Chemostratigraphic and Paleoenvironmental Analysis of Sedimentary Rocks Applied to VMS Exploration: Examples from the Bathurst Mining Camp, New Brunswick, Canada

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INTRODUCTION

In addition to lithogeochemical applications to VMS-related hydrothermal alteration studies, chemostratigraphy has significant potential in: 1) establishing a better understanding of local stratigraphy and 2) enhancing regional and local correlations within mineralized belts, especially in structurally complex areas where alteration or dynamic metamorphism has obliterated petrographic features. Unfortunately, there are very few specific lithogeochemical studies that try to understand the petrogenesis, chemostratigraphy, and depositional environment of sedimentary rocks that host massive sulphide deposits (see Lentz, 1996). Empirically based compositional and tectonic trace-element discrimination diagrams are now being used for characterizing the provenance, original composition and association, and tectonic environment of volcanogenic sedimentary rocks (*e.g.,* Slack and Stevens, 1994). Based on empirical observations, some studies have tried to devise tectono-environmental discriminants, i.e., continental arc, active and passive margins, etc. to characterize host sedimentary rock affinities around ore deposits (e.g., Slack and Stevens, 1994).

In the Bathurst Camp, it is important to know the association of sedimentary rock units because VMS mineralization has specific lithological associations. Chemostratigraphic research has shown that geochemical features of these sedimentary rocks may be used to distinguish formations, especially after alteration, deformation, and metamorphism, and therefore can enhance stratigraphic and structural interpretations thus impacting exploration. These chemostratigraphic features are of two types: immobile-element variations reflecting provenance of the terrigenous material, and mobile hydrothermal-hydrogenous-element differences indicative of depositional paleoenvironment. Analogous with volcanic rocks, high-field-strength elements (HFSE), such as Al, Ga, Ti, Sc, Zr, Hf, Y, HREE, and Th and possibly Nb, Ta, Cr, and V are generally immobile in sedimentary rocks under most geologic conditions (Taylor and McLennan, 1985; see Lentz, 1996), and therefore, may be used in provenance analysis.

PROVENANCE AND CHEMOSTRATIGRAPHIC ANALYSIS

In the Bathurst Camp, the similarity between grey to black slates of the Miramichi Group and Tetagouche Group is locally problematic. As a result, preliminary studies by Lentz *et al.* (1996) tried to find geochemical features that might help distinguish these units in areas with good stratigraphic control. Most trace elements in sedimentary rocks covary with Al_2O_3 reflecting micas (± feldspar), unless resistant phases are involved that are associated with detrital quartz (± feldspar). Therefore, a technique to enhance the differences between types and sources of sediments (i.e., for chemostratigraphic purposes) in any particular area involves normalization with respect to Al (e.g., Ti/Al, Th/Al).

In general, the sedimentary rocks of the Miramichi Group have higher Al_2O_3, LREE, HREE, Y, and Th than the Boucher Brook rocks, which is consistent with a weathered crustal source along the proximal continental margin preceding felsic volcanism, in contrast to a local, volcanic-dominated source for the post-volcanic black slates (Lentz *et al.,* 1995; Lentz *et al.,* 1996).

Chemostratigraphy has also helped to map out complexly folded sediments of the Miramchi Group versus the Nepisiguit Falls Formation (Tetagouche Group). Lentz and Goodfellow (1994) found that in the FAB zone, located between Brunswick No. 6 and No. 12 VMS deposits, the moderate to intense footwall alteration has destroyed many of the macroscopic features normally used to map out these rocks. Chloritic and pyritic alteration in both units has obliterated most major and trace element features as well, although a statistical analysis of the data showed that TiO_2, Sc, V, and Cr are higher in the Miramichi sedimentary versus the Tetagouche felsic volcaniclastic rocks, such that these units could be distinguished. Also, a study of the Heath Steele B Zone VMS deposit found chemical differences between the lower and upper footwall sedimentary units (Lentz and Wilson, 1997) which challenges the current structural interpretation that it represents the same unit repeated by folding. This has obvious implications for exploration along

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the Heath Steele Belt. This interpretation is also consistent with slight compositional differences found in the associated footwall and hanging wall volcanic rocks (Lentz and Wilson, 1997). Also, the Nepisiguit Falls sediments have HFSE differences from those of the Flat Landing Brook Formation (see Lentz, 1996; Lentz and Goodfellow, 1996), which is useful where the volcanic association is not obvious.

PALEOENVIRONMENTAL ANALYSIS AND CHEMOSTRATIGRAPHY

In general, seawater redox reactions control the distribution of the various hydrothermal components, particularly Fe and Mn (Whitehead, 1973). The presence of graphite is not a definitive indicator of redox conditions, but rather reflects the degree of production and preservation of carbon, which may be affected by several factors, only one of which is basin redox conditions. Fixation of metals (and sulphur) by organic carbon in the water column, at the sediment-water interface and during diagenesis, is very well known (Vine and Tourtelot, 1970). Therefore, in addition to carbon content, black shales anomalous in Ag, Cr, Cu, Mo, Ni, Pb, V, and Zn, as well as higher amounts of S, reflect the overall reducing depositional conditions at low rates of sedimentation. The accumulation of these elements is controlled by their fixation as sulphides and a function of the availability of H_2S derived by bacterial reduction of seawater sulphate. In addition, the formation and preservation of massive sulphide deposits is also a function of redox conditions and proportion of reduced sulphate (to H_2S) in the basin. Therefore it is important to recognize these paleoenvironmental features in exploration.

In addition to the notable provenance differences between the texturally similar Boucher Brook (upper) and Miramichi (lower) sedimentary rocks, there is also a considerable hydrogenous/hydrothermal component in the Boucher Brook rocks, which is not typical of the Miramichi black slates (Lentz *et al.,* 1995, 1996). Based on a detailed study of the sedimentary section north of Brunswick No. 12, the Boucher Brook black slates have higher Mn contents than the Patrick Brook Formation (Miramichi Group) slates (Lentz *et al.,* 1996). Fe_2O_3t, S, and C values are variable, although the Fe/Mn ratio is distinctly higher than the Boucher Brook slates, indicative of higher Eh conditions consistent with the higher Co and Ce anomaly in those rocks (Lentz *et al.,* 1996). On average, high concentrations of Cr, V, U, Mo, ± Ni and low Mn in the Caradocian black slates relative to other Ordovician sedimentary rocks in the Bathurst Camp (Lentz *et al.,* 1995) are consistent with hydrogenous/hydrothermal sedimentation (seawater scavenging) within a clastically starved, deep-basinal environment (Vine and Tourtelot, 1970). This contrasts with other age equivalent Boucher Brook sedimentary rocks, which have more oxidized signatures (higher Mn and Co contents (low Fe/Mn)). Lentz *et al.* (1995) have interpreted the red manganiferous slates to form either in the higher (oxygenated) levels of a stratified ocean (back-arc) basin, in contrast to the black shales, or as a result of local disruption of the stratified ocean due to concurrent volcanism and/or convective overturn related to thermal perturbations. The latter is consistent with the common association of red manganiferous slates and hydrothermal chert intercalated with mafic volcanic rocks in the camp, although there are some places where mafic volcanic rocks are intercalated with black slates.

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