Multi-element Distribution in Humus, Soil, Till, Rock and Tailings Associated with Historic Gold Districts of the Meguma Zone, Nova Scotia, Canada

T. A. Goodwin, P. K. Smith and M. B. Parsons[1]

Introduction

A three-year multi-disciplinary project was initiated in the spring of 2003 as part of the Geological Survey of Canada's Metals in the Environment (MITE) Program. The main objective of the project is to examine the distribution of metals in the environment associated with past producing gold districts throughout the province by characterizing regional and local background concentrations and speciation of the elements. Further, it is anticipated that off-site transport of the elements from mine waste such as tailings, and the transformation and fate of these elements in receiving environments can be quantified.

From 1862 to 1982, 1,198,619 troy ounces of gold were produced from over 50 gold districts in Nova Scotia (Bates, 1987). After crushing in a stamp mill, the gold was recovered from the host rock using one of three extraction methods: (1) gravity separation, (2) cyanidation and (3) mercury amalgamation. Historical records suggest that up to 25% of the mercury added during the amalgamation process was routinely lost to the tailings and to the atmosphere (Eaton, 1978). Arsenic, in the form of arsenopyrite, and other potentially harmful elements (Tl, Pb, etc.) are known to occur naturally in the host Meguma Group rocks, particularly in areas of gold mineralization (Lewis *et al.*, 1998).

In May 2003, all the provincial gold districts were evaluated using a criteria-based ranking system and ten districts were ultimately chosen for the initial stage of reconnaissance level multi-media sampling and subsequent evaluation. These sites were chosen using the following criteria: (1) known history of Hg amalgamation; (2) extensive tailings deposits; (3) no land ownership or mineral rights restrictions; and (4) little or no previous environmental work completed. The ten districts are located throughout southern Nova Scotia (Fig. 1), and encompass a wide range of environmental settings. The Nova Scotia Department of Natural Resources (NSDNR) sampling program involved the collection of humus, soil, till, rock and tailings. Analytical results are pending.

Additional research (not reported here) is also being carried out collaboratively by other government departments and universities (Parsons *et al.*, 2003). This research includes the collection and analysis of additional sample media including living plant material, surface waters and lake sediments, plus the acquisition of hyperspectral and radar data. At two sites (Lake Catcha and Lower Seal Harbour) processes controlling the formation of methyl mercury are also being investigated.

Geology and Geochemistry

Surficial Geology

Most of the surficial glacial deposits and associated landforms throughout Nova Scotia were formed during the Wisconsinan glaciation in the last 70 000 years (Lewis *et al.*, 1998). Superimposed till sheets and various multiple-flow directional indicators indicate that Nova Scotia is characterized by a relatively complex ice flow

[1] Geological Survey of Canada (Atlantic), PO Box 1006, Dartmouth, NS B2Y 4A2

Goodwin, T. A., Smith, P. K. and Parsons, M. B. 2004: *in* Mineral Resources Branch, Report of Activities 2003; Nova Scotia Department of Natural Resources, Report 2004-1, p. 7-14.

history (Stea *et al.*, 1992; Stea and Finck, 2001).

The oldest ice flow patterns mapped are toward the east and southeast and are responsible for the formation of the Hartlen Till associated with the Caledonia Phase (75-40 ka). This was followed by south and southwest ice flow of the Escuminac Phase (22-18 ka) and deposition of the Lawrencetown Till. During the Scotian Phase (18-15 ka), an ice divide was situated over Nova Scotia and the resulting ice flow varied from northwestward in northern Nova Scotia to south and southeast in southern Nova Scotia, followed by formation of the Beaver River Till. The Chignecto Phase (13-12.5 ka) was characterized by shifting ice flow associated with small ice caps, remnants of the waning stages of the Scotian Phase glacier (Stea and Finck, 2001).

