Chapter 7 - Mineral Resources of the Cumberland Basin

Introduction

Mineral occurrences of the Carboniferous basins of Nova Scotia can be divided or classified into numerous types based on host rocks and styles of mineralization (Fig. 7-1). In the following sections, types of mineralization in the Cumberland Basin are considered. For the purpose of discussion, the various types or styles of metallic mineralization are grouped together, on the basis of their inferred genesis. Models or affinities are examined here and evaluated in light of the thermal and geological constraints established in earlier chapters. This chapter synthesizes the essential character of the resources within a milieu of evolving genetic models of mineralization, regional tectonics and sedimentation. Every effort has been made to balance the treatment of these complex and often controversial subjects by incorporating and integrating previously published data within the context of thermal and basin development theories generated through this study.

Metallic Mineral Occurrences of the Cumberland Basin

Mineral occurrences in the Cumberland Basin (Figs. 7-2, 7-3) can be classified into several types: (1) sandstone-hosted (redbed), stratiform Cu, Ag, Zn, Pb, Co and Ba; (2) sandstone- and shale-hosted uranium occurrences; (3) carbonaceous shale or limestone-hosted, unconformity-related Cu-Ag; and (4) fault-related Cu, Pb, Zn and Ba occurrences. Also, potential exploration environments, as yet undocumented, may include: (i) carbonate-hosted Pb-Zn; (ii) carbonate-hosted Pb-Zn-Ag-Ba related to faulting; (iii) paleoplacers of Au and Sn; (iv) unconformity-related, sandstone-hosted Pb-Zn-Ag where grey carbon-rich sandstone onlaps basement; and (v) sulphate-hosted Ba and Sr deposits (Fig. 7.4).

Since most of the metallic mineral occurrences in the Cumberland Basin are sandstone- and shale-hosted redbed Cu-Ag deposits, they are the focus of this economic

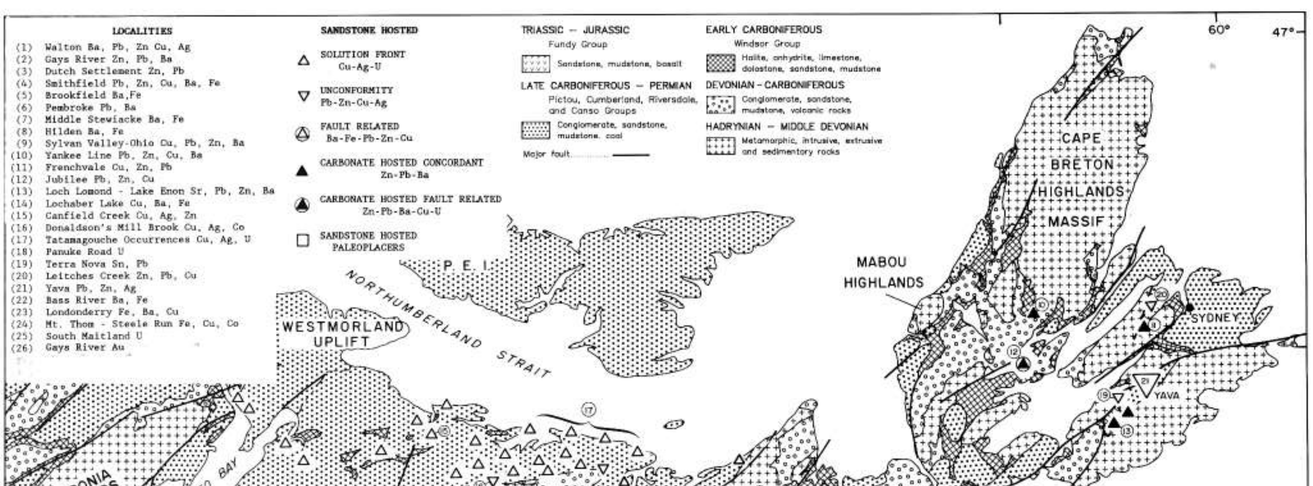


Figure 7-1. Metallic mineral occurrences of the Carboniferous basins of Nova Scotia.

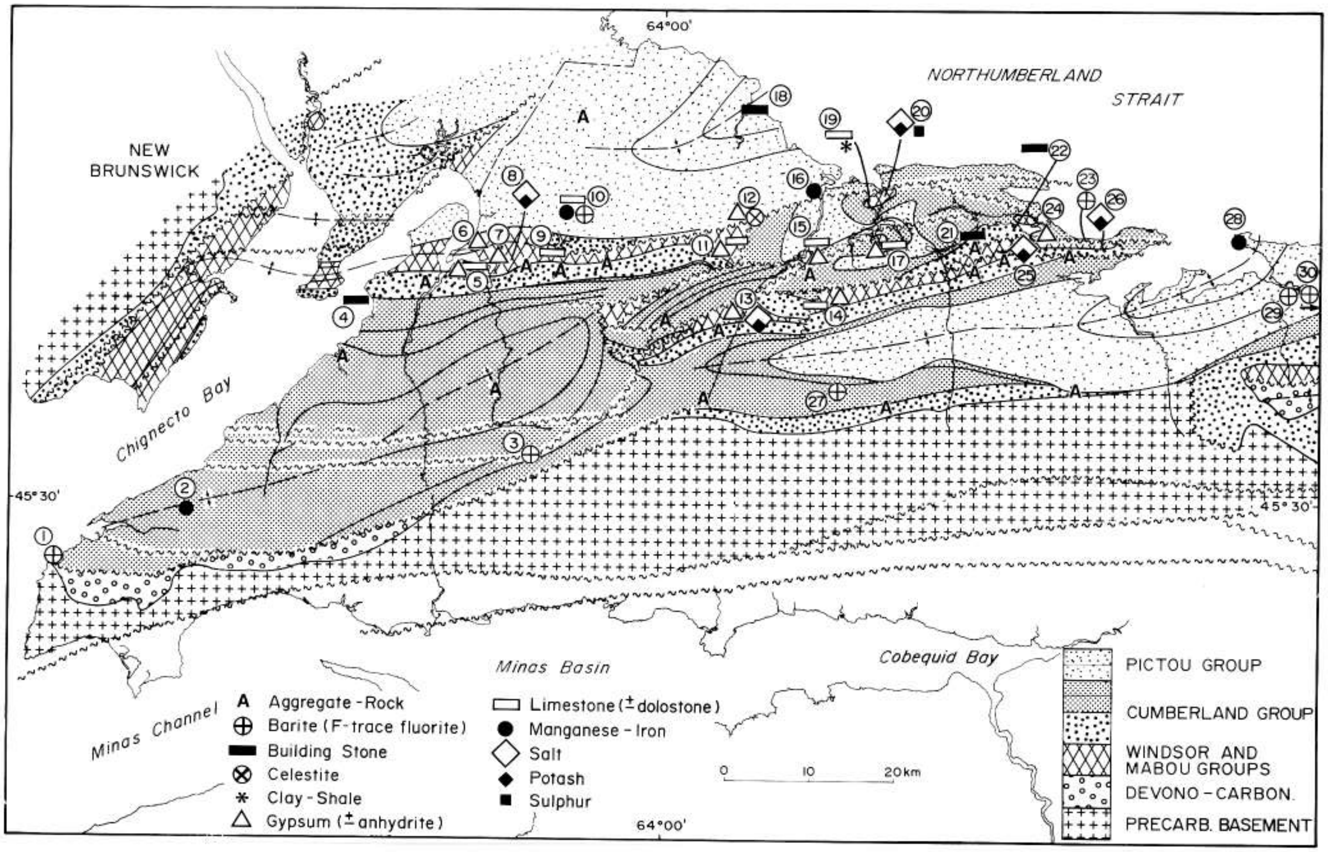


Figure 7-2. Location map of industrial mineral occurrences in the Cumberland Basin.

geology section. Mineral occurrences of the Cumberland Basin are examined and inferences are made based on this information in relation to the Maritimes Basin as a whole.

Sandstone-Hosted Cu-Ag Occurrences

The Cu-Ag occurrences (chalcocite, bornite) most commonly occur at, or near, the base of fining-upward fluvial sequences (Dunsmore, 1977a), where most of the coalified plant material is concentrated in channel lags. This is an important consideration because it means that the best mineral concentrations occur within channels; therefore, channels must be traced in order to attain the best results. Brummer (1958) suggested that chalcocite formed as a result of supergene enrichment, and that its vertical extent is limited to the local depth of the groundwater table. If true, this would seriously limit the size of potential deposits. However, more recently Ryan and Boehner (1986) observed chalcocite in drill core to a depth of 440 m, thus challenging a simple supergene (shallow) enrichment interpretation. These copper occurrences have varying amounts of associated minerals. At some localities, high-grade grab samples have yielded up to 10 oz. per ton Ag, up to several hundred ppm Co, and up to 0.5 oz. Au per ton has been reported, although values of 100 ppb Au are the norm.

Canfield Creek Cu Deposit

The best example of redbed sandstone-hosted Cu-Ag mineralization occurs at the Canfield Creek prospect (Fig. 7-5). The Canfield Creek deposit is situated in the central portion of the Cumberland Basin in northern Nova Scotia, approximately 5 km south of the town of Pugwash (Figs. 7-6, 7-7). There is little visible surface mineralization at this locality and most of the information on the deposit is derived from the drill cores. Continental clastics of the Mabou, Cumberland, and Pictou groups overlie the marine Windsor Group strata. In the central portion of the Cumberland Basin, Upper Carboniferous clastic strata are pierced by a series of diapiric evaporite domes. The Canfield Creek prospect flanks one of these domes (Fig. 7-6).

The Canfield Creek deposit contains approximately 300,000 tons of 1.2% Cu with minor zinc and silver showings (O'Sullivan, 1981). The deposit has not been tested at depths greater 120 m, and is open-ended in at least two directions. There are two surface occurrences

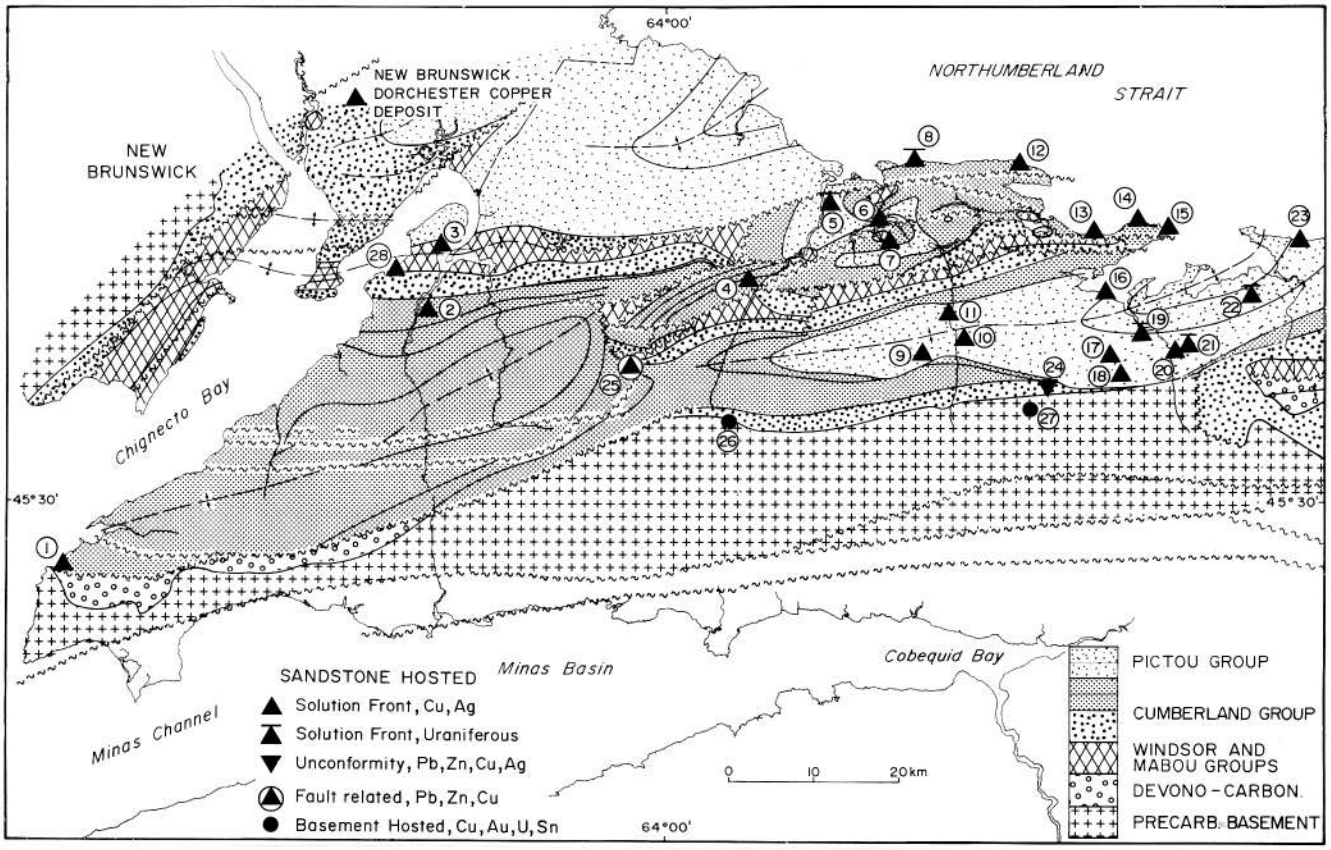


Figure 7-3. Location map of metallic minerals in the Cumberland Basin.

of copper in the Canfield Creek area, one 1.8 km west of the drill site, and the other in a geochemical sample trench 1.1 km south of the ore body (Fig.7.6). Drilling at Canfield Creek was initiated because of the occurrence of copper in chip samples from the potash drillhole SR-29-1 drilled in 1966 by Scurry Rainbow Exploration. Esso Minerals DDH-P1 was drilled close to the old drillhole (SR-29-1) and intersected 8.1 m of 0.53 % Cu at a depth of 74 m in grey sandstone of the Malagash Formation. A follow-up grid drilling program comprising 27 holes outlined 300,000 tons at 1.2% Cu, with traces of Ag (O'Sullivan, 1981; Fig. 7-7).

The ore is hosted primarily by grey medium- to coarse-grained sandstone. The sandstone is crossbedded, variably arkosic, and contains abundant plant debris along bedding planes. The sandstone is part of a multistoried, multilateral channel sandstone sequence and varies in thickness from 2-25 m (Fig. 7-8). The channel sequence sandstone is inter-crossbedded with thin grey mudstone (>30 cm) and calcareous mud chip conglomerate (>70 cm). Mud chip conglomerate represents the basal lags of channel sequences. These grey channel sandstone bodies occur within a primarily red mudstone overbank sequence. Chandler (1992, pers. comm.) has suggested that thin grey mudrocks interbedded within and overlying the mineralized channel sandstone bodies are lacustrine (Fig. 7-8). If his suggestion is correct it may help to explain why the sandstone bodies retained their grey coloration, are pyrite-bearing, and acted as redox boundaries.

Ore grade zones occur to a depth of at least 110 m, are up to 5.2 m thick (1.2% Cu), and appear to be open-ended. The drillhole profile (Fig. 7-8) indicates that drillholes on the eastern part of the grid may not have been drilled deep enough to intersect the main ore zone. The occurrence of malachite in a geochemical sample trench (see MacDonald *et al.*, 1992) at a higher stratigraphic horizon indicates that there may be stacked, mineralized horizons rather than the single horizon interpreted by Esso during their original exploration.

Mineralization occurs as disseminated chalcocite (Fig. 7-9), chalcocite nodules up to 3 cm in diameter (Fig. 7-10), and wispy infillings along parting planes

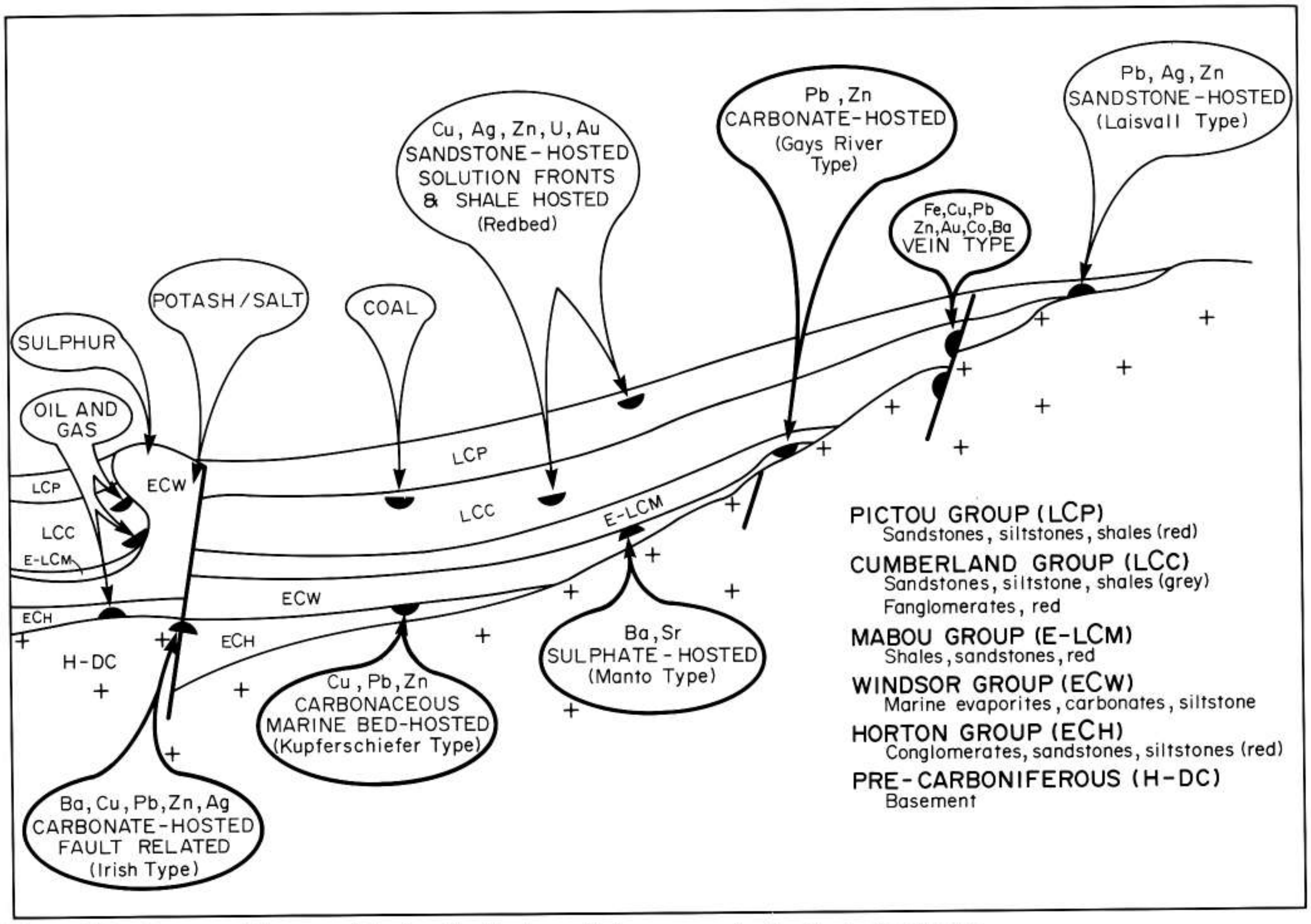


Figure 7-4. Cartoon of the potential mineralization types that may occur in the Cumberland Basin.

(O'Sullivan, 1981). The mineralogy and paragenesis of the ore minerals are discussed in a later section of this chapter.

Shale-hosted Cu-Ag Occurrences

In the Cumberland Basin, Boss Point Formation greybeds of continental origin are usually the first grey horizon overlying a thick succession of redbeds of Early Carboniferous age. Mineralization is common at this boundary (Stea *et al.*, 1986). The Windsor Group marine strata may also have a similar relationship to red clastic rocks of the Horton Group; however, this part of the stratigraphic section is not exposed at surface within the basin and, therefore, discussion will be limited to the better-exposed Boss Point Formation shale-hosted occurrences. The mineralogy of ore minerals is almost exactly the same as in the sandstone-hosted deposits of the area. Copper minerals include chalcocite and bornite with minor associated digenite and covellite. They occur as nodules or as replacement of coalified plant material within grey siltstone and shale. Copper minerals are usually closely associated with pyrite and some traces of sphalerite are also present. A detailed description of the ore mineralogy is presented in a later section of this chapter.

Scotsburn Brook Prospect

One of the best examples of this type of mineralization is located at Scotsburn Brook, near Scotsburn, Pictou County (Fig. 7-11). The original shaft sunk in the area prior to 1887 can no longer be seen, it may be represented by a water-filled hole now used for watering cattle. On the small stream near the original shaft approximately 2 m of mineralized mudstone and siltstone are exposed (Fig. 7-11). The mineralized horizon is confined to grey siltstone and mudstone occurring between two channel sandstones (Fig. 7-12).

Recent mapping (Yeo, 1987) in the area missed the Fitzpatricks Mountain Fault (shown on earlier series of geological maps) and also incorrectly assigned rocks at the mineral occurrence to the Claremont Formation

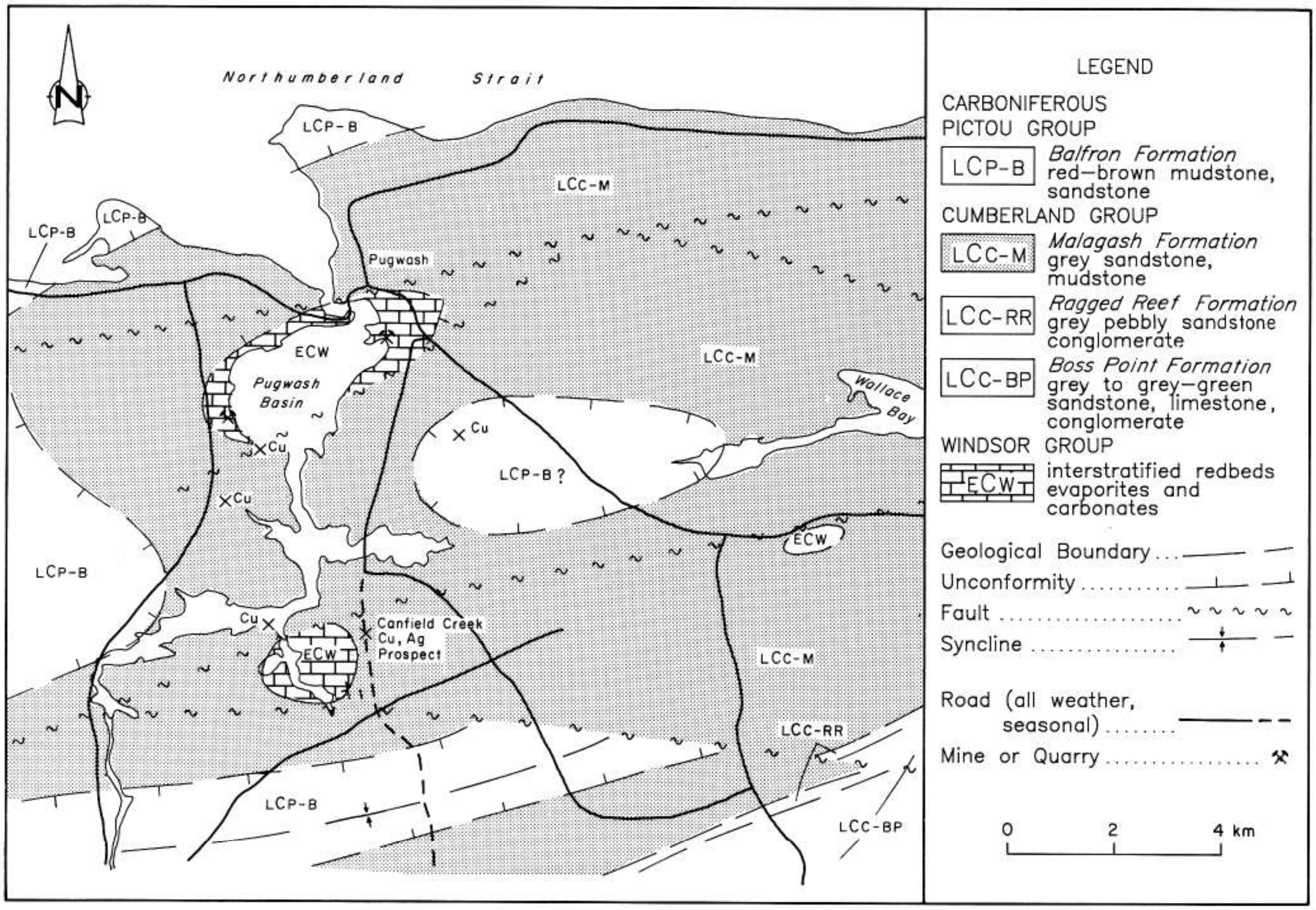


Figure 7-5. Location and generalized geology of the Canfield Creek occurrence.

(Fig. 7-11), whereas the host rocks of the occurrence should be assigned to the Middleborough Formation. The relationship of the fault to mineralization is unclear; however, there are numerous stream sediment geochemical trends that appear to be related to this fault (Fig. 7-13).

Mineralization is represented primarily as malachite stains in the grey mudstone, although minor amounts of chalcocite-bornite were observed associated with coalified plant material in the mudrock. Copper values are as high as 3.95% over 50 cm, with a grade of 1.66% Cu over a 1.5 m interval. The property is currently under exploration license to Cominco and is being assessed by diamond-drilling for its economic potential.

Donaldson's Mill Brook Prospect

Another example of this type of mineralization occurs at Donaldson's Mill Brook (Fig. 7-14). This occurrence is hosted in a 3 m thick, grey silty-shale of the Boss Point Formation, which overlies red siltstone and sandstone. The mineralized horizon is approximately 50 to 100 m stratigraphically above an unconformity with red conglomerate of Early Carboniferous age. Mineralization is represented by a 1-3 m thick horizon that contains chalcocite and bornite nodules up to 2 cm in diameter, and as coalified plant stems that have been permineralized by pyrite, chalcocite and bornite. The occurrence has an outcrop strike length of 45 m (Fig. 7-15).

