

STRATIGRAPHY AND ECONOMIC POTENTIAL OF PRECAMBRIAN-CAMBRIAN BOUNDARY STRATA, WERNECKE MOUNTAINS, EAST-CENTRAL YUKON

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INTRODUCTION

Precambrian-Cambrian boundary strata of the Wernecke Mountains east-central Yukon, comprise a succession of alternating carbonate and siliciclastic units (Eisbacher, 1981; Narbonne *et al.*, 1985). To date only minor showings of economic minerals have been found in the siliciclastic units, but significant zinc-lead deposits have been described from carbonate strata (eg. Dawson, 1975; Reeve, 1977). Most of these deposits are hosted by an unnamed Upper Proterozoic dolostone unit (map-unit 11 of Blusson, 1971), or by Lower Cambrian carbonates of the Sekwi Formation.

During the summer of 1984, five composite sections were measured in the Corn Creek/Goze Creek area on the southeastern edge of the Wernecke Mountains (Fig. 1). Lithostratigraphic, biostratigraphic and sedimentological studies of the entire Precambrian-Cambrian boundary succession were carried out in order to determine the depositional history and mineral potential. This report will focus on the uppermost Proterozoic (map-unit 11) and lowermost Cambrian (Vampire Formation) units, with only brief description of earlier units.

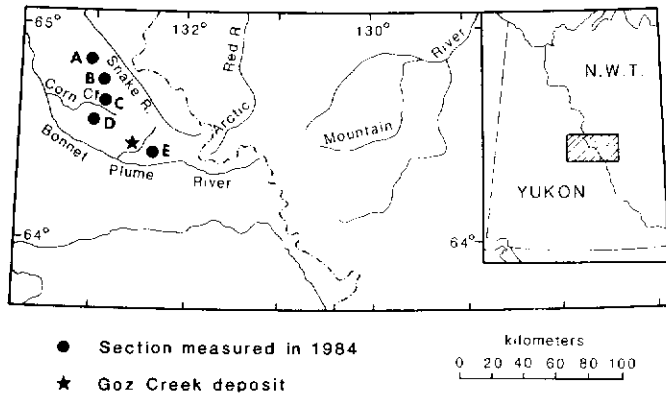


Figure 1. Location map

The study area lies on the extreme southern edge of the Yukon Stable Block (Jeletzky, 1962; Lenz, 1972), a site of predominantly shallow-water sedimentation throughout most of the Late Proterozoic and Early Paleozoic. The uppermost Proterozoic and lowermost Cambrian rocks described in this report occur southwest and south of the Mackenzie and Ogilvie Arches respectively, and were either never deposited, or are no longer preserved north and east of these arches. To the south of the study area, the shallow-water siliciclastics and carbonates pass into the deep-water shales and turbiditic conglomerates of the basal "Grit Unit" (Gordey, 1980; Aitken, in press).

STRATIGRAPHIC FRAMEWORK

The stratigraphic section at locality D (Fig. 2) is representative of the Upper Proterozoic and Lower Cambrian stratigraphy in the southeastern Wernecke Mountains. The uppermost (Cambrian) units have been formally named, but nomenclature in the lower part of the section (Upper Proterozoic) remains informal.

Upper Proterozoic strata comprise alternating units of recessive siltstone and resistant dolostone. The description and correlation of these units has been discussed by Fritz *et al.* (1983,

1984), Aitken (1984) and Narbonne *et al.* (1985). The uppermost Proterozoic unit, map-unit 11, is a resistant dolostone recognized by Blusson (1971) in the Sekwi Mountain area and traced north into the Wernecke Mountains by Fritz (1982) and Fritz *et al.* (1983).

The basal Cambrian unit, the Vampire Formation, was first determined by Fritz (1982) for a recessive unit of siltstone and fine sandstone in the Mackenzie Mountains. Fritz *et al.* (1983) extended the formal name into the Wernecke Mountains, and suggested that the Precambrian-Cambrian boundary lay at, or near the base of the Vampire Formation in this area. Aitken (1984) pointed out that the Vampire Formation of the Wernecke Mountains exhibits features transitional between the type Vampire Formation and the type Backbone Ranges Formation, but Fritz *et al.* (1984) defended the continued use of the term "Vampire Formation" in the Wernecke Mountains.