Enrichment of gold and arsenic with lesser enrichment of copper, lead, zinc, tungsten, bismuth, tellurium and iron (plus other elements and minerals) characterize the gold deposits of the Meguma Terrane (Kontak and Smith, 1993). These elements (and minerals) are commonly geochemically enriched in soil and till down-ice from known gold mineralization (Coker *et al.*, 1988) resulting from mechanical dispersion (erosion, transportation and deposition) by advancing glacial ice. Dispersal distances vary in Nova Scotia from hundreds of metres to several kilometres down-ice from source (Stea and Finck, 2001).

Bedrock Geology

Lode gold deposits occur within the Meguma Zone underlying southern Nova Scotia. The associated auriferous quartz veins and minor disseminations are hosted by a 10 km thick succession of lower Paleozoic, turbiditic, meta-sediments consisting primarily of the sandy Goldenville Formation and overlying argillaceous Halifax Formation (Keppie, 2000). A transitional sequence between these two formations, known as the Halifax-Goldenville Transition Zone (GHT), has variable thickness up to 1 km and is characterized by Mn-rich rocks. Although gold appears to occur throughout the entire succession, a high proportion of the gold districts lie (1) at, or near the GHT boundary, (2) ~2 km below the boundary and (3) ~4 km below the boundary (Malcolm, 1929).

Within individual deposits, the host rocks display large, distal to proximal, alteration zones, characterized by silicic bleaching, carbonate, sericite and sulphide zones, respectively. Although new alteration mineralogy partly reflects the regional metamorphism, it also overprints regional metamorphic minerals. All the alteration minerals are present in the mined and milled auriferous lodes; therefore, it is important to characterize the trace element content and mineralogy of these alteration assemblages to better understand the speciation of elements in the tailings.

The Meguma Group meta-sediments are conformably overlain by mixed Silurian sedimentary and volcanic rocks. These strata were deformed into variably plunging, east-west folds during the Devonian Acadian Orogeny and metamorphosed at greenschist to amphibolite facies ca. 400 Ma. They were subsequently intruded by late Devonian (ca. 375 Ma) per-aluminous granitoid plutons.

Field observations and Re-Os dating from several gold districts reveal that there are two ages of sulphide mineralization (~408 Ma and ~370 Ma; Morelli *et al.*, 2003). Younger brittle-ductile shear deformation has overprinted the lode mineralization and associated host rocks throughout the Meguma Terrane.

Previous Geochemical Sampling Programs

During the past several decades, Environment Canada has completed several site specific multi-media sampling programs designed to investigate the impact of toxic metals and metalloids associated with former gold districts in the Meguma Terrane (Eaton, 1978; Mudroch and Clair, 1986; Wong *et al.*, 1999, 2002). Although these studies identified elevated concentrations of many elements in tailings, stream sediments, surface waters and lake sediments, the results are not interpreted within the context of the naturally elevated background levels expected in these mineralized areas. The speciation of metals and

