Characteristics of the Yates Unit Amphibolite

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Introduction

The lowest known portion of the Poorman Formation as determined from diamond drilling and mapping is the Yates Unit. It largely comprises amphibolite, but also contains interbedded volcaniclastics, calc-silicate beds, metachert, and carbonate-rich semipelitic rocks. This unit is exposed at the surface in the Blacktail Gulch area north of Lead and continues down-plunge to the southeast through the core of the Lead Anticline. Extending from surface outcrops, amphibolite of the Lower Unit has been found in mine exposures to the 6800 Level and in drill core down to about the 8600 equivalent level; a known plunge length of eleven kilometers. In plan view, the amphibolite unit consists of multiple, lobate masses that are elongated NNW-SSE and comprise most of the core of the Lead Anticline. These large, nearly strain-resistant masses have served as structural "buffers" for the eastern ledges in the Homestake mine, compared to the highly attenuated structures found in the western ledges.

Megascopic Description

Fresh exposures of Yates Unit are dark green, fine- to medium-grained, massive to locally banded, moderately well lineated and are comprised of hornblende-plagioclase schist. White calcite bands and veinlets from 2-mm to 2-cm in thickness are found in minor to moderate amounts in nearly every occurrence. Surface and underground exposures are characterized as blocky with a wide-spaced (tens of centimeters) cleavage (Figure 1). Select surface exposures in Blacktail Gulch have structures reminiscent of relic pillows: rounded tops highlighted by chlorite-carbonate and wide, wedge-shaped bottoms, all stacked irregularly and are on the order of 0.3-1.0 meters across for individual "pillows". No evidence of vesicles has been found in any exposure examined. As noted by Campbell in Caddey et al. (1991), field relations indicate conformable contacts with intercallated and overlying lithologies. Intercallated metasediments include grunerite-bearing iron-formation, carbonaceous quartz-sericite-ankerite phyllite, very coarse-grained amphibole-bearing units, calc-silicate beds, salt and pepper textured volcaniclastic units, as well as cherty zones containing minor amounts of stilpnomelane, graphite, and pyrrhotite.

