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VOLCANOGENIC MASSIVE SULPHIDE ENVIRONMENTS OF THE TALLY POND VOLCANICS AND ADJACENT AREA: GEOLOGICAL, LITHOGEOCHEMICAL AND GEOCHRONOLOGICAL RESULTS

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ABSTRACT

Investigation of volcanogenic massive sulphide (VMS) occurrences within the Tally Pond volcanics supports previous inferences, that mineralization in the Duck Pond and Boundary deposit areas occurs at the same stratigraphic level, and is associated with quartz-phyric volcanic to reworked epiclastic rocks (the mineralized sequence). This probably reflects the presence of sub-volcanic intrusions that drove hydrothermal systems and provided suitable host/cap rocks for sub-seafloor deposition and preservation of sulphides. Some other significant prospects and showings in the Tally Pond volcanics are not associated with a quartz-phyric volcanogenic horizon and likely formed at different stratigraphic positions.

The recovery of 'inherited' Precambrian zircons of 573 ± 4 Ma from the Cambrian Tally Pond volcanics, provides the first evidence for the direct incorporation of Gondwanan continental crust during Cambrian Tally Pond magmatism. This result supports previous indications of continental crustal involvement suggested by the high radiogenic Pb contents of the Duck Pond and other Exploits Subzone deposits. Sampling of a previously inferred Silurian syntectonic quartz porphyry 'dyke' within the Duck Pond thrust, has returned a synvolcanic Cambrian age (U–Pb zircon date of 512 ± 2 Ma), which agrees well with previously obtained ages for the volcanic rocks. One sample of felsic volcanic rocks collected east of Sandy Lake and previously grouped within the Tally Pond volcanics, has returned a U–Pb zircon age of 422 ± 2 Ma., thus indicating a correlation with the adjacent Silurian Stony Lake volcanics.

Lithogeochemistry suggests that the Tally Pond volcanics comprise a bimodal, primitive island-arc assemblage that has, locally, transitional to calc-alkaline compositions, as documented historically. A suite of younger sills that intrude the Duck Pond deposit and Upper Block volcanics are of within-plate affinity, suggesting a shift to arc-rift volcanism. The within-plate Harpoon Hill intrusion has been dated as Middle Ordovician and is inferred to correlate with these Duck Pond area sills. Mafic and felsic volcanic signatures are very uniform throughout the Tally Pond volcanics, as sampled. However, Zr/Th, Zr/Nb and Y/Nb plots can discriminate some aphyric Tally Pond felsic volcanic rocks, and therefore show promise for stratigraphic mapping. It is inferred that the transitional calc-alkaline signatures of some mafic volcanic rocks are a product of element 'mobility' caused by structurally induced carbonatization. The lithogeochemical signature of a microgranite body, adjacent to the Lemarchant prospect, matches that of the Tally Pond felsic volcanics, suggesting it may have been the sub-volcanic intrusion responsible for the generation of the prospect's VMS alteration system.

The Burnt Pond VMS prospect is associated with a quartz-phyric volcanogenic epiclastic horizon similar to that at Duck Pond, but the sampled Burnt Pond area footwall volcanics are mostly mafic (flows) to intermediate (sills) in composition. Recent geochronological studies imply that the Burnt Pond volcanics may be Precambrian, thus not being related to the Tally Pond volcanics. They are spatially associated with quartz monzonites, which resemble nearby dated Precambrian plutons, but are separated by a fault zone. The Burnt Pond volcanics, as well as the adjacent quartz monzonites and the volcanic rocks that they intrude, are altered and mineralized, suggesting the quartz monzonite intrusion could have been the sub-volcanic heat source for the Burnt Pond VMS system.

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INTRODUCTION

The objective of this project is to document the geological settings of known volcanogenic massive sulphide (VMS) mineralization within the Tally Pond volcanics (TPV), utilizing geological, lithogeochemical and geochronological studies, as an aid to mineral exploration. These rocks are host to two economically important VMS deposits and sixteen other significant prospects and showings. The Duck Pond and Boundary VMS deposits are estimated to contain combined proven and probable reserves of 5.48 million tonnes grading 3.3% Cu, 5.8% Zn, 0.9% Pb, 59 g/t Ag and 0.8 g/t Au (Thundermin Resources press release, May 16, 2001).

This report presents the results of lithogeochemistry and geochronology undertaken during the 2002 field season, and results of geological investigations in the 2003 field season. The 2003 program continued detailed geological investigations at the Duck Pond deposit, the Burnt Pond prospect and the Spencers Pond showing. This report also incorporates much material from recent industry work (*see* Brace *et al*., 2000; Collins, 1989; Collins, 1991, 1992, 1993; Dimmell, 1986; Pesalj, 1982; Sheppard, 1996; Squires, 1988, 1994; Squires *et al.*, 1990, 2001a,b, 2002a,b; Squires and Hussey, 2001).

REGIONAL GEOLOGICAL FRAMEWORK

The Appalachian Dunnage Zone of central Newfoundland (Figure 1, inset), comprises two tectonostratigraphic subzones separated by an extensive fault system known as the Red Indian Line (Williams *et al*., 1988). Rocks west of the Red Indian Line (Notre Dame and Dashwoods subzones) formed on the Laurentian side of the early Paleozioc Iapetus Ocean (Williams *et al*., 1988; van Staal, 1994), whereas rocks east of the Red Indian Line (Exploits Subzone) are considered to have originated adjacent to Avalonia and the main Gondwanan continent (Neuman, 1984; Colman-Sadd *et al*., 1992). The TPV (Figure 1) represent vestiges of one of several bimodal Cambrian to Ordovician volcanic arcs within the Exploits Subzone. Together, with adjacent volcanic and sedimentary rocks of various tectonic affinities, the TPV are part of the informally defined Victoria Lake supergroup (Evans and Kean, 2002).

The Victoria Lake supergroup (Evans and Kean, 2002) includes all pre-Caradocian volcanic, volcaniclastic and sedimentary rocks that are located between Grand Falls-Windsor in the northeast and King George IV Lake in the southwest, and between the Red Indian Line in the north and the Noel Paul's Line in the south (Figure 1). Evans and Kean (2002) subdivide the Victoria Lake supergroup into a northern and southern terrane separated by the Rogerson Lake Conglomerate. They place the TPV on the southern edge of the northern terrane where the Victoria Lake supergroup is reported to be overlain unconformably by the Rogerson Lake Conglomerate (Mullins, 1961). The latter is considered to be either Middle Ordovician or younger (Kean and Jayasinghe, 1980), or Silurian age (Kean and Evans, 1988; Pollock *et al.*, 2002b). It is a fault-scarp, molasse-type sequence suspected to mask a Silurian or earlier structure (Kean and Evans, 1988). The southern contact of the Rogerson Lake Conglomerate is reported to be a fault. (Evans and Kean, 2002). The northern boundary of the TPV is against a regionally extensive unit of graphitic shales that is defined mainly by airborne electromagnetic surveys (Evans and Kean, 2002). This contact was originally considered to be conformable (e.g., Kean and Jayasinge, 1980) but, based on regional considerations and the results of exploration drilling, it was interpreted as a thrust fault (Trout Brook thrust; Squires, *et al.*, 1990). Its steeply dipping attitude, consistent linear nature, and truncation of other structures, suggest that it was modified by later strike–slip faulting (Squires *et al.*, 2001b). The conductive graphitic shale unit can be traced from Victoria Lake in the southwest to at least the Noel Paul's Brook area in the northeast (e.g., Oneschuk *et al*., 2001).

GEOLOGICAL SETTING

Evans and Kean (2002) divided the TPV into four volcanic and sedimentary subunits based on geographic distribution and rock types. These comprise i) the main bimodal volcanic belt, which includes the Lake Ambrose basalts that occurs between ii) the Stanley Waters sediments to the southwest and iii) the Burnt Pond sediments to the northeast. The fourth subunit is the bimodal volcanic rocks that occur east of the Burnt Pond sediments and include the Sandy Lake basalts.

The felsic volcanic rocks extend throughout the belt and are composed of flows, various autoclastic, eruptive and hydrothermal breccias, aphyric and crystal tuffs and their reworked derivatives, as well as porphyritic to aphyric synvolcanic hypabyssal intrusive rocks. Stratigraphically intercalated mafic volcanic rocks consist predominantly of massive to pillowed and brecciated, variably vesicular and locally porphyritic flows, but include subordinate autoclastic, hyaline and reworked tuffs, and dykes. The mafic volcanic rocks are subdivided into the Lake Ambrose and Sandy Lake basalt sequences, considered to be correlative (Evans and Kean, 2002). The Lake Ambrose and Sandy Lake basalts occur on opposite sides of the Precambrian (565 +4/-3 Ma; Evans *et al.*, 1990) Crippleback Lake plutonic suite (Figure 1), and are interpreted to be structurally interleaved with the TPV (Evans and Kean, 2002).