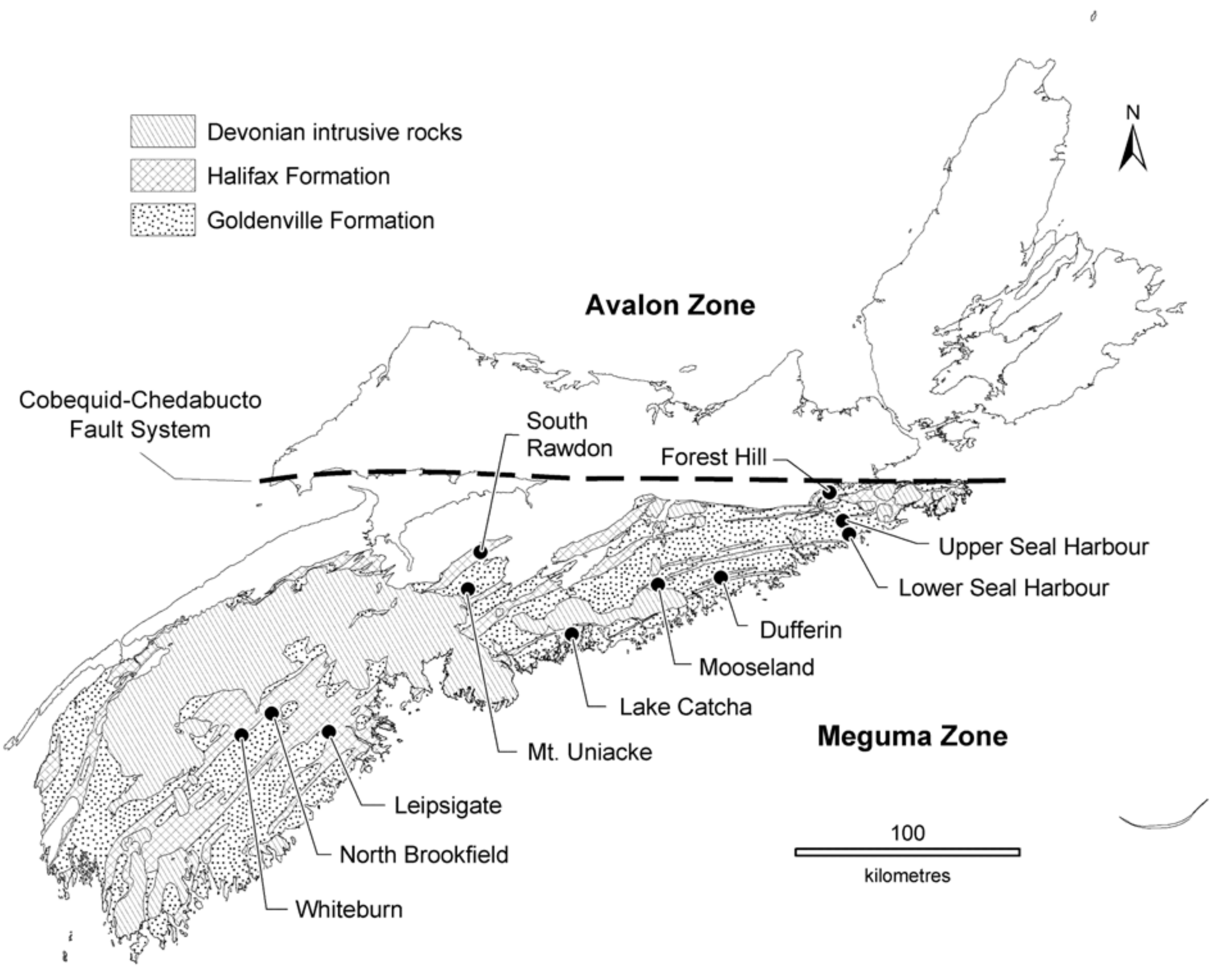

Figure 1. Location of the ten gold districts selected for sampling and analysis in this study. All districts selected lie in the Halifax and Goldenville formations of southern Nova Scotia (Meguma Zone).

metalloids was also not investigated in detail, which is essential for assessing the risks associated with these contaminated sites.

The Meguma Terrane has been extensively mapped and sampled by NSDNR and the Geological Survey of Canada, with numerous regional geochemical surveys including till (Stea and Fowler, 1979, 1981), lake sediment (Bingley and Richardson, 1978; Richardson and Bingley, 1980), and vegetation surveys including balsam fir twigs and red spruce bark (Dunn *et al.*, 1989, 1992, 1994). Detailed multi-media orientation surveys are also available (Coker *et al.*, 1988).

Additional regional geochemical surveys have also been completed by numerous exploration companies in their search for gold, tin, tungsten and other commodities. These data are accessible from company-filed assessment reports available through the NSDNR library in Halifax, Nova Scotia. For example, one of the most comprehensive industry-based regional geochemical surveys was an extensive helicopter-assisted regional soil and till sampling program over the Meguma Group metasediments during 1986, 1987 and 1988 completed by Seabright Resources (Woodman *et al.*, 1994).