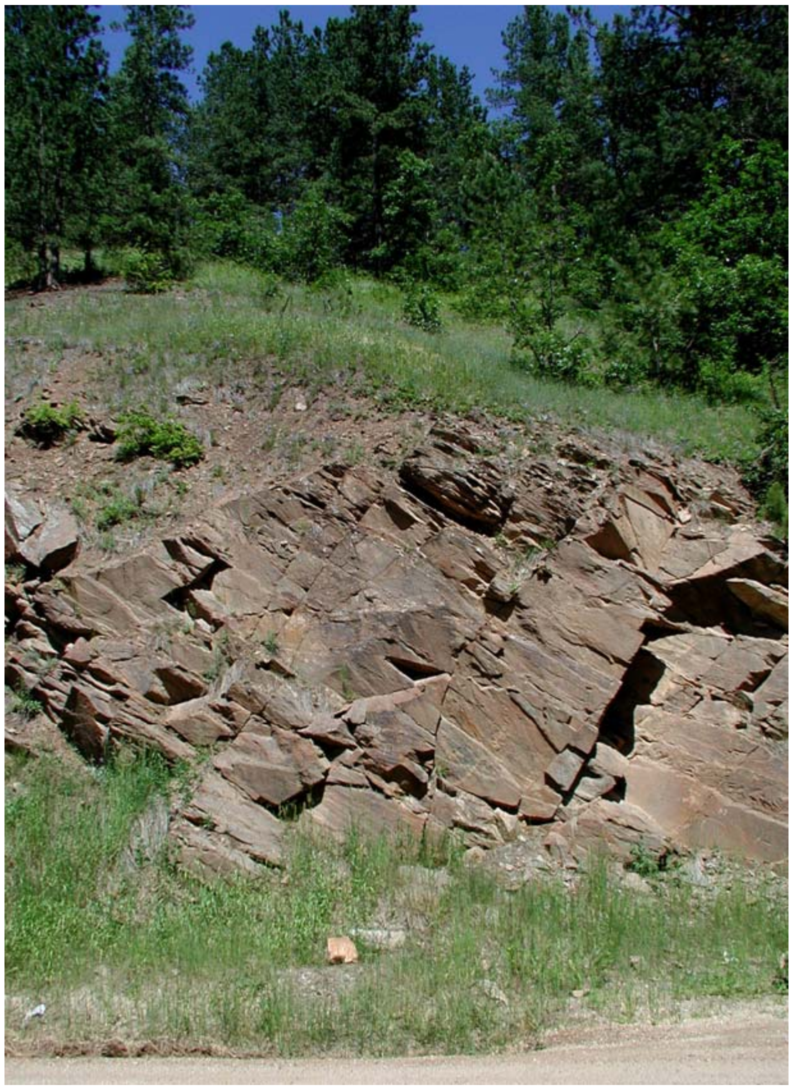

Figure 1. Yates Unit exposure in Blacktail Gulch north of Central City, South Dakota. Width of photo is approximately fifteen meters.

Petrography

As determined by Campbell (1984) minerals comprising the Yates Unit, in decreasing order of abundance, are hornblende, plagioclase, calcite, dolomite, and ankerite. Biotite and chlorite occur locally. Minor and trace constituents include ilmenite, magnetite, titanite, "leucoxene", pyrrhotite, and pyrite. As taken from Campbell in Caddey et al. (1991), "hornblende exists as 0.1-4.0-mm, subhedral prismatic, subnematoblastic to randomly oriented grains. Anhedral, 0.05-0.2-mm, untwinned grains of plagioclase are interstitial to hornblende and commonly occur as poikilitic inclusions in the amphibole." In polished thin sections, pyrrhotite is found to replace ilmenite and magnetite and near Tertiary igneous intrusions, all of these minerals are locally replaced by Tertiary-age pyrite.

Petrography and microprobe analyses of the amphibolite show specifically that ferro-magnesio-hornblende and oligoclase-andesine are the dominant hornblende-plagioclase pair in rocks of amphibolite facies. In greenschist facies rocks actinolitic hornblende and albite are the dominant amphibole-plagioclase phases. The overall mineralogy and textural characteristics of this rock type result in a very tough and competent lithology.

Geochemistry

The Yates Unit amphibole can be simply characterized as having a Fe:Mg ratio of approximately 2:1 and an average SiO_2 content of 50 weight percent. The chemical composition of hornblende-plagioclase schist samples indicates a basalt protolith. Eighteen samples plotted on the cation plot of Jensen (1976) reveals that all but three samples fall within the compositional range of tholeiitic basalt and all but one falls within the iron tholeiite field. Three samples have relatively high MgO values and were tentatively interpreted as basaltic komatiite, as noted by Campbell in Caddey and others (1991), but further work has revealed them to be altered by hydrothermal fluids. Samples plotted on an AFM diagram fall within the tholeiitic field, as defined by Irving and Baragar (1971). Hornblende-plagioclase schist samples from the Yates Unit were also plotted in a KTP diagram, as used by Pierce and others (1975), to discriminate between continental and oceanic basalt. All but three fall within the oceanic basalt field.

Geochemical data for amphibolite schist samples of the Yates Unit are similar to available data on amphibolite data from other areas of the Black Hills (Norby, 1984; Tapper, 1984).

Interbedded Lithologies

Grunerite-bearing Schist

Coarse-grained, medium to dark green, grunerite-quartz-biotite+/-chlorite schist is very locally interbedded with the Yates Unit amphibolite. Grunerite occurs as 0.5 to 2 cm prismatic, randomly oriented, intergrown crystals with quartz, biotite and rare siderite that occupyies interstices between grunerite crystals.

Chlorite-Ankerite-Talc Schist

This unit is found interbedded with amphibolite in the Blacktail Gulch area north of Lead both in diamond drill core and surface exposures. Chlorite-ankerite-talc schist has also been found locally interlayered with amphibolite in underground core from the Homestake Mine in holes drilled into the eastern limb of the Lead Anticline. This lithology is medium grained, light olive green, and moderately well foliated; locally exhibiting a mottled light and medium olive green appearance.