UNNAMED DOLOSTONE AND SILTSTONE UNITS

These strata comprise the "Sheepbed Carbonate," unnamed dolostone and three unnamed siltstone units (Fig. 2). Very few prospects were observed. Faults and fractures in a thick-bedded quartzarenite in unnamed siltstone unit 2 (Fig. 2) along a small creek 2 km east of section D (Fig. 1) are heavily mineralized with pyrite. Extensive karst breccias occur in the "Sheepbed

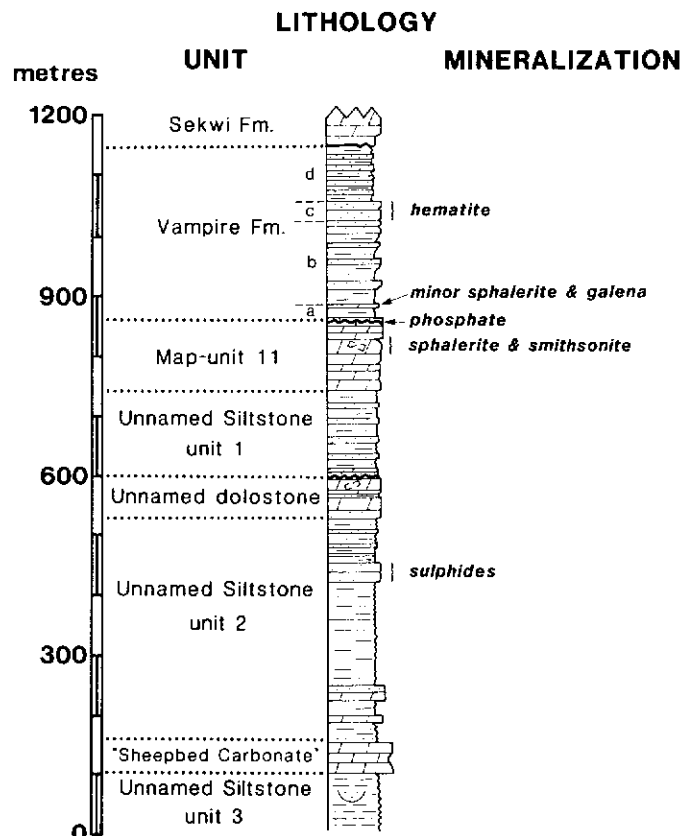


Figure 2. Upper Proterozoic and Lower Cambrian strata at locality D. Lithologic data from Narbonne *et al.* (1985, Fig. 71.3) and Fritz *et al.* (1983, Fig. 44.2a).

Carbonate" at locality A (Aitken, 1984) and in the unnamed dolostone unit at localities A and D, but no associated sulphides were noted.

MAP-UNIT 11

Description

Map-unit 11 consists predominantly of medium- to very thick-bedded dolostone with some siltstone, limestone and dolostone breccia near the top. It is light grey to grey-buff, and weathers with a distinctive orange-pink hue. Extensive dolomitization has obliterated most primary sedimentary structures, but secondary features such as vugs and horizontal stylolites are common. The dolostone is finely to coarsely crystalline with 1-2% quartz, most of it authigenic. Porosity is generally less than 2% and is partially occluded by bitumen. Finely disseminated, inter-crystalline pyrite comprises less than 1% of the rock.

Various lines of evidence suggest that the upper surface of map-unit 11 represents a significant disconformity:

- 1) Small shelly fossils (eg. *Protohertzina anabarica*) and Cambrian-type complex burrows (*Phycodes pedum*) occur immediately above the contact in the Wernecke Mountains (Fritz et al., 1983; Nowlan et al., 1985), whereas they occur several hundred metres above the contact in the June Lake area to the southeast (Fritz, 1980; Aitken, 1984).
- 2) The thickness of map-unit 11 decreases northward from 151 m at locality D to 29 m at locality A (Fig. 3). This trend is typical of several disconformities in the area, which progressively bevel older strata onto the Mackenzie and Ogilvie Arches (eg. Aitken, 1982).
- 3) The upper contact of map-unit 11 is extremely sharp and exhibits at least minor relief at most localities.
- 4) Patchy development of phosphatic coatings and breccia-filled, solution-enlarged fractures (Fig. 6) on the upper contact attest to a prolonged period of chemical action on the lithified surface.

- 5) Dolostone breccias occur near the upper contact of map-unit 11 at localities D and E (Figs. 4, 5). Breccias occur as irregular tabular, pod-shaped and columnar bodies up to 55 m thick. The breccia is composed of pebble- to cobble-sized, predominantly subangular clasts of grey dolostone cemented by dolomite and lesser quartz, sulphides and hematite. Shapes of the breccia bodies (Fig. 4), their consistent association with disconformities (Fig. 4), and the local occurrence of breccia-filled, solution-enlarged fractures (Figs. 4, 6) are indicative of a karstic origin.

This disconformity occurs at the top of map-unit 11 in all sections studied (Fig. 3), and can be traced into the Mackenzie Mountains (Fritz et al., 1984, Fig. 44.2). In addition, two local disconformities (each characterized by erosional relief, phosphatic coatings, and dolostone breccias) occur in the upper part of map-unit 11 at section D (Fig. 4).

Depositional Model

Although primary sedimentary structures are poorly preserved, the presence of planar cross-lamination, scours and beds of flat-pebble conglomerate suggest that deposition occurred on a shallow carbonate shelf. The presence of desiccation cracks and karstic erosion surfaces in the upper part of the unit indicates intermittent subaerial exposure. The disconformity at the top of the unit may be related to a global regression that occurred in the latest Precambrian (cf. Brasier, 1982).

