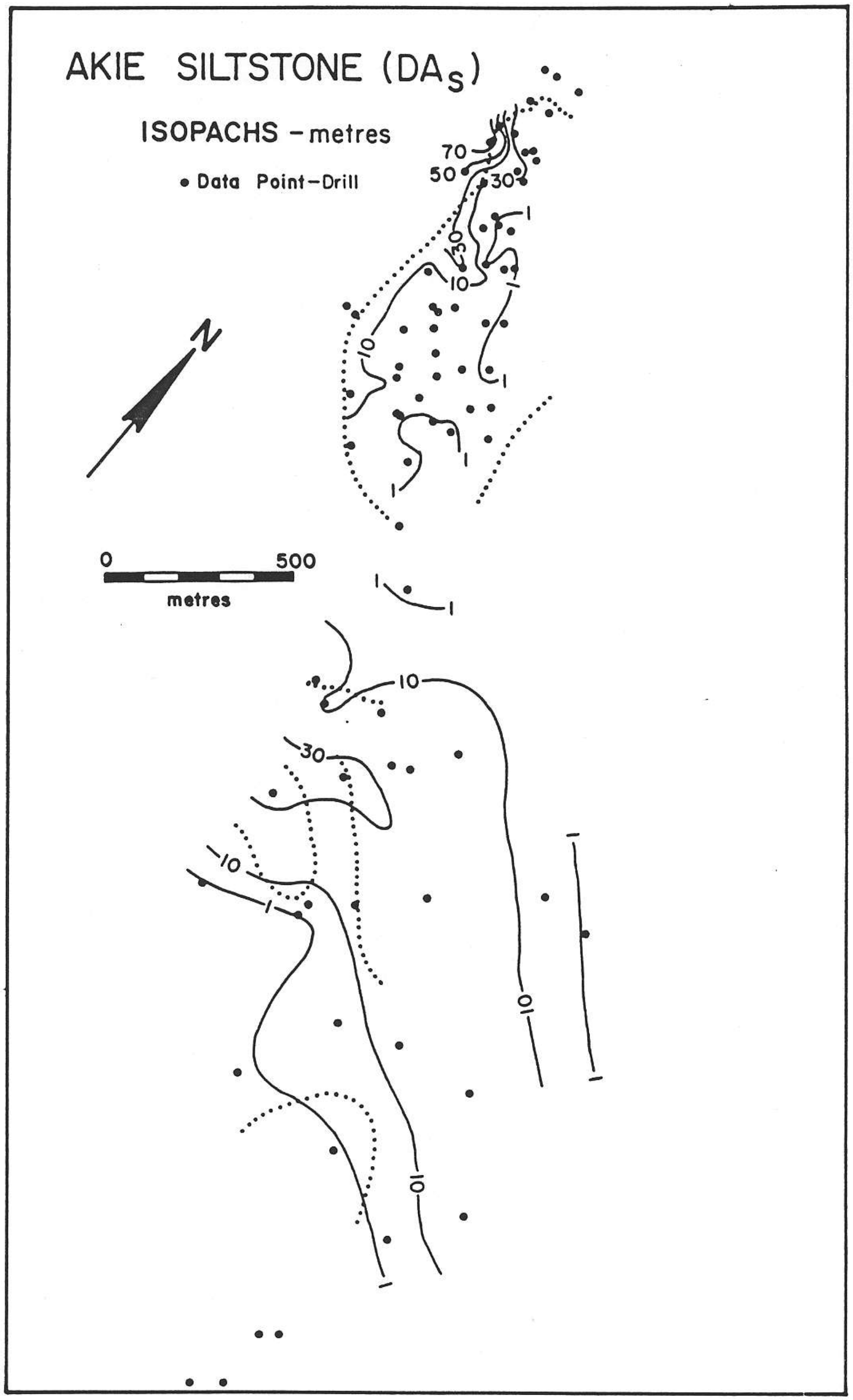

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