The host rock of this occurrence is greenish-grey mudstone and fine siltstone. The mudrocks are finely laminated and contain thin wisps of organic debris along parting planes. Minor crosslaminations are found within the silty beds. The unit is variably calcareous and contains a few rhizoconcretions (calcium carbonate concretions surrounding plant roots), which occur is distinct bands in the mudrocks.

As part of this study samples from three assay channels were analyzed, delineating a 110 cm zone of 1% Cu with 0.25 oz. Ag per ton. High grade grab

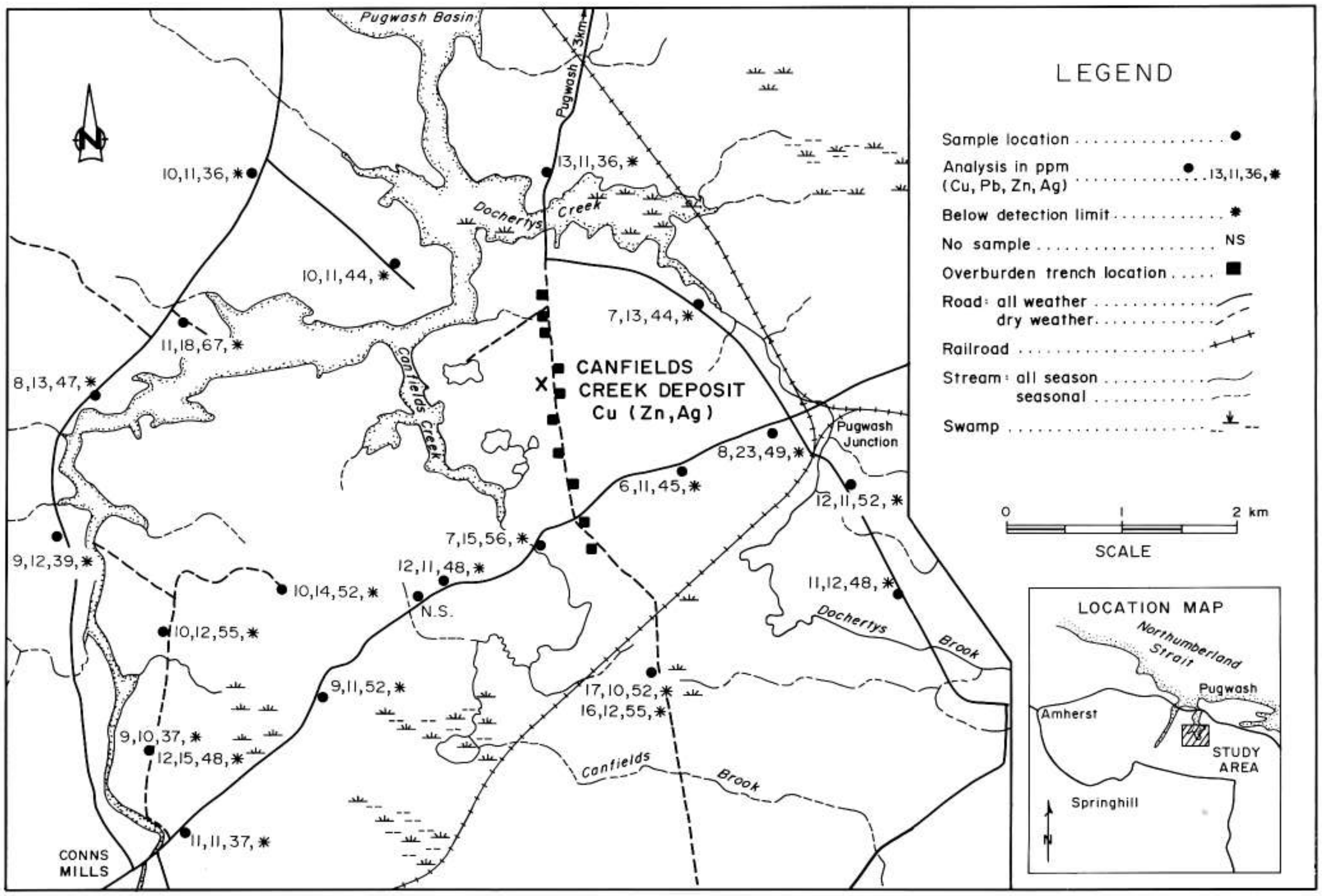


Figure 7-6. Detailed location map of the Canfield Creek deposit and a plot of the -230 mesh fraction of the regional till samples (after MacDonald *et al.*, 1992).

samples from the occurrence contain up to 17 oz. Ag per ton. This property is currently under exploration license to Cominco and is being assessed for economic potential.

Mineralogy of the Copper Occurrences

The mineralogy of the two types of redbed Cu mineralization in the study area show great similarity. Examination of polished thin sections suggests that separate discussions of the mineralogy of various deposit types is therefore unwarranted, and the following section applies to all of the Cu occurrences studied.

Papenfus (1931) demonstrated that the Cu-Ag-U ore in the Cumberland Basin occurs in three different forms: (1) nodules and concretions of chalcocite, bornite and pyrite; (2) chalcocite replacing pre-existing cementing material in the sandstone; and (3) chalcocite and pyrite associated with coalified plant material. In each case, much of the chalcocite occurs as replacement of pyrite and/or rose coloured bornite. Digenite and covellite are also present in minor amounts. Papenfus (1931) demonstrated that many of the chalcocite nodules are pseudomorphs after pyrite nodules, and Shumway (1951) found that many of these chalcocite nodules have pyrite cores.

Where chalcocite, bornite and pyrite are found in association with coalified plant material, the pyrite occurs originally as: (1) coatings on the coalified plant material, (2) botryoidal nodules, or (3) replacement of the plant material. Some well preserved examples of mineralized fossil-wood fragments exhibit replacement of original cell structure by some combination of pyrite, bornite, chalcocite and digenite (Fig. 7-16).

Barite commonly occurs adjacent to or associated with redbed Cu mineralization as cement or as replacement of coalified plant material (e.g. Treen Bluff). The concentration of barite is generally less than 1% and, therefore, not of economic importance by itself.

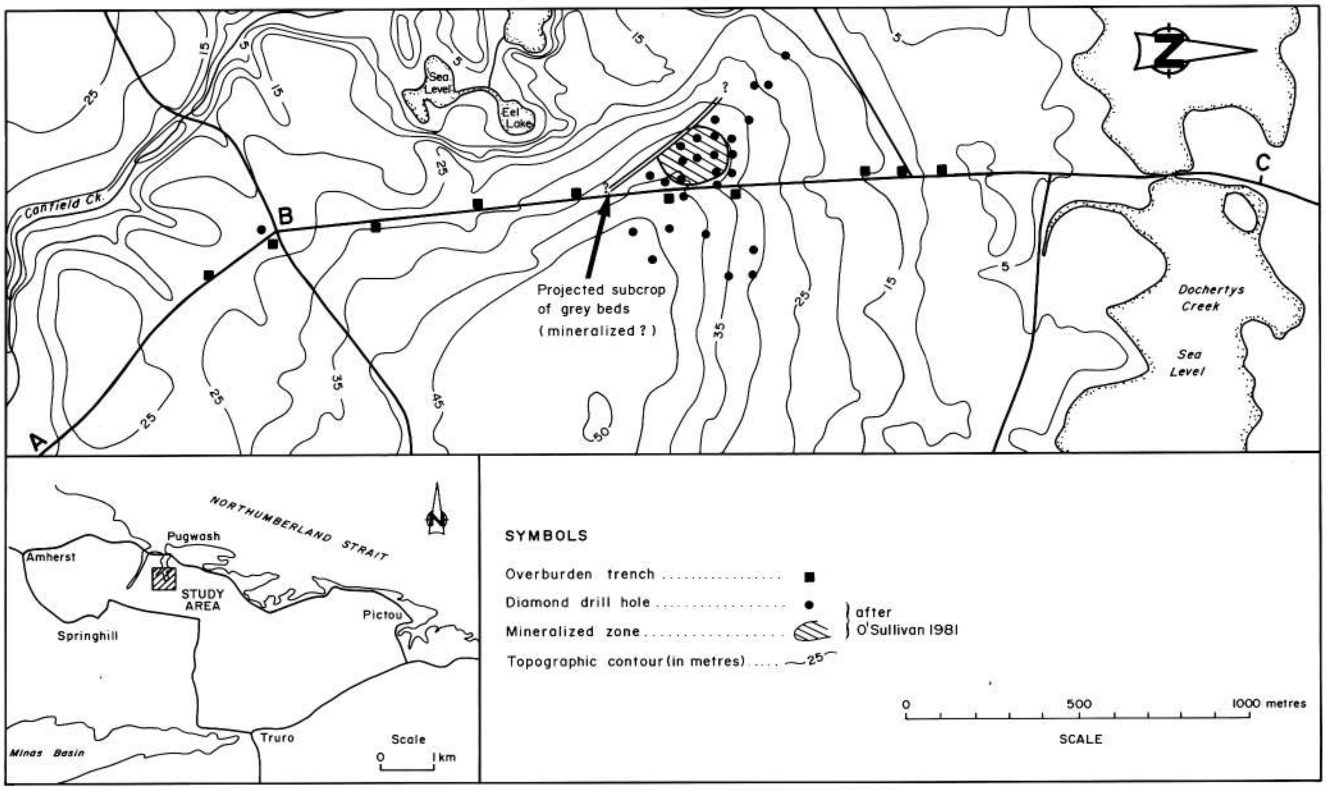


Figure 7-7. Location of drilling, trenches, and ore zone at the Canfield Creek deposit (after MacDonald *et al.*, 1992).

Pyrite occurs as replacement of original coalified plant material, cement, and as small nodules, and is replaced or cut by all of the other ore minerals (Fig. 7-17). The polished sections studied did not have pyrite replacing or cutting any of the other ore minerals. Pyrite can rarely occur with sphalerite intergrowths, but only in the absence of copper minerals. This relationship suggests that, at times, pyrite and sphalerite were cogenetic.

Bornite from the Cumberland Basin occurrences always exhibits exsolution or replacement textures (Fig. 7-18). Host phase, rose-coloured bornite locally exhibits basket weave texture with chalcopyrite as the exsolved phase. More commonly, rose-coloured bornite is intricately intergrown with chalcocite-digenite as a cogenetic suite or occurs as a roughly cubic network of chalcocite replacing bornite. Bornite often replaces pyrite forming a micro-brecciated sub-cubic network of veinlets emanating from star-shaped blebs (Fig. 7-19).

Chalcocite and digenite occur primarily as replacements of pyrite and bornite, or more rarely as mono-minerallic nodules. Chalcocite can also occur in apparent equilibrium with bornite where mutual replacement occurs. Digenite and covellite are minor constituents of the ore and occur as replacements of pyrite or chalcocite.

The mineralogy of uranium occurrences associated with redbed copper is unclear (Chatterjee, 1977); however, radioluxographs indicate that the radioactivity eminates from crustified layers enclosing the primary pyrite or Cu-Ag ore minerals. Similar observations were made by MacKay and Zentilli (1976) on samples from one of the occurrences at Black Brook. MacKay and Zentilli (1976) found traces of pitchblende surrounding the copper sulphides and concluded that uranium mineralization occurred after copper mineralization. These observations indicate that uranium mineralization postdates the copper ore and pyrite, and could possibly represent a much later mineralizing event or phase.

Textural relationships of the ore minerals, as observed in polished sections, indicate the following order of mineralization from oldest to youngest: (1) pyrite; (2) sphalerite and pyrite; (3) bornite with traces of chalcopyrite; (4) chalcocite, digenite, barite and silver (native and within the chalcocite lattice); and later, (5) uranium. There is a possibility that this mineral

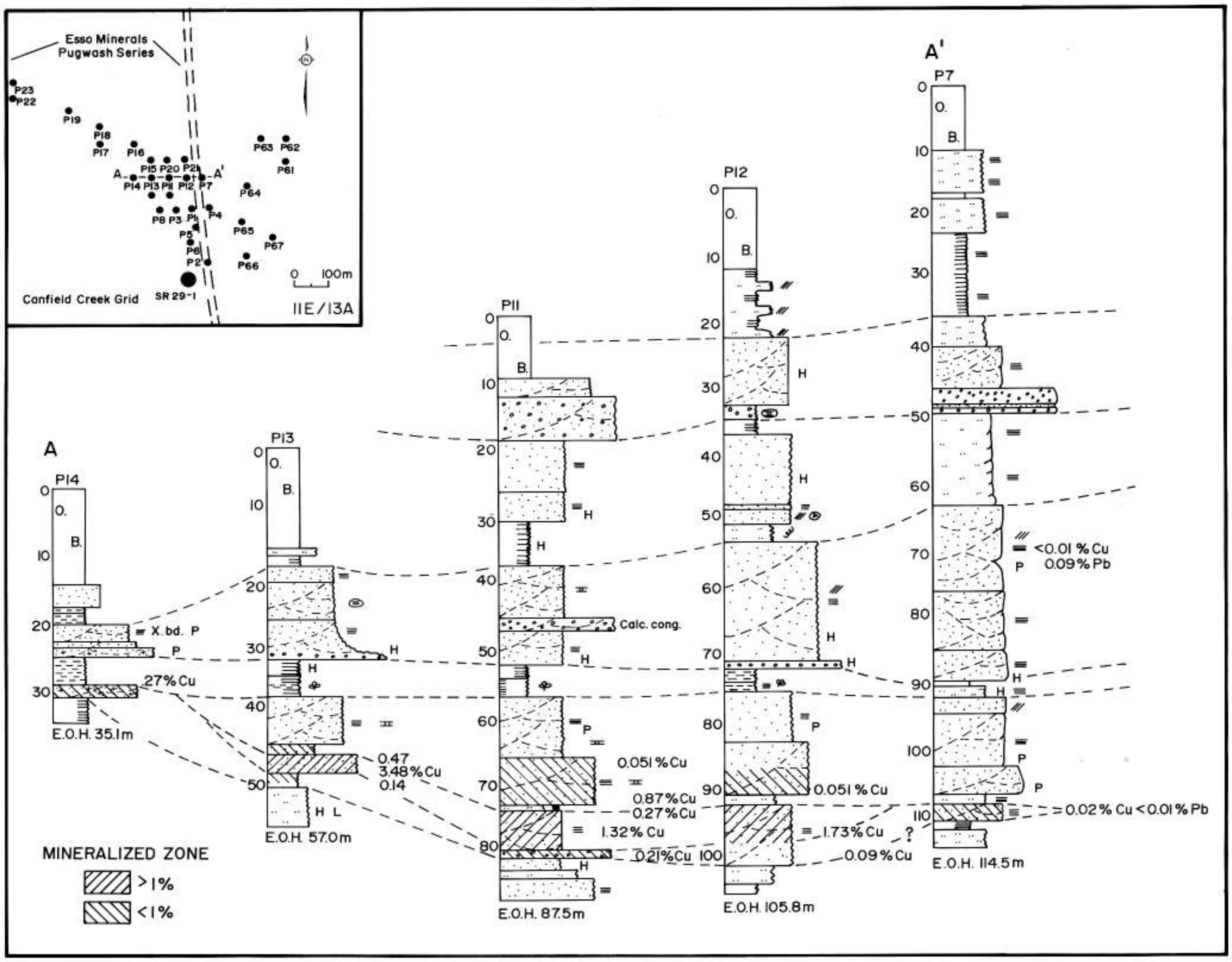


Figure 7-8. Cross-section of drillholes from the Canfield Creek Cu deposit. Note the upper pyrite with trace of sphalerite zone and the underlying Cu zone.

assemblage represents a metamorphic, post-mineralization overprint. If the timing of heating extrapolated from the burial plots is correct then the mineralization postdates maximum burial and, therefore, the mineral assemblage should closely resemble the original.

Zonation

The poor exposure and lack of drilling information for most of the occurrences in the study area makes speculation as to mineral zonation within the occurrences difficult. At the Canfield Creek copper prospect, where drilling has defined a crudely zoned ore body, there is an upper pyrite-sphalerite zone above the chalcocite ore zone (Fig. 7-8). The configuration of till Cu and Pb anomalies in the Canfield Creek area suggests similar zonations may occur laterally. The Cu anomalies in till occur several kilometres east of the ore body whereas Pb anomalies occur immediately adjacent to the occurrence. Stea *et al.* (1986) indicate that the glacial dispersion of till should be approximately equal for all samples in this area; therefore, the displacement of anomalies in relation to the ore zone may reflect mineral zonations within the occurrence. At Skinner's Cove, Pictou County, a boulder of mineralized galena-sphalerite channel lag was found along the beach. This occurrence may represent a Pb-Zn zone of mineralization adjacent to a Cu-Ag occurrence.

Temperature of Copper Mineralization

In order to better understand the mineralizing processes

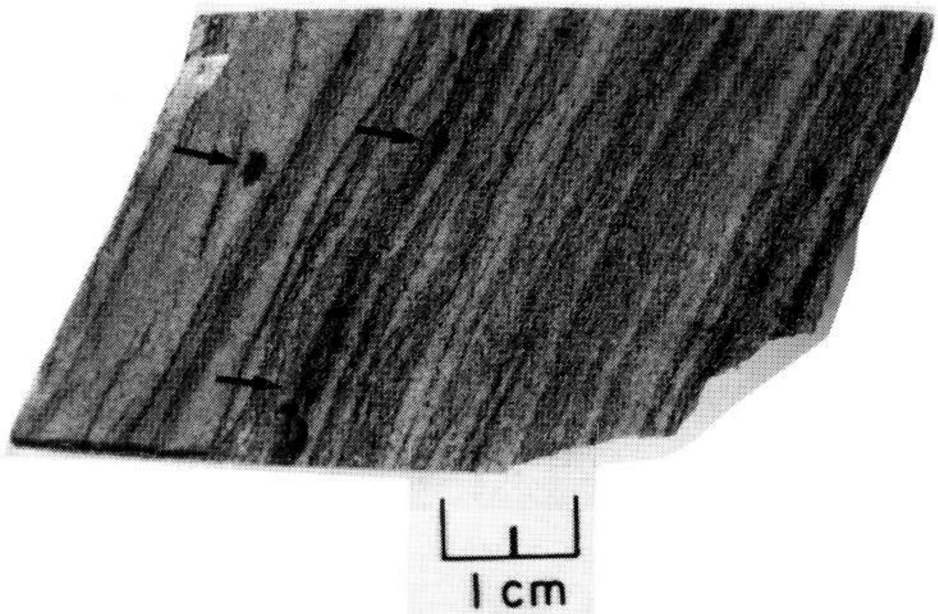


Figure 7-9. Core sample from ESSO drilling at Canfield Creek with disseminated chalcocite.

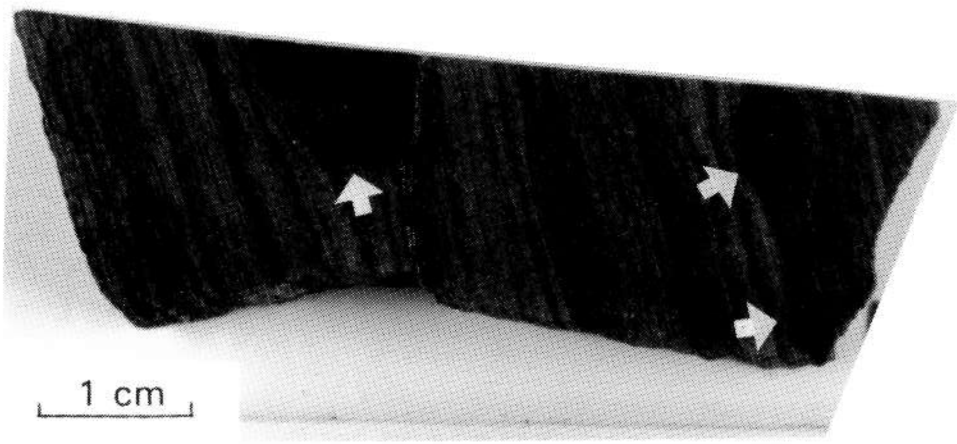


Figure 7-10. Core sample from ESSO drilling at Canfield Creek showing chalcocite nodules up to 2 cm in diameter.

for these occurrences attempts to quantify temperature constraints were undertaken as part of this research. Examination of polished sections from the various occurrences in the study area revealed a paucity of two-phase fluid inclusions directly correlative to mineralization; therefore, temperature estimates by this method could not be ascertained.

Ore mineralogy does provide some constraints on the temperature of mineralization. The cogenetic suite of digenite, chalcocite and rose-coloured bornite strongly suggests a low mineralization temperature. Lur'ye and Gablina (1976) examined and experimented with temperature stability on similar ore suites from redbed Cu-Ag deposits of the Dzhezkazgan district in the U.S.S.R. They concluded that these minerals could only coexist, as primary ore, at temperatures less than 75° C.

Vitrinite reflectance studies, carried out for the author by the Atlantic Coal Institute, revealed no significant difference in average reflectance values between the mineralized zones and the coeval unmineralized strata (Ro = 1.0%). A few slightly elevated values occur in mineralized samples causing a bimodal Ro population (Fig. 6-3); however, this variance is rarely greater than 0.20% Ro, and therefore is

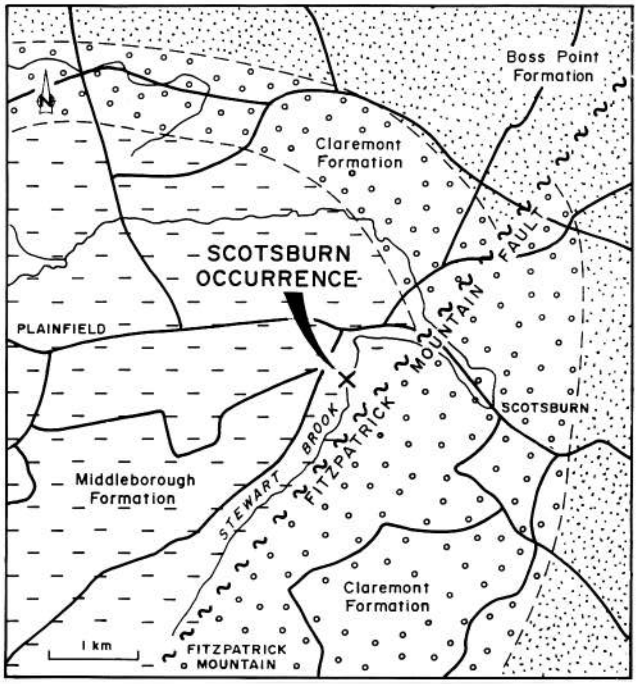


Figure 7-11. Location and generalized geology of the Scotsburn copper occurrence.

considered insignificant. Most of the mineralized samples have a unimodal distribution of vitrinite reflectance values with a mean Ro = 1.0%. Variables other than temperature can lead to vitrinite reflectance variation (Heroux *et al.*, 1979). Variables that might have influenced the samples with bimodal distributions are: (1) type of kerogen, (2) problems of temperature and time relations, and (3) secondary oxidation. The Cumberland Basin vitrinite reflectance study indicates that the mineralized beds were not subjected to temperatures greater than normal geothermal gradients which affected all of the strata in the basin; therefore, the temperatures of mineralization must have been low (less than 120° C), based on diagenetic features of the strata. The time-temperature paths, coupled with the age of reddening of the sandstones (related to the mineralization), suggest that mineralization occurred in the late Permian or early Triassic and, therefore, temperatures inferred here are maximum rather than minimum estimates.

Sulphur Isotopes

Twenty samples were selected for sulphur isotope determinations, twelve from chalcocite, six from pyrite, and two from galena. These samples were collected from four occurrences in the Cumberland Basin. All of the sulphur isotopes are strongly negative and range in value between -29 and -51‰. These values compare favourably with those of the Dzhezkazgan and the Kupferschiefer deposits (Fig. 7-20), which have been interpreted as being derived from oxidizing meteoric waters (Gustafson and Williams, 1981). Strongly negative sulphur isotope distributions are generally considered indicative of sulphide formation by bacterial sulphate reduction (Schwarcz and Burnie, 1973; Haynes, 1986). The sulphur isotope values suggest similar mineralizing conditions for the chalcocite, pyrite and galena mineral phases in all of the occurrences in the Cumberland Basin.

The similarity of sulphur isotope values between pyrite and the copper minerals can occur because of inheritance of the sulphur isotope signature from the early diagenetic pyrite (cf. Brown, 1971; Gustafson and Williams, 1981). Haynes (1986) suggested that bornite or chalcopyrite would be expected to precipitate with chalcocite during the replacement of pyrite if the reaction was represented by: $2FeS_2 + 4Cu^+ + 3O_2 + 2H_2O \rightarrow 2Cu_2S + 2Fe^{+2} + 2SO_4^{-2} + 4H^+$

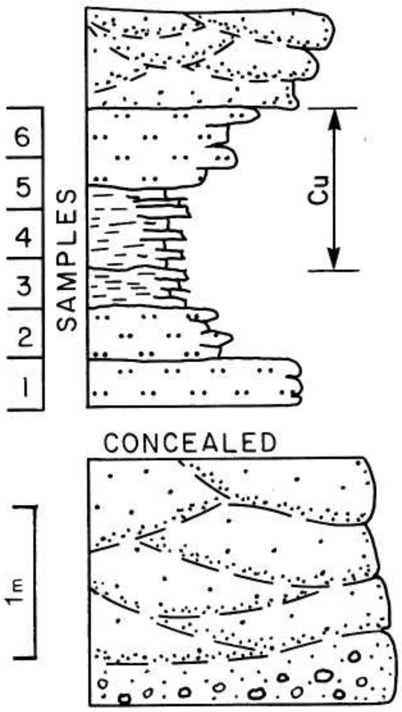
Brown (1971) suggested that the ferrous iron released during this equation might be removed by incorporating iron in the silicates such as chlorite. Haynes and Bloom (1987) suggest on the basis of modelling that bornite and/or chalcopyrite precipitation would preclude the appearance of iron-bearing silicates under the pH range, oxygen fugacities, and temperatures likely in the host rocks. Haynes (1986) suggested that replacement of pyrites and inheritance of their sulphur isotope signature is unlikely because of an absence of bornite and Fe-silicate minerals with chalcocite from the deposits that he studied. However, in the Cumberland Basin occurrences, bornite and to a lesser extent chalcopyrite are commonly associated with chalcocite. Given the mineral assemblage of the Tatamagouche occurrences it is unlikely that the depth and timing constraints on copper mineralization proposed by Haynes (1986) are applicable in the Cumberland Basin.