Economic Potential

Fritz et al. (1983) first noted that the Goz zinc deposit is hosted by map-unit 11. At the Goz deposit, ten drill intersections have proven almost 2 million tonnes of zinc in 18% protore with a total potential of 5 million tonnes of 13% zinc or better. Reeve (1977) noted the association of the mineralization with breccia zones within the thick-bedded dolostone. The Goz zinc deposit can be regarded as a Mississippi Valley type deposit, but contains more smithsonite (Zn CO₃) and silicified dolostone than is typical of most of this type of deposit (Reeve, 1977).

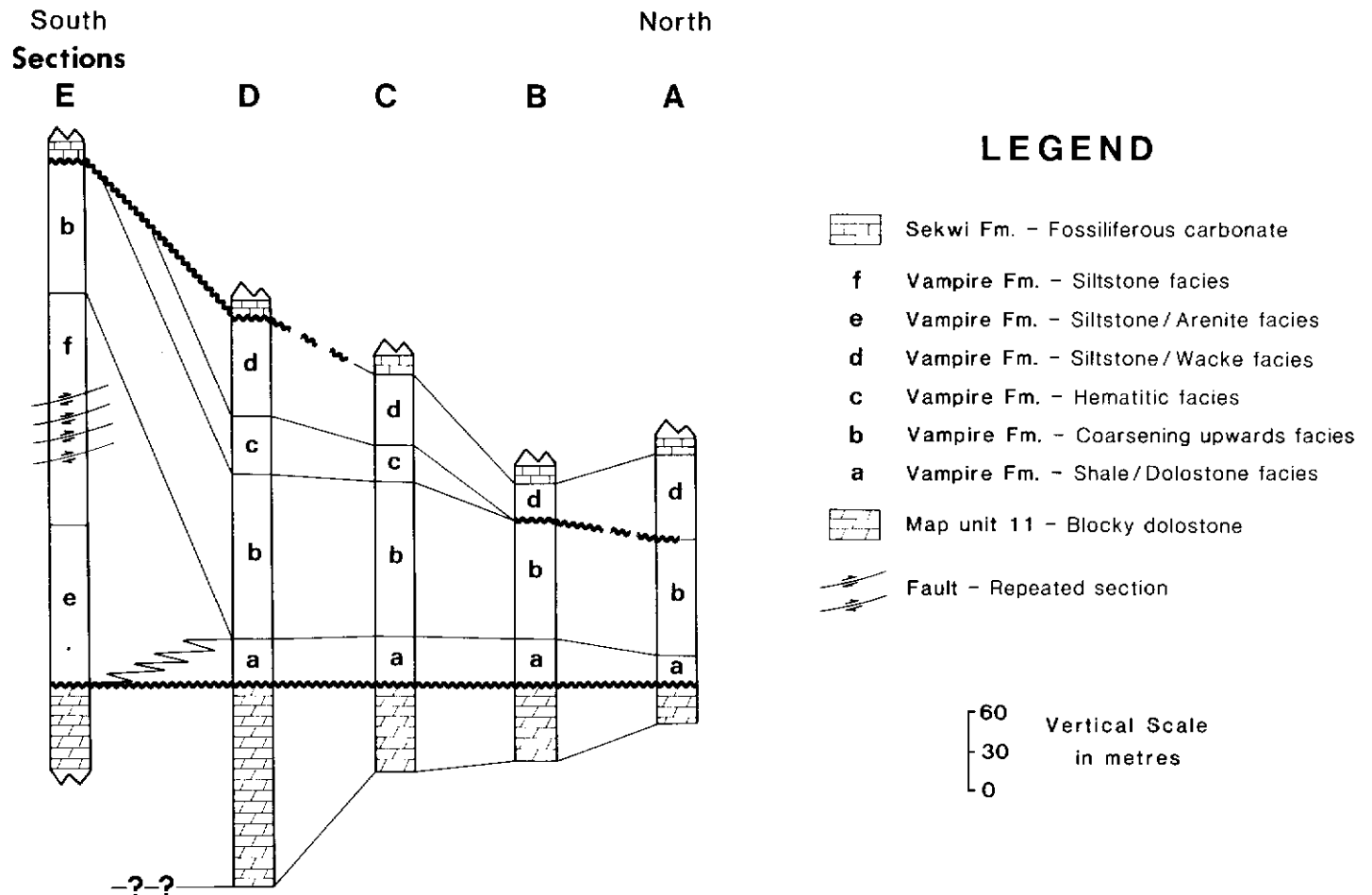


Figure 3. Lithofacies and correlation of map-unit 11 and the Vampire Formation.