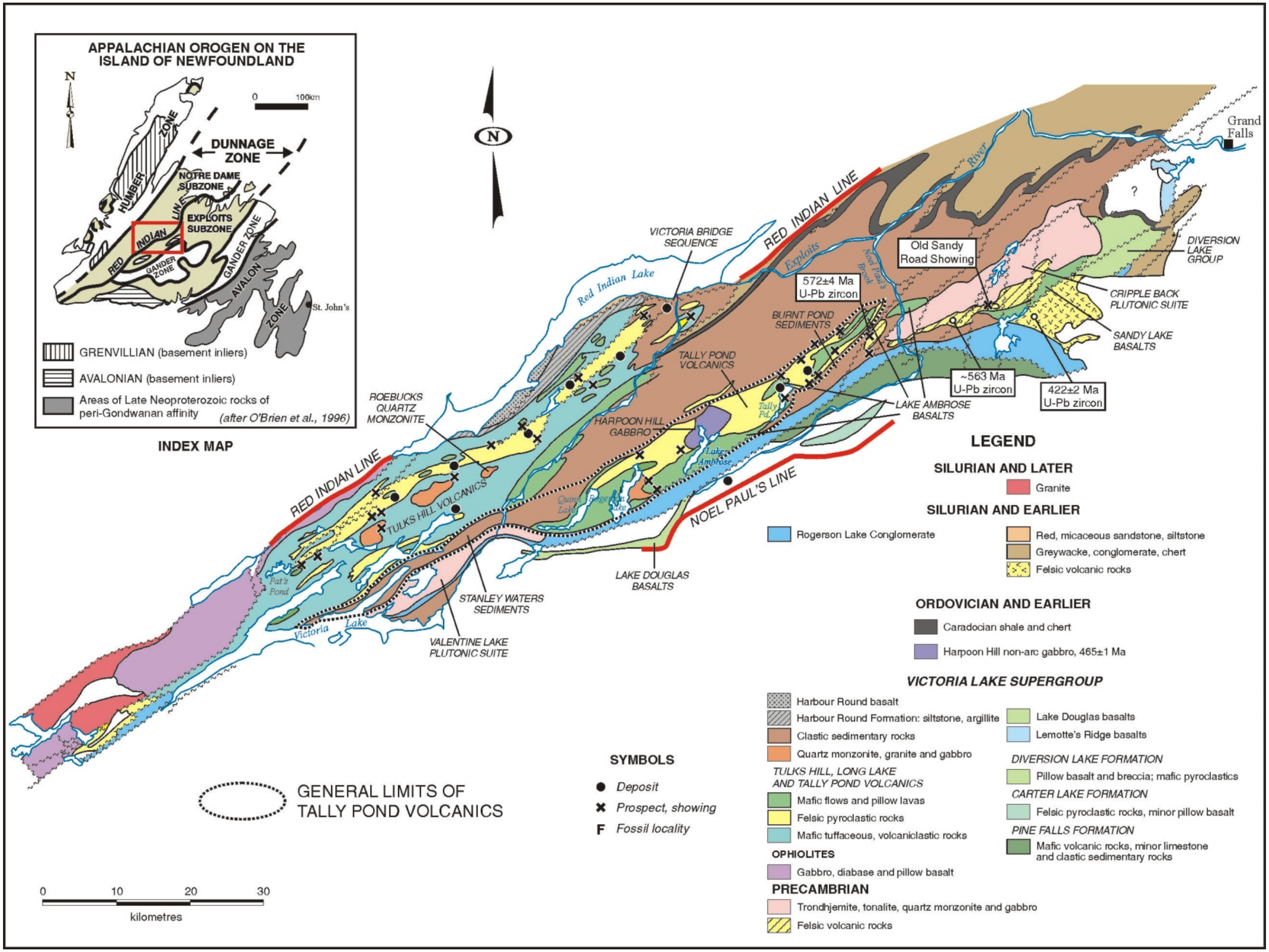

Figure 1. *Simplified geology map of the Victoria Lake supergroup showing the location of the Tally Pond volcanics and associated volcanogenic massive sulphide occurrences, as well as geochronological results and features outside of the area depicted in Figure 2 (modified after Kean and Evans, 2002).*

Trace-element lithogeochemical investigations indicate that the Lake Ambrose basalts and adjacent felsic volcanic rocks include relatively primitive arc tholeiites, variably light rare-earth-element-enriched transitional tholeiitic to calc-alkalic basalts (basaltic andesites) and rhyolites (Dunning *et al*., 1991). The Sandy Lake basalts exhibit island-arc-tholeiitic signatures, similar to those of the Lake Ambrose basalts (Evans and Kean, 2002), but there are lithogeochemical differences. Pollock and Wilton (2001) confirmed the variably depleted to enriched arc-tholeiitic nature of the Lake Ambrose basalts, and confirmed the presence of later non-arc ('within plate') tholeiitic dykes that were previously documented during exploration (Collins, 1989). Similar dykes are reported from other Dunnage Zone volcanic belts, and record arc-rifting or back-arc basin development (Swinden, 1987). Pollock and Wilton (2001) demonstrated arc signatures in aphyric to feldspar-phyric felsic volcanic units, as had also been identified by Dunning *et al.* (1991) for the quartz-phyric felsic volcanic rocks at Tally Pond.

Evans and Kean (2002) define two siliciclastic sedimentary sequences within the TPV. Black shales to greywackes and tuffs of the Stanley Waters sediments (Figure 1), on the southwest end of the TPV, are suggested to be stratigraphically equivalent to the volcanic rocks because both occur south of a regionally extensive conductive linear, although they could belong to the Ordovician sediments that flank the TPV (B.F. Kean, personal communication, 2003).

The Burnt Pond sediments (Figure 2) extend from immediately south of Tally Pond, northward to at least Noel Paul's Brook (Evans *et al*., 1994a). They separate the main TPV from volcanic rocks near the Burnt Pond area and are described by Evans and Kean (2002) as a sequence of black shale to conglomerate intercalated with lateral equivalents of the volcanic sequences (e.g., Burnt Pond area; Dimmell, 1986). In the Duck Pond area, they consist of graphitic argillite and siltstone, visually identical to the dated Trout Pond ridge sediments to the northwest (Squires *et al.*, 1990), and hence they may be Ordovician. Exploration drilling that has intersected the southeast contact of the TPV (Overview thrust; Squires *et al*., 1990) with the northwest flank of the Burnt Pond sediments, in the Duck Pond area, was examined during this study. Alhough the thick sedimentary rocks are frequently strongly deformed, faulting is not obvious at the immediate contact with the volcanic rocks. However, cross-sections interpreted from industry drilling (*see* Old Camp and Loop Road sections below) and surface geology/geophysics (Figure 2), demonstrate that graphitic argillites of the Burnt Pond sediments truncate both shallow-dipping volcanic stratigraphy, and faults within the volcanic rocks, strongly suggesting a tectonic contact. The southeast contact of the Burnt Pond sediments at the Burnt Pond prospect was interpreted to be conformable with the adjacent volcanic rocks (Collins, 1991), but re-examination indicates a steeply dipping sheared contact between undeformed cherty siltstones and sheared, mineralized volcanogenic sediments. The mineralized volcanogenic sediments are likely conformable with the mineralized footwall volcanic rocks to the east, but their relationship with the Burnt Pond sediments is unknown. Recent laser-ablation zircon dating of a gabbro dyke interpreted to intrude the mineralized volcanic rocks at Burnt Pond, returned an age of 572 ± 4 Ma (D.H.C. Wilton, personal communication, 2004).This implies that the Burnt Pond volcanics are older than the TPV, and the shearing noted may represent part of a fault zone that juxtaposes the two.

The TPV and adjacent sediments are cut by intrusive rocks of inferred Cambrian to Devonian age. Gabbro sills of 'within-plate' affinity in the Duck Pond deposit area (Figure 3) are interpreted as pre-Silurian because they cut Cambrian volcanic rocks, but are themselves cut by the inferred Silurian Duck Pond thrust (e.g., Figure 3; also Figure 3 of Squires *et al*., 1990). The Harpoon Dam gabbro has a lithogeochemical signature identical to that of the Duck Pond sills. The Harpoon Hill gabbro (Pollock *et al.*, 2002a), which is along strike from the Duck Pond deposit area sills, has recently been dated at 465 ± 1 Ma (Pollock, 2004). The similar chemistry and geological occurrence of these three intrusive bodies suggest they are all products of the same Middle Ordovician magmatic event. A unit of fine-grained granite ('microgranite') located adjacent to the Lemarchant prospect, was suggested to be related to the Precambrian Valentine Lake quartz monzonite, based partly on the presence of distinctive xenoliths and other textural criteria (D. Barbour, personal communication, 2003). However, this intrusive body is geochemically similar to the TPV. Intrusive porphyry bodies have been identified in the vicinity of the Duck Pond deposit and throughout the TPV. They are possible offshoots of a synvolcanic magma chamber that generated the mineralized sequence, and related alteration and mineralization. Some of these 'porphyries' have subsequently been reclassified as volcanic rocks.

U–Pb GEOCHRONOLOGY AND EVIDENCE FOR CONTINENTAL CRUSTAL INVOLVEMENT

U–Pb zircon dates for selected quartz-phyric volcanic units considered to correlate with the mineralized sequence near the Duck Pond and Boundary deposits range between 513 ± 2 Ma (Dunning, 1986) and 509 ± 1 Ma (Pollock *et al*., 2002a). The younger age represents an altered quartz crystal tuff capping the Boundary deposit, while the older age represents an altered quartz-phyric flow or autobreccia 1 km southwest of the Boundary deposit sample. Dunning (1986) collected a second sample that returned an age of 513 ± 2 Ma from a quartz-feldspar-phyric tuff (B.F. Kean, personal communication, 2003) adjacent to the Lemarchant prospect. A massive quartz porphyry body, entrained within the Duck Pond thrust, immediately above the Upper Duck lens, and originally interpreted as a younger syntectonic dyke (Squires *et al*., 2001b) has returned a synvolcanic date of 512 ± 2 Ma (McNicoll, 2003), suggesting it is actually a structural 'lithon' of a synvolcanic dyke or massive flow. Several attempts to date the underlying aphyric to feldspar-phyric footwall felsic volcanic rocks to the Duck Pond and Boundary deposits have failed due to the paucity of zircons (e.g., Figure 3). Attempts to date the mafic sills of 'within-plate' affinity have also failed, also due to a lack of zircons.