Geochemistry of Copper Deposits and Host Rocks

Geochemical studies of the Cumberland Basin copper deposits and host rocks were undertaken in order to enhance our understanding of the mineralizing processes. Geochemical investigations into mineralization also permit inferences to be made about the best geochemical exploration methods to be used to find these deposits. Results of the geochemical investigations have a direct bearing on Cu-Ag metallogenesis in the Cumberland Basin.

SCOTSBURN BROOK

Samples are roughly 30 cm channel samples, however whereas the dips are not well documented these thicknesses are only estimates.



Sandstone, med. grained, light grey-brown, abnt. plant debris, trough cross stratification, trace of malachite staining, laminated.

Siltstone, fine grained sandstone, grey, abnt. plant debris, coarsening upward, malachite is abundant.

Mudstone, grey, abundant plant debris, no apparent laminations, pervasive malachite and a few blebs of chalcocite-bornite, the chalcocite appears to be replacing pyrite permineralization of plant detritus.

Mudstone, red-grey transition zone.

Siltstone, red-brown, minor grey mottling.

Sandstone, fine grained, reddish-grey, slightly arkosic, small trough cross strata, paleocurrent at 330°, med. grained at base, basal calcareous mud-chip conglomerate inter-cross bedded with the sandstone.

SAMPLES	Cu %	Ag ppm	Co ppm	Cr ppm	Au ppb
# 6	0.09		20		<2
# 5	0.36		21		<2
# 4	3.95		15		<2
# 3	2.86	6	14		<2
# 2	0.99		20	110	<2
# 1	0.16		29	120	<2

1.5 m of 1.66% Cu

Figure 7-12. Detailed section as exposed on the stream at the Scotsburn occurrence.

Lithogeochemistry of Unmineralized Sandstone

All of the redbed mineral occurrences described in the previous section show a strong correlation with red to grey sandstone and shale colour boundaries. Ryan *et al.* (1989) and Ryan (1991) speculated that oxidation and reddening of primary grey sandstone may have liberated the Cu and Ag that form the local ore deposits. Sediment dispersal patterns (Ryan, 1985), petrographic studies (Ryan, 1985), quartz surface textures (D'Orsay

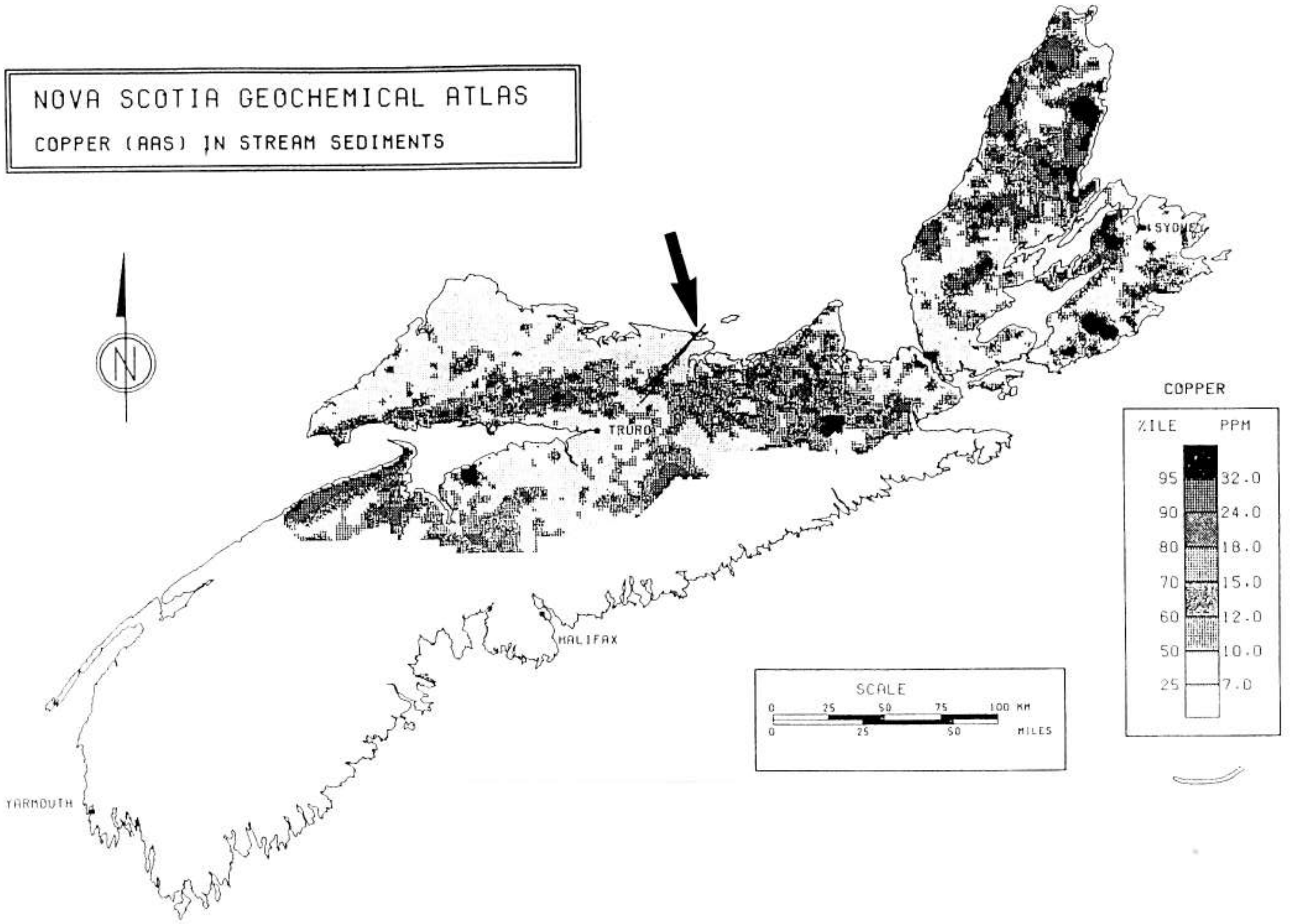


Figure 7-13. Stream geochemical anomalies associated with the Fitzpatrick Mountain fault, the Scotsburn occurrence.

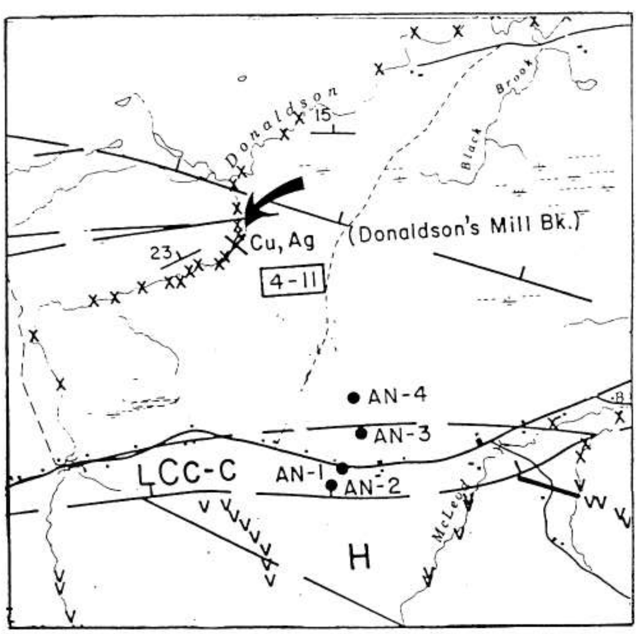


Figure 7-14. Location and generalized geology of the Donaldson's Mill Brook occurrence.

and van de Poll, 1985) and stratigraphic correlation (Ryan, 1985; van de Poll and Ryan, 1985) all indicate that the red sandstone was deposited as grey beds, and that both red and grey sandstones had the same source. Although many other factors may have had an influence on the original geochemistry of the rocks, it is probable that the red and the grey sandstones had very similar original composition. A brief summary of the preliminary results of this study were presented in Ryan *et al.* (1989), where they have described geochemical variations in a few of the red and grey sandstones from the Cumberland Basin. In order to better understand the significance of this colour boundary, 48 samples of unmineralized red and grey Pictou Group sandstone were analyzed for both major and trace elements (Table 7-1). An additional 15 samples from unmineralized rocks were analyzed for Cu, Pb and Zn (R. V. Kirkham, pers. comm., 1985).

Analyses reveal distinct geochemical differences between the red and grey sandstones. The most striking of the differences between red and grey sandstones

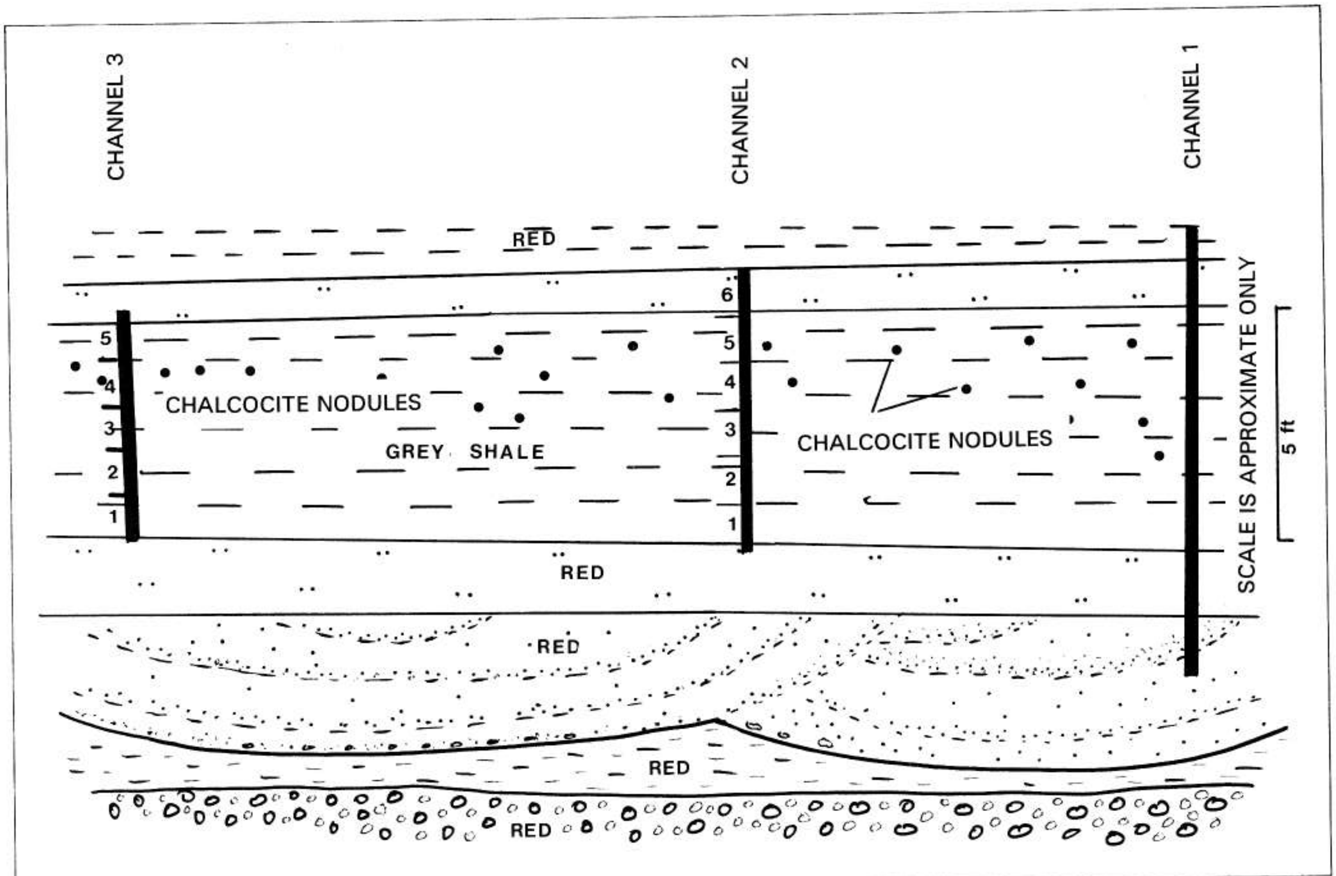


Figure 7-15. Sketch of the mineralization at Donaldson's Mill Brook.

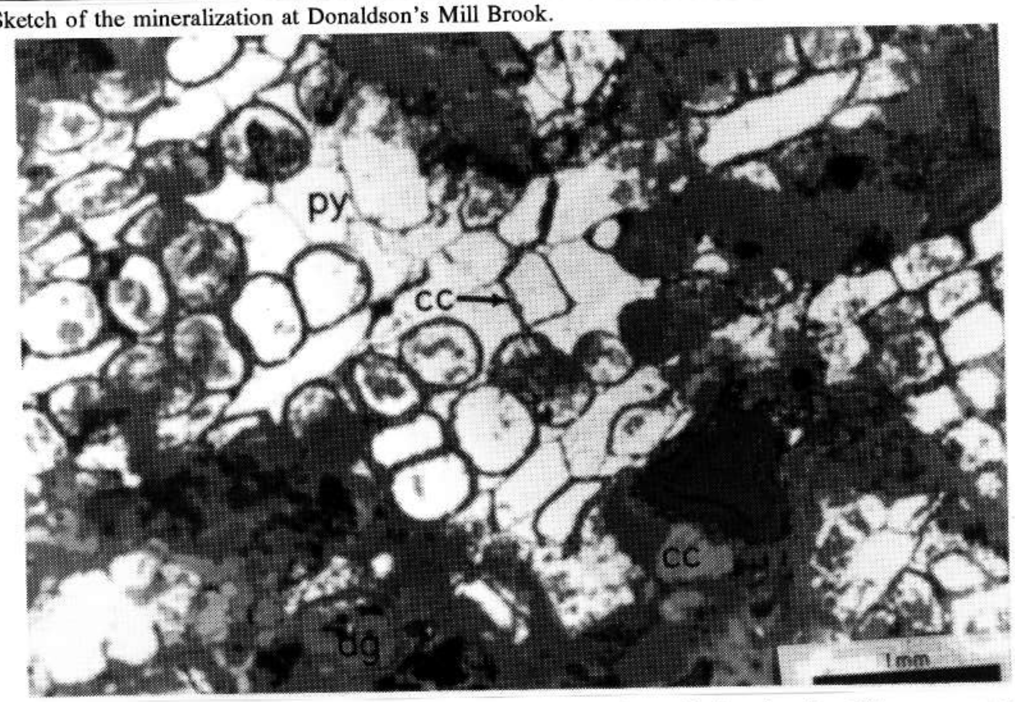


Figure 7-16. Permineralized plant cell structure, replaced by pyrite, chalcocite, and minor bornite, Oliver occurrence, French River. Note the detail that is preserved by the sulphide minerals. Some workers have argued that this proves that the copper mineralization was early diagenetic; however, only the pyrite need be early as the other minerals replaced pyrite. Py = pyrite, BO = bornite, CC = chalcocite, Dg = digenite.

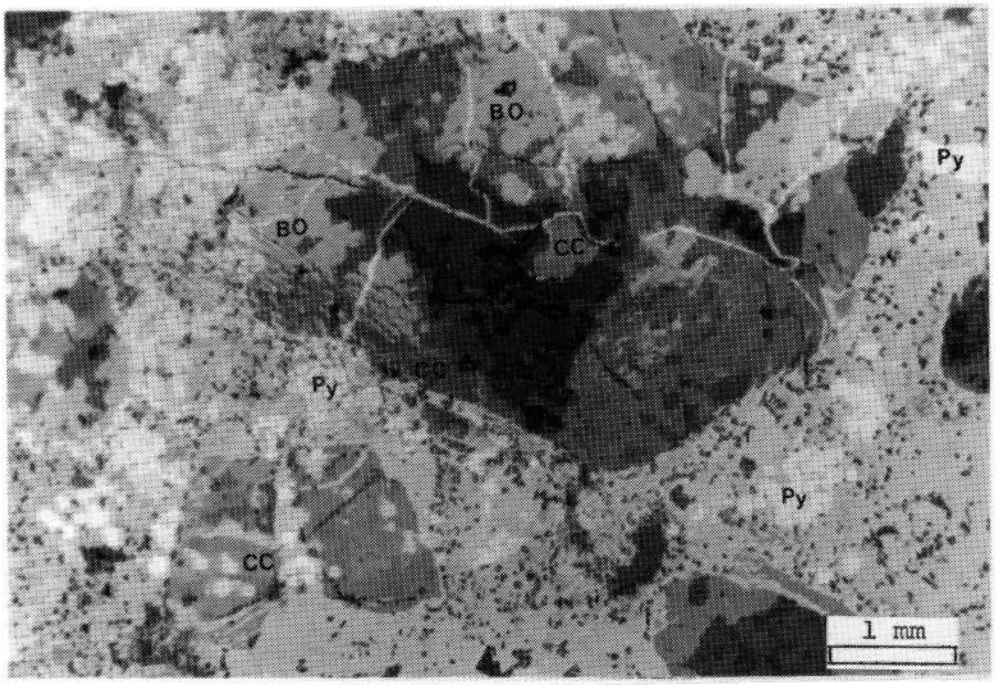


Figure 7-17. Pyrite replaced by bornite and chalcocite, sample is from a chalcocite nodule from the Oliver Copper Mine, on French River. This sample is the exception to the rule, as there is perhaps a little late-stage pyrite present. Py = pyrite, BO = bornite, CC = chalcocite, Dg = digenite.

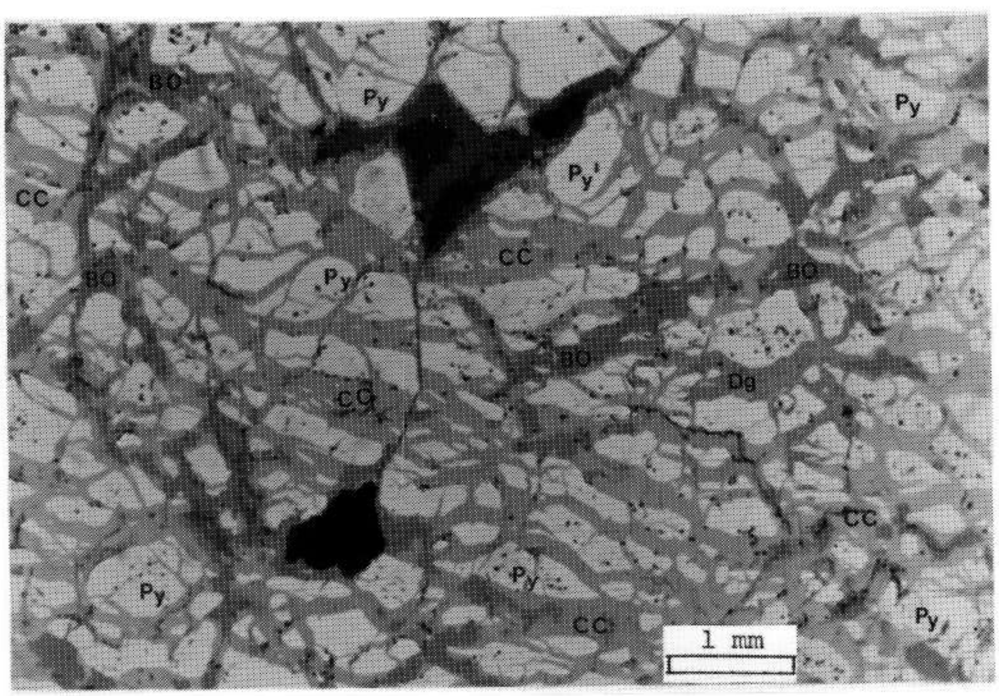


Figure 7-18. Exsolution features in pyrite and bornite, replaced by chalcocite and digenite. Py = pyrite, BO = bornite, CC= chalcocite, Dg = digenite.

are: (1) the relative depletion of Cu and Zn in red sandstones (Fig. 7-21); (2) the increase in SiO_2 in red sandstones (Fig. 7-22); and (3) the FeO/Fe_2O_3 ratios (Fig. 7-23). Other compositional variations occur; however, the limited dataset and small variations make such observations difficult to interpret with any reliability.

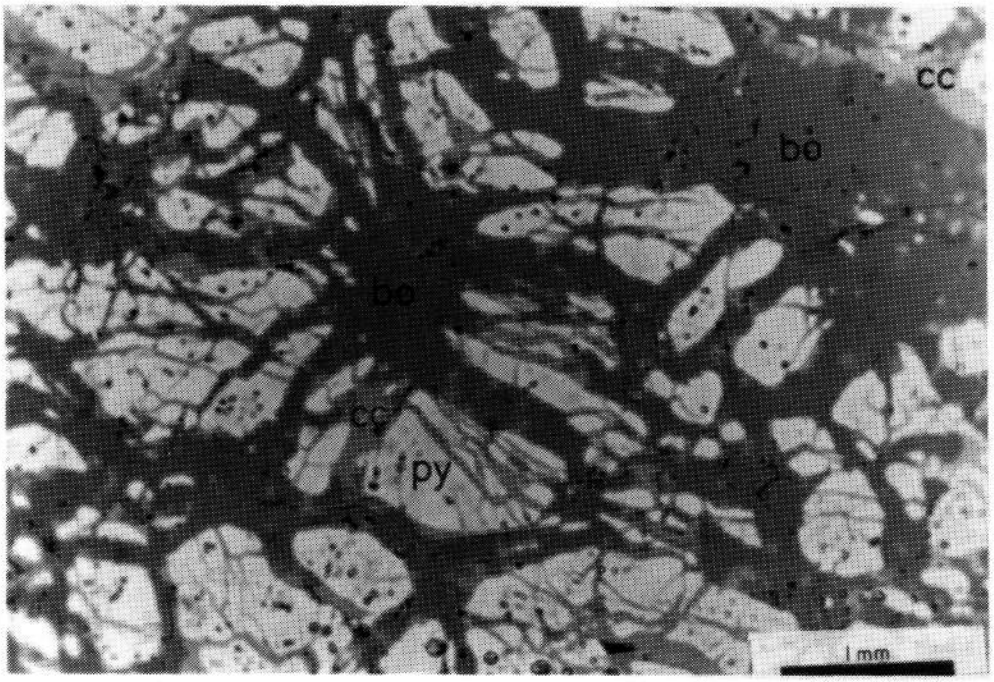


Figure 7-19. Star-shaped blebs of bornite in a pyrite matrix, from large nodules collected at the Donaldson's Mill Brook occurrence; outer parts of the nodule are massive chalcocite. Py = pyrite, BO = bornite, CC = chalcocite, Dg = digenite.

In the Tatamagouche area the red and grey sandstones have mean Cu concentrations of 16 ppm and 33 ppm, respectively (Fig. 7-22). Analytical results for copper in grey sandstone exhibit no evidence of enrichment, and are in fact lower than the levels of Cu found in similar sandstone from Germany where the mean is 45 ppm Cu (Wedepohl, 1963).

The mean Zn concentration for red and grey sandstones from the Tatamagouche area are 46 ppm and 63 ppm, respectively (Table 7-1). Data from other areas in the Cumberland Basin and Prince Edward Island do not seem to show the same depletion of Zn in the redbeds (Table 7-1), suggesting that the depletion may be limited geographically. Within the Tatamagouche data, standard deviations are high and the two subsets could possibly be coincident. However, Zn depletion is found within the red clast subset of the till geochemistry which strongly suggests that Zn is depleted in red sandstone. Additional analyses should help to quantify the observed depletion.

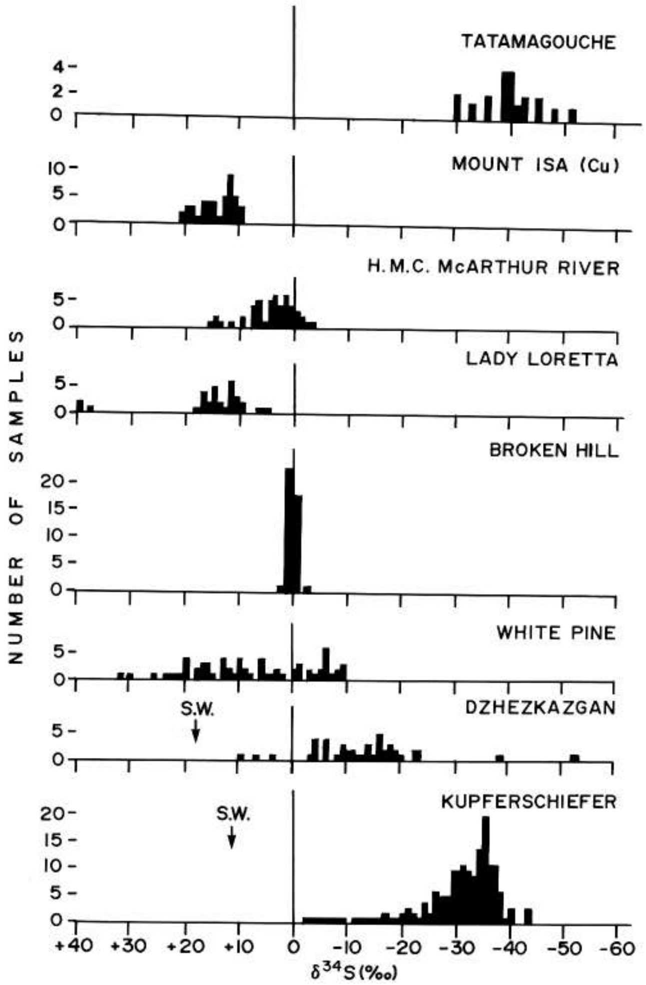
The total iron content is similar in both the red and grey sandstones. The differences in Fe are in the FeO/Fe_2O_3 ratios. Red sandstone has ratios of <1.2 whereas grey sandstone has ratios of >1.2 (Fig. 7-23). Differences in the FeO/Fe_2O_3 ratios reflect the oxidation event that reddened the sandstones. The fact that the total Fe content of grey and red sandstones is the same suggests that the two were originally similar in colour and geochemical composition.

The relatively higher content of SiO_2 in red sandstone is most likely the result of a slight depletion of other elements from these rocks rather than any addition of silica.