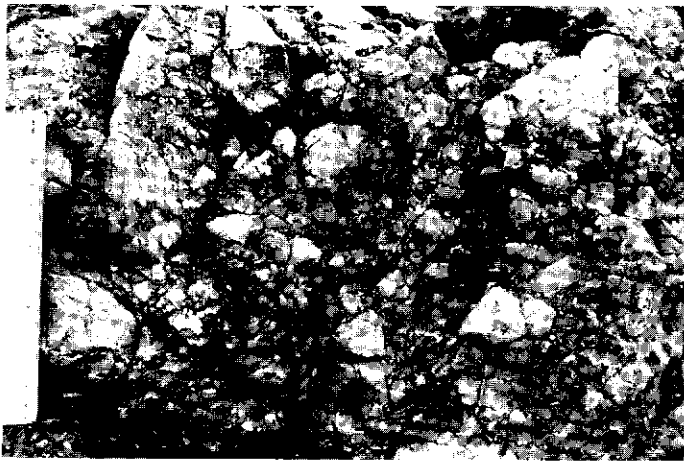


Figure 4. Mineralized dolostone breccia in map-unit 11 at Section E.

Similar mineralized breccias were identified by Fritz *et al.* (1983) at sections D and E. Investigation in the summer of 1984 allowed us to typify these deposits and to determine a common paragenetic history. Brief examination of the Goz zinc deposit confirmed that it is similar to the deposits at sections D and E, but is considerably more silicified.

At section E, the uppermost 10-55 m of map-unit 11 consists predominantly of well-indurated, dolomite breccia that overlies thick-bedded dolostone with a sharp, but highly irregular contact (Fig. 5a). The thick-bedded dolostone exhibits several high angle, low displacement normal faults, and numerous quartz and galena-filled fractures. Dolomite, quartz, galena, sphalerite and smith-

sonite occur as void-filling cements between clasts in the dolostone breccia.

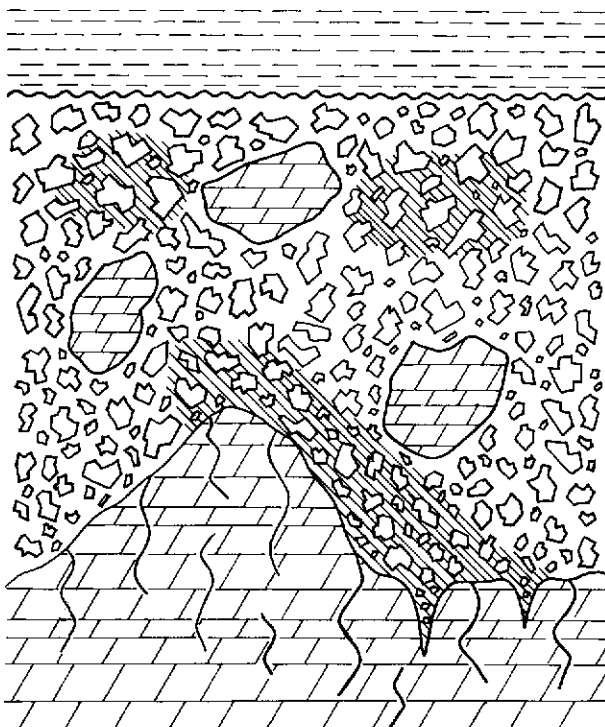
At section D, pod-shaped and columnar breccia bodies 5-20 m deep occur beneath disconformities at two levels in the upper part of map-unit 11 (Fig. 5b). Breccias are poorly indurated, and spaces between clasts are partially cemented by dolomite, quartz and hematite (secondary after pyrite). Quartz-filled fractures occur in both the thick-bedded dolostone and the breccia.

Analyses of thin sections and polished sections from localities D and E and hand samples from the Goz deposit suggest that a common paragenetic sequence typifies these deposits. Differences in the type and abundance of sulphide minerals in the three areas probably reflect local variations in the duration and intensity of particular diagenetic processes. A complete description of the paragenetic history of these deposits will be presented elsewhere, but our major conclusions are summarized below.

Mineralization occurred as part of a complex paragenetic sequence that took place in telogenetic (under influence of meteoric waters) and mesogenetic (deep subsurface) diagenetic environments (terminology after Choquette and Pray, 1970). Early telogenetic processes included dolomitization, karstic dissolution, and cementation by zoned dolomite and (?) calcite. The apparent absence of shale in the breccias of map-unit 11 suggests that at least the upper part of the breccia was cemented prior to the deposition of the overlying Vampire Formation. Following burial, the pores were reopened by dissolution of much of the zoned dolomite and all of the (?) calcite cementing the clasts. Bitumen, quartz, sulphides (galena, sphalerite and pyrite), sparry dolomite and saddle dolomite subsequently migrated and precipitated in the reopened pore spaces (Figs. 7, 8). Later uplift associated with the Laramide Orogeny resulted in fracturing and formation of smithsonite (Fig. 9) in a telogenetic setting (cf. Sangster, 1975).