However, a thick, feldspar-phyric dacitic flow sequence, from the "Upper Block" structural panel (Figure 3) has returned a maximum crystallization (?) age of 514 ± 7 Ma, but contains clearly inherited zircons dated at 573 ± 4 Ma (McNicoll, 2003); this suggests that the source magma, which incorporated pre-existing continental crust, is similar in age to that of the Crippleback Lake and Valentine Lake plutonic suites (McNicoll, 2003). Due to the very small size of the 514-Ma zircon fraction, McNicoll (2003) suggested that these were inherited from a slightly older source (These data were acquired using the SHRIMP sampling method). This is the first direct evidence for the incorporation of Gondwanan continental crust in Cambrian magma of the Victoria Lake supergroup (*see* Moore, 2003 for further discussion of continental contamination in the Exploits Subzone). This argues against previous suggestions that the TPV formed in an entirely oceanic (ensimatic) arc-setting (Dunning *et al*., 1991). It also supports previous indications of continental-crust involvement from the high radiogenic Pb contents at Duck Pond (Pollock and Wilton, 2001) and other Exploits Subzone sulphide deposits (Swinden and Thorpe, 1984). The transitional to calc-alkalic signatures of some of the Lake Ambrose basalts (Dunning *et al*., 1991) may also suggest the involvement of continental material. Finally, immobile-element plots suggest that some TPV are of andesitic affinity (Squires *et al*., 2002b), which is also consistent with this interpretation. Regionally, if the parent magmas to the Tally Pond volcanics encountered Precambrian crust, it is probable that these terranes were physically associated in the Cambrian and their contact relationship would have been unconformable.

Except for the above example, geochronological studies of the TPV indicate the same age of volcanism within error limits. This suggests that they represent products of the same magmatic event, and is consistent with the presence of mineralization and alteration in many of these units. The consistency of lithogeochemical patterns amongst the TPV may also indicate that they were erupted over a restricted time interval (*see* later discussion). However, a larger geochronological database is required to better quantify the age range of the TPV.

A felsic volcanic unit located east of Sandy Lake (Figure 1), which was previously grouped within the TPV, has now returned a U–Pb zircon age of 422 ± 2 Ma., indicating it may actually correlate with the Silurian Stony Lake volcanics, immediately to the east (McNicoll, 2003).

Four additional U–Pb zircon samples were collected for further geochronological studies. These will hopefully date the host quartz-phyric tuff to the Upper Duck lens, a mineralized footwall porphyry (synvolcanic) intrusive located 50 m beneath the Upper Duck lens, a quartz-crystal tuff (potential mineralized sequence) in the structural hanging wall of the Upper Duck lens, and the quartz-phyric volcanogenic epiclastic sediment host to the Burnt Pond prospect.

SETTINGS OF DEPOSITS, PROSPECTS AND SHOWINGS

The TPV, as defined by Evans and Kean (2002), host many significant occurrences of volcanogenic massive sulphide mineralization. This section identifies and describes eighteen of these occurrences (Figures 1 and 2), which range from single-hole intercepts to potentially economic deposits. They are organized into three groups based on genetic similaritities (or lack thereof), inferred stratigraphic position and geographic distribution. The first group comprises occurrences in the TPV, west of the Burnt Pond sediments that are associated with quartz-phyric volcanic rocks. The second group comprises occurrences in the same area that are not associated with quartz-phyric volcanic rocks. The third group includes occurrences in volcanic rocks east of the Burnt Pond sediments. The following sections cover some aspects of the geology of these three groups. Squires *et al.* (2001b), Moore (2003) and Evans and Kean (2002) provide more comprehensive treatments of the overall stratigraphy of the TPV.

GROUP I: VMS MINERALIZATION WEST OF THE BURNT POND SEDIMENTS, AND ASSOCIATED WITH QUARTZ-PHYRIC VOLCANIC ROCKS

Most of the occurrences in this group are linked by a common stratigraphy. This group includes the Duck Pond deposit (Upper Duck lens, Lower Duck lens and Sleeper zones), and its associated Serendipity prospect and TP-109A showing. It also includes the Boundary deposit (Boundary North, Boundary South and Boundary Southeast zones), as well as the Boundary West, Loop Road and Old Camp showings. The East Pond prospect and Trout Pond showing are included with this group partly on the basis of their proximity to Boundary and Duck Pond deposits, respectively.

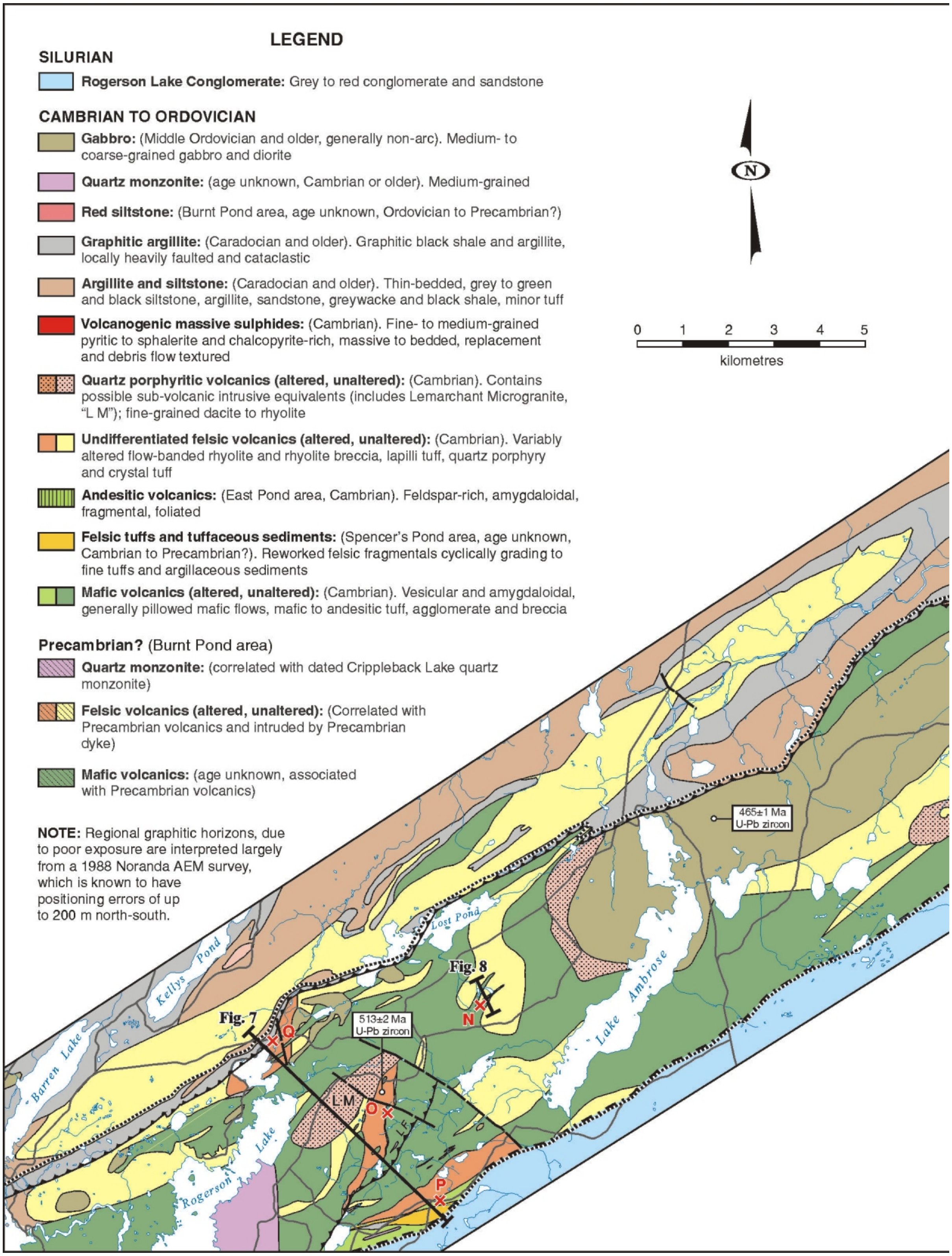

Figure 2. *Geological map of the Tally Pond volcanics between Burnt Pond and Rogerson Lake, illustrating volcanogenic massive sulphide deposits, prospects and showings, geochronological sample results and features noted in text (newly modified and compiled from industry sources-Noranda, Thundermin, Altius, Aur; modified after Squires* et al.*, 2001b and Evans* et al.*, 1994b).*