Geochemistry of Mineralized Rocks

Eighteen high-grade grab samples of mineralized bedrock and two samples of Pb-Zn mineralized boulders were selected from the various occurrences in the Cumberland Basin. Each of the samples was analyzed for 29 elements and the results are summarized in Table 7-2.

The X-Y plots of mineralized samples show little correlation between the various elements (Ryan, 1991). The mean Ag content of the rocks is 107 ppm (2.44 oz./ton) with a maximum value of 532 ppm (17.2 oz./ton). The mean gold concentration is 18.7 ppb with a maximum value of 110 ppb. Cobalt has a mean value of 73 ppm and a maximum value of 270 ppm. Cobalt could prove to be a valuable byproduct if copper mining were to proceed in this basin. An anomalous Se concentration of 240 ppm occurs in a sample from the



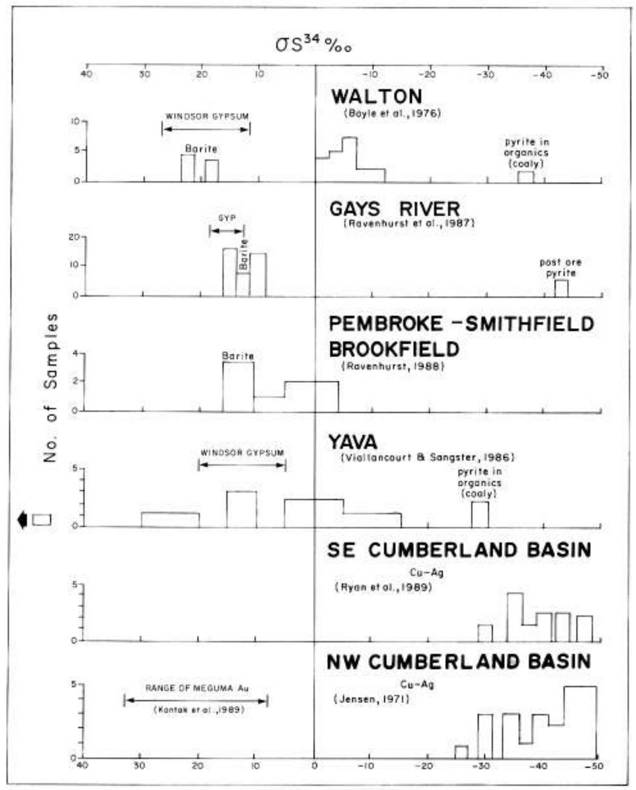


Figure 7-20. Plot of sulphur isotopes contrasting the Tatamagouche (Cumberland Basin) occurrences with world class deposits.

Oliver copper occurrence, and this anomaly should be followed up with addtional sampling in the area. The initial indication from these analyses is that the Cu-Ag occurrences of the Cumberland Basin have numerous associated metals which enhance their atractiveness as exploration targets. The presence of precious metals in grab samples significantly increases the value of the ore.

Till Geochemistry

Upon discovering the significant differences in the geochemistry of the red and grey sandstones, it was decided to see if these variations were also discernable in the tills derived from these beds. The Cumberland Basin - Cobequid Highlands Massif area has been subjected to continental glaciation and is now covered by Late Wisconsinan glacial deposits. A south-southwestward ice flow deposited the Eatonville Till over most of the Cumberland Basin (Stea and Finck, 1984).

Stea *et al.* (1986) and Ryan *et al.* (1989) demonstrated that there are significant variations in element concentraations related to the colour of the dominant till clasts. Ryan *et al.* (1989) divided the Eatonville Till into two subsets based on clast colour: (1) till with greater than 80% red clasts, and (2) till with greater than 80% grey clasts.

The first subset consists of samples with greater than 80% red sandstone clasts and a mean concentration of 27 ppm Cu in the clay fraction, whereas the second subset is composed of till samples with greater than 80% grey clasts and an average of 56 ppm Cu in the clay fraction. A plot of Cu versus Zn for Eatonville till samples (n = 598) exhibits a distinct separation between the red and the grey subset populations (Fig. 7-24). The distinct chemistry of the red clast till and the grey clast till further supports the evidence of chemical variations observed in the smaller bedrock geochemistry dataset.

Table 7-1. Major and trace element analyses of unmineralized red and grey sandstone from the Tatamagouche area.

Sample	SiO_2	Al_2O_3	FeO(T)	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni
	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
RJR-1	72.85	12.94	3.92	1.80	0.41	1.67	2.48	0.83	0.08	0.19	228	79	82	25	190	15	5	15	14	82	20	24
-8	75.92	10.39	2.16	1.33	1.88	1.60	1.19	0.79	0.40	0.10	169	48	73	24	196	13	7	11	12	77	69	16
-15*	78.22	10.35	4.18	1.09	0.00	1.27	1.39	0.95	0.06	0.13	446	56	109	34	395	18	9	26	11	66	10	21
-26*	79.72	9.05	3.52	0.81	0.37	0.95	1.21	0.55	0.11	0.13	1126	51	186	21	138	9	8	15	11	52	14	14
-28	83.25	6.86	1.36	0.79	1.55	0.96	0.63	0.24	0.24	0.10	86	24	45	13	63	5	2	10	7	32	12	8
-30*	79.62	10.65	2.62	1.05	0.20	1.45	1.23	0.65	0.06	0.11	706	51	75	16	128	10	6	12	11	51	8	16
-61*	81.81	6.47	1.87	1.57	1.63	1.33	0.47	0.27	0.23	0.10	75	16	35	15	86	6	4	13	7	35	9	9
-77*	78.13	8.75	3.52	0.86	1.16	1.23	0.96	1.36	0.28	0.14	596	40	254	23	211	15	5	20	9	59	16	15
-116	76.1	11.36	3.45	1.59	0.45	1.71	2.14	0.62	0.09	0.16	527	70	74	21	134	12	7	16	12	65	28	16
-121	86.70	5.56	1.59	0.76	0.42	1.17	0.37	0.14	0.07	0.11	75	12	29	11	59	3	2	12	4	33	7	4
-127	69.49	3.44	1.16	1.13	10.66	0.57	0.44	0.28	0.71	0.10	121	13	70	22	98	6	2	9	6	41	10	8
-130	77.14	10.63	2.43	1.23	1.25	1.83	1.28	0.92	0.18	0.14	575	51	85	25	299	13	10	17	11	49	40	14
-139	76.33	4.93	1.03	0.46	4.91	0.84	0.49	0.16	0.29	0.10	139	14	218	11	56	4	1	10	6	23	26	8
-229	74.56	7.47	1.84	0.61	3.75	1.29	0.53	0.32	0.20	0.11	1194	20	453	13	81	6	0	17	6	114	58	4
-237*	70.71	6.69	3.74	0.66	6.02	0.90	0.64	0.28	0.35	0.13	532	23	459	16	87	6	2	10	5	33	12	8
-242	73.68	13.31	3.82	1.53	0.24	1.53	1.93	0.94	0.10	0.14	332	70	94	25	208	15	6	12	17	111	71	24
-245	82.57	8.03	2.49	0.68	0.74	1.45	0.59	0.25	0.11	0.13	438	23	61	14	70	5	3	11	7	30	14	8
-261*	79.17	9.83	3.70	1.34	0.08	1.80	1.17	0.66	0.04	0.16	153	47	63	16	206	11	6	13	11	52	16	17
-275*	84.29	6.11	2.49	0.91	1.01	0.90	0.79	0.79	0.18	0.12	201	20	65	20	96	10	2	11	6	46	16	8
-276*	81.79	6.37	3.16	0.84	0.45	1.01	0.64	0.65	0.21	0.11	121	40	70	21	59	11	3	15	14	45	14	17
-277*	80.19	6.39	2.41	1.35	0.96	1.16	0.59	0.59	0.18	0.14	301	23	88	20	106	11	4	26	22	47	18	16
-278*	82.17	6.12	1.92	1.53	0.70	1.29	0.69	0.32	0.52	0.11	75	26	29	19	126	11	6	10	11	50	16	15
-301*	86.14	6.10	3.16	1.01	0.45	1.06	0.83	0.79	0.31	0.12	126	50	33	17	211	10	5	12	10	42	25	12
-302*	80.11	5.31	2.94	1.03	0.79	1.51	0.91	0.01	0.19	0.15	81	69	46	25	130	9	5	20	9	59	17	11
-303*	80.17	6.39	1.97	1.14	0.96	1.21	1.34	0.77	0.29	0.11	206	69	28	22	121	9	5	12	10	38	14	1
-306*	82.26	6.48	3.41	0.93	1.01	1.33	1.28	0.66	0.54	0.12	512	60	128	21	119	8	4	16	9	46	28	61
-309*	80.79	7.14	2.61	0.87	0.97	1.30	0.49	0.59	0.18	0.12	139	28	101	23	111	5	5	20	8	61	16	8
-314*	81.11	9.97	1.98	0.79	0.98	1.41	1.28	0.71	0.35	0.11	176	71	35	20	110	7	7	13	9	29	25	9
-318*	80.19	5.11	3.24	1.14	0.99	1.15	0.44	0.55	0.23	0.12	333	66	76	22	109	8	10	12	6	70	17	7
-320*	80.16	5.33	1.79	1.16	1.45	1.25	0.97	0.49	0.14	0.11	88	70	88	20	131	11	4	10	11	23	17	10
-321*	83.21	4.71	3.38	1.20	1.31	1.27	0.99	0.70	0.28	0.12	253	29	61	19	128	9	4	15	10	69	16	11
-326*	82.22	8.01	1.52	1.35	0.96	0.95	1.01	0.54	0.13	0.11	511	64	60	23	99	9	6	20	9	23	15	9
-329	79.24	6.75	1.58	0.93	1.21	1.45	1.11	0.48	0.16	0.12	87	80	134	26	101	10	5	11	9	60	26	12
-331	79.99	6.19	1.02	0.99	1.30	1.23	0.54	0.69	0.37	0.11	169	61	73	20	117	9	5	13	6	69	37	16
-332	79.16	7.85	1.84	0.84	1.11	1.70	0.64	0.66	0.11	0.14	79	29	61	19	129	8	0	12	8	63	28	10
-333	79.54	7.66	1.96	1.13	1.21	0.56	0.71	0.53	0.57	0.12	63	55	88	20	110	6	1	10	8	75	33	9
-341	80.01	8.95	1.97	1.14	1.31	0.83	0.73	0.46	0.16	0.11	511	60	72	21	96	6	1	17	4	90	37	8
-343	81.01	8.18	2.01	1.09	0.45	1.28	0.79	0.63	0.27	0.12	275	30	90	16	84	4	10	10	7	20	29	7
-344	79.16	4.11	2.23	0.87	0.39	0.84	0.65	0.52	0.52	0.11	168	54	221	15	57	11	6	10	8	49	40	4
-345	78.14	8.07	1.45	0.88	0.77	0.57	0.61	0.47	0.12	0.12	366	50	66	13	66	11	5	10	11	69	26	14
-346	79.11	6.54	1.99	0.99	0.97	1.81	0.93	0.62	0.36	0.11	44	53	91	21	91	11	9	9	12	73	25	19
-347	80.11	4.11	1.10	0.79	1.49	1.70	1.12	0.51	0.21	0.12	501	31	70	34	117	10	7	11	6	75	48	22
-349	79.96	7.75	2.01	1.01	2.45	0.59	1.01	0.46	0.17	0.11	66	59	90	24	128	12	6	15	4	79	51	11
-350*	79.19	7.19	2.64	1.02	2.10	0.96	0.65	0.61	0.52	0.13	281	40	131	35	126	15	5	20	6	61	15	15
-401	79.14	8.94	3.01	1.15	1.17	1.03	0.35	0.48	0.11	0.11	169	33	63	35	117	13	5	15	11	59	34	14
-404	80.40	6.01	3.06	1.35	0.91	1.66	0.28	0.55	0.57	0.12	377	20	71	19	90	15	6	12	12	49	32	11
-441	83.91	7.97	2.95	0.96	1.11	1.17	1.35	0.50	0.32	0.13	71	79	95	16	81	9	8	13	11	69	36	16
-461	82.22	9.09	1.66	0.87	1.25	1.90	1.23	0.60	0.21	0.13	395	36	65	15	114	6	8	10	10	57	30	12

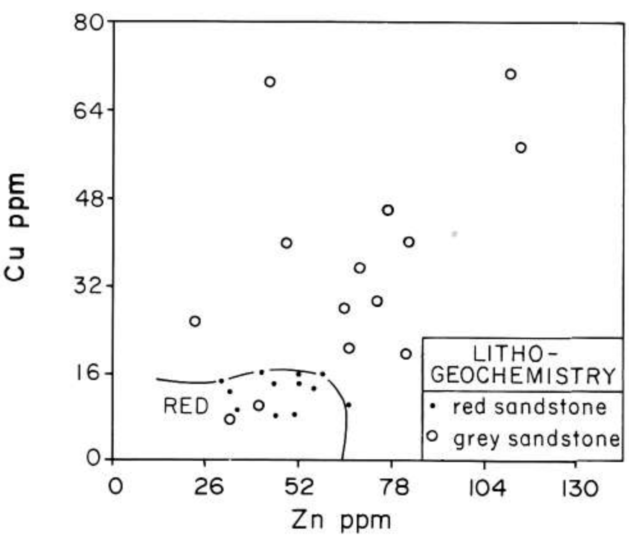


Figure 7-21. Copper versus zinc for unmineralized red and grey sandstone.

Differences in the Cu concentrations of the two till subsets are proportional to the chemical differences between the red and the grey sandstone bedrock of the area. Differences in the absolute values of Cu in sandstone bedrock as compared to till occur because the till analyses were carried out on the clay fraction. This clay fraction is composed of comminuted grey and red mudstone in addition to sandstone. In the Cumberland Basin, mudstone has a higher Cu and Zn content than sandstone, and the relative abundances of elements in the clay fraction of tills primarily reflect the geochemical combination of sandstone and mudstone metal content.

Regional Cu levels for the Cumberland Basin are very low, which is surprising considering the abundant Cu occurrences in the area. The low values (negative anomalies) reflect the depletion of Cu from the redbeds, which are the dominant rock type exposed at surface.

Stream Sediment Geochemistry

Stream sediment geochemistry also reflects the differences between red and grey sandstones in the Cumberland Basin. Stream sediment data were divided into two subsets, one for streams that erode predominantly red sandstone and the other for streams that erode predominantly grey sandstone. Regional stream sediment geochemical data were investigated by

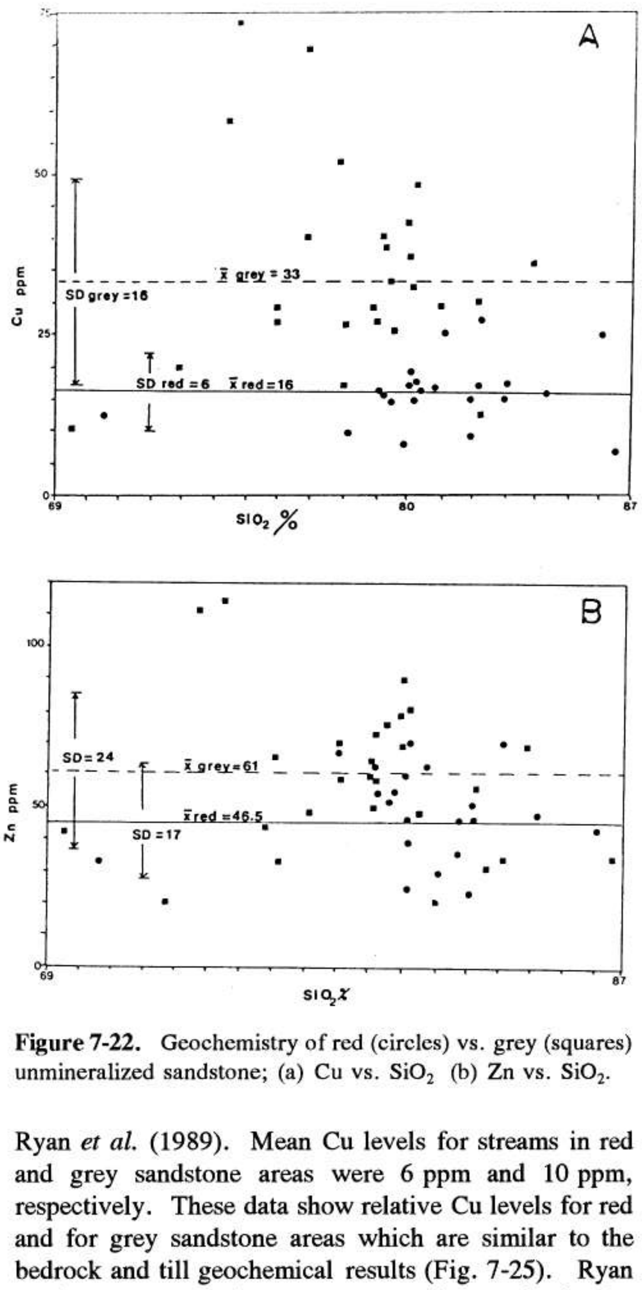


Figure 7-22. Geochemistry of red (circles) vs. grey (squares) unmineralized sandstone; (a) Cu vs. SiO_2 (b) Zn vs. SiO_2.

Ryan *et al.* (1989). Mean Cu levels for streams in red and grey sandstone areas were 6 ppm and 10 ppm, respectively. These data show relative Cu levels for red and for grey sandstone areas which are similar to the bedrock and till geochemical results (Fig. 7-25). Ryan *et al.* (1989) used a Cu-As catchment basin plot (Fig. 7-26) to illustrate distinct variations between the low Cu levels of the Cumberland Basin and the relatively higher Cu levels from the Cobequid Highlands and Minas Basin to the south. The Cumberland Basin shows a paucity of high Cu levels and abundant low Cu levels. The relatively low levels reflect the abundance of redbeds which contain less Cu. The significance of the stream sediment geochemical variations from red to grey sandstone areas is that it demonstrates that the red sandstone to grey sandstone depletion of Cu is widespread and not a local effect.

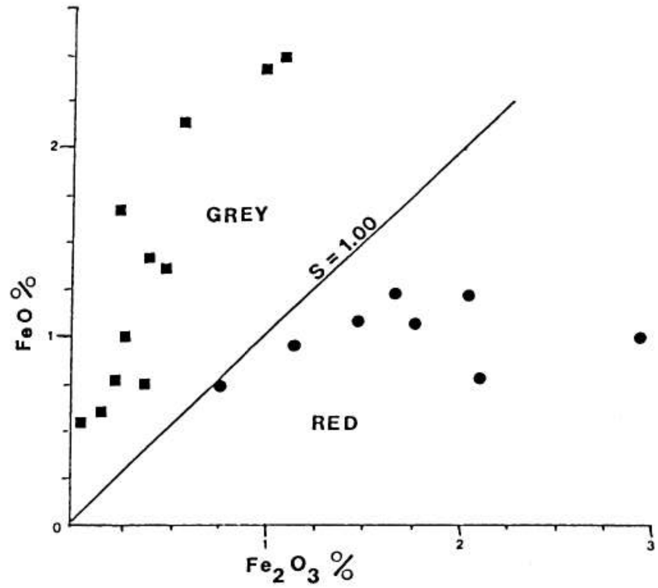


Figure 7-23. FeO vs. Fe_2O_3 plot with grey sandstone as squares and red sandstone as circles; where values of the slope (S) are greater than 1.00 the rocks are grey, if they are less than 1.00 they are red.

Genetic Models for Redbed Copper Deposits

Various genetic models have been proposed to explain fluid migration related to stratiform redbed-related copper deposits (Kirkham, 1989). In this section various models are introduced so that the reader may evaluate the model proposed for the origin of copper occurrences in the Cumberland Basin.

Sabkha Model

A sabkha model invoking evaporitic pumping in a sabkha environment was proposed by Renfro (1974) and Smith (1976) to explain some stratiform copper deposits. This model suggests that evaporitic pumping of fluids in and beneath sabkha environments leaches and concentrates base metals. The metals are usually hosted by carbonaceous, black, stromatolitic supratidal carbonates. This model is not applicable to Cumberland Basin copper occurrences because there is no evidence in the rock record of significant deposition in a sabkha environment.

Formation Dewatering Due to Compaction

Formation dewatering related to basin compaction was suggested as a possible origin for stratiform copper deposits by White (1971) and Lustwerk and Wasserman (1989). Updip migration of metalliferous saline

Table 7-2. Results of analyses for 29 elements in 20 mineralized grab samples from the eastern Cumberland Basin.

		Cd	Sb	Cs	Ba	La	Eu	Tb	Yb	Hf	Ta	W
Gravois	RJR 84-1	< 5	3.1	1.1	370	49	1	1.1	3	28	0.6	< 1
McLean	RJR 84-2	57	3.7	1.9	140	30	2	0.8	< 2	3	0.8	< 1
Hansford	RJR 84-3	< 5	0.5	1.6	120	11	1	0.6	< 2	2	< 0.5	< 1
Wallace R.	RJR 84-4	< 5	1.4	1.3	120	24	< 1	< 0.5	3	14	< 0.5	3
Wentworth	RJR 84-5	< 5	0.5	3.2	200	34	1	0.9	3	7	0.5	2
Seafoam	RJR 84-6	38	5.5	2.5	130	33	1	1.1	2	10	0.6	< 7
Skinners	RJR 84-7	140	0.6	0.5	76	12	< 1	< 0.5	< 2	< 1	< 0.5	< 1
Skinners	RJR 84-8	60	0.2	2.5	210	20	1	0.8	< 2	2	< 0.5	< 1
Wallace R2	RJR 84-9	< 11	6.2	< 0.5	570	4	< 1	< 0.5	< 2	< 1	< 0.5	< 13
Blockhouse	RJR 84-10	26	32.8	< 0.9	2900	5	< 1	< 0.5	< 2	< 2	< 0.5	< 11
Hole Brook	RJR 84-11	< 5	0.6	1.8	230	32	1	0.6	2	4	0.5	2
Yalagash	RJR 84-12	< 17	37.8	< 0.8	4600	8	< 1	< 0.5	< 3	< 2	< 0.5	< 40
Oliver	RJR 84-13	< 5	0.5	1.7	170	29	< 1	< 0.5	< 2	5	< 0.5	< 8
Miller Bk	RJR 84-14	< 13	5.7	< 0.7	< 68	6	< 1	< 0.7	< 3	< 1	< 0.7	< 22
Woodlock Bk	RJR 84-15	97	2.4	2.7	240	50	< 1	< 1.5	4	4	.08	3
Donaldsons	RJR 84-16	< 12	15.9	2.9	8940	10	< 1	< 0.5	< 2	< 1	< 0.5	< 63
Bailey Bk	RJR 84-17	12	14.5	< 0.6	1700	6	< 1	< 0.5	< 2	< 1	< 0.5	< 12
Brule	RJR 84-18	< 5	0.4	2.3	300	28	1	0.9	4	10	1.4	2
Cape John	RJR 84-19	24	0.4	1.8	260	40	3	2.8	5	5	0.5	< 1
DDH-SM-4	RJR 84-20	< 5	0.8	3.9	220	39	< 1	3.2	15	22	4.4	< 1

		Sc	Cr	Fe	Co	Ni	Zn	As	Se	Rb	Mo	Ag
Gravois	RJR 84-1	2.4	< 20	20.0	46	43	5700	188.0	< 6	20	45	28
McLean	RJR 84-2	5.7	51	4.1	100	26	8000	807.0	< 6	57	52	16
Hansford	RJR 84-3	3.2	< 20	1.7	18	< 20	< 100	19.0	< 5	26	3	< 2
Wallace R.	RJR 84-4	3.3	38	12.0	43	23	< 100	94.0	< 5	27	21	100
Wentworth	RJR 84-5	7.7	58	0.8	6	< 20	< 100	1.7	< 5	61	8	16
Seafoam	RJR 84-6	5.3	36	21.8	130	42	2000	839.0	< 7	48	39	11
Skinners	RJR 84-7	1.2	23	14.0	51	< 20	23200	9.0	< 5	13	3	11
Skinners	RJR 84-8	2.9	< 20	21.6	87	20	18300	9.4	< 5	27	2	< 2
Wallace R2	RJR 84-9	0.6	< 20	21.8	130	24	140	1100.0	< 8	23	124	100
Blockhouse	RJR 84-10	< 0.4	25	24.0	160	< 23	16600	1220.0	< 13	< 13	27	532
Hole Brook	RJR 84-11	4.3	57	0.9	6	< 20	< 100	5.2	25	35	12	41
Yalagash	RJR 84-12	< 0.4	< 20	29.6	120	< 21	6000	1460.0	< 11	13	27	311
Oliver	RJR 84-13	3.8	< 22	0.9	13	< 20	< 100	5.8	240	43	5	303
Miller Bk	RJR 84-14	0.4	28	23.0	270	73	675	622.0	< 8	< 12	28	149
Woodlock Bk	RJR 84-15	11.0	24	4.1	46	< 20	2900	398.0	< 6	61	132	22
Donaldsons	RJR 84-16	0.7	26	7.3	28	< 20	190	1020.0	< 7	25	18	449
Bailey Bk	RJR 84-17	< 0.3	< - 20	28.4	150	78	480	1340.0	< 8	17	58	35
Brule	RJR 84-18	10.0	72	1.7	14	< 20	< 100	7.5	< 5	59	1	2
Cape John	RJR 84-19	5.3	42	1.0	130	35	3900	3.4	< 5	27	< 1	< 2
DDH-SM-4	RJR 84-20	8.2	40	2.8	14	< 20	600	2.4	< 5	130	2	< 2

		Ir	Au	Th	U	WT	Re	Cu	Pb
Gravois	RJR 84-1	< 50	18	14.0	3.4	12.15	< 1	6.53	144
McLean	RJR 84-2	< 50	< 5	6.8	41.7	8.95	< 1	1.16	158
Hansford	RJR 84-3	< 50	6	2.6	1.0	10.53	< 1	0.27	16
Wallace R.	RJR 84-4	< 50	10	5.9	12.0	14.16	< 1	13.10	288
Wentworth	RJR 84-5	< 50	15	7.8	93.6	7.66	< 1	4.80	72
Seafoam	RJR 84-6	< 50	20	7.8	3.6	13.32	< 1	0.61	144
Skinners	RJR 84-7	< 50	110	0.8	5.4	8.61	< 1	0.05	7460
Skinners	RJR 84-8	< 50	20	2.5	13.0	11.91	< 1	0.07	6590
Wallace R2	RJR 84-9	< 50	20	1.2	1.1	14.30	< 1	23.50	282
Blockhouse	RJR 84-10	< 76	15	< 0.8	< 0.4	4.83	< 1	26.00	552
Hole Brook	RJR 84-11	< 50	10	5.5	15.0	9.12	< 1	7.50	46
Yalagash	RJR 84-12	< 63	36	< 0.7	< 0.8	11.49	< 1	12.70	316
Oliver	RJR 84-13	< 50	10	6.2	19.0	14.53	< 1	31.00	176
Miller Bk	RJR 84-14	< 50	26	< 0.5	83.4	9.10	9	11.50	290
Woodlock Bk	RJR 84-15	< 50	6	9.5	134.0	7.93	< 1	2.50	88
Donaldsons	RJR 84-16	< 50	17	2.1	1.9	12.11	< 1	42.40	858
Bailey Bk	RJR 84-17	< 50	< 9	0.7	< 0.6	12.41	< 1	0.81	160
Brule	RJR 84-18	< 50	5	8.8	7.6	10.24	< 1	0.70	2
Cape John	RJR 84-19	< 50	8	5.2	120.0	9.41	< 1	0.62	2
DDH-SM-4	RJR 84-20	< 50	7	19.0	5.2	8.00	< 1	0.46	16

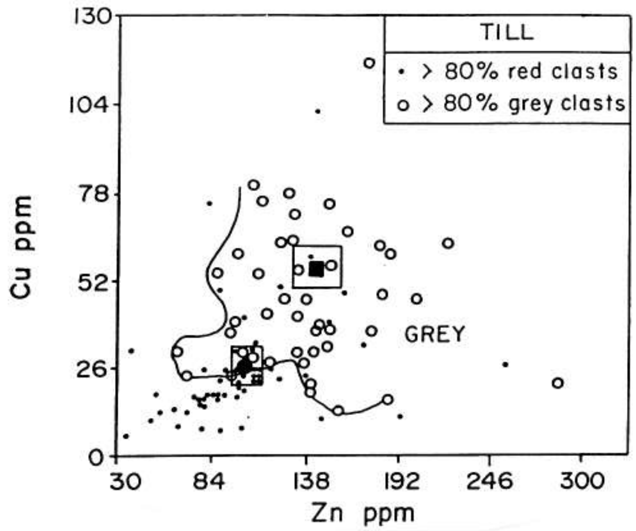


Figure 7-24. Geochemistry of the Eatonville till in the Cumberland Basin. Dots are samples with 80% red clasts and circles are grey clast dominated, the line indicates the limits of the grey subset, and the boxes represent the mean and standard deviation for the red and grey populations. These plots show the same depletion of Cu+Zn for redbeds.

formation waters due to compaction within the sedimentary basin is a plausible explanation for many deposits. Kirkham (1978) and Ravenhurst and Zentilli (1987) have proposed this kind of mechanism to explain basal Windsor Group carbonate-hosted deposits within the Maritimes Basin. The Cumberland Basin redbed copper occurrences do not appear to be related to this process. The Cumberland Basin copper has associated redbeds that are depleted in copper and exhibit no elevation of copper in coeval grey beds. This would not be characteristic of dewatering of the basin because redbeds in the near-surface are commonly represented by grey strata downdip and basinward. If metalliferous brine moved updip, why were the reduced beds basinward not mineralized and, similarly, why are there mineralized horizons of grey strata completely surrounded by red strata? The updip migration of metalliferous, reducing basin brines may have played a role as a reductant in the mineralizing process in the Cumberland Basin copper occurrences but it is unlikely that such a migration was responsible for the transport of copper.