Methodology

Introduction

During the 2003 field season, a total of 50 humus, 50 soil and 50 till samples were collected from ten past-producing gold districts: Leipsigate, North Brookfield, Whiteburn, Mount Uniacke, South Rawdon, Lake Catcha, Mooseland, Dufferin (Salmon River), Lower Seal Harbour and Upper Seal Harbour (Fig. 1).

For the humus/soil/till sampling program, a review of the local (1) ice flow history, (2) bedrock stratigraphy, (3) bedrock structure, (4) vein orientation and (5) mining development, including the location of tailings ponds and mill structures for each district, was undertaken prior to sampling. Sample sites were carefully chosen to provide (1) a broad aerial distribution of sample sites over each gold district, (2) representative coverage of the major surficial units within the study area, (3) representative coverage of the major lithologic units within the study area and (4) easy access by taking advantage of pre-existing roads. Most samples were collected along approximately NW-SE to N-S lines utilizing existing roads and/or traverse lines through the woods.

At each sample site, detailed field descriptions including observations on till type, colour and texture were recorded. Sample sites were geo-referenced to the Universal Transverse Mercator (UTM) grid (NAD 27) with a GARMIN GPS 12 using the averaging function. Each sample site was photographed for future reference.

In addition to the humus, soil and till, samples of bedrock waste material and bulk samples of tailings were collected to establish background trace element levels and for mineralogical examination. A total of 59 bedrock samples (2-10 kg each) and 55 bulk tailing samples (~5 kg each) were collected from the sites listed above, and from the Montague and Molega districts.

Field Sampling Methodology

A-horizon humus samples were collected, in general, simply by pulling off the live, moss-covered forest floor and collecting the black, decaying humus material by hand. Generally, the A-horizon was relatively thin (<5 cm). Pebbles and soil attached to the humus were shaken out of the sample and any living plant matter was also selectively removed prior to placement into a Kraft bag. Approximately 300 g of humus were collected from each site from an average sampling depth of 5 cm.

B-horizon soil samples were collected at each site by shovel and/or auger from an average sampling depth of 20 cm. Approximately 500 g of soil were collected from each site and placed into Kraft sample bags for future geochemical analysis. Visible organic material was selectively removed prior to placing the sample in the bag.

The C-horizon till samples were collected by shovel and/or auger from small hand-dug pits with an average sampling depth of 75 cm. Approximately 500 g of till were collected from each site and placed into Kraft sample bags for geochemical analysis. In addition to the samples placed in Kraft sample bags, approximately 4 kg of till were collected from each site and placed into 4 mil plastic bags for geochemical analysis. Once again, all visible organic material was removed from the sample prior to placement into the plastic bags, as were pebbles >4 cm in length.

Bedrock samples representative of all the major rock types were collected from each of the gold districts examined. These consisted of 1-5 kg samples collected from the waste piles surrounding the various shafts and mill sites, which should be representative of the ore and associated gangue material that was crushed and discarded into the tailings. The major rock types included within the sample suite were quartz veins, meta-greywacke, meta-siltstone and slate. An effort was made to include all the altered (carbonitized, sulphidized, sericitized and silicified) equivalents of the ore-bearing rocks.

Two or more bulk tailings samples were collected from each district in an attempt to give a preliminary indication of proximal verses distal distribution of minerals and elements relative to the milling facilities. If more than one mill structure was present within a single district, then one or more samples were collected depending on the areal distribution and thickness of the tailings. At each sample site a hole ranging in diameter up to 1 m was dug to a depth ranging from 30 to 200 cm. With rare exception, the water table was encountered in all holes. At each site a composite sample was collected consisting of tailings material from top to bottom of the hole.

Laboratory Preparation and Analytical Methodology

At the time of writing, all humus, soil and till samples were in the final stages of preparation at DalTech Minerals Engineering Centre (Dalhousie University) in Halifax. All samples were air dried to a maximum drying temperature of 30°C to minimize loss of volatile elements such as mercury.