Despite examination of map-unit 11 at a number of localities

SECTION E



SECTION D

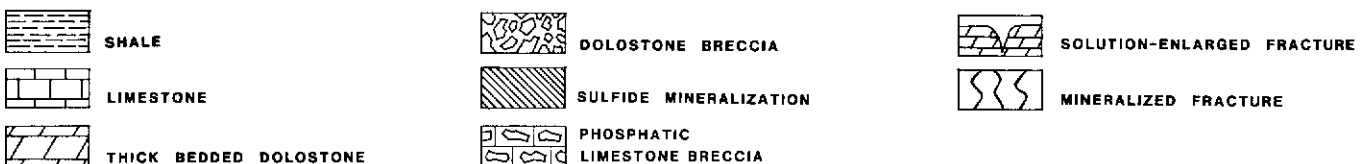
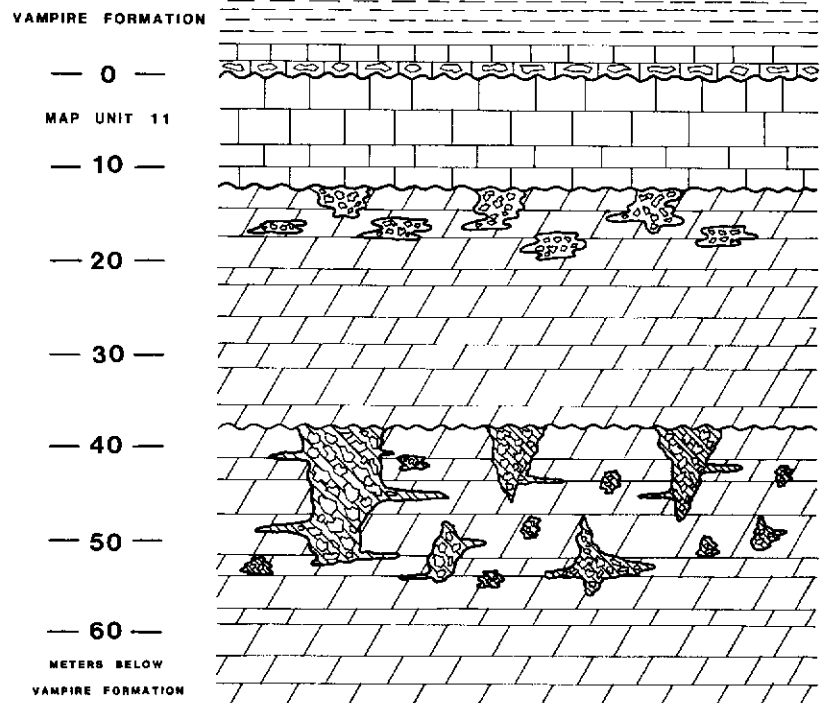


Figure 5. Occurrence of breccias in map-unit 11 and the basal Vampire Formation. 5a — Section E; 5b — Section D.



Figure 6. Breccia-filled, solution enlarged fracture in thick-bedded dolostone of map-unit 11. Locality E.

in the Wernecke Mountains (Fig. 1), lead and zinc mineralization has thus far been observed only in the southernmost sections adjacent to the deeper-water shales. This appears to be related to two factors:

- 1) Most Mississippi Valley type deposits in the Canadian Cordillera are located at or near a platform margin adjacent to a shale basin (MacQueen, 1976), possibly because these shales acted as a source for the metal ions (cf. Jackson and Beales, 1967).
- 2) Although map-unit 11 shows evidence of extensive pre-Vampire erosion in all sections studied (Fig. 3), karstic breccias have thus far been observed only in the southernmost sections.

VAMPIRE FORMATION

Description

In the study area, the Vampire Formation consists predominantly of sandstone, siltstone and shale with subordinate carbonate. The formation ranges in thickness from 150.5 m at section B to 392.1 m at section E, and can be subdivided into six lithofacies (Figs. 3, 10).

The Shale/Dolostone Facies (Facies "a") consists predominantly of recessive, grey-black shales and subordinate, resistant, orange-buff weathering dolostones. This basal Vampire facies disconformably overlies map-unit 11 in sections A, B, C and D. The thin- to medium-bedded dolostones of the facies are typically silty and commonly exhibit relict structures of intraclasts and ooids. Sedimentary structures, including parallel lamination, small-scale planar cross-lamination and hardgrounds are common in the dolostones. A thin- to thick-bedded arenite near the top of the facies exhibits a variety of sedimentary structures including parallel lamination and cross-lamination. Phosphate occurs at the base of the shale/dolostone facies in section D, and is commonly associated with stromatolites and thrombolites. The shale/dolostone facies contains numerous complex Cambrian trace fossils such as *Cruziana*, *Rusophycus* and *Phycodes pedum* (Nowlan et al., 1985); these trace fossils are typical of Seilacher's (1967) *Cruziana* ichnofacies. The presence of flat pebble conglomerates, desiccation cracks and evaporite pseudomorphs in the phosphatic dolomitic limestone suggests periodic emergence of the basal facies. The overlying thrombolite mounds suggest a deepening to a subtidal environment. The intraclasts and ooids of