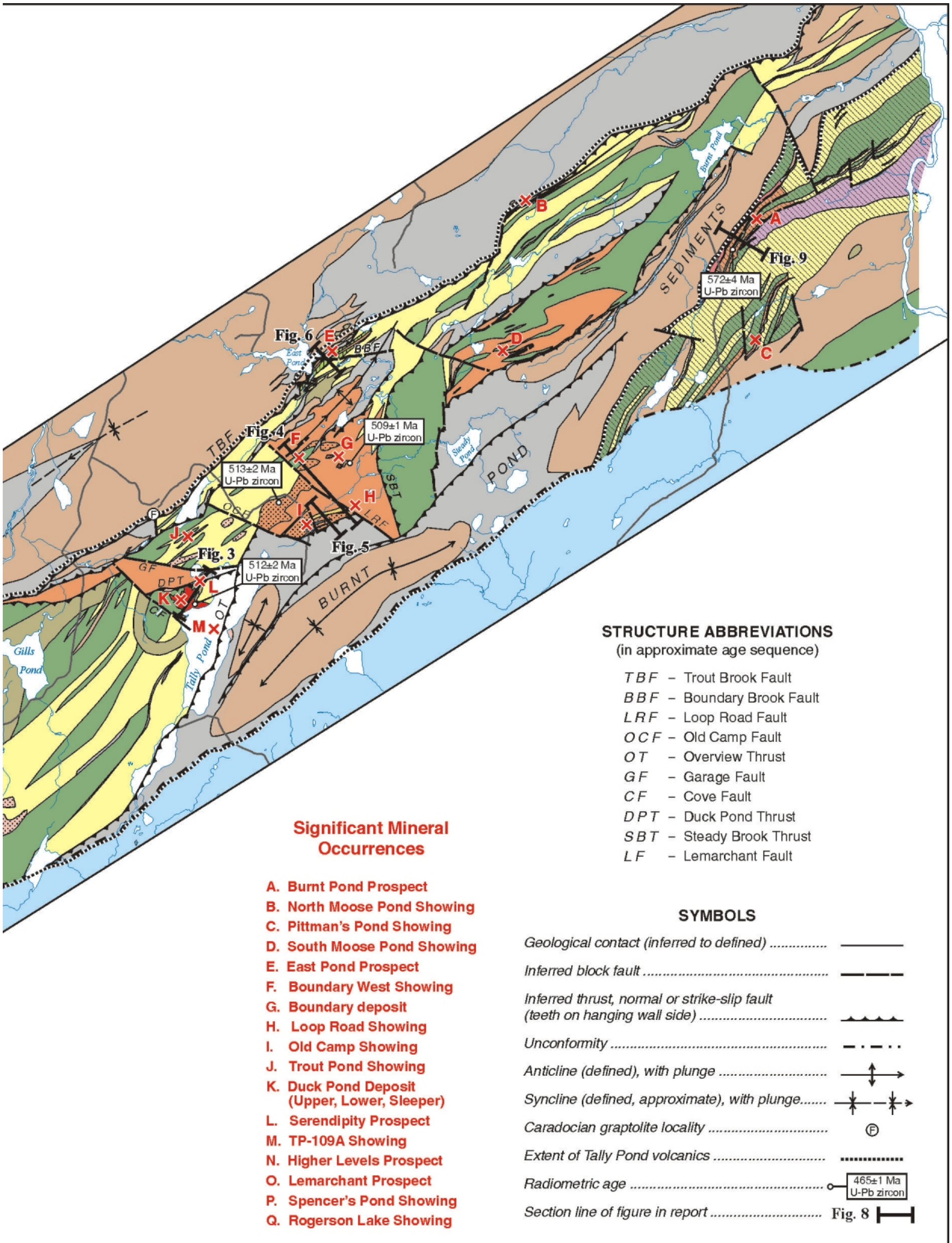

Figure 2. *(Continued)*

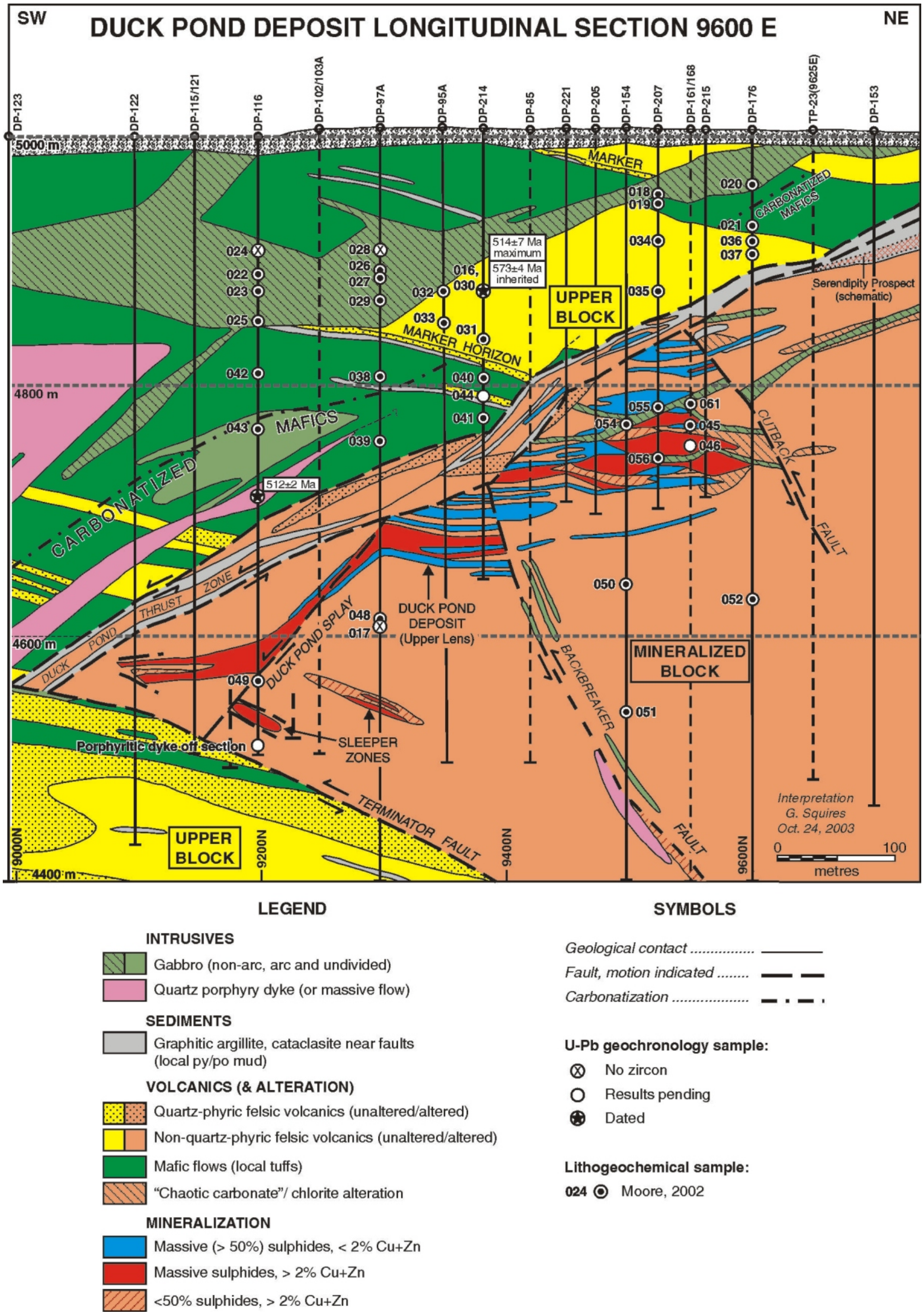

Figure 3. *Longitudinal section through the Upper Duck lens and Sleeper Zones, Duck Pond deposit, illustrating lithogeochemical and geochronological sample locations (modified after Squires* et al.*, 2001b; Moore, 2003).*

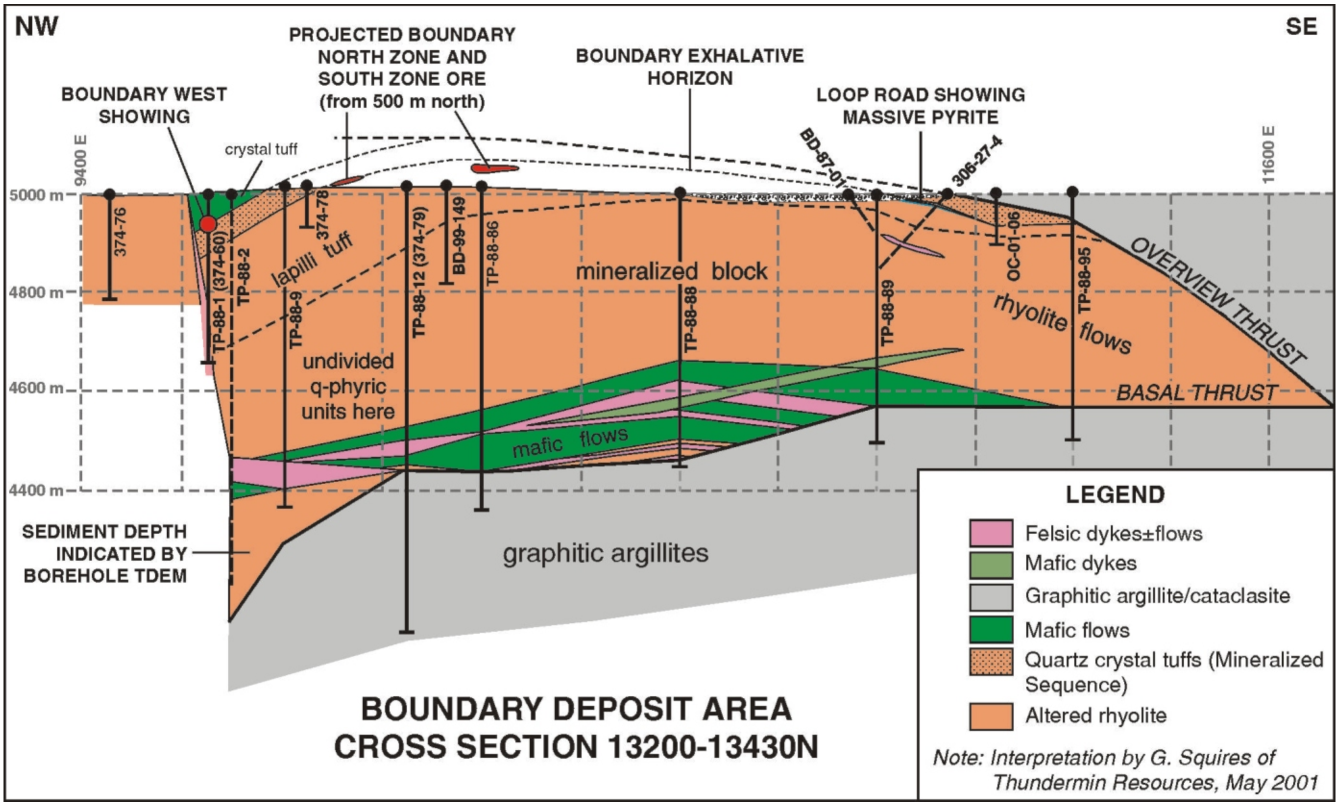

Figure 4. *Cross-section through the Tally Pond volcanics in the Boundary deposit area, illustrating the Boundary Mineralized Block anticline with the Boundary West and Loop Road showings preserved in the mineralized sequence quartz crystal tuffs, on the flanks of the broad anticline.*

Duck Pond and Boundary Deposits

Stratigraphy

Stratigraphic, textural, geochemical and geochronological evidence collected strongly supports previous suggestions that the Duck Pond and Boundary deposits formed simultaneously at essentially the same stratigraphic horizon (Squires *et al*., 2001b). Both deposits exhibit sulphide lamination and debris-flow textures, sulphide-replacement textures, and a unique ‘chaotic carbonate’ alteration unit. Both are hosted by altered quartz-phyric tuffs above a thick sequence of generally ‘aphyric’ footwall felsic flows (Squires *et al*., 2001b). This quartz-phyric felsic tuff, to reworked epiclastic tuffaceous sediment (Squires *et al*., 2001b; Moore, 2003), referred to as the “mineralized sequence” (Moore, 2003), is variably intercalated with, directly overlies, or is replaced by massive sulphides at the Duck Pond deposit, and at the Boundary deposit (Figure 2). The Serendipity prospect, 200 m north of the Upper Duck lens, consists of identical sulphide mineralization and alteration as clasts in submarine debris flows. The TP-109A showing is a structurally displaced portion of the Lower Duck lens, displaced 500 m east of the Lower Duck lens along a segment of the Duck Pond thrust. The enigmatic Sleeper zones could represent footwall mineralization to the Duck Pond deposit, a separate exhalative horizon or structurally displaced portions of the Upper Duck lens.