Three vials of <2000 μm and one vial of <63 μm were prepared for each medium of humus, soil and till. Humus, soil and till samples will be analyzed for Au-Hg, multi-element analysis (ICP-MS) and organic content. Heavy mineral concentrates (HMC) for microscopic examination and mineralogical identification were prepared from the 4 kg till samples collected from the Dufferin Gold District using a combination of a Wifley table and heavy liquid separation. The >2 mm size fraction was sieved, washed and bagged for future lithologic identification.

Rocks were crushed in a jaw crusher and pulverized with ring and puck to <105 μm and will be analyzed for Au-Hg and multi-element geochemistry. Selected samples from each district were prepared for polished thin sections at Vancouver Petrographics and pulverizing at DalTech for later whole-rock geochemistry. Arsenopyrite crystals up to 10 mm in size (to be inspected using a binocular microscope for the presence of gold, silver and cinnabar) were chipped from rock samples collected from waste rock dumps from the Dufferin Gold District.

Each bulk tailings sample was dried at a maximum drying temperature of 35°C and a split of four vials was separated. One vial was used for mineral identification, two vials were used for further pulverizing and whole-rock geochemistry, and the remaining vial was archived. The remainder of the bulk sample was processed for heavy minerals using a Wifley table at DalTech's Minerals Engineering Centre. These concentrates were retained for subsequent microscopic examination and microprobe chemistry.

Quality Assurance/Quality Control

A number of quality assurance/quality control (QA/QC) measures were incorporated into the sampling program and the preparation and analytical procedures to ensure the highest confidence in the quality of the data.

In the field, all personnel were trained with respect to standard sampling procedures and the acquisition of necessary site description information. Multiple sources of contamination were expected from historical gold mining operations (e.g. mill emissions, windblown tailings) and all identifiable sources were noted when observed. Field duplicates to test for site variance were not collected during the reconnaissance-level fieldwork in 2003.

All samples were kept out of direct sunlight in order to minimize the loss of volatile elements such as mercury. Photographs of most sample sites plus representative views of each gold district were taken for future reference.

Certified and in-house reference materials and preparation splits will be routinely submitted with all batches. All the humus, soil and till samples collected from the Dufferin Gold District, representing 10% of all the humus, soil and till samples, will be analyzed for Hg-As-Au at two laboratories as a check against inter-laboratory variance. Extra vials of sieved material were retained for future reference.

Results

Analytical results are pending for all samples. It is anticipated that analysis will take place early in 2004.

Discussion of Field Observations

In general, where the overburden profile is thin (<50 cm over bedrock), soil and till horizons are characterized by heavy oxidation, making it difficult to differentiate the boundary between B- and C-horizons based solely on colour. In areas where the till is relatively thin, the clast (and matrix) composition strongly reflects the underlying lithology, indicating that the till is locally derived. The local nature of the till is further demonstrated by the angularity of the clasts, the presence of large boulders and the compact nature of the till. Greater that 90% of the till samples collected for this study were from the local Beaver River Till.

Lawrencetown Till, which was characterized by clasts reflective of a distal provenance, was locally encountered in areas of thicker overburden. Less than 10% of the till samples collected were Lawrencetown Till. Clasts tended to be rounded and consist of variable rock types that include but are not limited to pink granite, diorite, red and grey siltstone, and mafic volcanics. The ochre red colour of the Lawrencetown Till often made it difficult to differentiate the B soil from the C till horizon. Although the boundary was recognizable, the colour change between the B- and C-horizon was very subtle.

In oxidizing environments, a typical tailings profile consisted of an upper stratified, light grey-brown to yellow-brown oxidized portion, underlain by a thin (~10 cm) yellow to orange hardpan layer, which was in turn underlain by grey un-oxidized tailings. At several sample sites, a thin peat horizon representing two distinct periods of mining activity separated a lowermost, grey, un-oxidized tailings layer from an overlying, grey, un-oxidized tailings layer. At these sites, an effort was make to collect each of the un-oxidized tailings separately. Un-oxidized tailings were always encountered below the water table, and in areas where vegetative cover limited oxygen penetration.