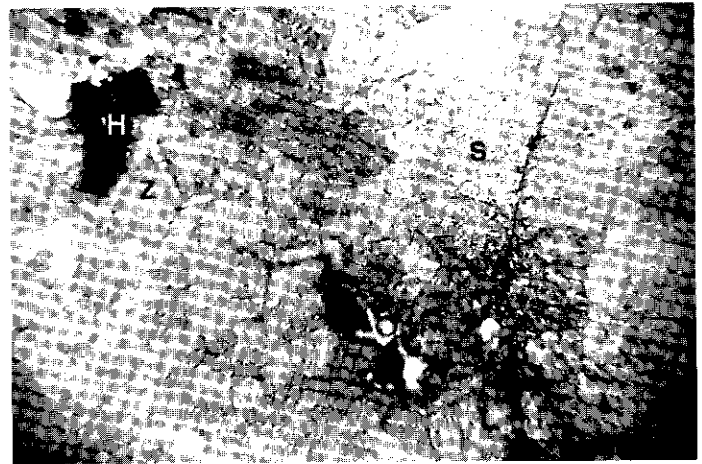


Figure 7. Void fill in dolostone breccia at Section D. Zoned dolomite (Z) shows evidence of partial dissolution. Later cements are hematite (H) and saddle dolomite (S). Hematite occurs as cubic pseudomorphs of pyrite crystals. Field of view is 4 mm.

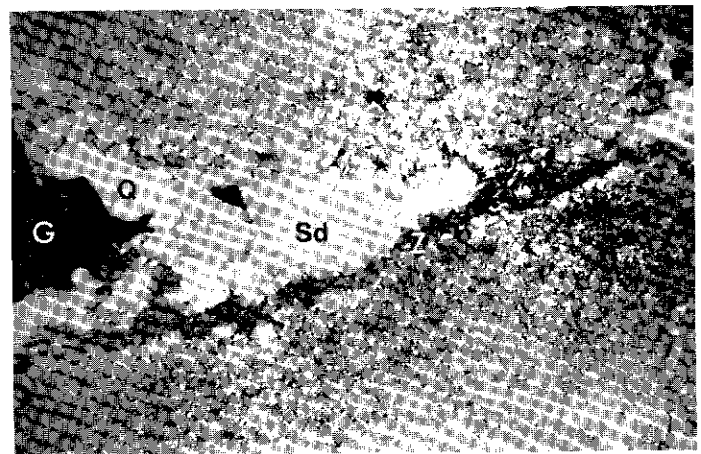


Figure 8. Void fill in dolostone breccia at Section E. Zoned dolomite (Z) shows evidence of partial dissolution. Later cements are quartz (Q), sparry dolomite (Sd) and galena (G). Field of view is 10 mm.

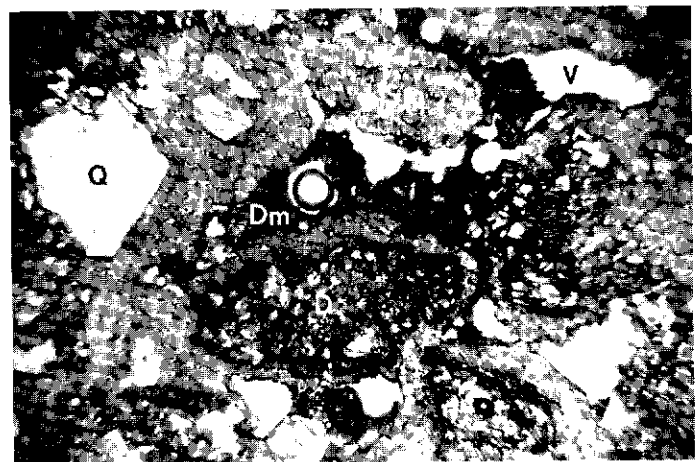


Figure 9. Late telogenetic features in dolostone breccia at Section E. Smithsonite cement (Sm) lines quartz crystals (Q) and remnant corroded dolomite (D). Note abundant detrital material (Dm) and secondary porosity (V). Field of view is 4 mm.

the dolostones of the facies suggest energetic conditions, whereas the shales of the facies were probably deposited during calmer periods. These features collectively suggest that, except for the basal transgressive deposits, offshore subtidal conditions prevailed throughout deposition of most of the shale/dolostone facies.

The Coarsening-Upward Facies (Facies "b") consists of arenites, grey siltstones and grey, laminated shales deposited in numerous coarsening-upward cycles 5 to 25 m thick (Fig. 11). The thin- to thick-bedded arenites contain sedimentary structures including parallel lamination, planar cross-lamination, trough cross-lamination, load structures, and hummocky cross-stratification. Graded beds occur rarely in basal portions of the coarsening-upwards facies. Trace fossils are common, and include representatives of the Skolithos and Cruziana ichnofacies of Seilacher (1967). The coarsening-upward cycles of this facies represent shallowing of the depositional environment, with the shales and siltstones deposited under lower energy conditions and the arenites deposited in an energetic environment. The presence of load structures suggests a higher sedimentation rate and sediment instability. Abundant wave-produced structures suggest a wave and/or storm dominated depositional setting, with graded beds most likely representing storm deposits. Deposition probably occurred under predominantly nearshore conditions.