Within a 2 km radius of the Boundary deposit, a closely similar mineralized sequence, is preserved as two limbs of a broad open fold along the northwest and southeast flanks of the TPV. These quartz-phyric units host the Boundary West, Loop Road and Old Camp showings (Figures 4 and 5).

This paper suggests that the association of mineralization with a specific volcanic unit indicates a genetic and depositional link. The quartz-phyric mineralized sequence suggests a contemporaneous sub-volcanic magma chamber in which the quartz phenocrysts nucleated. This magma chamber provided the extra heat flow needed to enhance hydrothermal circulation and produce larger volumes of altered rock and metal-rich fluids. Also, its volcanic products, mainly fine-grained, stratified quartz-crystal tuffs, provided a suitable cap/host sequence (along with local contemporaneous sedimentation) that trapped ascending fluids beneath the ocean floor, facilitating precipitation and preservation of the sulphides.

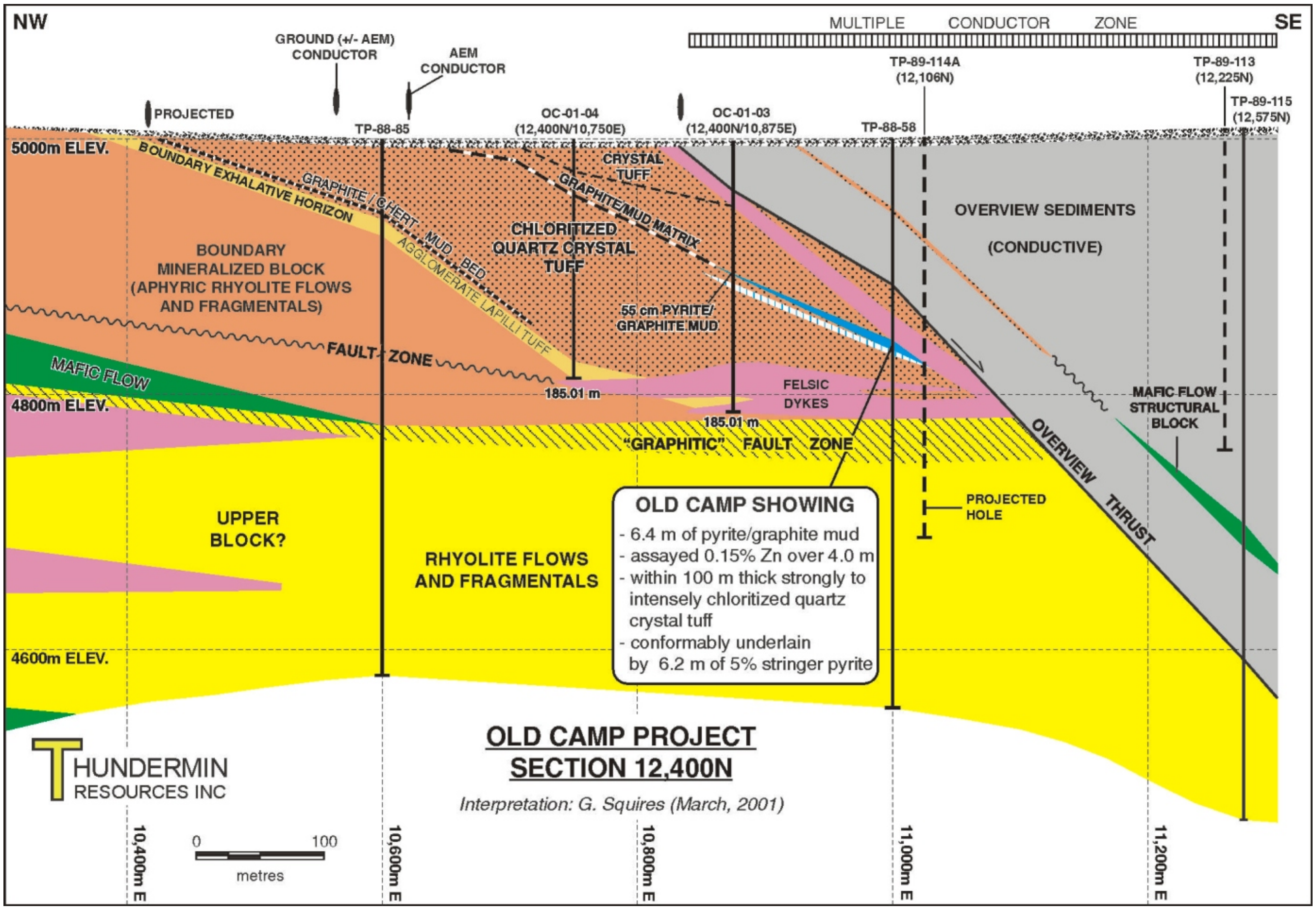

Figure 5. *Cross-section in the Old Camp showing area, illustrating the east flank of the Boundary Mineralized Block anticline. The Old Camp showing is preserved within mineralized sequence quartz crystal tuffs on the flanks of the broad anticline, and appears to be truncated to the east by faulting.*

In the past, many quartz porphyritic units were grouped as intrusive ‘porphyries’. Although quartz-phyric tuffs were recognized at Duck Pond (e.g., Squires *et al*., 1990), and at the Boundary deposit (Brace *et al*., 2000), the full extent of quartz-phyric volcanic units (as opposed to intrusive equivalents) was not recognized until this study. Careful discrimination between quartz-phyric intrusive (massive, isotropic, less altered) and extrusive (fragmental, bedded, crystal-rich matrix, altered) rocks is necessary for confident identification of the prospective mineralized sequence. Part of the 2003 field season was devoted to relogging core, to distinguish the various quartz-phyric units in the vicinity of the Upper Duck lens. Results suggest that quartz-phyric tuffs are more extensive around the Upper Duck lens, and also occur in the Upper Block, above the Duck Pond thrust. Overall, quartz-phyric intrusions are less prevalent than previously indicated.

At the Duck Pond deposit, the mineralized sequence passes upward into deep-water graphitic and argillaceous sedimentary rocks, suggesting that a hiatus in volcanism followed deposition of the quartz-phyric tuffs. This relationship is clearest north of the Upper Duck lens at the Serendipity prospect, where these rocks host 'reworked' sulphides in debris flows. In the southern portion of the Upper Duck lens, the remnants of this horizon are stratigraphically overlain by altered and mineralized aphyric felsic flows, demonstrating the cessation of ‘quartz-phyric’ volcanism.

The panel of bimodal volcanic and sedimentary rocks that structurally overlies the Duck Pond thrust and Upper Duck lens is informally termed the Upper Block (Figure 3; e.g., Squires *et al*., 2001b). Included within this block is a thin succession of graphitic to sulphidic argillaceous sedimentary rocks overlain by felsic fragmental rocks. This sequence is sandwiched between thick, underlying submarine mafic flows and overlying feldspar-phyric rhyolitic flows. This distinctive unit has historically been utilized as a stratigraphic marker horizon (the ‘Marker Horizon’; Figure 3) in the vicinity of the Duck Pond deposit. Moore (2003) noted that some of the felsic fragmental rocks within the marker horizon were quartz-phyric. He suggested that the marker horizon could represent a structurally juxtaposed distal stratigraphic equivalent of the mineralized sequence that hosts the Duck Pond and Boundary deposits. A sample of quartz-crystal tuff, from immediately beneath the marker horizon, has been sent for U–Pb zircon dating to test this possibility. Lithogeochemical data suggest that volcanic rocks on either side of the Duck Pond thrust are similar in composition, so correlation of stratigraphy across this feature would appear to be possible.

Structure

Primary stratigraphic hanging-wall contacts are rarely preserved in the vicinity of the Upper Duck lens due to the presence of the overlying and crosscutting Duck Pond thrust (Figure 3; Squires *et al*., 2001b; Moore, 2003). This structure is evident in drill core, and varies from cataclastically disrupted graphitic argillaceous sediments and rhyolite flows to mylonitized basalt flows and massive sulphides. In cross-sections, displacements of lithological units (massive sulphides, graphitic sediments) within the thrust zone and along its splays indicate a top-block-down (southward) sense of movement on the structure (Squires *et al.*, 2001b; L. Winter, personal communication, 2002). Extensive historical drilling indicates that at least several kilometres of movement has occurred along the thrust, as stratigraphic markers observed in the Upper Block have never been identified on the opposite side of the displacement zone. It is classified as a thrust due to its low angle relative to stratigraphy, its structural style (T. Calon, personal communication, 1988) in drill core and its inferred significant displacement. Kinematic indicators in drill core record both normal and reverse movement on the structure, while attenuation of affected units on cross-sections is only recognized to indicate top-block-down (normal) motion.