Most samples collected in the field were of excellent quality. However, at a few sites, the humus layers may have been very thin and some mineral soil may have been introduced into the sample, some soil horizons were relatively organic-rich, and some till sites were highly oxidized. Locally, particularly around the former mill sites, the presence of tailings was often noted and efforts were made to relocate soil sampling sites to less disturbed areas.

Anthropogenic effects were not limited to the presence of tailings. Waste rock piles, bush roads and building foundations were common to each district sampled. Locally, drill steel, stamp mill pads, assay equipment and related mining artifacts were observed. Recent anthropogenic effects include household and commercial garbage dumped down mine shafts, filling trenches as well as sporadically strewn along bush roads and/or piled in clearings.

Summary

Ten past-producing Nova Scotia gold districts were carefully selected for multi-media geochemical sampling after all districts were ranked according to their production history, use of mercury during the gold recovery process, and the known extent of tailings at each site. Humus, soil, till, rock and tailings samples were collected to determine their multi-elemental content. Analytical results are pending.

Field observations in 2003 show that most sites contain large volumes of unconfined tailings, which are generally located in low-lying areas (e.g. swamps, streams) downslope of the stamp mill sites. In some districts (e.g. Lower Seal Harbour, Dufferin) the tailings have been transported significant distances (>2 km) off-site by local drainage. At most sites, the tailings are very overgrown and often difficult to recognize; however, some tailings areas are being actively reworked by human activities (gold panning, off-road vehicle usage).

Once all the analytical results are received, a mass balance calculation will be completed to determine the relative volumes of metals that characterize each major lithology. It is anticipated that the natural levels of toxic elements will be distinguished from anthropogenic levels within the various environmental media at each mine site.

References

Bates, J. L. E. 1987: Gold in Nova Scotia; Nova Scotia Department of Mines and Energy, Information Series No. 13, 48 p.

Bingley, J. M. and Richardson, G. G. 1978: Regional Lake Sediment Surveys for Eastern Mainland Nova Scotia; Nova Scotia Department of Mines and Energy, Open File Report 371, scale 1:100 000.

Coker, W. B., Sexton, A., Lawyer, I. and Duncan, D. 1988: Bedrock, Till and Soil Geochemical Signatures at the Beaver Dam Gold Deposit, Nova Scotia, Canada; *in* Prospecting in Areas of Glaciated Terrain - 1988, eds. D. R. MacDonald, K. A. Mills and Y. Brown; The Canadian Institute of Mining and Metallurgy Eight International Symposium on Prospecting in Areas of Glaciated Terrain, p. 241-255.

Dunn, C. E., Adcock, S. W. and Spirito, W. A. 1992: Reconnaissance Biogeochemical Survey, Southwestern Nova Scotia, Part 1 - Red Spruce Bark, Parts of NTS 20O, P, 21A, B; Geological Survey of Canada, Open File 2556, 36 p.

Dunn, C. E., Adcock, S. W. and Spirito, W. A. 1994: Reconnaissance Biogeochemical Survey, Southwestern Nova Scotia, Part 2 - Balsam Fir Twigs, Parts of NTS 20O, P, 21A, B; Geological Survey of Canada, Open File 2757, 31 p.

Dunn, C. E., Banville, R. M. P. and Adcock, S. W. 1989: Reconnaissance Biogeochemical Survey, Eastern Nova Scotia; Geological Survey of Canada, Open File 2002, 10 p.

Eaton, P. 1978: Investigation of Mercury Related Environmental Effects Associated with Abandoned Amalgamation Operations in Nova Scotia; Montreal Engineering Company, Limited for Environmental Protection Service (Atlantic Region), Fisheries and Environment Canada, 37 p.