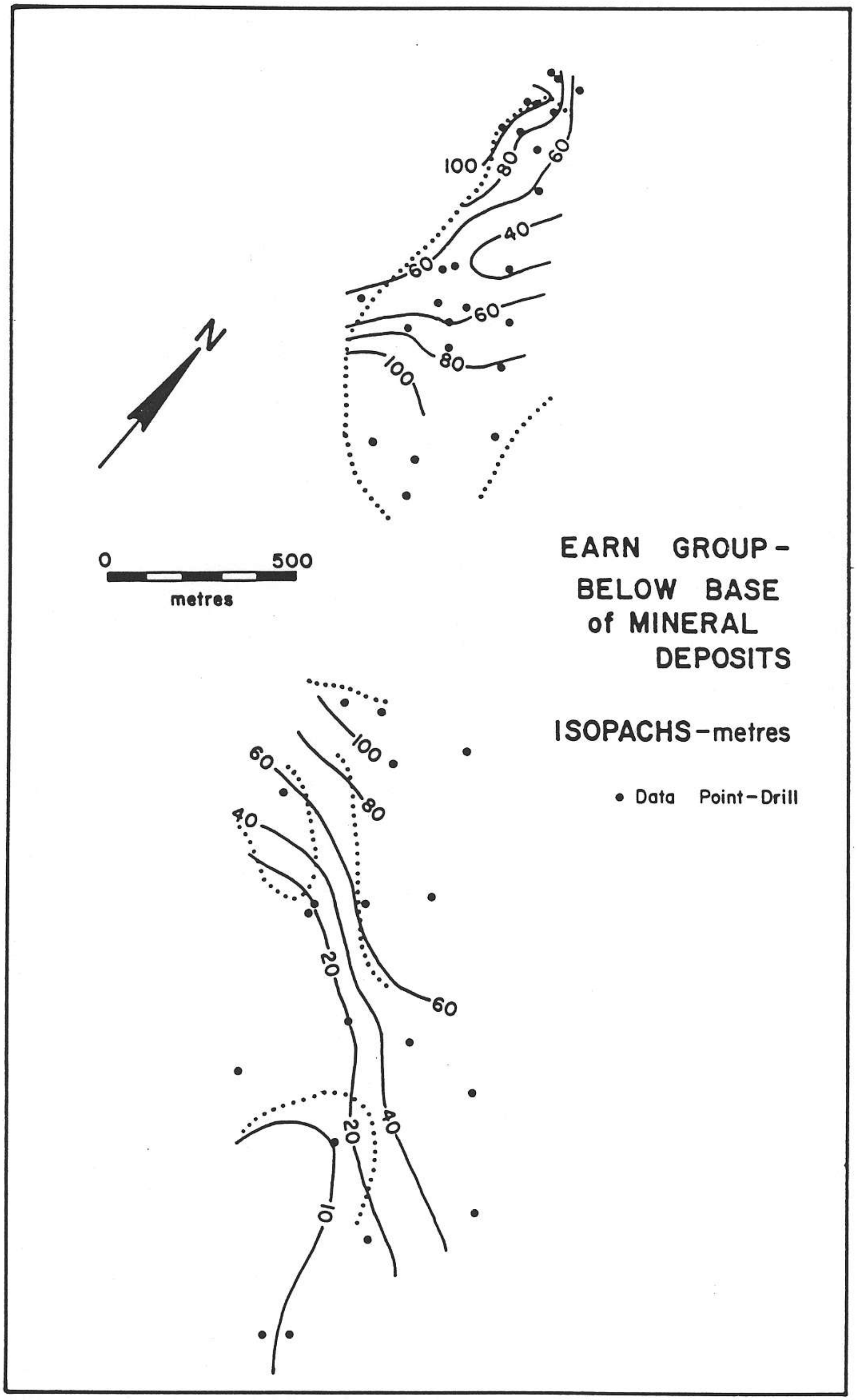

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