Pre-thrusting structures (Figure 3) that affect the Upper Duck lens and its immediately adjacent stratigraphy (Duck Pond Splay, "Terminator Splay", Backbreaker and Cutback faults) were resolved by the senior author while working for Noranda Ltd. and Thundermin Inc. (e.g., Squires *et al*., 2001b). Subsequent preliminary work by Moore (2003) and Aur Resources (L. Winter, personal communication, 2002) has suggested the presence of most of these structures.

In plan view (not depicted in this report), the pre-thrust structures are interpreted to strike nearly perpendicular to the main ore trend of 040° (i.e., perpendicular to Figure 3) and demonstrably offset mineralization and alteration zones. These relationships, and their orientations, indicate that they did not act as conduits for the mineralizing fluids. A hydrothermal conduit system for the Upper Duck lens has not been confidently recognized. However, intense chlorite alteration zones in footwall felsic volcanic rocks to the immediate northwest of the Duck Pond deposit, may represent structurally offset portions of such a conduit system (Squires *et al*., 2001b). Squires *et al*. (2001b) have suggested that the Duck Pond deposit was separated from its conduit system, by southeast movement along a splay of the Duck Pond thrust.

Post-thrusting structures near the Upper Duck lens (Terminator fault - Figure 3; Garage and Cove faults - Figure 2) have received some recent attention. Work by Aur Resources Ltd. (L. Winter, personal communication, 2002) has verified that the Upper Duck and Lower Duck lenses are structurally offset portions of an originally continuous lens, as previously suggested by Squires *et al*. (1990, 2001b).

Duck Pond Deposit Mineralization

In the Duck Pond deposit area, the original single lens of massive sulphides has been disrupted into the Upper Duck and Lower Duck lenses and, in part, Sleeper Zones (Figure 3; Squires *et al*., 2001b). The Upper Duck lens accounts for greater than 85 percent of the proven, probable and inferred reserves at the deposit. The Upper Duck 'lens' is approximately 'T'-shaped in plan, and actually consists of three horizontal, vertically stepped, structurally disrupted segments, which occur between 200 and 450 m depth (Figure 3). It is 500 m long, up to to 400 m wide and intercepts are commonly 20 m thick. Maximum ore-grade thickness is 43 m (DP-154), although locally (e.g., DP-207), massive sulphides dominate over thicknesses of greater than 100 m. The Lower Duck lens occurs below the Terminator fault of Figure 3 (not depicted in this report). It is shallow dipping, approximately 600 m long, up to 100 m wide and up to 15 m thick. Mainly because of insufficient delineation it is not included in the 2001 feasibility reserve (Squires *et al*., 2001b). The Sleeper Zones are interpreted as a series of shallow-dipping stringer to massive sulphide bodies that are generally 5 to 20 m thick and lie within several enigmatic subhorizontal mineralized horizons between 50 and 200 m below the Upper Duck lens. Breccia and local shearing textures are common. Some of these zones appear to be structural offsets of the Upper Duck lens, while others may represent near-surface footwall 'feeder' or 'semi-conformable' mineralization, or an earlier, seafloor mineralizing event. Pre-faulting reconstruction of the Duck Pond deposit lenses indicates that it once formed a single body having a minimum length of one kilometre, containing more than 10 million tonnes of both pyritic and base-metal-rich massive sulphides (Squires *et al*., 2001b).

Boundary Deposit Mineralization

The Boundary deposit contains three sub-cropping to shallow lenses referred to as the North Zone, South Zone and Southeast Zone (Squires *et al.*, 2001b). The North Zone is 275 m long, 25 to 50 m wide and up to 25 m thick. The South Zone is 115 m long, up to 75 m wide and ranges in thickness up to 25 m. The Southeast Zone is indicated to be a southeastern extension of the South Zone and occurs at the same stratigraphic level, but drilling and gravity data suggest that massive sulphide mineralization is not continuous.

Squires *et al.* (2001b) speculate the North and South zones either represent separate occurrences, each with their own feeder alteration 'pipe', or structurally offset segments of a once single linear feeder (Wagner, 1993). Alternately, as the undulating stratigraphic package hosting the two zones appears to have been eroded off between the zones, it is possible that the pre-erosion Boundary deposit may have been a single broad lens that has been eroded off in its structurally more elevated central portion.

Serendipity Prospect

As discussed previously, the Serendipity prospect is hosted by graphitic argillites and subordinate quartz-crystal-bearing epiclastic remnants of the mineralized sequence (Moore, 2003) that form part of the capping sequence to the Duck Pond deposit. The argillites contain coarser debris-flow beds and pyritic and ore-grade massive sulphide, chaotic carbonate, and rhyolite clasts, commonly with a quartz crystal-rich sediment matrix. This clast assemblage provides convincing evidence of submarine exposure and erosion of the Duck Pond deposit. The best intersection of this horizon is in hole DP-88-156, which intersected 7 beds (total 18.4 m) of 30 to 60 percent clastic sulphides as debris flows in the 31.3 to 67.4 m (36.1 m thick) depth range. This zone returned 1.9 percent combined base metals (best 5.0 percent base metals over 2.0 m) as a result of dilution by non-debris flow beds (Noranda Exploration Company Ltd., 1990).

This showing became known as the Serendipity prospect after the true significance of the intersection was recognized, two years after drilling, when the core was 'serendipitously' pulled from the core racks to see the nature of the graphitic sediments. It is nearly certain that this horizon subcrops, and is the source of the massive sulphide float at Tally Pond that prompted Noranda to persevere and eventually discover the blind Duck Pond deposit, which never comes closer than 200 m below surface. This area is still considered to have significant potential to host near-surface 'debris-flow' mineralization potential in immediate proximity to the Duck Pond deposit. It also is an example of VMS mineralization within a thick graphitic sediment package, and highlights the potential of the broad conductive zones in the area.

TP-109A Showing

The TP-109A showing occurs approximately 500 m southeast of the Duck Pond deposit (Figure 2). Deepening of vertical hole TP-88-109A intersected 1.3 m of 0.39% Cu and 7.77% Zn (1234.9 m to 1236.2 m depth) as tectonized sphalerite veins or massive sulphide fragments in an aphyric rhyolite breccia (Squires, 1994). The setting appears to indicate that the mineralization has been dragged down-dip to the southeast from the vicinity of the Lower Duck deposit along a segment of the Duck Pond thrust (*see* Figure 3 of Squires *et al*., 2001b; the mineralization was intersected in the unit marked 'M.B.' in that figure). Alhough very deep, this mineralization demonstrates that the Duck Pond mineralized horizon continues to the most easterly drilling on the property.

Trout Pond Showing

Hole TP-88-17, collared approximately 800 m north of the Duck Pond deposit (Figure 2), intersected a "6.4 m wide zone… of 1.7% Cu" (Noranda Exploration Company Ltd., 1988) at approximately 450 m depth. The mineralization occurs as chalcopyrite and pyrite in quartz veins, and in altered mafic flow and aphyric rhyolitic wallrock. The veining appears to be filling a fault breccia. The rhyolite at the mineralized zone is narrow and is probably a pre-veining dyke. Most of the drillhole consists of moderately to strongly carbonatized mafic flows containing significant disseminated pyrite and local chalcopyrite mineralization. Outcrops of mafic flows near Trout Pond are also pervasively pyritized, suggesting significant widespread alteration. This is interesting, as it is one of the rare instances of well-developed alteration and mineralization in the rocks of the generally unmineralized Upper Block (Squires *et al*., 2001b). The area of this occurrence has only been tested by 400-m-spaced drilling, so retains significant potential near the Duck Pond deposit.

Boundary West Showing

Noranda originally discovered the Boundary West showing (Figures 2 and 4) by testing a ground EM conductor approximately 300 m northwest of the Boundary deposit North Zone in hole 374-60. The hole intersected 8 m of stringer mineralized, cherty to graphitic sediments and underlying quartz crystal tuffs that returned assays of up to 4.12% Zn and 1.24% Cu. Overlying mafic flows are heavily stringer pyrite mineralized. Relogging by Thundermin (Squires *et al*., 2002b) established that the crystal tuffs, which are 50 m thick, correlate with the mineralized sequence hosting the Boundary deposit North Zone to the southeast. Furthermore, the base of the crystal tuff in hole

374-60 is marked by a 10 cm band of massive pyrite, at the exact stratigraphic level of the Boundary North Zone. The stratigraphy at Boundary West represents the northwest limb of a broad anticline. As the axis of this anticline appears to parallel the trend of the TPV, it is possible that this limb preserves prospective rocks along strike. Hole 374-60 is the only one currently indicated to preserve uneroded stratigraphy above the Boundary deposit mineralized sequence quartz-crystal tuffs. It documents the presence of hanging-wall graphitic sedimentary rocks, as at Duck Pond, overlain by mineralized mafic volcanic rocks. However, the poor preservation of the rubbley core at the sediment horizon still permits the contact to be structural.

Loop Road Showing

The Loop Road showing, outcrops 800 m southeast of the Boundary deposit (Figures 2 and 4), and is one of the best outcrops of Mineralized Block mineralized aphyric footwall breccias in the TPV. It has returned grab assays of 3.1% Zn and 2.1% Pb (Squires *et al*., 2001a). However, immediately to the east, Noranda hole 306-27-4 intersected a sequence of crystal tuffs that are underlain by thin graphitic argillites and two beds (1.0 m and 1.2 m of "up to 50%") of semi-massive and 'clastic' pyrite, which are in turn underlain by aphyric rhyolite fragmentals (Squires *et al*., *op. cit*.). This documents the classic Boundary deposit stratigraphy, with 'hiatus' sulphides and deep-water sediments occurring exactly at the 'exhalative' position of the Boundary deposit. This general stratigraphy was subsequently confirmed in drill core by Thundermin (Hole OC-01-06, Squires *et al., op. cit*.). The productive stratigraphy is interpreted to be truncated by structurally emplaced graphitic argillites and siltstones. Similar to at the Boundary West showing, the exhalative stratigraphy is preserved on the flank (southeast flank in this case) of the TPV, where structural down-warping of the stratigraphy prevented it from being eroded. This suggests that this area has potential for future discoveries.