Keppie, J. D. (compiler) 2000: Geological Map of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Map ME 2000-1, scale 1:500 000.

Kontak, D. J. and Smith, P. K. 1993: A Metaturbidite-Hosted Lode Gold Deposit: The Beaver Dam Deposit, Nova Scotia: I. Vein Paragenesis and Mineral Chemistry; Canadian Mineralogist, v. 31, p. 471-522.

Lewis, C. F. M., Taylor, B. B., Stea, R. R., Fader, G. B. J., Horne, R. J., MacNeill, S. G. and Moore., J. G. 1998: Earth Science and Engineering: Urban Development in the Metropolitan Halifax Region; *in* Urban Geology of Canadian Cities, eds. P. F. Karrow and O. L. White;, Geological Association of Canada Special Paper 42, p. 409-444.

Malcolm, W. 1929: Gold fields of Nova Scotia; Geological Survey of Canada, Memoir 156, 253 p.

Morelli, R. M., Creaser, R. A., Kontak, D. J., Horne, R. J. and Selby, D. 2003: Re-OS Arsenopyrite geochronology of the quartz veining and Au mineralization, Meguma Terrane, Nova Scotia, Canada; *in* Geological Association of America Annual Meeting, Seattle, 2003.

Mudroch, A. and Clair, T. A. 1986: Transport of Arsenic and Mercury from Gold Mining Activities Through an Aquatic System; The Science of the Total Environment, v. 57, p. 205-216.

Parsons, M. B., Smith, P. K., Goodwin, T. A., Hall, G. E. M., Sangster, A. L. and Percival, J. B. 2003: Distribution and Speciation of Elements Associated with Historical Mine Tailings at Selected Lode Gold Deposits of the Meguma Terrane, Southern Nova Scotia; Nova Scotia Department of Natural Resources, Report ME 2003-2, p. 11.

Richardson, G. G. and Bingley, J. M. 1980: Regional Lake Sediment Survey, Southwestern Nova Scotia; Nova Scotia Department of Mines and Energy, Open File Report 453, scale 1:100 000.

Stea R. R., Conley, H. and Brown, Y. (compilers) 1992: Surficial Geology of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Map 92-3, scale 1:500 000.

Stea R. R. and Finck, P. W. 2001: An Evolutionary Model of Glacial Dispersal and Till Genesis in Maritime Canada; *in* Drift Exploration in Glaciated Terrain, eds. M. B. McClenaghan, P. T. Bobrowsky, G. E. Hall and S. J. Cook; Geological Society of London Special Publication No. 185, p. 237-265.

Stea, R. R. and Fowler, J. H. 1979: Pleistocene Geology, Eastern Shore Region, Nova Scotia (sheets 1-3), scale 1:100 000; *in* Minor and Trace Element Variations in Wisconsinan Tills, Eastern Shore Region, Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 79-4, 30 p.

Stea, R. R. and Fowler, J. H. 1981: Pleistocene Geology and Till Geochemistry of Central Nova Scotia, (sheet 4), 1980; Nova Scotia Department of Mines and Energy, Map 81-1, scale 1:100 000.

Woodman, K. K., Duncan, D. R., Graves, R. M., Hudgins, A. B. and Rogers, P. J. 1994: Compilation of Seabright Resources Inc. Till and Soil Geochemical Data, Nova Scotia, Nova Scotia Department of Natural Resources, Open File Report 94-021, 238 p.

Wong, H. K. T., Gauthier, A., Beauchamp, S. and Tordon, R. 2002: Impact of Toxic Metals and Metalloids from the Caribou Gold-Mining Areas in Nova Scotia, Canada; Geochemistry: Exploration, Environment, Analysis, v. 2, p. 235-241.

Wong, H. K. T., Gauthier, A. and Nriagu, J. O. 1999: Dispersion and Toxicity of Metals from Abandoned Gold Mine Tailings at Goldenville, Nova Scotia, Canada; The Science of the Total Environment, v. 228, p. 35-47.