The Hematitic Facies (Facies "c") consists of medium- to thick-bedded, hematite-cemented sublitharenite. This facies is present only in sections C and D, but apparently was removed by erosion at section B and possibly A. Most beds are apparently structureless, with only rare parallel lamination and planar cross-lamination. Simple trace fossils occur very rarely in thin siltstone interbeds. These fossils are indicative of a marine-influenced environment, but further work is necessary to determine the precise depositional setting.

The Siltstone/Wacke Facies (Facies "d") consists of grey-brown siltstones and subordinate, thin- to medium-bedded, grey

matrix-rich arenites and wackes. This facies is present in sections A, B, C and D. The wackes and arenites exhibit a variety of relatively small-scale sedimentary structures including parallel lamination, low angle planar cross-lamination, and symmetric ripple marks. Trace fossils are common; most are typical of the Cruziana ichnofacies (Fig. 12), but representatives of the Skolithos and Zoophycos ichnofacies occur rarely. The dominance of siltstone also suggests deposition under relatively quiet water conditions, possibly in an offshore subtidal environment.

Facies "e" and "f" are present only in section E, and consist mainly of dark grey siltstones (Fig. 3). The Siltstone/Arenite Facies (Facies "e") disconformably overlies map-unit 11 and contains subordinate amounts of very fine-grained, medium-bedded arenites with wavy bedding, parallel lamination and slumps. Trace fossils are mostly facies-crossing forms such as Cochlichnus and Didymaulichnus. The dominance of siltstones and horizontal trace fossils in Facies "e" suggests a relatively low energy environment. Slumps within the siltstone/arenite facies suggest deposition on a slope.

The Siltstone Facies (Facies "f") consists predominantly of resistant, medium- to very thick-bedded, dark grey siltstones (Fig. 13). These siltstones contain few sedimentary structures except for parallel lamination and slumps. Thin, graded beds of sandstone are a minor component of the facies. Trace fossils are extremely rare. The siltstones suggest a relatively low energy depositional environment, whereas the graded beds may represent turbidity current deposits or storm deposits. The presence of numerous slumps suggests sediment instability, perhaps due to rapid sedimentation on a slope.

Depositional Model

The distribution of facies in the Vampire Formation (Fig. 3) indicates that significant differences in depositional environment existed between areas A-D and area E.



Figure 10. Lithofacies of the Vampire Formation at locality D. M-U 11 = map-unit 11; a = shale/dolostone facies; b = coarsening-upwards facies; c = hematitic facies; d = siltstone/wacke facies; S.F. = Sekwi Formation.



Figure 11. Typical coarsening upwards cycle in the Vampire Formation at locality B. The staff is 1.5 m long.

Areas A-D (Fig. 1) exhibit lithotypes and sedimentary structures typical of shallow shelf environments. This is supported by the trace fossil assemblage, which is dominated by representatives of the typically shallow marine *Skolithos* and *Cruziana* ichnofacies. In contrast, the time-equivalent thick siltstones and minor graded sandstones that characterize the lower two-thirds of section E lack shallow water features. Numerous load structures and slumps suggest rapid deposition on a slope. Trace fossils are rare and low in diversity, a feature typical of Cambrian deep-water environments (Crimes, 1974). This section shoals upward, and is capped by near-shore deposits of the coarsening-upwards facies. These relationships suggest that section E represents a deeper-water equivalent of sections A-D, possibly deposited in a prodelta or upper basin slope environment.

Economic Significance

A phosphatic limestone bed up to one m thick occurs at the base of the Vampire Formation at section D (Figs. 2, 5b). Phosphate occurs sporadically throughout the bed as hardground coatings, small shelly fossils, clasts, and clast coatings (Fig. 14), and locally comprises up to 40% of the bed (average 5%). Phosphate also occurs at the base of section B as thin hardground coatings. The phosphate probably originated as primary phosphate mud and as very early diagenetic replacement of carbonate. Phosphatic beds occur commonly in Precambrian-Cambrian boundary deposits, and are extensively mined in South America, Australia, Africa and Asia (Cook and Shergold, 1984).

Sulphide mineralization occurs sporadically in the basal facies of the Vampire Formation at section D (Fig. 2). Sphalerite, galena, quartz and dolomite occur as vug-fillings in oolitic and intraclastic dolostone. The sulphides are economically insignificant, but may provide some indication of the timing of sulphide mineralization in the Wernecke Mountains.

Detrital hematite grains constitute 1-2% of all facies of the Vampire Formation, but significant accumulations are restricted to the hematitic facies (facies "c") at localities C and D (Fig. 3). The



Figure 12. Trilobite trace fossils *Rusophycus* and *Cruziana* on a lower bedding surface in the siltstone/wacke facies of the Vampire Formation, locality D.