Old Camp Showing

Hole TP-88-58 (Figure 5) intersected 6.4 m of pyrite–graphite mud at approximately 165 m depth, that returned 0.15% Zn over 4.0 m (Squires *et al*., 2001a). This intersection is underlain by 6.2 m of 5% stringer pyrite, indicating its VMS-style exhalative origin and is within the middle of altered quartz crystal ash and lapilli tuffs that are over 150 m thick. Lithological correlation with the Loop Road and Boundary deposit stratigraphy (*see above*) indicates that this mineralization occurs within the Boundary deposit mineralized sequence crystal tuffs, approximately 100 m stratigraphically higher than the Boundary deposit, and in association with a discontinuous graphitic horizon, suggestive of a brief hiatus in the eruption of the mineralized sequence. As at the Boundary West and Loop Road showings, the Old Camp area mineralized sequence owes its preservation to the fact that it is on the flank of a broad anticline. The stratigraphy to the immediate east of this sequence is truncated by the structurally emplaced, inferred Ordovician argillites and siltstones of the Burnt Pond sediments via the Overview thrust (Squires *et al*., *op. cit*.). Other workers suggest the contact between the TPV and the overlying Burnt Pond sediments may be stratigraphic (T. Brace, personal communication, 2003), with at least the lower part of the sediments being Cambrian. If the latter is true, this contact would be considered as favourable for hosting VMS mineralization as at Duck Pond.

East Pond Prospect

This prospect is located two kilometres north of the Boundary deposit (Figures 2 and 6). It consists of an outcropping, up to 50 m wide, locally sheared, weakly quartz-phyric rhyodacitic debris-flow conglomerate or agglomerate containing up to 5% sulphide clasts. The mineralized rhyodacitic is flanked on both sides by sheared, olive green, sericitic, feldspar-rich, locally amygdaloidal tuffs. Immobile-element lithogeochemistry suggests that these are of andesitic composition (Squires *et al.*, 2002b), a very rare composition for the TPV. The original relationship between the andesitic tuffs and the mineralized rhyodacite fragmental rocks is uncertain, due to shearing. They may be structurally or stratigraphically intercalated, or the mineralized rhyodacite may occupy the core of a fold. Outboard of the mineralized rhyodacite and andesite units are other felsic and mafic volcanic rocks, as well as sheared graphitic sediments and possible porphyry dykes. Structural interpretation of the surface geology suggests the down-dip extent of the mineralized horizon may be structurally offset only a minor amount along the Boundary Brook fault, thus suggesting further potential at depth. Mineralization consists of massive pyrite, banded pyrite-sphalerite, massive sphalerite and rare massive pyrrhotite clasts. One deformed clast is 50 cm long (by 5 cm thick), one sphalerite clast assayed 40% Zn and a pyrite clast assayed 1.6g/t Au. The best mineralization occurs at a structural break in the stratigraphy. The horizon is open along strike and down dip.

Lemarchant Prospect

This prospect (Figures 2 and 7) was intensely explored in the past because of the significant similarities it shares with the Buchans deposits. In particular, it contains an intense stringer barite footwall gangue, and discovered mineralization to date is generally Zn–Pb-rich, with significant Ag and Au values. For example, hole LM-91-01 returned assays of 0.6% Cu, 6.3% Pb, 7.4% Zn, 1516 g/t Ag and 11.4

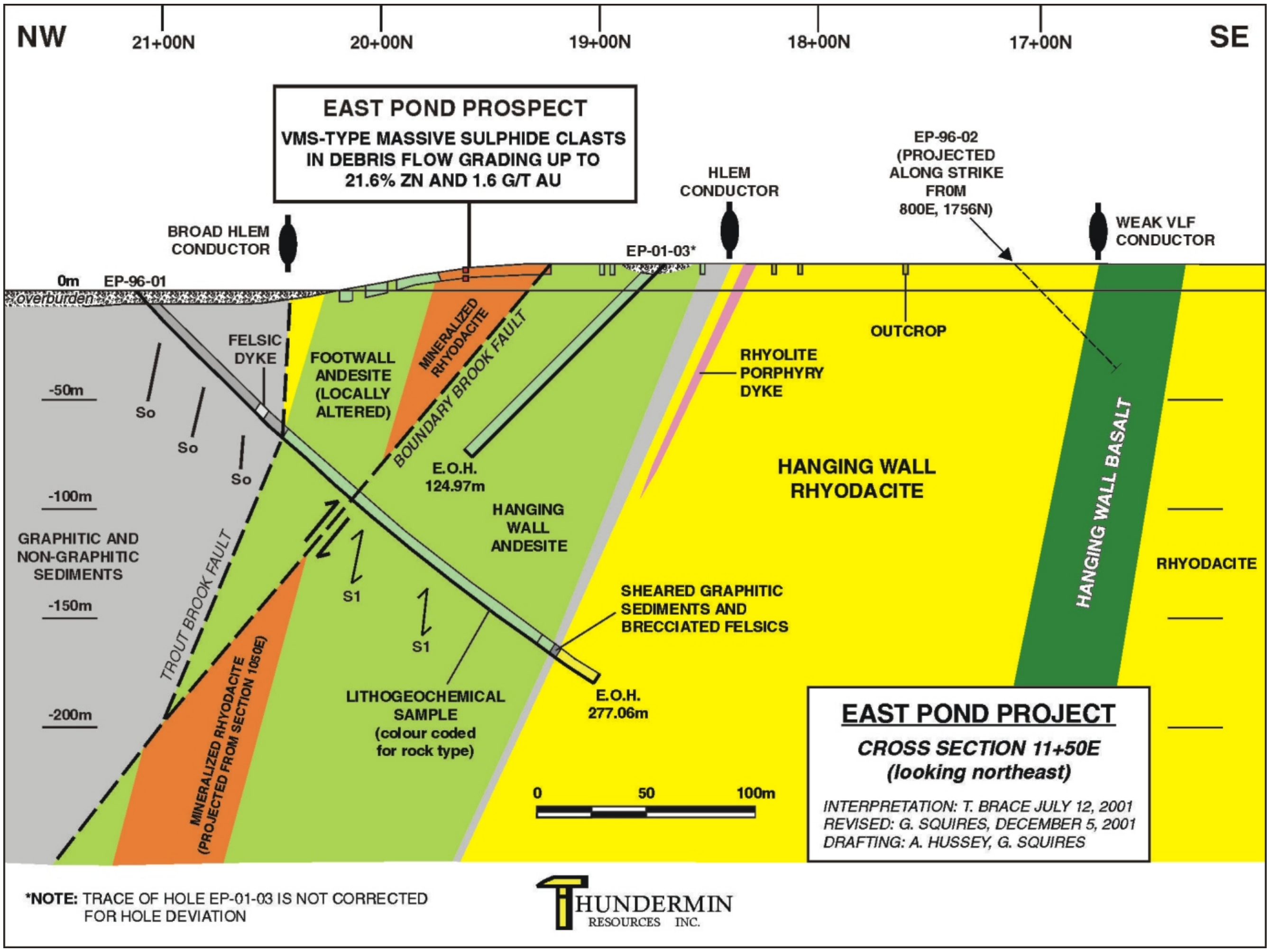

Figure 6. *Cross-section in the East Pond prospect area, illustrating the host East Pond mineralized rhyodacite agglomerate sandwiched between andesitic volcanics and structurally offset at depth by the Boundary Brook fault.*

g/t Au over 0.6 m in footwall stringer mineralization (Collins, 1992). The prospect also hosts a single 0.3 m occurrence of laminated base-metal-rich massive sulphides containing 4.5% Cu, 0.33% Pb, 5.70% Zn, 272.5 g/t Ag and 1.06 g/t Au (hole LM-92-07, Collins, 1993).

Mineralization occurs mainly as footwall stockwork in a strongly altered (barite, silica, sericite, local chlorite) brecciated aphyric rhyolite (Collins, 1992; Moore, 2003). This unit is locally capped by a thin, commonly pyritic graphitic argillite (locally chert), which hosts the thin, base-metal-rich massive sulphides. This graphitic unit is in-turn overlain by a sequence of pillowed mafic flows. All units are intruded by mafic sills and dykes, which are particularly prevalent around the mafic–felsic volcanic contact. The sills and dykes are chilled and generally appear to be post-mineralization (although they are commonly altered). Fragmental quartz-phyric flows occur at the same stratigraphic position, less than 400 m north along strike from the stratiform massive sulphide mineralization intersected by diamond drilling (Moore, 2003). This quartz-phyric rhyolite is considered to be equivalent to a nearby quartz-phyric volcanic (B. Kean, personal communication, 2003, exact location not now known) that returned an U–Pb zircon date of 513 ± 2 Ma (Evans *et al.*, 1990; Dunning *et al.*, 1991). Based on these similarities, it is suggested that the Lemarchant mineralization may be coeval with mineralized sequence rocks hosting the Duck Pond and Boundary deposits (Moore, 2003). Approximately 500 m west of the Lemarchant alteration zone, a series of outcrops of microgranite are exposed. Sampling of this body returned lithogeochemical results (*see* lithogeochemistry section for details) comparable to those received for the felsic volcanic rocks. This suggests that the granitic body is related to the volcanic rocks and may have been the subvolcanic intrusion responsible for the development of the nearby alteration.