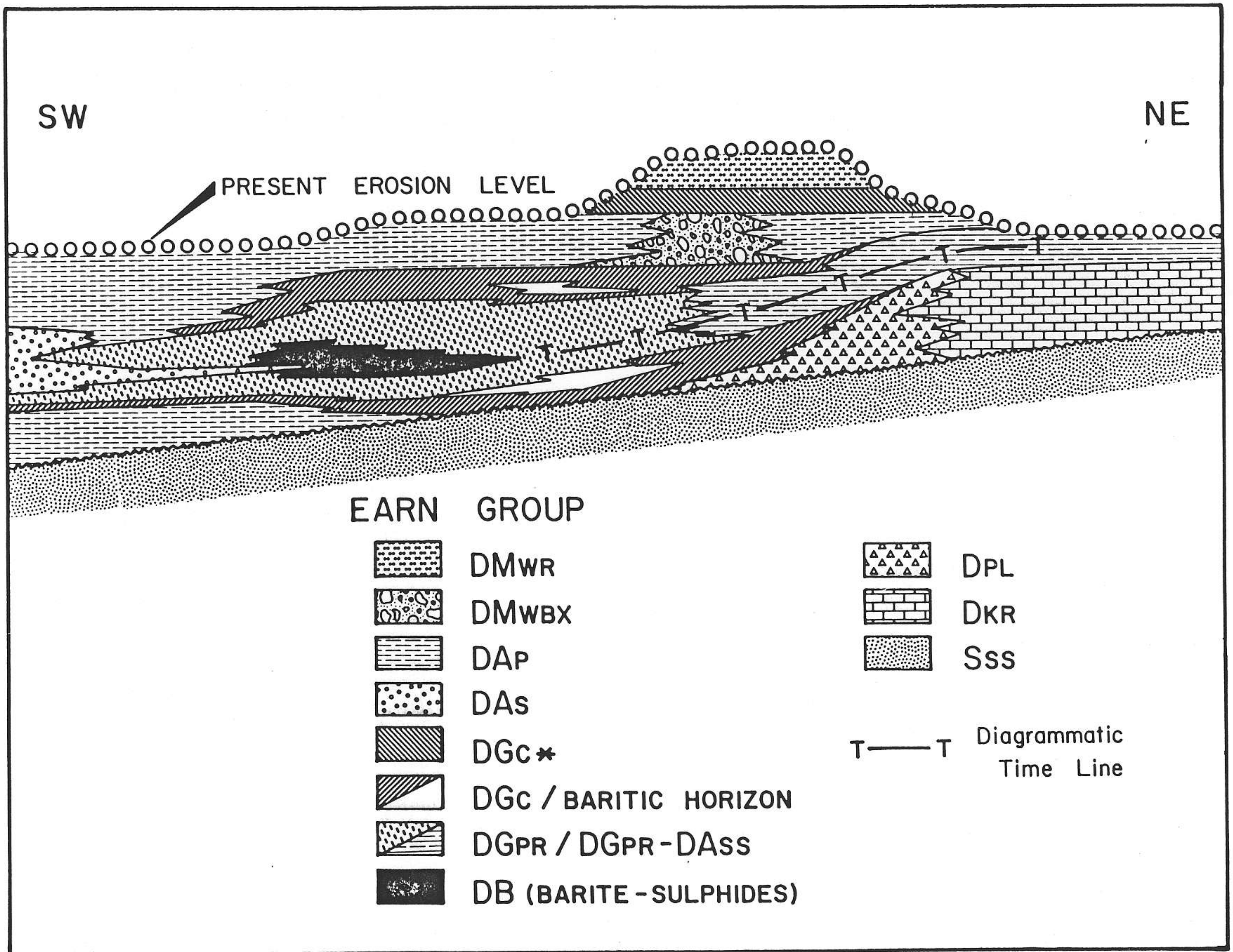

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