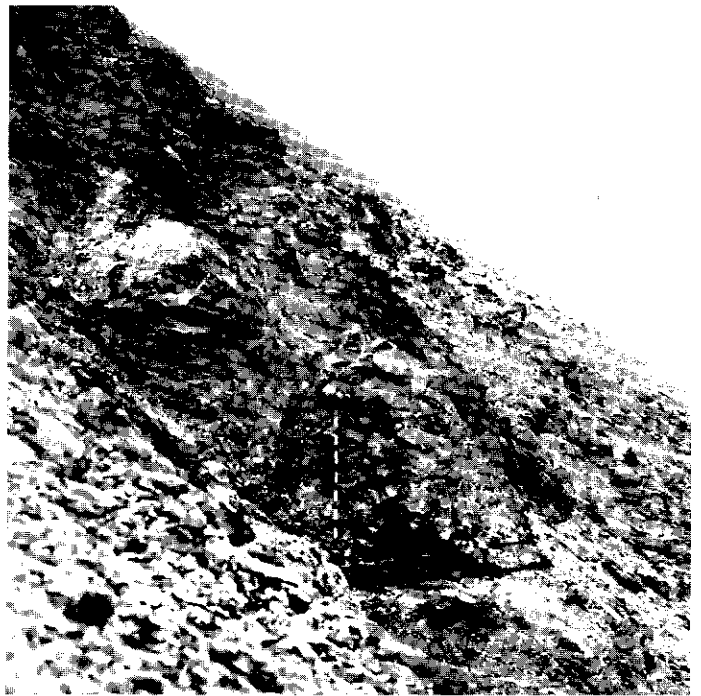


Figure 13. Siltstone facies of the Vampire Formation at locality E. Divisions on the staff are in decimeters.

hematitic facies is up to 45 m thick, and contains 30-40% hematite by volume. Poorly developed, centimetre-scale banding of iron-rich and iron-poor layers occur sporadically, but much of the facies is structureless. The hematite is black and aphanocrystalline; it occurs both between grains and as a grain-replacement. The apparent absence of chert and magnetite, the poor development of banding, and the abundance of siliciclastic detritus distinguish these Lower Cambrian deposits from typical Precambrian iron formations, whereas the absence of goethite and oolitic textures distinguishes them from typical Phanerozoic ironstones. The economic potential of the Vampire hematite deposits is enhanced by their proximity to massive iron deposits in the Rapitan Group near the headwaters of the Snake River to the north (cf. Green and Godwin, 1962).

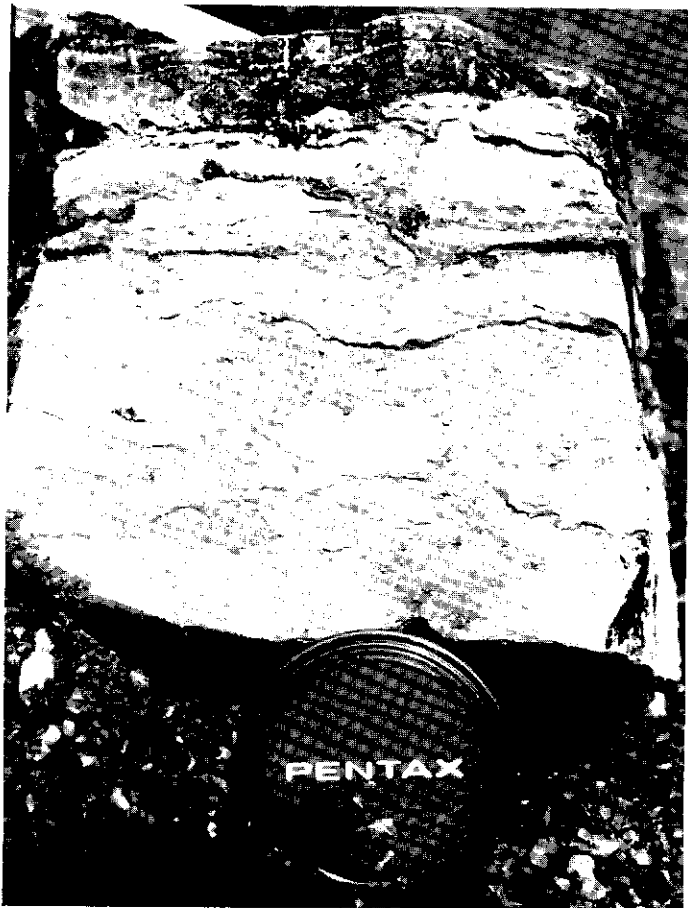


Figure 14. Abundant phosphate in limestone breccia at the base of the Vampire Formation, locality D. Phosphate (black) occurs as small grains, clast-coatings and as a laminated hardground coating (top of photo).

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