Gravity Hydraulic Head after Marine Transgression

Paleotopographic gravity hydraulic head that persists in underlying fluvial strata after marine transgression has been suggested by Lur'ye and Gablina (1972) as a cause

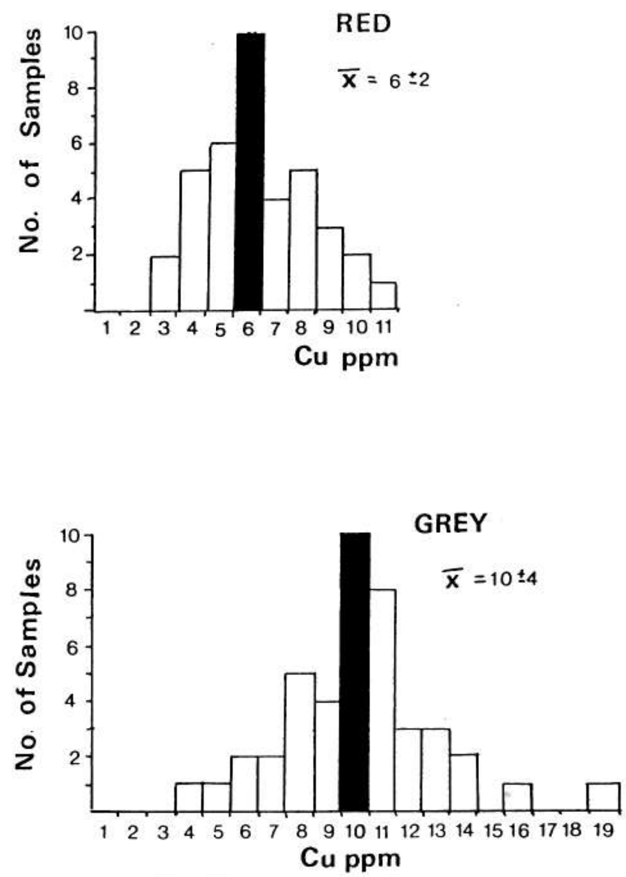


Figure 7-25. Plot of stream sediment geochemistry for streams in the Cumberland Basin. The stream sediment samples taken over redbeds show a depletion of Cu similar to the bedrock and till geochemistry.

of possible fluid migration related to stratiform copper mineralization. Groundwater regimes are altered greatly by marine transgressions, especially in basins below sea level. Within the Maritimes Basin, Windsor Group rocks represent the only evidence of major marine transgression. Kirkham (1989) suggested that this mechanism may have played a role in copper mineralization at the Horton - Windsor contact. There is no evidence of major marine transgression during the Late Carboniferous. A few hints of thin, short-duration marginal marine incursions are found in the Sydney area but these transgressions were not significant enough to create a gravity hydraulic head in the underlying strata.

Release of Pressure During Tectonism

Release of basin fluid (brine) pressure during tectonism was suggested by Breit *et al*. (1987) as a

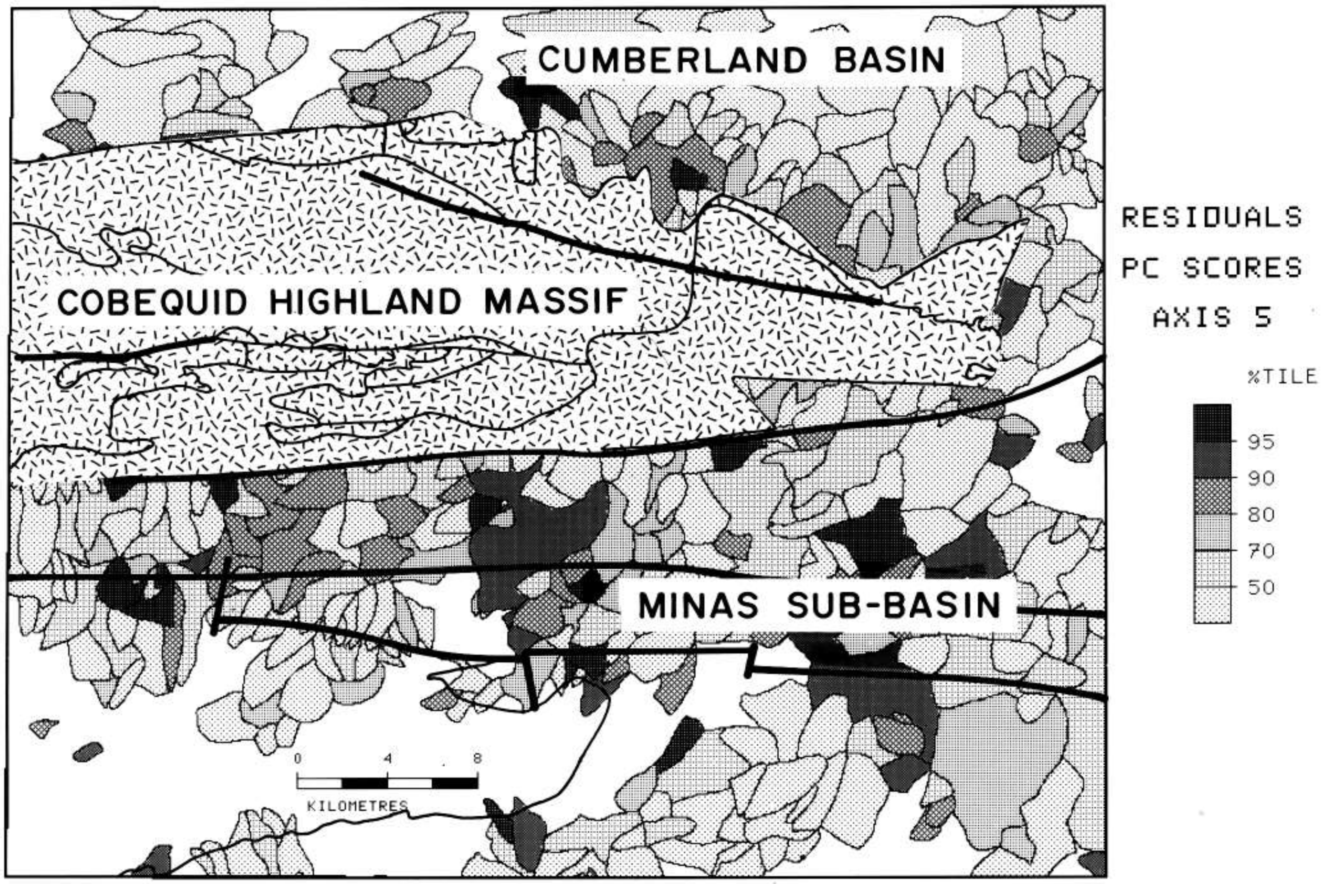


Figure 7-26. Catchment basin geochemistry plot of residual Cu-As. Note that although the Cumberland Basin area has numerous Cu occurrences the geochemical background is low (negative anomaly).

possible explanation for the formation of some of the stratiform copper deposits in Utah and Colorado. Fluids released in this manner would tend to be hot basin brines, which would be reflected in the mineralogy of deposits formed by this mechanism. Copper deposits in the Cumberland Basin are not consistent with this hypothesis because of the low-temperature mineralogy and because grey strata downdip of the occurrences have not been enriched in copper as one might expect if mineralizing fluids were travelling updip. The possibility remains that the fluids escaped through faults and therefore did not redden the downdip grey strata; however, faulting has rarely been documented adjacent to the Cumberland Basin Cu occurrences. Although this mechanism does not explain the redbed copper occurrences in the Maritimes Basin, Ryan and Boehner (1991) suggested that it is probably applicable to basin brine expulsion models for the carbonate-hosted and fault-related deposits in the basin.

Thermally Induced Rise of Fluids

A decrease in buoyancy and rise of fluids caused by thermal activity has been suggested by Brown (1984) and Jowett (1986, 1989) as a mechanism related to stratiform copper mineralization. No evidence of increased temperatures related to deposits such as those seen at Annels, Montana (Hayes *et al.*, 1989), has been documented in the Cumberland Basin examples. The thermal study undertaken as part of this research found no evidence to support a widespread Triassic rift thermal event in the Maritimes Basin. Paleomagnetic studies of the reddening event (intricately involved in mineralization) indicate that the development of hematite predates rifting. The morphology, distribution of occurrences, and thinness of the underlying redbed succession are not compatible with a redistribution of copper within the Cumberland Basin by this mechanism. Copper occurrences in the

Cumberland Basin are not confined to a particular bed or group of beds.

Fluid Migration Related to Diapirism

The diapiric rise of salt structures causing and permitting fluid migration has been suggested by Light *et al.* (1987) and Kirkham (1989) as a possible mode of fluid migration related to stratiform copper deposits. Diapirism in the Cumberland Basin is syndepositional and therefore predates the copper ore. Redbeds within the basin are secondary (originally grey). The grey sandstone and mudrocks that host the occurrences exhibit no evidence of being re-reduced beds. If the host grey beds were re-reduced by hydrocarbons, as suggested for the Dzhezkazgan deposits in the USSR, there would be abundant finely disseminated pyrite derived from the hematite. Beds immediately adjacent to diapirs in the Cumberland Basin are redbeds. If the diapir-related fluids migrated up from the diapir the adjacent beds should be reduced. Another feature of the deposits that does not fit this mode of fluid migration is that there should be a significant heat flux related to diapirism and yet low-temperature mineral assemblages are found at these occurrences. It is hard to differentiate between the role of diapirs as chloride sources for groundwater and their possible role in providing brines or reductant hydrocarbons. The lack of evidence for re-reduction of the strata, the absence of hydrocarbons in the host rocks, and the presence of similar deposits distal to diapirs suggest that mineralization was not controlled directly by fluid migration related to rising evaporite diapirs.

Topographic Inversion and Meteoric Groundwater Flow

Topographic inversion and subsequent groundwater flow has been proposed as a possible fluid migration mechanism related to redbed copper deposits (Garven and Freeze, 1984; Bethke, 1986; Oliver, 1986). Shockney *et al.* (1974) and Sangster and Viallancourt (1990) have suggested that this type of fluid migration resulted in mineral deposits. This type of fluid movement seems to be compatable with the observations of morphology and nature of the copper occurrences in the Cumberland Basin and will be discussed in more detail in the following section of this chapter.

Genetic Model for the Cumberland Basin Copper Occurrences

Copper mineralization occurs at, or near, the boundary between red sandstone and grey sandstone in the Cumberland Basin. This spatial relationship implies a genetic link between the coloration of the strata and the concentration of copper. It is therefore very important to ascertain whether the red coloration was primary or secondary in nature. The mudrocks of the study area are mostly red in colour. The presence of abundant soil horizons (calcrete and rooted horizons) and red mudrock clasts within grey channel lags suggests that most of the mudrocks were reddened by early diagenetic mechanisms while exposed during drier periods on the floodplain. Sandstone, on the other hand, is believed to have remained grey until after lithification and have been subsequently reddened by late diagenetic oxidation.

Turner (1980) summarized the criteria for recognition of secondary redbeds, and many of these are present in the redbeds of the Pictou Group in the Cumberland Basin. Paleoclimatic conditions, as interpreted from quartz grain surface textures, indicate little variation in paleoclimate for the Upper Carboniferous red and grey rocks of the Maritimes Basin (D'Orsay and van de Poll, 1985). Fossil floral evidence suggests that climatic variations within the Late Carboniferous were minor although Permian flora may indicate a drier climate (van de Poll and Forbes, 1984). Little or no variation in the style of sedimentation can be observed when comparing the red and the grey Pictou Group strata.

The most convincing evidence for the secondary nature of the red coloration in sandstone comes from paleomagnetic studies (see Ryan, 1993). In the Cumberland Basin, most of the red sandstone in the Pictou Group is of secondary origin (Ryan *et al.*, 1989) and paleomagnetic studies carried out as part of this research by Morris and Associates (Morris, 1987) confirmed this hypothesis. This work and the work of Symons (1990), Roy (1963, 1966) and Tanczyk (1988) have indicated that magnetization for the Pictou Group strata is Late Carboniferous to Late Permian in age. Care must be taken in the interpretation of data because the fine-grained overbank rocks of the Pictou Group are primary redbeds, as opposed to the secondary (late diagenetic) red coloration of most of the sandstone. Morris (1987) suggested that the "Cu4" age of the hematization present in mineralized sandstone is related to Late Permian oxidation by mineralizing fluids.

Many other features also suggest a secondary diagenetic origin of the reddening. For example, hematite occurs as grain coatings; however, it is absent at grain to grain boundaries (Fig. 7-27), suggesting that

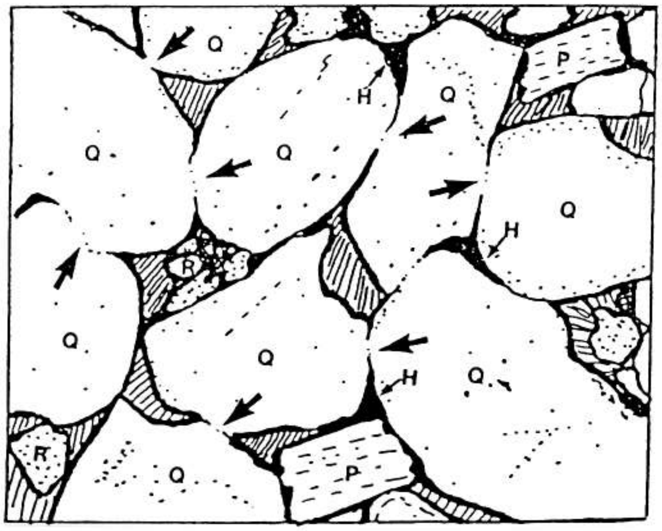
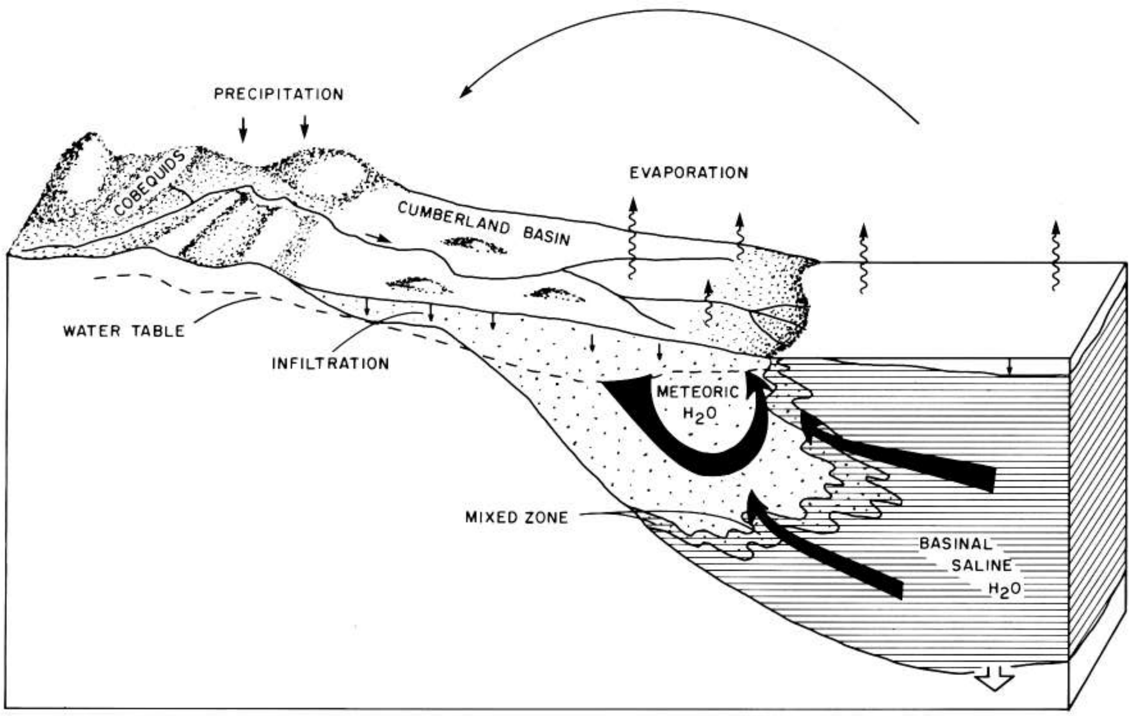


Figure 7-27. Drawing of quartz grain to matrix relationships in a typical red sandstone. Note that hematite never occurs between the quartz grain contacts, indicating a later diagenic timing for the reddening. Q = quartz, H = hematite, R = rock fragment, P = plagioclase. Striped areas are fine clay matrix or primary porosity.

the hematite coating post-dated deposition and lithification (cf. Van Houten, 1973). Overbank mudstone immediately below red channel sandstone is commonly grey to green in colour, which indicates reducing conditions prevailed during sedimentation. Other features, such as the near-absence of primary ferromagnesian minerals in the redbeds, the alteration of siderite and pyrite concretions to hematite, the occurrence of reddened plant material, and the replacement of coal material by carbonates, all indicate secondary diagenetic reddening. Vitrinite reflectance studies carried out for the author by the Atlantic Coal Institute on ten correlative red and grey rocks, also suggest that the red coloration may be secondary. Vitrinite in the redbeds has been oxidized some time after the regional basin maturation was achieved. Clay mineralogy X-ray diffraction studies (Colwell, 1987) were carried out on the same samples as part of this study. The red sandstone usually contained zeolites, whereas these minerals were absent in the grey beds. The presence of these zeolites suggests that the redbeds underwent a thermal or oxidizing event that did not appear to affect the grey strata.

Van de Poll and Ryan (1985) suggested that the reddening was diachronous, and occured from the top down, as is the case in the redbeds of the Upper Coal Measures of the United Kingdom (Trotter, 1954; Mykura, 1960). Archer (1965) and McBride (1974) proposed that such reddening events result from the syndepositional lowering of the water table and the development of well drained, oxygenated conditions within a basin. Contrary to the vertical interpretation of reddening proposed by van de Poll and Ryan (1985), it is more reasonable to assume that lateral infiltration of oxidizing fluids occurred in permeable sandstone aquifers as opposed to downward percolation through relatively impermeable mudrock interbeds.

The arid conditions that prevailed at the time of the Permian-Triassic transition in the Maritimes Basin (cf. van de Poll, 1978) could possibly be responsible for reddening of the Pictou Group strata. Under these circumstances, in a basin margin onlap setting, oxygenated surface water runoff from the Cobequid Highlands may have flowed into the sandstone aquifers and flowed to the north, forcing the interface between basinal waters and oxygenated groundwater deeper into the basin (Fig. 7-28). The timing of these event apparently corresponds to the erosion event documented by the fission track study. Rose (1976) and Rose and Bianchi (1985) have demonstrated that, at low temperatures, oxygenated groundwater is an efficient transport medium for metallic ions, especially when chloride or carbonate complexes are present in the groundwater. Early Carboniferous evaporite diapirs of the Windsor Group occur in the Tatamagouche area and may have provided the chloride and carbonate to form complexes necessary to facilitate transport of Cu and Ag (Fig. 7-29). Haynes and Bloom (1987) suggested that alluvial fans containing basalt or granite-rhyolite lithic fragments can generate metal-transporting fluids. The sandstone and pebbly sandstone of the Upper Carboniferous strata in the Cumberland Basin contain abundant lithic fragments of both basalt and granite-rhyolite composition. Breakdown of these lithic fragments could also generate the metals necessary for mineralization (Haynes and Bloom, 1987). Zielinski *et al.* (1983) demonstrated, in a study of redbeds, that metals migrate from detrital phases in the sediment to secondary ferric oxides. These authors also suggested that leaching of the metal fraction increases with the intensity of the ferric iron production. Although no depletion was observed by Zielinski *et al.* (1983) from their examples, it is clear that depletion of the Cu in redbeds of the Tatamagouche area is consistent with the leaching mechanism they proposed. Lur'ye (1978) points out that if highly oxidizing groundwater is transporting Cu, the physicochemical parameters lie outside of the stability field for Cu(I); therefore, high chloride concentrations are not required to increase the copper level in solution. Boyle (1968) suggests that the most likely sources of Cu-Ag for redbed deposits



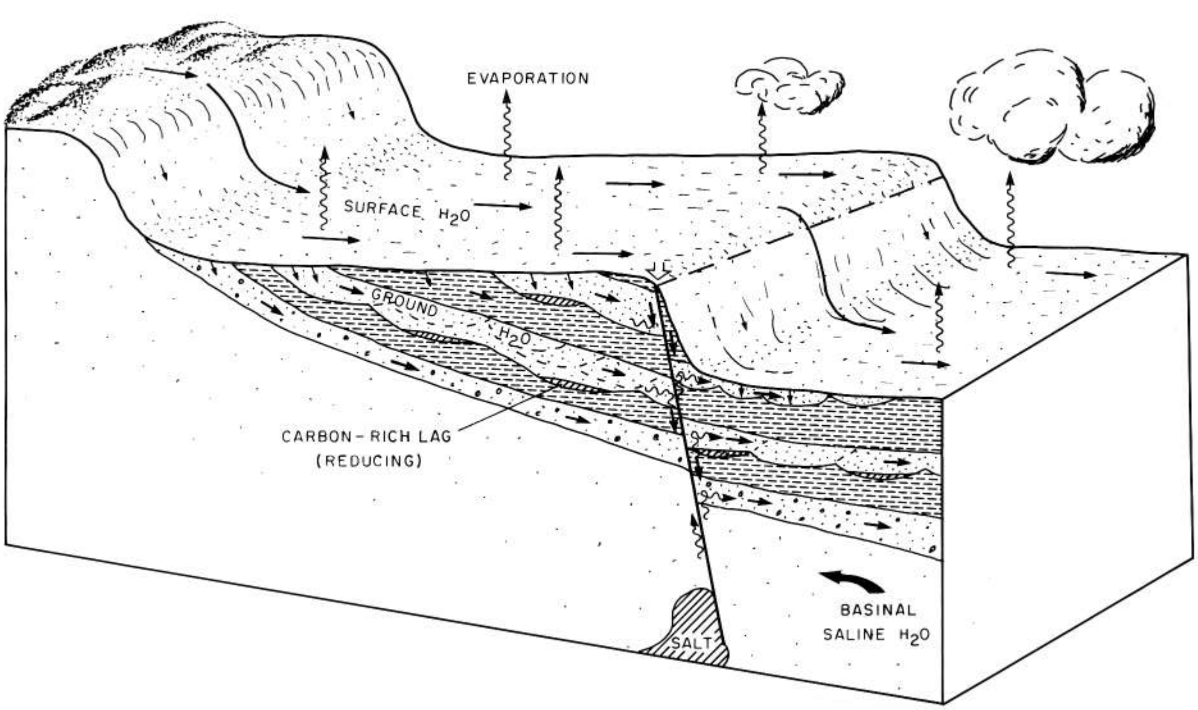


Figure 7-28. Cartoon of a cross-section of the Cumberland Basin indicating the relative position of basin saline brines and meteoric water interface. Cartoons show that there is an infiltration of oxygenated groundwater entering porous sandstones, which reddens them except for the carbon-rich lags at the base of the channel sequences.