Volcaniclastic Rocks

Mafic volcaniclastic rocks interlayered with the amphibolite were only recently recognized in drill core from holes drilled north of the Homestake mine. Since the origin of some of these clastic units can only be inferred, the term “volcaniclastic” is used as a catch-all in most cases. When appropriate, the volcanic terminology of Fisher (1997) is used.

Drill holes DBM88-1 and DBM89-2 revealed several fine- and coarse-grained volcaniclastic lithologies. Fine-grained, dark green and off-white, salt and pepper textured units interlayered with amphibolite near the upper contact. These units are one to three meters thick, locally associated with metachert and carbonate-rich semipelites and exhibit conformable contacts with these rocks. Coarse-grained, 1-4 mm subangular to subrounded, light green to medium green, volcaniclastic units occur interbedded with the Yates Unit near the upper contact. Rare occurrences of epiclastic debris are found near the upper contact of the Yates Unit very locally and occur as 3 to 10 cm beds that contain 1 to 4 mm, subangular to subrounded clasts of metabasalt and rare carbonate-rich phyllite and black, carbonaceous rock fragments. True thickness of these units in hole DBM88-1 range from one to six meters and are interlayered with amphibolite.

Core from DBM89-2 contains over half a kilometer of volcaniclastic material interbedded with “calc-silicate” beds and phyllite-hosted dolomitic flat pebble conglomerate (described below). Volcaniclastics are greenish to greenish gray, moderately well foliated rock containing fine- (0.5-1.5 mm) to coarse-grained (1-5 mm), subangular to subrounded clasts that exhibit poor sorting. Based on petrographic analysis, clasts are composed of plagioclase feldspar, rock fragments, and quartz, listed in decreasing abundance. Epiclastic debris also occurs interbedded with other volcaniclastics in hole DBM89-2. Volcaniclastic occurrences within mine exposures of the Yates Unit are rare and, prior to this study, went unrecognized for the mine’s 127 years of operation.

Calc-silicate Beds

These units were recently noticed in core and comprise a fine-grained, medium gray matrix with randomly oriented porphyroblasts of coarse-grained (4-10 mm long), dark green amphibole and 3-7 mm, dark pink, subhedral to euhedral, andradite garnet. In thin section, the gray matrix consists of a very fine- to fine-grained quartz and calcite or dolomite. These units conformably overlie the Yates Unit locally, but are commonly interbedded with volcaniclastic units and amphibolite in drill hole DBM89-2. Beds range from less than a meter up to 7 meters in thickness. Calc-silicate beds are very similar in mineralogy and texture to rocks interpreted by Redden (2003, personal commun.) as calc-silicate concretions found in metagraywackes in the Hill City area of South Dakota. This lithology may be the higher metamorphic grade equivalent of the cacite-rich rock/phyllite described below.

Dolomitic Flat-Pebble Conglomerate

Dolomitic flat-pebble conglomerate represents a newly recognized lithology found in the re-logging of hole DBM89-2. It is a gray-brown, fine- to medium-grained, moderately well foliated, biotite-carbonate-muscovite phyllite, that contains numerous, large, flattened gray clasts of dolomite ranging from 3 mm to 1.5 cm in thickness and approximately 10 cm in maximum dimension with clast flattening parallel to foliation. Dolomite clasts are matrix supported. These units occur interbedded with the above described volcaniclastic lithologies and exhibit minor folding.

Metachert

In the Lower Unit of the Poorman Formation, metachert forms as discrete layers within certain lithologies but does not constitute a distinct unit. It is rarely found in drill core as 2 to 6 cm thick layers comprised of pale gray-white, fine-grained (almost saccharoidal) quartz with 1 to 2 mm whisps of dark gray carbonaceous material. These layers are associated with volcaniclastic material, rarely as thin beds lying directly in contact with the Yates Unit amphibolite.

Banded Siderite-Chlorite Rock

This lithology was found associated with volcaniclastics and calc-silicate horizons in drill hole DBM89-2. It is fine-grained, moderately well-foliated and consists of alternating medium green chlorite-siderite-quartz bands and light gray quartz-siderite (metachert) bands.

Yates Unit Interpretation

Based on conformable contacts, intercallated sediments, structures interpreted as relic pillows, and whole rock geochemistry, the amphibolite of the Yates Unit is interpreted as a sequence dominated by oceanic tholeiitic basalt flows. These basalt sequences locally exhibit a volcaniclastic apron comprising tuffaceous and volcaniclastic debris, eroded and reworked volcanics consisting of epiclastic debris, along with local accumulations of chemical sediments.