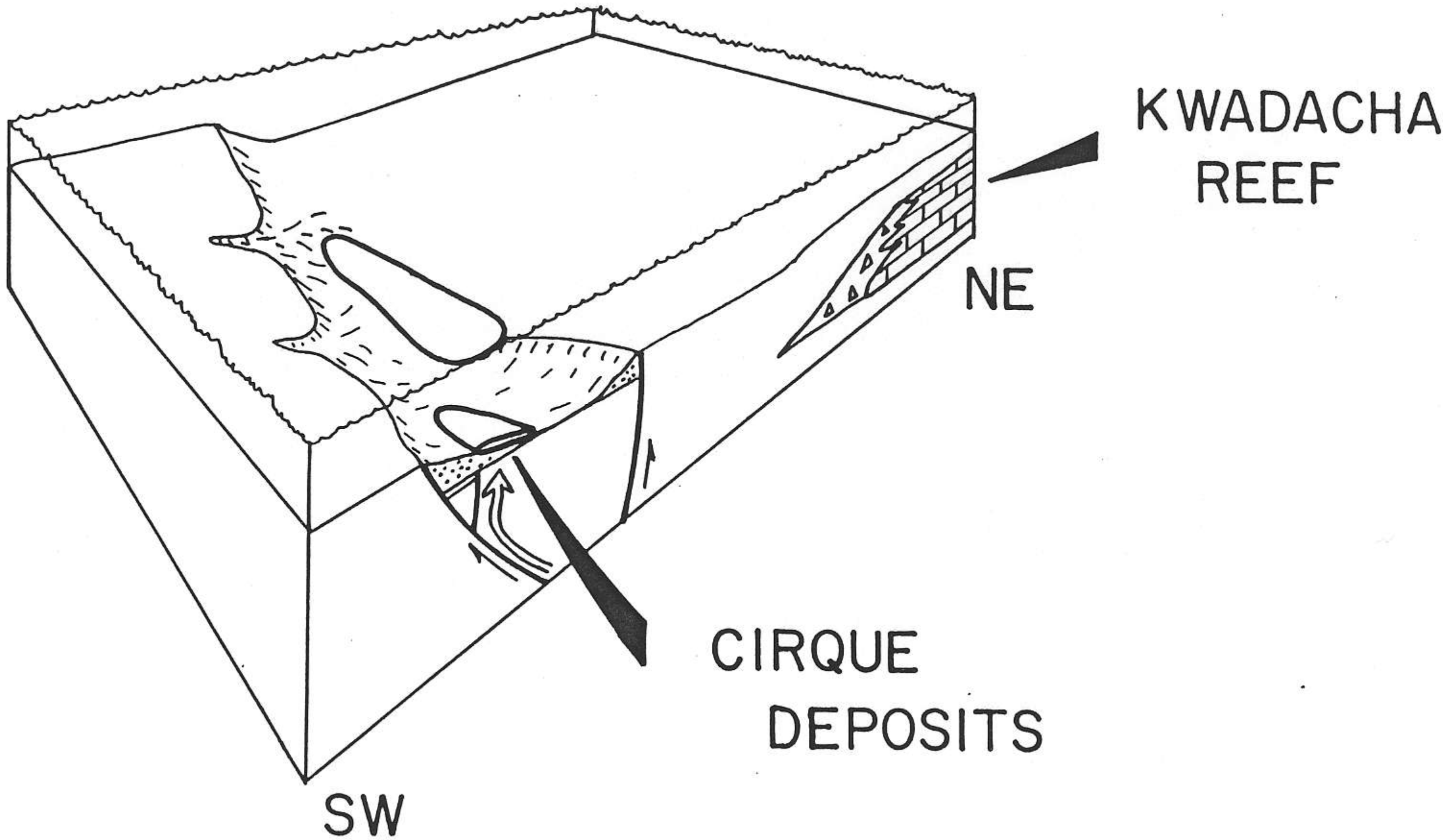

PIGAGE, L.C. Figure 18