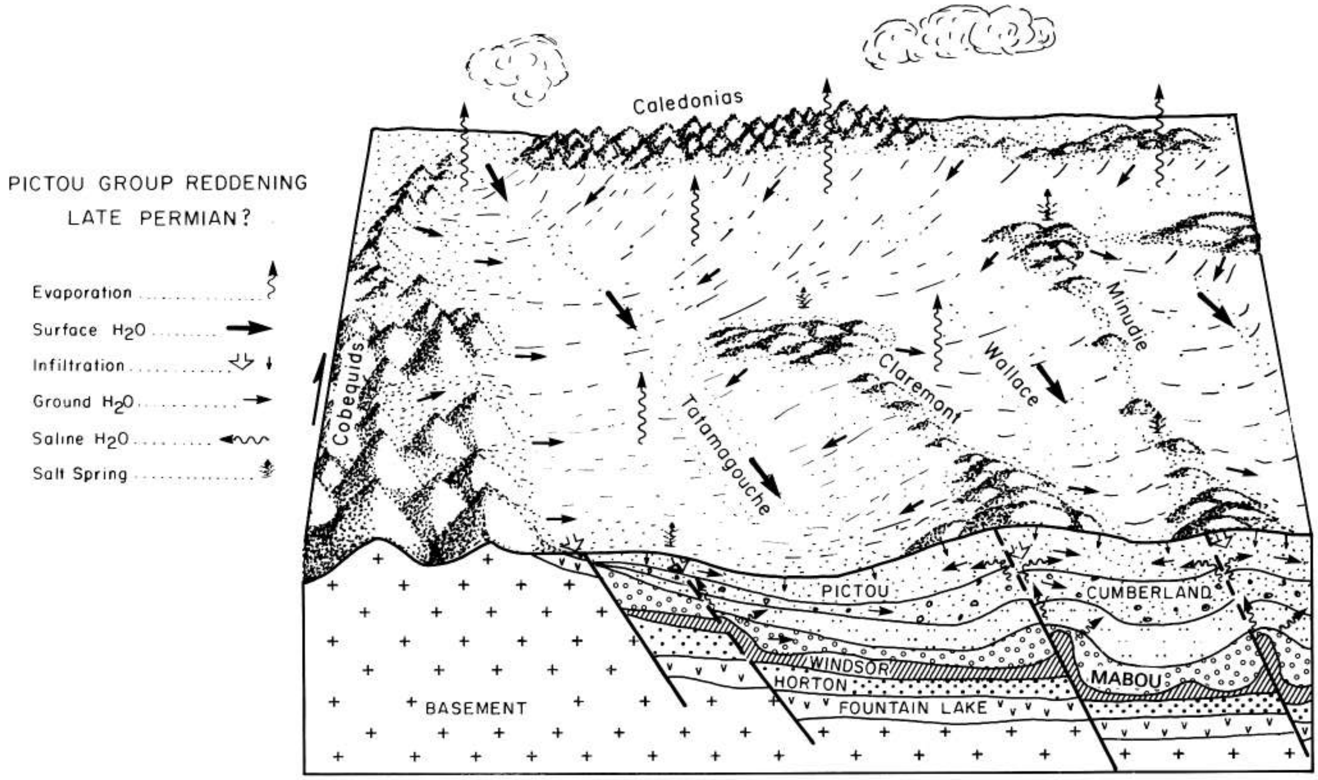


Figure 7-29. Possible paleogeographic reconstruction of the Cumberland Basin in the late Permian, looking southwest. Note the infiltration of the oxygenated water and the possible mixing with chlorine-rich salt springs.

were: (1) volcanogenic beds, (2) petroliferous shale, dark mudrocks and limestone, and (3) the redbeds themselves. Boyle (1968), Lur'ye (1978), Zielinski *et al.* (1983) and Haynes and Bloom (1987) postulate that redbed Cu-Ag deposits need no external source for Cu-Ag because deep, intense weathering and leaching would liberate enormous amounts of these elements under oxidizing conditions and these metals would be absorbed by Fe and Mn oxides and clays. Later diagenesis and groundwater movement would reconcentrate the Cu-Ag at redox boundaries creating redbed mineralization. The observations of various workers, based on geochemical principles, led all of them to the conclusion that, in most cases, the Cu-Ag in redbed Cu-Ag deposits comes from the sedimentary pile itself. Holmes *et al.* (1983) similarly proposed, based on geochemistry and petrography of mineralized and unmineralized sandstones of Triassic age from England, that redbed mineralization involves the dissolution and release of trace metals from detrital minerals during diagenesis. They suggest that the metals are retained in saline interstitial solutions which migrate to suitable sites where precipitation and deposition occur by reaction with trapped hydrocarbons or reducing sulphur. The details of composition and the thermodynamics of transport and precipitation of the Cu ores is beyond the scope of this study; however, composition can be assumed to be similar to that proposed by Haynes and Bloom (1987; Rose, 1989). Haynes and Bloom (1987) suggested that although the metal-transporting fluid compositions are based on the hypothesis of 50 cm depth at a temperature of 25°C, the compositions are applicable to later diagenetic processes up to 100°C.

The geochemical characteristics of the rocks, tills and stream sediments in the Cumberland Basin are consistent with Cu-Zn depletion in Pictou Group redbeds. The till and stream sediment samples delineate large areas of low Cu values throughout the Cumberland Basin, which is unexpected considering the numerous Cu-Ag occurrences. The depletion of Cu and associated elements within reddened strata, and little evidence of anomalous Cu values in the grey beds, except in close proximity to redbeds, strongly suggest a diagenetic model of ore formation.

Solution Fronts

The Cu-Ag solution front deposits described by Shockney *et al.* (1974) for the Paoli, Oklahoma, area appear to be similar to the occurrences in northern Nova Scotia. The redbed Cu deposits of New Mexico, in particular the Nacimiento Deposit (LaPoint, 1979), and the Dzhezkazgan Cu-Ag deposits of the U.S.S.R. (Baskov, 1987) also show striking similarities to the occurrences in the study area. These deposits have cogenetic bornite and chalcocite with strongly negative sulphur isotope values. Unlike many other redbed Cu deposits, the deposits named above and those of the Cumberland Basin represent Cu mineral replacement of original early diagenetic pyrite.

In the proposed model (Fig. 7-30) Cu and Ag were subjected to selective leaching and transport during the diagenetic reddening event by mechanisms similar to those proposed by LaPoint (1979) for the New Mexico redbed Cu-Ag deposits. Metal-bearing solutions migrated until they encountered reducing conditions. The reducing conditions necessary for precipitation occur primarily: (1) where sufficient coalified plant material and pyrite was preserved within channel lags; (2) at contacts with pyrite-bearing organic-rich grey shale; and (3) presumably at the interface between oxidizing groundwater and reducing basinal fluids (Fig. 7-28). In the Dzhezkazgan redbed Cu-Ag district of the U.S.S.R., grey strata are interpreted as being re-reduced by hydrocarbons (Baskov, 1987). The physicochemical

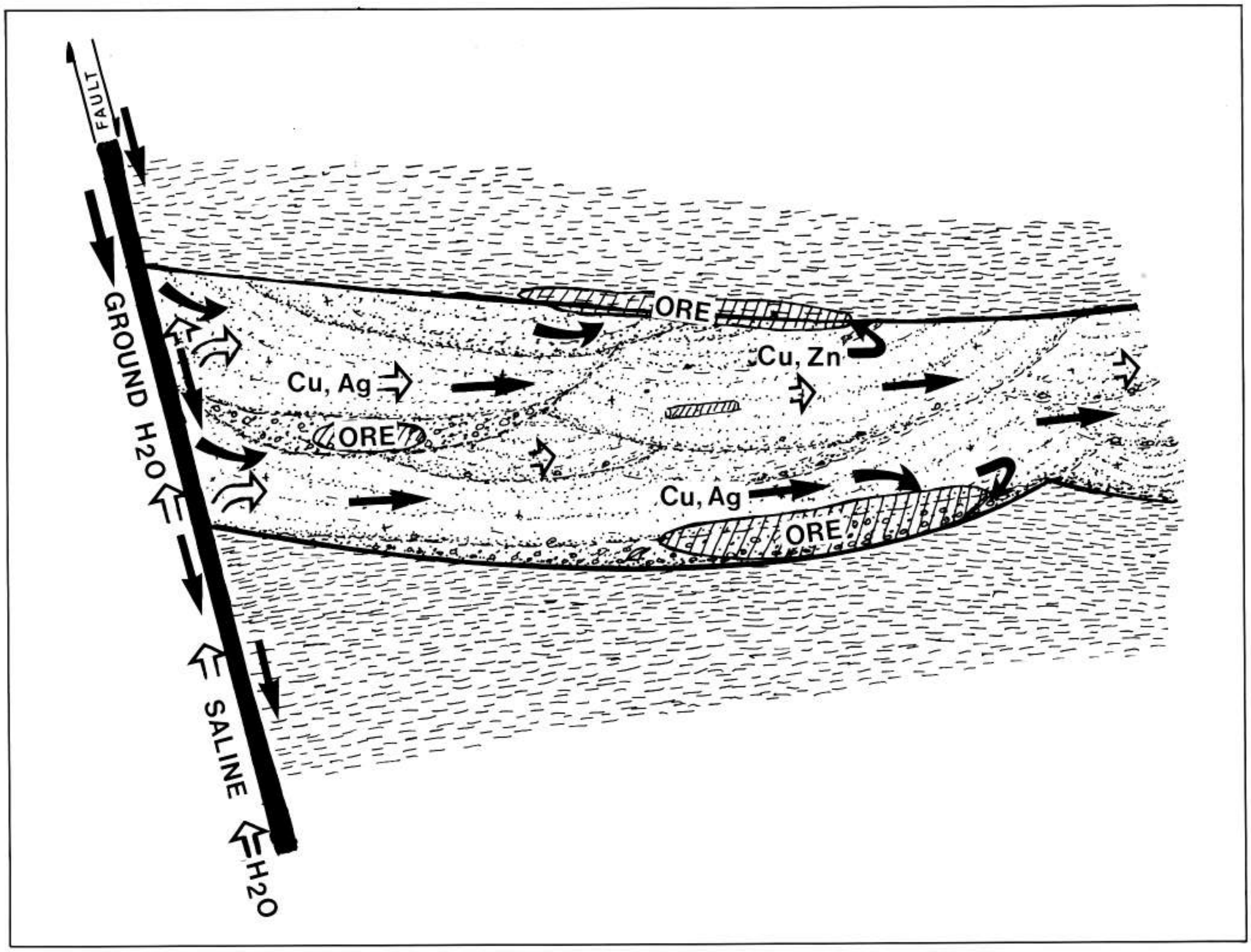


Figure 7-30. Sandstone-hosted redbed Cu occurrence with the reddened strata and the concentration of Cu-Ag-Zn, etc., at the interface with the local reduced beds at the channel lag or with overlying grey organic and pyrite-rich mudstone.

parameters for migration of metal-bearing solutions in these strata are very similar to those proposed for the Nova Scotia examples; however, the Nova Scotia occurrences do not show any evidence of a secondary origin for the greybeds.

Kupferschiefer Type Deposits

Kupferschiefer deposits are named for the mining district at Mansfeld in Germany. The name refers to the "copper shales" which were first mined around 1199 and are still being mined today. The term Kupferschiefer comes from the fact that the deposits are hosted by grey to black organic-rich shale and carbonates. These shale beds typically overlie red sandstone sequences and, therefore, form a natural reduction - oxidation boundary. Jowett (1989) provides a succinct summary of the evolution of ideas relating to the genesis of these deposits. The term Kupferschiefer-like, as referred to herein, refers to shale-hosted Cu deposits that are hosted by the first grey bed overlying a thick redbed succession. The fine-grained grey strata act as a site for reduction of metal-bearing solutions migrating upward out of the red strata. Kupferschiefer deposits have been interpreted as resulting from mineralizing brines from the underlying redbeds that migrate updip to organic-rich beds by convective flow, in response to rifting (Jowett, 1986, 1989). The metal-bearing solutions in the Cumberland Basin are interpreted to be due to oxygenated groundwater flowing downdip from basin margins or from fault zones and, therefore, although similar in geological setting the mechanisms of mineralization differ from the European examples. Groundwater chemistry was similar to that proposed for the solution front mineralization of the Cumberland Basin. The similarity of mineralogy and proximity of this deposit type to solution front mineralization suggests that the mechanism of transport and deposition of Cu and Ag were also similar. It is proposed that chloride-bearing, oxygenated groundwater entered the red coarse clastics that underlie the Boss Point Formation, leached and transported Cu-Ag as chloride or carbonate complexes out of the redbeds, and precipitated the metals at the redox boundary with overlying pyrite-bearing grey shale beds. The relative importance of updip migration of basin brines is difficult to assess for these occurrences, although some influence on mineralization may be assumed (Fig. 7-31). The economic potential of this type of occurrence is very significant because of the high probability for lateral continuity of a mineralized horizon.

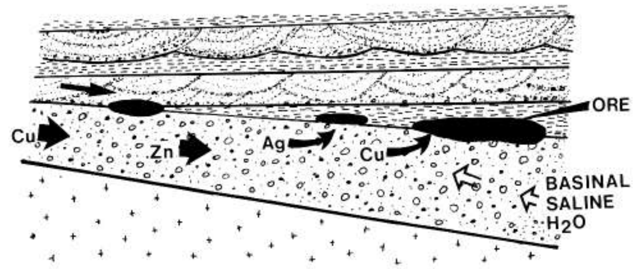


Figure 7-31. Cartoon depicting the possible origin of the shale-hosted redbed copper occurrences in the Cumberland Basin.

Exploration Model for the Cumberland Basin Cu Occurrences

Figure 7-32 outlines responses of the various geochemical methods employed in the Cumberland Basin and should be a guide to expected results in similar geological settings.

Mineral exploration should take into account the following criteria and procedures: (1) large areas containing regionally low Cu values (negative anomalies) that contain numerous Cu-Ag occurrences have a good potential for this type of mineralization; (2) the presence of red to grey colour boundaries is essential for this type of mineralization; (3) grey horizons are usually found in association with coalified plant material in channel lags, at the interface with reducing basinal waters and in zones where H_2S and hydrocarbons were trapped adjacent to evaporite diapirs; (4) small positive Cu anomalies can be found by combining bedrock prospecting, till geochemistry, and stream sediment analyses; (5) many of the smaller occurrences are associated with channel lags and, therefore, sediment dispersal patterns and fluvial modelling must be undertaken to define the distribution of carbon-rich (potentially mineralized) zones; (6) drilling programs should be carried out on a closely spaced grid pattern to maximize the potential for intersection of the mineralized channel lags; (7) exploration for grey to red boundaries of greater extent, like those in the Dzhezkazgan USSR region (e.g., adjacent to diapirs and at basinal facies transitions), should be carried out to maximize the potential tonnage of such deposits.

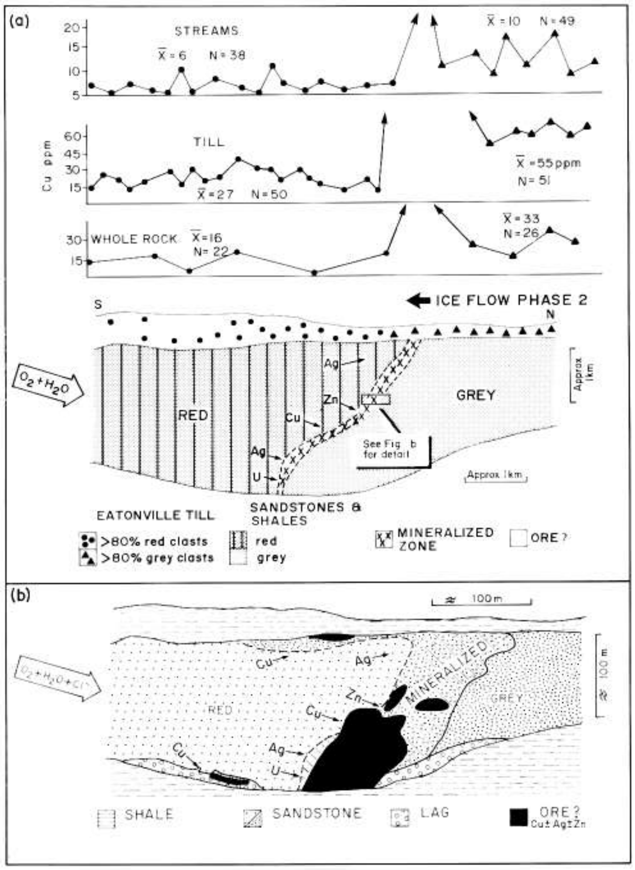


Figure 7-32. Exploration model for the sandstone-hosted redbed, Cu deposits of the Cumberland Basin: (a) large scale overview of the redox boundary with the various geochemical responses; (b) a close up view of the redox boundary depicting the remobilization of the chalcophile elements to the redox front or interface.

Integration of geochemistry with sedimentology and geological mapping provides the basic data necessary to suggest exploration models for these Cu-Ag-U occurrences. The association of Au with these occurrences enhances their attractiveness as exploration targets. In the Cumberland Basin, stream sediment gold anomalies (Ryan, 1988), with several values greater than 860 ppb, can, for the most part, be correlated to conglomeratic units and, therefore, are believed to be related to paleoplacer gold enrichment (Ryan, 1988). However, numerous anomalies in the area north of Pugwash, near Northport, Cumberland County, may be related to remobilization of gold by solution fronts. Although there are no documented mineral occurrences in outcrop in this area, several Cu-bearing mineralized boulders have been found along the beach. In support of the Au mobilization hypothesis, Boyle (1968) and Maynard (1983) suggested that under the conditions of redbed Cu mineralization Au should be geochemically mobilized along with Cu and Ag.

The Cu-Ag occurrences and deposits in the Cumberland Basin are related to diagenetic reddening caused by the percolation of oxygenated groundwaters. The reddening of sandstone within the sedimentary succession liberates Cu-Ag and associated minerals and deposits them at a boundary with reducing grey strata or where the groundwater mixes with basin brines. All of the deposits in the Maritimes Basin that are associated with groundwater mobilizing metallic ions and redepositing elements at redox boundaries can collectively be referred to as groundwater diagenetic deposits. This group or type of deposit is referred to in Chapter 1 as genetic affinity type 3, stratabound shale- and sandstone-hosted deposits.

The following conclusions can be drawn: (1) There are numerous known Cu-Ag occurrences within the study area, and more to be discovered; (2) some of these occurrences contain high concentrations of Ag, Au, Co and other elements, which may enhance their eventual economic potential; (3) the ore mineralogy and vitrinite reflectance studies indicate a low temperature of mineralization (<100°); (4) bedrock, till, and stream sediment geochemistry indicate that there are low Cu values in the redbeds of the area; (5) diagenetic indicators, surface textures, paleobotany, sedimentological features, sediment dispersal patterns, vitrinite reflectance, and paleomagnetics indicate that the red coloration of sandstone is a late diagenetic feature; (6) the mineralization occurs at or adjacent to red-grey boundaries; (7) sulphur isotopes indicate mineralization included sulphur produced by bacteria; (8) the grey sandstone is not enriched in Cu, Ag or Zn relative to normal concentrations for similar rocks elsewhere; (9) mineralization was diagenetic with Cu, Ag, Zn and U being leached and transported during the reddening event and deposited at redox boundaries; (10) if laterally extensive redox boundaries can be defined within the study area they will delineate areas that may have great potential as hosts for large ore deposits.

Uranium Roll (Solution) Fronts

Geological Setting

Closely associated with the Cu-Ag occurrences there are several significant uranium occurrences within the study area, the most noteworthy are: (1) Louisville, Pictou County, (2) Port Howe, Cumberland County, (3) McLean Beach, Cumberland County and

(4) Woodlock Brook, just south of Tatamagouche, Colchester County (Fig. 7-3). During the late 1970s and early 1980s several exploration companies, including Noranda Exploration and Lacana (McNabb, 1978), were actively involved in uranium exploration in the study area. Drillhole data generated by this exploration activity has provided much of the subsurface compilation.

The maximum concentration of uranium in these occurrences rarely exceeded 2 lbs. per ton; at current prices this is not economic. The Louisville (McNabb, 1977) and McLean Beach uranium prospects (Chatterjee, 1977) are perhaps the best known, although drill core from Port Howe (Fig. 7-33) probably best exemplifies the secondary roll front nature of mineralization and the exploration difficulties.

Model

The mineralization style as summarized by Dunsmore (1977b) is very similar to the Cu occurrences of the area and uranium may occur with or without associated copper mineralization. Dunsmore (1977a, 1977b) points out that the most of the occurrences are located near the base of fining upward cycles where uranium precipitated due to the reducing conditions created by carbon-rich lags. Nash *et al.* (1981) state that organic adsorbent-reductant deposits, such as the ones in the Tatamagouche area, are invariably hosted in sandstone with abundant coalified plant material. These occurrences suggest that uranium-rich solutions passed through the strata, perhaps at the same time as Cu and Ag solutions, and uranium was precipitated in pyrite- and carbon-rich lags at the base of fining upward cycles. This primary uranium is commonly hydraulically remobilized by subsequent oxidizing groundwater. Most of the uranium is flushed downdip deeper into the basin but some of uranium migrates up the channel sandstone body flanks (Fig. 7-34). Remobilization and redistribution of the primary ore is common in this type of deposit (Nash *et al.*, 1981) and tends to obscure the original nature of the deposit. The model implies that secondary roll fronts develop adjacent to channel lags on the channel flanks. However, the rolls are usually small and very difficult to delineate without very closely spaced drillholes.

Paleoplacers

Introduction

Paleoplacers have long been known in the clastic Carboniferous strata of Atlantic Canada. The most noteworthy deposit is the Gays River Gold Mine (Fig. 7-35). Over 2000 oz. of gold were reportedly recovered from the Gays River Mine and produced at the stamp mill operation from 1871-1881. Gold at the Gays River Mine occurred as flakes, grain coatings, and small sand-size particles in the matrix of a polymictic conglomerate. The gold was concentrated near the base of the conglomerate at the topographically irregular contact with Meguma Group rocks. Fractures, joints, and small paleovalleys or erosional gullies in the underlying Meguma Group meta-greywacke were preferential sites of gold deposition.

Ryan *et al.* (1988c) described an integrated approach to paleoplacer geology and exploration strategy involving heavy mineral studies in conjunction with: (1) stream sediment geochemical surveys, (2) till mapping and geochemical surveys, and (3) bedrock geological surveys. These studies have all documented the occurrence of cassiterite in heavy mineral fractions of the various sampling media being studied.

Although basin areas adjacent to the Meguma Terrane may have better potential for Au paleoplacers (Fig. 7-35), the detailed sediment dispersal and heavy mineral studies for the Cumberland Basin were used by Ryan *et al.* (1988c) to demonstrate the methodology that could be applied to Carboniferous strata in other areas of the Atlantic region. Cassiterite and wolframite were used to demonstrate the mechanisms of paleoplacer and glacial transport and to define the geochemical dispersion.

The study area comprises two distinct physiographic regions, the Cumberland - Pictou Lowlands, underlain by basin fill strata, and the Cobequid Highlands, composed of pre-Carboniferous crystalline and metamorphic basement rocks. Bedrock, till, and glaciofluvial, glaciomarine, alluvial, colluvial, marine, and organic sediments make up the surface material of the area (Stea *et al.*, 1986). The Eatonville till sheet covers most of northern Nova Scotia (Stea and Finck, 1984). Stea *et al.* (1988) estimates the average glacial transport within the Eatonville Till, with greater than 50% sedimentary clast composition, to be approximately 3 km southward, although locally some of the till has been slightly modified by a subsequent northward flow.

Determination of the ancient sediment dispersal trends is essential to paleoplacer exploration. Dispersal trends define the basin configuration and help to predict where strata might be composed of detritus from mineralized source areas.

Sediment dispersal trends compiled in this report

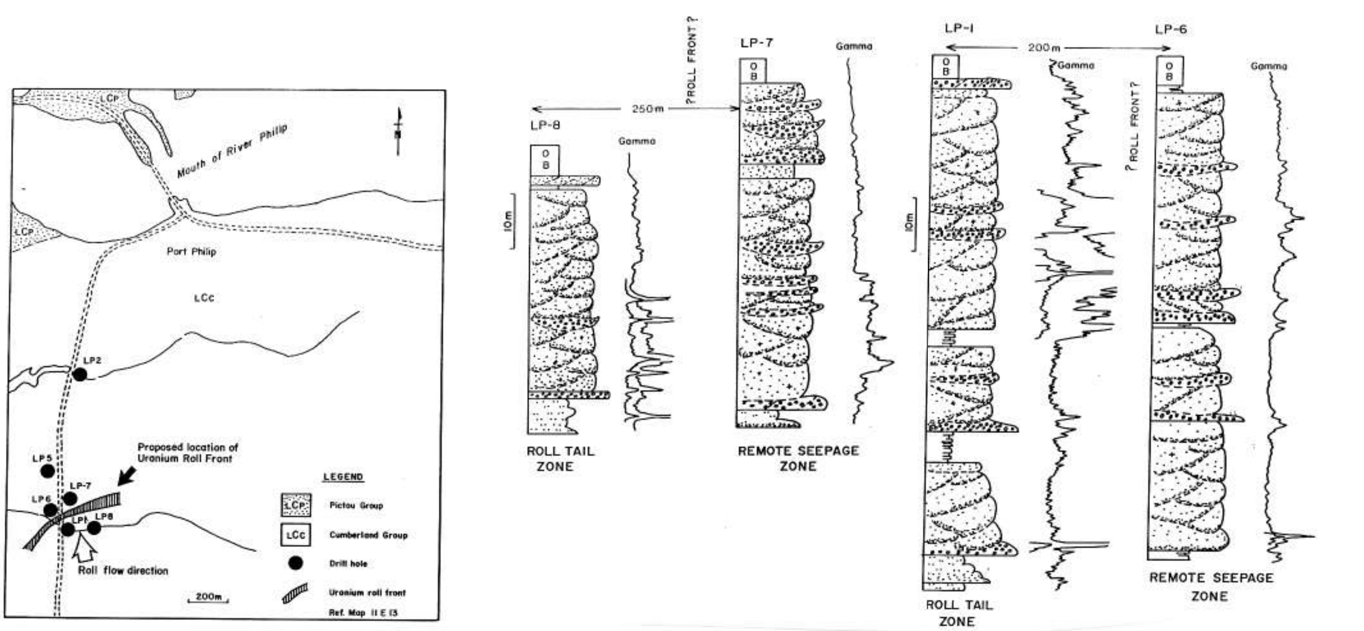


Figure 7-33. Possible location of a uranium roll front in the Port Phillip area. Drillholes have gamma ray responses typical of backtails (updip from roll front) and remote seepage zones (downdip from roll fronts). The roll front possibly occurs between these drillholes.