Based on the tholeiitic composition of the amphibolite, absence of relict vesicles, and the very fine-grained nature of the overlying metasediments, the Yates Unit of the

Lower Poorman Formation is interpreted here as a deep-water basin sequence dominated by tholeiitic basalt flows and associated volcaniclastic debris. Jones (1969) and Moore and Schilling (1973) related vesicle size and abundance to basin depth for volcanic rocks in basin sequences and mid-ocean ridges. The lack of evidence for explosive volcanism in the Homestake Basin and the absence of vesicles in Yates Member metavolcanics indicate a deep-water setting, below the 3,150 meter limit given by Jones (1969) and Moore and Schilling (1973). They attributed high overlying hydrostatic pressures in the deep basin to the lack of vesicles at this depth. The relatively thick sequence of volcaniclastic debris found locally near or at the upper contact of the Yates Unit suggests that a moderate volcaniclastic apron was developed on the basalt flows, especially in the area of drill hole DBM89-2 near Maitland. Distribution of this apron, especially to the north of the mine, is not well defined since it is based on two diamond drill penetrations and exposures within the mine are fine-grained and difficult to distinguish from metabasalt in underground exposures. Amphibolite units interbedded with volcaniclastics in DBM88-1 near Maitland are interpreted as an alternating sequence of volcanically derived clastic material and basaltic sheet flows.

Calc-silicate horizons, metachert, dolomitic flat pebble conglomerate, banded siderite-chlorite rock and grunerite-bearing schist are all chemical sediments intercalated with the amphibolite in the Maitland area. Banded siderite-chlorite rock and grunerite schist are interpreted as iron formation. Based on cross-sectional interpretation, these chemical sediments are located in the middle to upper portions of the volcano-stratigraphic succession. Paucity of additional diamond drill hole data precludes the determination of lateral facies equivalency within the typical Poorman-Homestake-Ellison sequence.

Lithologies found in core from diamond drill hole penetrations near Maitland provided the greatest insight to the volcano-stratigraphic succession related to the Yates Unit. The large amphibolite body found in this area as shown on plan maps and cross-sections consist largely of deep water tholeiitic flows that progressively grade into volcaniclastics and chemical sediments higher in the sequence and laterally. Drill hole DBM89-2 and drill hole penetrations from the North Homestake Drift on the 6800 Level of the mine reveal a large mass of amphibolite that partially define a thick sequence of basaltic flows that may represent a large volcanic edifice that was undoubtedly subaqueous, but possibly subareal in its upper extremes. Drill hole DBM88-1 penetrates a flank of this volcanic pile and the heterogeneity of lithologies represented in this hole, represented by volcaniclastics and interstratified chemical metasediments with basalt flows indicate a lateral extension of lithologies representing a variety of subaqueous paleodepositional environments. The dolomitic flat pebble conglomerate may represent a relatively shallow water near shore environment if analogies with similar occurrences in the Cambrian age Deadwood Formation can be made

Tholeiitic basalt is common in back arc basins and Archean granite-greenstone terrain worldwide. As stated by Campbell in Caddey and others (1991), "the voluminous nature of the Yates Unit at Lead suggests possible greenstone affiliations of earliest Proterozoic age rocks, not fully appreciated from limited surface exposures". Trace element geochemistry of this unit, however, indicates that a back arc basin is the most likely tectonic environment. As suggested by Redden and others (1990) and Campbell (Homestake internal reports), iron tholeiite of the Yates Unit and possibly other iron-tholeiite of similar early Proterozoic age rocks in the northern Black Hills, as those of Norby (1984) and Tapper (1984), may represent basalts related to a rifting event with the development of a back-arc or possibly intracontinental basin.

Interbedded volcaniclastic units, calc-silicate beds, amphibolite, and other associated interbedded lithologies found in hole DBM89-2 are interpreted here to represent a volcaniclastic apron with interbedded chemical sediments along the flank of a series of large, mafic subaqueous volcanoes, represented by the main masses of Yates Unit amphibolite.