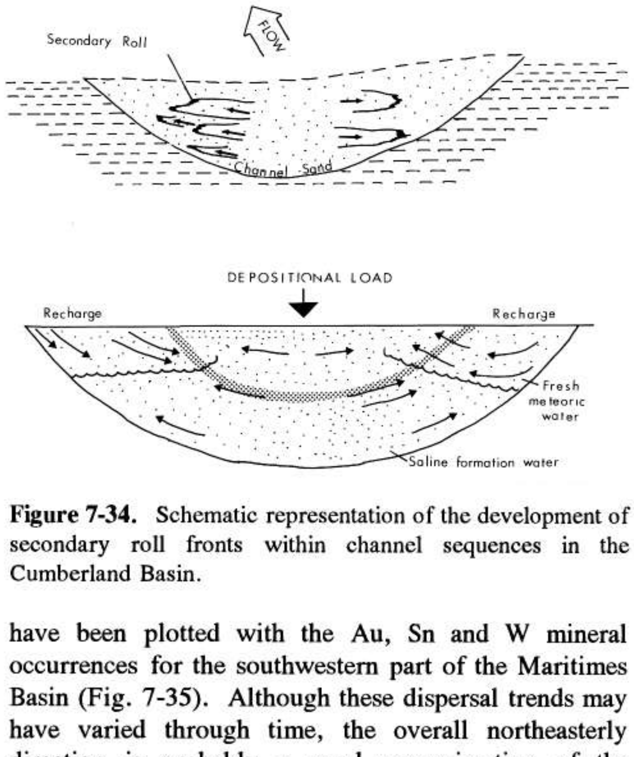


Figure 7-34. Schematic representation of the development of secondary roll fronts within channel sequences in the Cumberland Basin.

have been plotted with the Au, Sn and W mineral occurrences for the southwestern part of the Maritimes Basin (Fig. 7-35). Although these dispersal trends may have varied through time, the overall northeasterly direction is probably a good approximation of the prolonged sediment dispersal trend for the southern half of the Maritimes Basin. This information was utilized by Ryan *et al.* (1988c) to define large areas of the basin fill which may have been derived from mineralized highland or platform basement rocks. These areas have good potential for paleoplacers.

In the eastern Cumberland Basin the vector mean trend is at a variance of about 50° to the dispersal trend in the rest of the southern part of the Maritimes Basin (Fig. 7-35). Proximity to the Cobequid Highlands Massif, which was a local source area (Donohoe and Wallace, 1985) supplying stream discharge into the basin, caused local variations in dispersal trends. The influence of the Cobequid Highlands Massif on sedimentation is clearly demonstrated by the thick alluvial fanglomerate deposition recorded by the Cumberland Group. The presence of fans indicates that there were significant quantities of detrital material entering the basin from the highland area. It is likely that this influx may have influenced dispersal patterns for several kilometres into the basin. The presence of material derived from the Cobequid Highlands Massif within the fanglomerates that interfinger with extra-basinal basin fill units, such as the Boss Point Formation (Ryan *et al.*, 1987), indicates that the Cobequid Highlands Massif was a persistent source area throughout most of the Late Carboniferous.

The north-northwest sediment dispersal trend of approximately 340°, adjacent to Sn mineralization in the Cobequid Highlands Massif, delineates a large area of paleoplacer potential for Sn in the Cumberland Basin (Fig. 7-36).

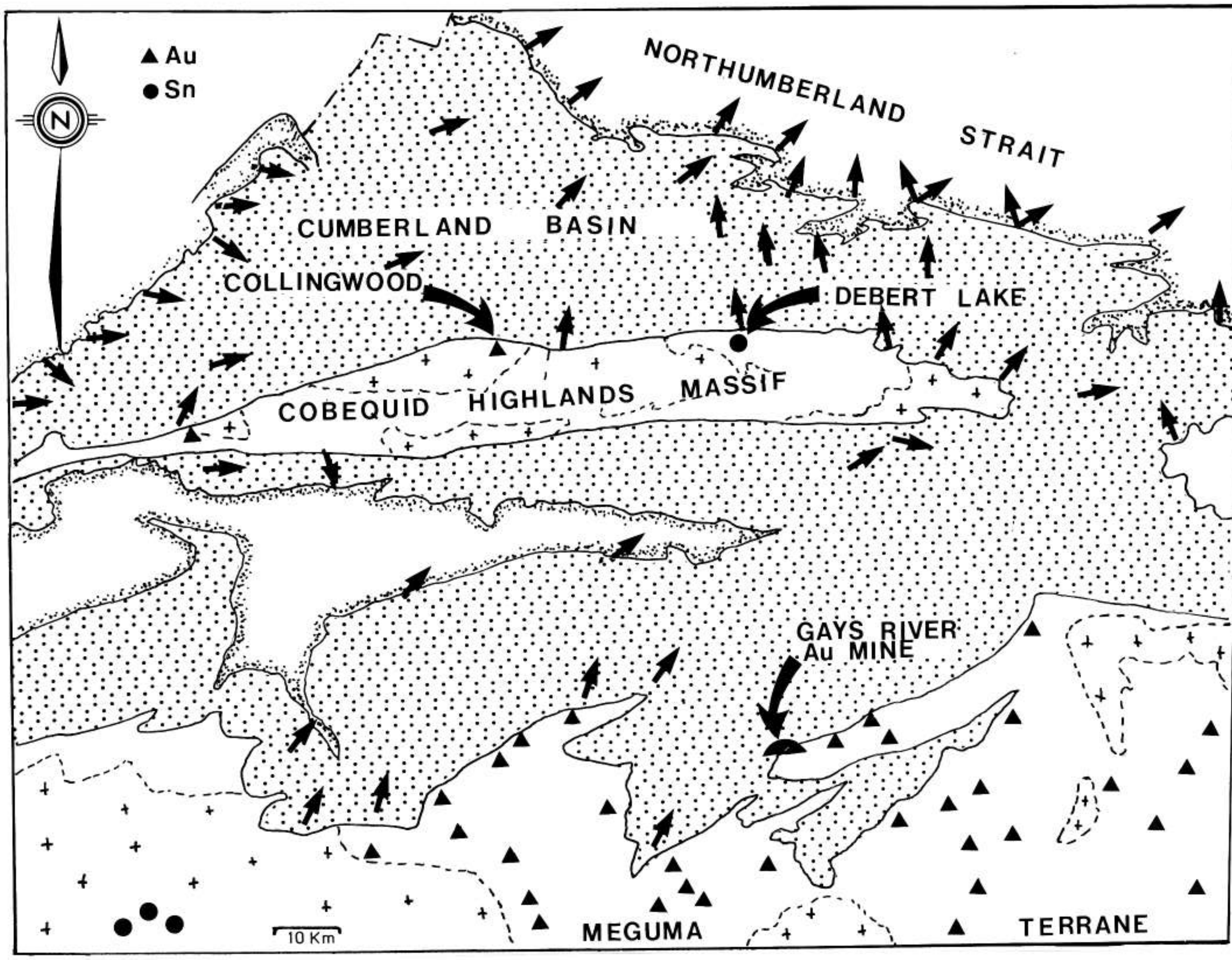


Figure 7-35. Gold occurrences and sediment dispersal patterns for northern Nova Scotia (after Ryan *et al.*, 1988). Triangles = Au occurrences, circles = Sn occurrences, and arrows indicate Carboniferous paleoflow directions.

Exploration Model for Sn-W Paleoplacers

The model proposed by Ryan *et al.* (1988c; Fig. 7-37) is based on the following assumptions of heavy mineral derivation to the various sampling media: (1) the source area is mineralized; (2) the source area is uplifted and subsequently eroded; (3) transport of the economic heavy mineral grains was in a steep gradient stream that facilitated transport of abundant heavy minerals; (4) seasonal flow variations or reduction of the stream gradient resulted in deposition of heavy minerals; (5) tills contain incorporated heavy minerals derived from the mineralized sedimentary and basement rocks; and (6) streams erode and transport heavy minerals derived from all the media including multicycled till, clastic bedrock, and first cycle Sn-W from primary basement sources. Ryan *et al.* (1988c) demonstrated that the cassiterite and wolframite grains found in the Cumberland Basin can be traced from the igneous source at Debert Lake to the tills, streams and Carboniferous sandstones in adjacent areas. These data indicate potential for paleoplacers in the Carboniferous strata of northern Nova Scotia. Use of the scanning electron microscope, in conjunction with heavy mineral separations, to determine the texture and mineralogy of the grains can help to demonstrate the derivation of cassiterite, and define paleoplacer exploration potential in areas of glaciated terrane.

Potential for Au Paleoplacers

Arsenopyrite has been found as detrital grains in

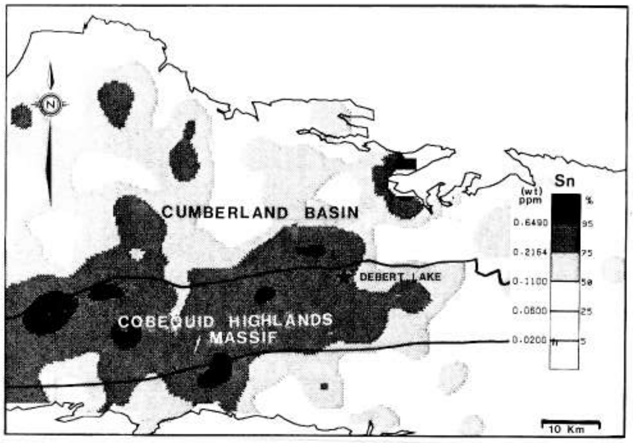


Figure 7-36. Weighted fine fraction Sn values for tills in the Cumberland Basin - Cobequid Highlands Massif areas. Note that the high tin values extend into the basin although the till moved predominately southward. This indicates a Carboniferous source for the Sn values (after Ryan *et al.*, 1988).

stream sediment samples at Collingwood, Cumberland County, along the southern margin of the Cumberland Basin (Fig. 7-35). This locality is near the Williamsdale gold occurrence in basement rocks of the Cobequid Highlands Massif. The association of arsenopyrite as a gangue mineral with the primary mineralization in basement rocks of the Atlantic Canada area may make it a good indicator mineral for gold paleoplacers. Arsenopyrite may be derived directly from the basement rocks or perhaps from a paleoplacer in the Carboniferous strata of the area.

Anomalous gold contents (up to 110 ppb) in the low temperature Cu-Ag occurrences in the eastern Cumberland Basin (Ryan, 1985), and stream sediment anomalies up to 860 ppb Au (Mills, pers. comm.) also suggest that elevated amounts of Au are locally present. Most of the stream sediment Au anomalies occur in areas of conglomeratic outcrop, suggesting a placer mechanism of concentration (Ryan, 1988c; Fig. 7-38).

Exploration Considerations

Regional basin-fill sediment dispersal trends should be used to ascertain areas where sedimentary rocks may have been derived from mineralized basement sources (Fig. 7-35). In these areas, stream sediment and/or till heavy mineral separates from samples should be examined to determine if Sn, Au and W mineral grains are present. The sampling medium should be selected on the basis of the thickness of till cover, stream density and stream gradients. Geochemical analyses of the heavy mineral concentrates may be used to determine which of the samples should be examined with an electron microscope, and these analyses should include possible tracer elements (e.g. As for Au). Where elevated concentrations or anomalies define bedrock areas, a detailed bedrock sampling program should be carried out. Samples of bedrock should be taken primarily from the conglomerate and sandstone that constitute channels lag deposits near the base of fining upward sequences. A careful paleocurrent analysis of the area should determine the sediment dispersal trends and help to define the limits and orientation of potential paleoplacers. Wherever possible the beds being explored should be composed of strata deposited by low-sinuosity high-gradient streams (braided or anastomosing) as a steep stream gradient is necessary to transport economic quantities of heavy mineral grains. Using the Gays River Gold Mine as an example, particular emphasis should be placed on finding areas with irregular basement topography or paleovalleys where gold may be preferentially concentrated.

The study suggests that the clastic sedimentary rocks, which contain from 1 to 9 wt% heavy minerals, have excellent potential as hosts for paleoplacer deposits. Cassiterite and wolframite found in the Cobequid Highlands Massif and the Cumberland Basin can be used to demonstrate the mechanics of transport and to propose an exploration model. This model, developed for Sn-W occurrences, is probably applicable to other areas in the Maritimes Basin where paleoplacer gold potential is enhanced by the fact that the basin fill units are derived directly from terranes with known gold deposits.

Industrial and Nonmetallic Minerals

Fault-related Mineralization

There are numerous examples of fault-related or structurally discordant mineral occurrences in the Cumberland Basin, including barite, celestite, galena, hematite-limonite, and manganese. The following are descriptions of a few of the better exposed occurrences.

Celestite-Galena

At Beckwith, Cumberland County (Fig. 7-2), celestite and trace to minor galena are exposed near surface in red unconsolidated mud and poorly consolidated redbeds (Felderhof, 1978). The celestite occurs as loose crystal aggregates (0.5-3 cm) and small to large nodules (up to several metres in diameter). There appears to be a relationship with hydration zones filled with unconsolidated mud (Fig. 7-39). The minerals

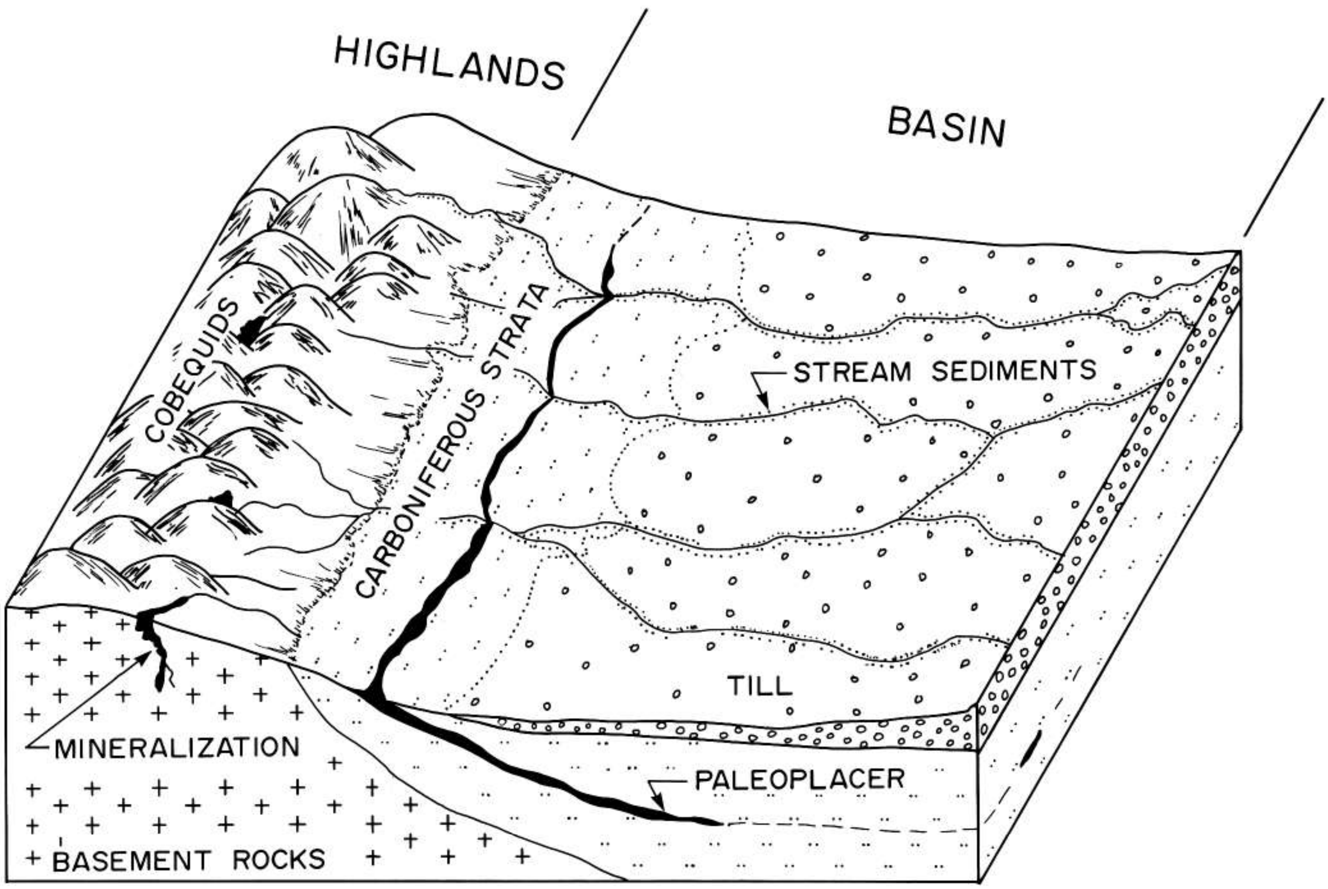


Figure 7-37. Cartoon model for tin paleoplacer concentration in the basin fill strata of the Cumberland Basin (after Ryan *et al.*, 1988).

occur in close proximity to gypsum and anhydrite outcrops and drill intersections of the Windsor Group. The occurrence is located along a complex, poorly defined fault zone which juxtaposes Lower Carboniferous evaporitic marine strata of the Windsor Group with Upper Carboniferous siliciclastics. Recent exploration trenching and drilling by Jascan Resources Inc. has delineated a small deposit of relatively pure celestite occurring within 20 m of surface (Felderhof, pers. comm.). Mineralized bedrock has not been found, suggesting that the mineralization may have occurred *in situ*, within the red mud of a paleokarstic solution zone. This zone is probably the result of hydration and solution of Windsor Group evaporites along the fault zone that separates gypsum and anhydrite from the clastic sedimentary rocks of the Upper Carboniferous and perhaps may be analogous to similar residual celestite deposits in England. A relationship to a lithified bedrock vein or stratabound-manto type mineralization has not been recognized. Visible, finely crystalline galena is often present within the celestite nodules, although galena never occurs by itself. The tonnage of this deposit is probably small (50,000 tons or less). However, the relatively pure celestite may be exploitable on a limited scale.

Potential exists for similar deposits along the faulted axis of the Minudie Anticline which extends 45 km west to Minudie. Deposits could be of two styles: (1) the Beckwith faulted style or (2) the Loch Lomond stratabound style (Forgeron, 1977) within less disturbed parts of the Windsor Group.

Barite

Several occurrences of discordant or fault-related barite are found in the Cumberland Basin (Felderhof, 1978). These occurrences are: (1) Welsford, (2) North Shore, (3) River John, (4) Spicers Cove and (5) South Brook. The occurrences at Welsford, North Shore and Spicers Cove have been previously described by Felderhof (1978). The barite occurrence at River John, Pictou County (Fig. 7-2), has not been previously described. The River John occurrence consists of fault-

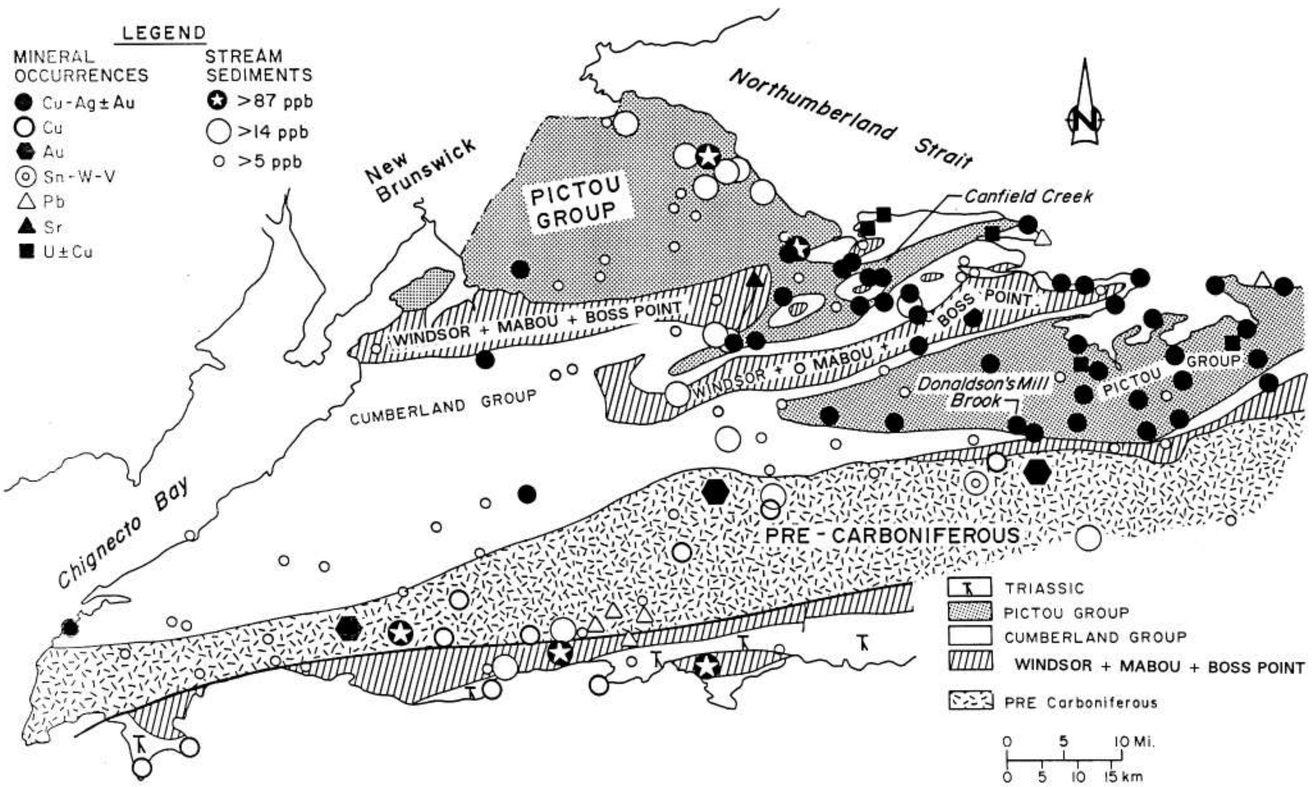


Figure 7-38. Plot of the Au stream geochemistry and mineral occurrences for the Cumberland Basin. The Au anomalies closely correspond to outcrops of conglomeratic strata.

related vein barite hosted by Upper Carboniferous sandstone and mudrocks. The vein of coarsely crystalline barite cuts the sandstone and is highly discordant to bedding. The vein dips at approximately 80° to the north and has a strike of 050°. The vein varies from 10 to 20 cm in width.

Similar veins occur along the faulted boundary of Upper Carboniferous strata and the Cobequid Highland Massif at Spicers Cove in the western part of the Cumberland Basin (Felderhof, 1978). At Spicers Cove, several veins up to 26 cm in width are exposed in the cliff and in the tidal zone. The continuity of the steeply dipping veins is difficult to determine and their thinness makes these barite occurrences unlikely exploration targets, unless larger replacement or stockwork zones can be delineated. Replacement or manto type stratabound deposits may occur in appropriate horizons related to the structurally controlled vein type mineralization.

At South Brook, in the southwestern part of the basin (Fig. 7-2), there are two localities with fault-related barite veins. The veins are up to 15 cm wide, nearly vertical and strike at approximately 100°.

Manganese

A minor manganese occurrence is found within a fault zone near Cape John, Pictou County. The manganese occurs as massive, finely crystalline pyrolusite and as coatings on clasts in the fault gouge.

Bishop and Wright (1974) reported that manganese was extracted in small quantities from the Kinnear Quarry near Brookdale. The manganese oxide occurred in irregular cavities and along fractures in a karstified limestone of the Windsor Group (Lime-kiln Brook Formation). A similar occurrence has been reported in the Canfield Creek area.

Salt and Potash

The Cumberland Basin of northern Nova Scotia is the major salt producing area in Atlantic Canada. Canada's first underground salt mining operation was established at Malagash by the Malagash Salt Company in 1919 and continued production until 1959 (Boehner, 1986). At present, two deposits in the area are in production: (1) The Nappan brining operation of Sifto

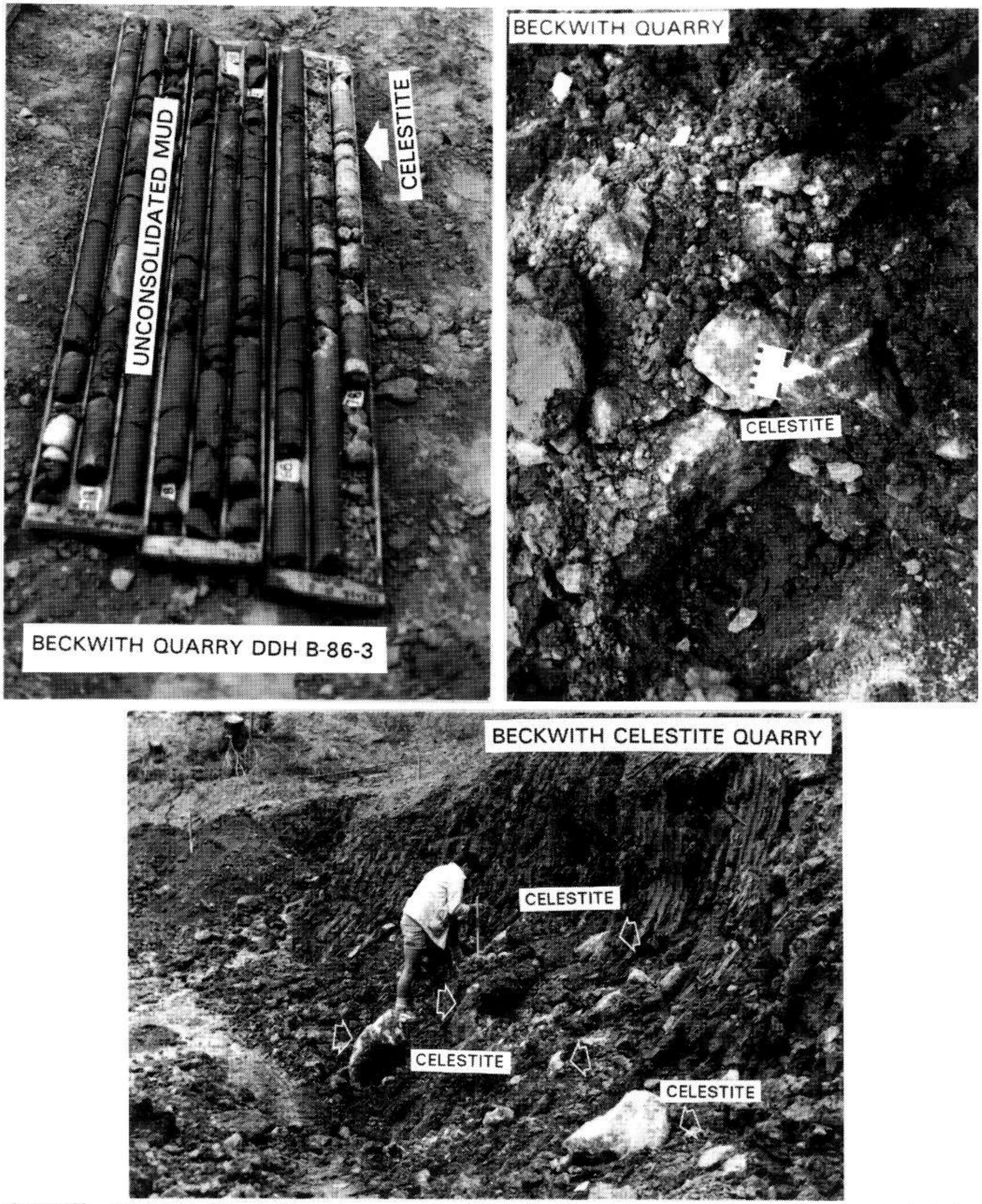


Figure 7-39. Photographs of the celestite - galena occurrences at Beckwith. The celestite appears to be crystallizing in a clay hydration zone between the evaporates and Upper Carboniferous strata that are in fault contact with each other.

Canada, Incorporated; and (2) the Pugwash underground mine operated by the Canadian Salt Company Limited. These operations began producing in 1947 and 1959, respectively. Boehner (1986) estimates recent production as 65,000 tonnes at Nappan and approximately 800,000 tonnes at the Pugwash Mine. Two other salt deposits and two salt occurrences were also recognized by Boehner (1986) in the Cumberland Basin area: (1) the Malagash deposit, (2) the Oxford deposit, (3) the Beckwith occurrence, and (4) the Roslin occurrence (Fig. 7-2). Salt probably occurs at Canfield Creek, Hansford, and in the Salt Springs and Black River area near Springhill, but has not been proven by deep drilling.

Potash-mineralized intervals (trace to minor) have been reported from the salt at Nappan, Malagash, Oxford, and Pugwash (Boehner, 1986; Carter, 1987). The potash occurrences are small, discontinuous, and low grade, generally less than 5% K_2O. Although these potash occurrences are minor, their presence may indicate potential for thicker potash concentrations elsewhere in the Cumberland Basin area. Boehner (1986) summarized the geology of the salt deposits for this area in his report on salt and potash in Nova Scotia, and in addition, the Pugwash Mine geology has been the subject of a detailed study by Carter (1986, 1990).

Most of the salt and potash occur within the Pugwash Mine Formation in the lower part of the Windsor Group. These beds dominate the diapiric evaporite structures in the axes of the Minudie and Claremont-Malagash anticlines, as well as the isolated diapirs that occur between the diapiric anticlines. The structural geology is very complicated (Carter, 1989; Evans, 1972) in these structures making exploration for potash deposits difficult.

Several of the salt deposits in the Cumberland Basin, including Nappan, Oxford and Beckwith, as well as potential deposits near Springhill, may be suitable for underground storage developments.

Limestone and Dolomite

Limestone and dolomite (dolostone) have been produced on a limited basis for agricultural application and as aggregate. Two principal deposits have been exploited: Dewar Hill Quarry near Pugwash and, Lime-kiln Brook Quarry near Upper Nappan. Both deposits are in relatively thick, steeply dipping carbonate members of the Lime-kiln Brook Formation of the Windsor Group. They are exposed on the flanks of diapiric anticlines. Potential exists for similar, small tonnage deposits of limestone and dolostone, particularly in the along-strike extensions near Fenwick and Brookdale, and perhaps in the more isolated localities near Little River, Oxford and Pugwash River. In the subsurface, certain carbonate units of the Lime-kiln Brook Formation appear to be thicker (10-14 m), relatively homogeneous and potentially laterally persistent. However, steep dips, relatively thin zones, impure interbeds, excessive overburden, and difficult access commonly limit the potential of these strata for exploitation.

Gypsum and Anhydrite

The gypsum and anhydrite potential of the Cumberland Basin has been examined by Adams (1991) as part of a province-wide study. Gypsum and anhydrite are interstratified with redbeds and carbonates in the Lime-kiln Brook Formation (Fig. 7-2). They also occur in the locally extensive residual collapse breccia zone (up to 300 m thick) in the complex axial regions of diapirs.

Gypsum was produced by Maritime Gypsum Company in limited quantities near Amherst Point in the early 1900s (1912-13) and in a larger operation near Nappan by Alabastine Canada Ltd. and Domtar Gypsum between 1959 and 1962. Exploitation of the deposit at Nappan was hindered by quality prohlems related to the locally extensive infiltration of red mud to gritty sandstone into a complex karst system of fractures and cavities. This material is partially lithified, occurs to depths of 100 m or more, and is locally horizontally stratified. The lithology is similar to Upper Carboniferous to Lower Permian siliciclastics or perhaps may be as young as the lower Mesozoic redbeds.

Gypsum outcrop and shallow subsurface localities have been identified at Little River, Beckwith, Oxford, Pugwash River, Roslin and Lazy Bay. Drilling at Lower Maccan (LMA 88-1) has established the presence of anhydrite strata in the Lime-kiln Brook Formation. Bell (1944, 1958) postulated the presence of evaporites in this part of the section based on sinkholes in the Lower Maccan area. Anhydrite and salt are also confirmed in this unit in borehole Pacific Fox Harbour C- 96V, near Wallace. The anhydrite interbeds are up to 10 m thick in drillhole LMA 88-1. They are believed to have been removed, to a large degree, in many surface and near-surface exposures by dissolution and karst processes.

Sulphur

Native sulphur has recently been recognized and reported as a trace to minor occurrence in the Pugwash Mine by Carter *et al.* (1988, 1987c). The fine-grained disseminated sulphur is associated with anhydrite (cap anhydrite) believed to have formed by caprock processes at one locality near the flank of the Pugwash Diapir. The sulphur occurs with light brown carbonate, as a thin envelope or film separating or surrounding anhydrite nodules. The host anhydrite is in direct contact with hydrocarbon-bearing clastics (Carter, 1986). Carter *et al.* (1988, 1987) postulated that the sulphur was bioepigenetic. The exploration potential for caprock-related bioepigenetic sulphur remains unknown and virtually untested.

Building Stone

Building stone production has had a long but sporadic history in the Cumberland Basin, beginning in the early to mid 1800s (Parks, 1914; Messervey, 1926; Dickie, 1989). Major producing areas (Fig. 7-2) included Amherst (Pictou Group red sandstone) and Wallace River, and subsequently Wallace (Boss Point Formation, olive to grey sandstone). Limited production occurred from localities at Lower Cove near Joggins, Northport, River Philip, Tatamagouche and River John. Production from the Wallace area was probably the most significant, with the export of stone for use in buildings in Halifax and Charlottetown, and as far away as Ottawa and New York City. In addition, high quality grindstones were quarried and manufactured at Lower Cove as early as 1875 and were widely exported.

Energy Resources

There is potential for three types of energy resources in the Cumberland Basin: (1) coal, (2) oil shale and (3) oil and gas. Coal has been the major resource exploited in the area. Coal mining in the district began in 1858 and continued at various locations in the basin until 1983. Potential for oil and gas and oil shale development has attracted oil industry activity at various times, particularly since the 1920s. Major exploration projects have been conducted by International Petroleum (Imperial Oil Ltd.), Sun Oil Company, Pacific Petroleums, Gulf Oil, Anschutz Petroleum and most recently by Chevron Canada Ltd. Minor hydrocarbon occurrences are known from core drilling at South Athol (minor natural gas in NSDME drillhole SA88-1), Pugwash Salt Mine (minor natural gas in No. 1 Shaft, and oil seeps underground) and Oxford (Amax AOP-1, minor natural gas). Surface shows have been reported in West Branch River John and at Scotsburn (Short, 1986).

Coal Resources

Springhill Coalfield

The Springhill Coalfield occurs in the south-central part of the Cumberland Basin (Fig. 7-40) within Cumberland Group strata. The coalfield has been moderately to severely deformed by tectonic transpression and Windsor Group evaporite diapirism centralized at the Black River Diapir at the terminus of the Claremont - Malagash Anticline. Calder (1985a) describes the structural configuration of the coalfield as a southwesterly-plunging anticline, the axis of which is severely faulted. The coal measures (Springhill Mines Formation) attain a maximum thickness of 1,080 m on the north limb of the anticline (Calder, 1985a). The coal measures thin, undergo facies change, and onlap fanglomerates towards the south and southeast adjacent to the Cobequid Highlands Massif. Calder (1985a) suggested that the centre of coal deposition migrated southerly through time, with each successive seam having a more southerly depocentre.

The major coal seams in the coalfield are, in ascending order (after Calder, 1985a): (1) Gesner, (2) Number 6, (3) Number 7 (upper and lower), (4) Number 2 (upper and lower), (5) Number 1, (6) Number 3, (7) McCarthy, (8) Rodney, (9) Harrison and (10) Golden.

Calder (1981) summarized the thickness of the various seams in the coalfield and the thickest seams are: (1) on the north limb the No. 2 (2.7 m thick) and the No. 3 (3 m thick); (2) in the axial region the Rodney (2.0 m thick), the McCarthy (1.9 m thick), and the No. 3 (2.2 m thick); (3) on the south limb the Rodney, McCarthy, and the No. 3 seams are all thinner with the Rodney at 1.8 m being the thickest. The coal is characterized as high to medium volatile, A bituminous. Calder (1985a) noted that the workings in the Springhill area below a vertical cover of 450-600 m are prone to rock bursts or "bumps", which forced the closure of many of the collieries in the late 1950s.

Calder (1984b) proposed that coal deposition took place in elongate mires adjacent to alluvial fans emanating from the Cobequid Highlands Massif. North of Springhill, the coal swamp development was controlled by the northeasterly-trending trunk river system. It can be postulated that the coal swamp development and preservation may have resulted from elevated water tables due to the damming effects of basinward building fans. This model contrasts with the

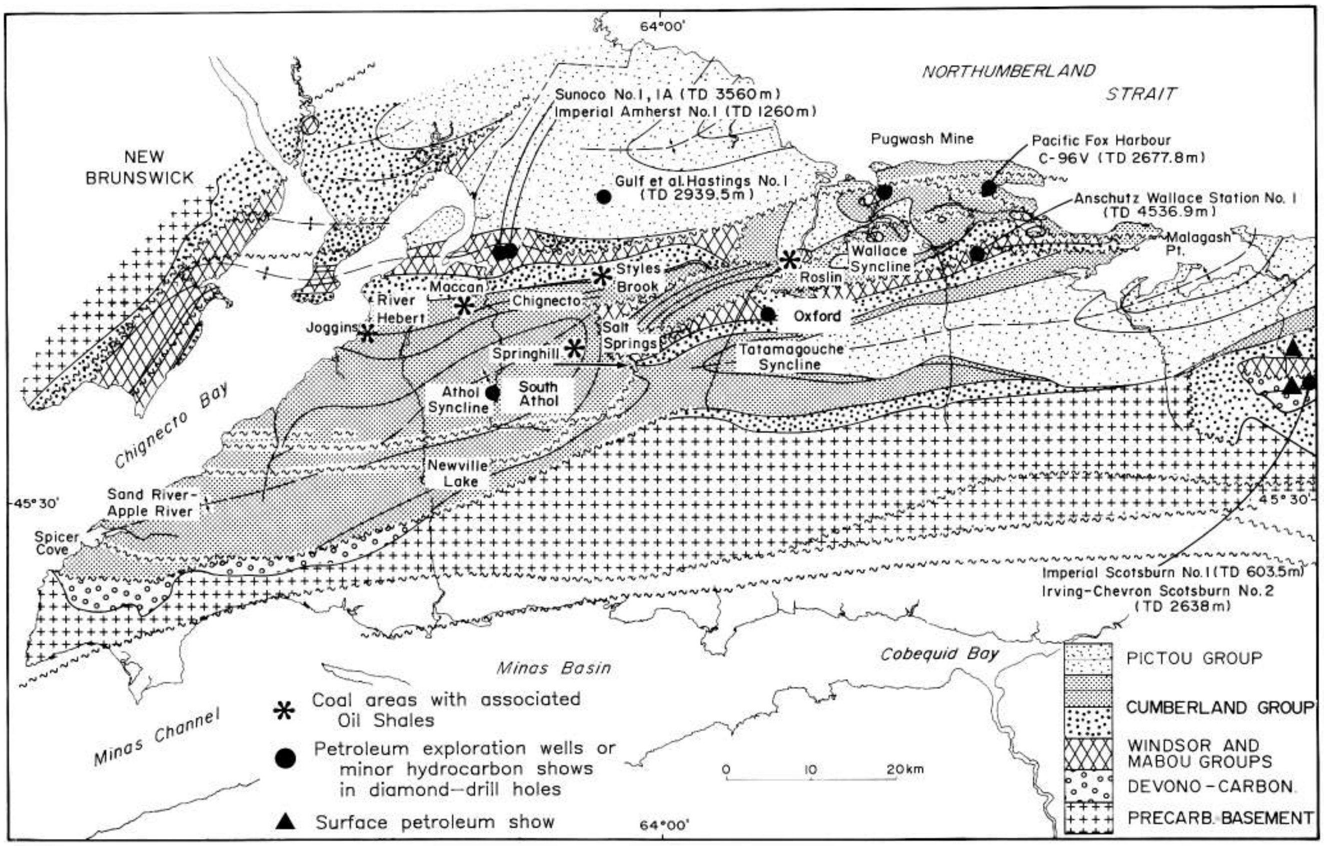


Figure 7-40. Energy resource occurrences in the Cumberland Basin.

lacustrine coal deposition found in the Joggins area in the western part of the basin. The geology and coal petrography of the Springhill Coalfield was the subject of Ph.D. research by John Calder of the Nova Scotia Department of Natural Resources (Calder, 1991).

Joggins - Chignecto Coalfield

The Joggins - Chignecto coalfield stretches over 30 km from the shores of Chignecto Bay in the west through River Hebert, Maccan, Chignecto and Fenwick to Styles Brook in the east (Fig. 7-40). The seams dip to the south along the south flank of the Minudie Anticline. At Joggins, the coal section (Joggins Formation of the Cumberland Group) is approximately 1450 m thick; however, it thins dramatically to the east.

Coal seams in the coalfield are characteristically less than 1 m in thickness (Calder, 1985a). The western coalfield seams include, from youngest to oldest, the Joggins, Queen, Rector, Jubilee, Kimberly, Forty Brine and Fundy seams (Fig. 7-40). In the eastern part of the coalfield the coal is represented by a single seam, the Chignecto. Although the seams are thin, they have been extensively mined, with the last mining operation closing down in 1979 (Calder, 1985a). It is believed that most of the exploitable coal resources of the coalfield have been exhausted. Coal from the Joggins -Chignecto coalfield has a rank of high volatile B bituminous. The Joggins - Chignecto coal can be distinguished from coal from the Springhill Mines Formation by their sapropelic tendencies and their close association with bivalve-bearing lacustrine limestones.

Potential Exploration Areas

Athol Syncline

Recent drilling and seismic surveys in the Athol Syncline area of the Cumberland Basin have indicated that there are exploitable coal resources at depth within the central part of the Athol Syncline. Seismic surveys carried out by the Geological Survey of Canada in cooperation with the Coal Division of the Nova Scotia Department of Natural Resources have delineated several geophysical reflectors which have been documented by recent diamond-drilling (NSDME drillholes SA-88-1a & 1b) to be correlative to grey coal-bearing strata. The coal-bearing strata are at depths between 3500 and 4000 feet (approx. 1100 m), prohibitive to exploration at this time. Although drilling in the South Athol area has confirmed the presence of coal, the suitability for mining has not been fully assessed and the coal seams encountered in this initial drillhole are too thin to exploit at this time. Work on the potential for coal within the Athol Syncline continues to have a high priority for the Coal Division of the Department of Natural Resources.

Newville Lake

Coal has been reported historically from drillholes in the area near Newville Lake and Pettigrew, along the southern flank of the Athol Syncline in the western part of the Cumberland Basin. Unfortunately the cores from these drillholes have been lost and, therefore, verification of the occurrences is impossible. Recent seismic data, both from Chevron Standard lines and Geological Survey of Canada lines, indicate the presence of reflectors which may be correlative to coal measures. The age of these coal-bearing horizons is difficult to determine because of the presence of faults immediately north of the reported occurrences. It has been speculated that the coal is either equivalent to the Springhill Mines Formation or the Joggins Formation. Further exploration for coal resources in the area is planned by the Nova Scotia Department of Natural Resources, Coal Division.

Wallace Syncline

The Nova Scotia Department of Natural Resources and various exploration companies, such as BP Resources and Esso Resources Canada, have examined the possibilities of coal deposits in the eastern part of the Cumberland Basin. BP Resources drilled several holes in the east and central part of the basin in 1981. The drilling results indicate that there is potential in the Wallace Syncline area north of the Claremont - Malagash Anticline. The Tatamagouche Syncline area, on the other hand, does not appear to have strong potential. Lithostratigraphic correlation of western Cumberland Basin units (coal-bearing facies) into the Wallace Syncline area, together with similar sediment dispersal patterns, indicate that the potential for coal in this area is excellent. Preliminary palynological work suggests that many of the rocks in the area have, in the past, been incorrectly assigned to older units, giving the impression that the coal-bearing stratigraphic horizon (Cumberland Group) was absent.

Roslin

One hole (R-1) was drilled by the former Nova Scotia Department of Mines and Energy to assess the potential for coal in the Roslin area of the Wallace Syncline. This drillhole and a hole, OX-BP-9, previously drilled by BP Resources Canada, confirmed the presence of thin, impure coal in the area. Unfortunately, these drillholes may not have penetrated to a depth necessary to assess the coal potential of the Springhill Mines Formation. The holes were stopped short of the prospective coal horizon due to miscorrelation of conglomeratic units in the area. New stratigraphic and palynological information indicates that the conglomeratic units at the bottom of the drillholes, which were interpreted as basal Cumberland Group, may in fact be an upper conglomeratic unit (Ragged Reef Formation) that stratigraphically overlies the Springhill Mines Formation coal measures.

Tatamagouche Syncline

On the north limb of the Tatamagouche Syncline and within the Wallace Syncline a thin, impure coal seam (only 10-30 cm thick) with associated lacustrine limestone may be traced in outcrop for many tens of kilometres (Fig. 7-40). The age of the thin seam is Westphalian C-D, which is younger than the exploited Springhill coal. The seam may be tentatively correlated with the Jungle seam, which outcrops northeast of Springhill. The lateral persistence of the coal seam suggests that the conditions necessary for coal accumulation and preservation may have existed throughout the area. The new palynological and stratigraphic information provided by this study may be an incentive to re-evaluate the coal potential of higher parts of the Springhill Mines Formation.

Seismic data also show good reflectors, at depth near the axis of the western part of the Tatamagouche Syncline. These reflectors may represent a coal-bearing package laterally transitional with alluvial fan conglomerate at the basin margin. Strata represented by these reflectors may be equivalent in age to either the Ragged Reef Formation or the Springhill Mines Formation. Diamond-drill hole BP4, drilled by BP Exploration Co., appears to have penetrated the Ragged Reef Formation at a level appropriate to explain the seismic reflections. At the time of drilling, however, the interval was correlated with the Boss Point Formation.

Sand River and Apple River

The Sand River - Apple River area in the western part of the Cumberland Basin contains a potential coalfield. On the basis of stratigraphic and palynological work it is likely that the Springhill Mines Formation (presumably coal-bearing) outcrops just offshore from Sand River to Cape Capstan (Fig. 7-40). These beds dip at 5-15° to the east and, therefore, are covered by only a veneer (up to 300 m) of Ragged Reef Formation rocks over a large area of the adjacent onshore. The presence of coal seams in this formation in the southwestern part of the basin is untested, but warrants further investigation and exploration.

Oil Shales

Oil shale beds are common within the Cumberland Group, particularly in the Joggins and Springhill Mines formations, in the western Cumberland Basin. Petroliferous and variably fossiliferous shaley limestone and oil shale occur at Joggins, Maccan, Chignecto, Styles Brook, Springhill and Spicers Cove. Smith and Naylor (1990) report that at Joggins, strata beneath the Joggins-Queen seams contain thin (10 cm typical but locally up to 1.7 m) oil shale beds and petroliferous limestone. Hydrocarbon yields range from 0.7-41.0 l/t, total organic carbon (TOC) is 0.9-12.0%, and organic matter was in an immature to near mature stage of thermal diagenesis. Similar but generally lower yields were reported from the other localities.

The only oil shale occurrence in the eastern Cumberland Basin is at Roslin where drilling (BP-OX-9) intersected a 10 m thick interval containing black, organic-rich, bivalve-bearing calcareous shale. The yields of hydrocarbons from this interval are sub-economic, and similar to those above, with 1.3-4.3% TOC, 1.6-11.4 l/t yields, and immature to near mature thermal diagenesis. The significance of the occurrence may be greater as a guide to coal exploration. These organic-rich rocks may also be more significant as possible source rock for petroleum resources than for oil shale exploration.

Oil and Gas

Drilling Data

Oil and gas exploration in the Cumberland Basin has been sporadic, with only 12 petroleum wells drilled to date (Fig. 7-40). Only three of these wells had petroleum shows: (1) Imperial Amherst No. 1, which had some oil staining in Windsor Group anhydrite at 362-365 m; (2) Imperial Scotsburn No. 1, where there was an oil show at 253 m in an organic-rich limestone of the Fountain Lake Group (McMahon *et al.*, 1986); and (3) Chevron-Irving Scotsburn No. 2. In 1963, Pacific Petroleums Ltd. drilled a wildcat hole, Pacific Fox Harbour C-96V, at Fox Harbour, which intersected some pyro-bitumen at 760 m. In 1972, Anschutz Canada drilled a dry and abandoned wildcat hole at Wallace Station (Wallace Station No. 1) to a depth of 4536 m. Gulf Oil encountered a slight gas kick in Upper Carboniferous rocks in the Hastings No. 1 well drilled near Amherst in 1975. The most recent exploration well drilled in the area was the Scotsburn No. 2 well, drilled by Chevron Standard/Irving Oil in 1981. This well was a retest of the Scotsburn No. 1 well drilled 50 years before. The Scotsburn No. 2 well contained three oil shows occurring at 115-120 m, 170-175 m, and 400-410 m. The shows were confined to organic-rich calcareous shale in the Fountain Lake Group strata. The well bottomed at 2638 m in volcanic rocks probably the lower part of the Fountain Lake Group (McMahon *et al.*, 1986). In the past twenty years many line-kilometres of seismic data have been acquired by various petroleum exploration companies. Much of these data remain confidential.

Surface Oil Shows

Surface oil shows are rare in the basin. The two previously documented oil shows occur at: (1) West Branch River John, near the Scotsburn wells; and (2) on River John above the Millsville Formation (Fig. 7-40). Short (1986) described the West Branch occurrence as albertite on joint fractures within the Fountain Lake Group. Oil staining of several grey sandstone horizons has been observed a few hundred metres north of this locality along River John. Roliff (1932) found liquid petroleum in calcareous mud pebble conglomerate of the Boss Point Formation just above the contact with the Millsville conglomerate on River John. This occurrence has not been confirmed in our present investigations and it is possible that erosion by the river during the past 50 years may have covered or removed the showing.

Potential Resources

Bell (1958) assessed the petroleum possibilities in the Cumberland Basin and concluded that the potential is limited primarily by the lack of source rock. He pointed out that only the western part of the basin has any significant quantities of organic-rich shale. Chevron

Standard have come to similar conclusions (Nantais, pers. comm.) and future work is therefore concentrating in the western part of the basin. Possible Windsor and Horton group sources and traps within the Cumberland Basin are limited geologically by severe structural complications in the near-surface diapiric anticline areas. These complications plagued much of the early drilling. The Horton and Windsor group oil play horizons in areas more distant from the anticlines are also limited by prohibitive depths and maturation levels.

Future petroleum exploration in the Cumberland Basin will probably be limited to the western part of the basin, where source rock potential is perceived to be greatest.

Coalbed Methane

Geological cross-sections of the Cumberland Basin indicate that Cumberland Group strata extend in the subsurface throughout most of the western part of the basin. Seismic profiles (cf. Bromley and Calder, 1987) suggest that coal occurs at depths of 3-5 km within the central parts of the western basin. This coal is too deep to exploit as coal reserves but may represent significant reserves of coalbed methane.

New information provided by the Nova Scotia Scotia Department of Natural Resources, including this Memoir and Maps 90-11 to 90-14, may be used as a starting point in the evaluation of this potential energy resource.