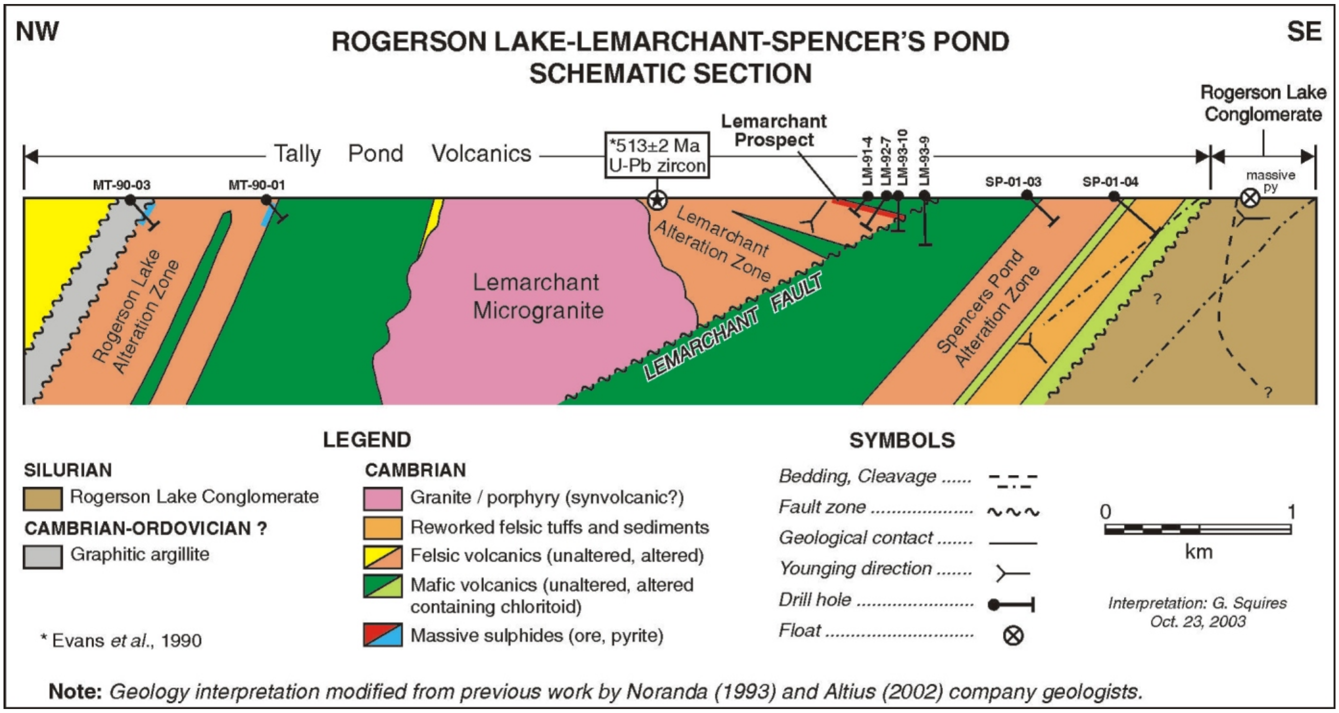

Figure 7. *Schematic cross-section across the Tally Pond volcanics in the Rogerson Lake showing–Lemarchant prospect–Spencer's Pond showing areas. Note the overturned nature of the volcanics and Rogerson Lake conglomerate to the east, the truncation of the mineralization by the Lemarchant fault and the location of the Lemarchant microgranite.* See *text for further details.*

Noranda had previously interpreted that the moderately to steeply east-dipping mineralized stratigraphy could not be extended along strike at surface, and was truncated down-dip by a shallow west-dipping fault (here termed the Lemarchant fault). At the time it was believed that the Lemarchant and Spencer's Pond stratigraphy were connected via an open syncline. Discussions with Altius Resources personnel (D. Barbour, personal communication, 2003) and check mapping this summer do not support this model (*see below*).

Spencer's Pond Showing

The Spencer's Pond showing is located approximately one kilometre southeast of the Lemarchant showing (Figures 2 and 7). From northwest to southeast, the stratigraphy consists of mafic flows, generally quartz phenocryst-deficient felsic flows, fragmentals and tuffs, interbedded and graded tuffs and argillites and a chloritoid-bearing altered mafic (?) unit. The latter appears to be in structural contact with the Rogerson Lake Conglomerate (Figure 7) to the southeast. The area has long been known to contain hydrothermally altered and locally mineralized felsic volcanic rocks (Collins, 1993). As noted above, it was interpreted that the favourable host rocks of the Lemarchant prospect continued to this area.

Two holes were relogged during the past season. A single quartz-phyric tuff unit (ddh SP-01-04 @ 50.1-58.9 m) was noted, which is pervasively carbonatized and sericitized and has 1 to 2 percent disseminated pyrite with traces of sphalerite and chalcopyrite. Though mineralized and altered, it is not yet known to be directly associated with any exhalative mineralization. The showing is covered in this section mainly because of its proximity to the Lemarchant showing.

Discussions with Altius Resources indicated that the Spencer's Pond stratigraphy is overturned (D. Barbour, personal communication, 2003). Check mapping and relogging confirmed that graded bedding tops indicators, and bedding/cleavage relationships in drill core and outcrop, confirmed that both Spencer's Pond tuffs and sediments, as well as bedded sandstones of the Rogerson Lake Conglomerate, are overturned, dip northwest and young to the southeast, thus invalidating the simple synclinal model. A large exposure of chloritoid-bearing (D. Barbour, personal communication, 2003) volcanic rocks was mapped within 25 m of the

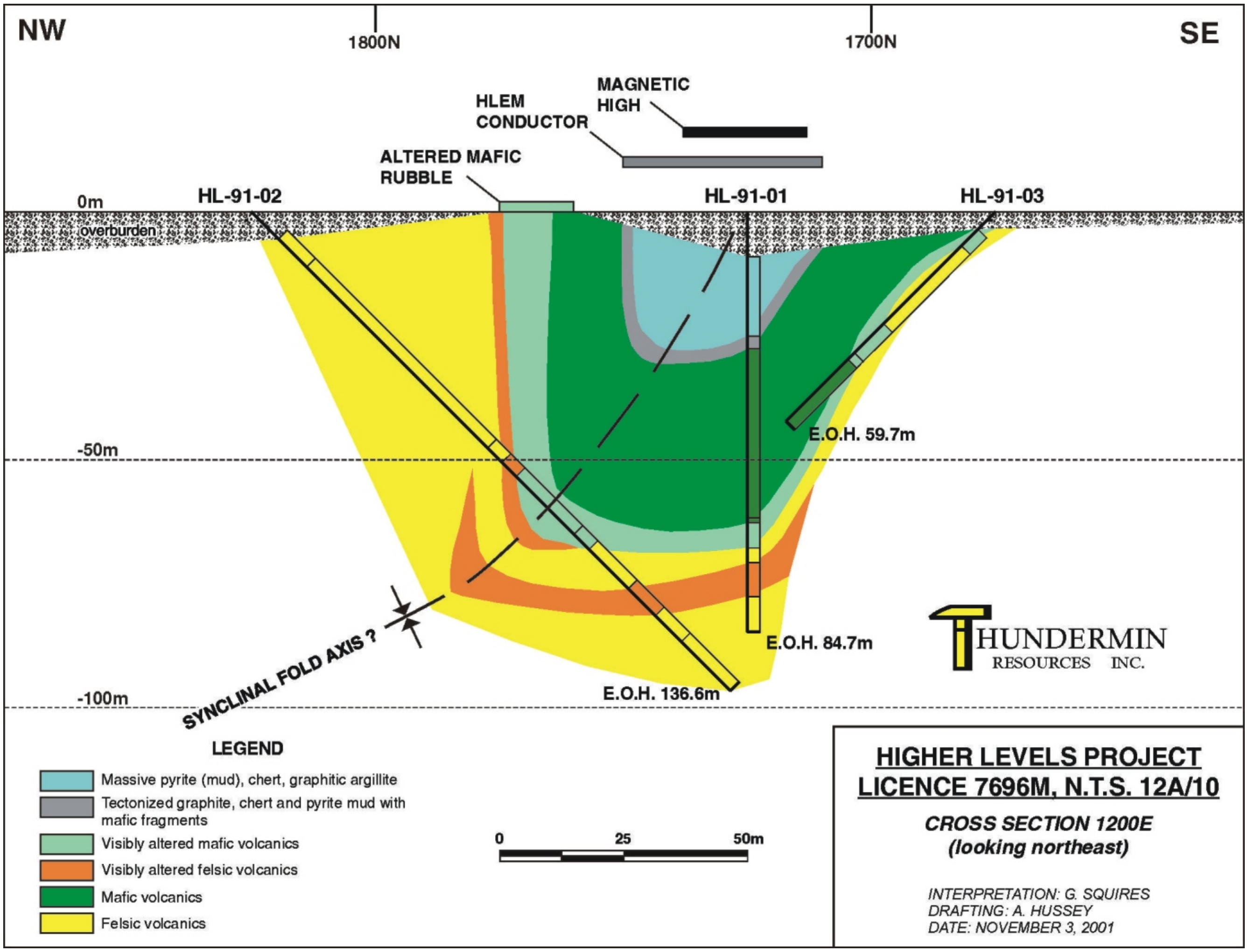

Figure 8. *Cross-section in the Higher Levels prospect area, illustrating the interpreted synclinal nature of the stratigraphy and the preservation of 18.5 m of massive pyritic sulphides in the core of the syncline.*

nearest Rogerson Lake Conglomerate outcrop to the southeast. Pertaining to the potential nature of this contact, it has a moderately north-dipping foliation that may be thrusting-related. Rosettes of acicular chloritoid overgrow the foliation, suggesting its posttectonic growth. The nearest outcrop of conglomerate has stretched cobbles dipping steeply north.

Relogging of hole SP-01-04 has revealed that the last 80 cm of the hole ended in mineralized aphyric rhyolite with quartz vein- and wallrock-hosted pyrite, chalcopyrite, sphalerite and galena disseminations totalling 1 to 2 percent locally. This is believed to be the most significant mineralization yet discovered in the Spencers Pond area. The hole was deepened at a later date (D. Barbour, personal communication, 2003), but the core was unavailable for study. During mapping, a semi-massive pyrite boulder was located in Rogerson Lake Conglomerate terrane, 350 m from the volcanic rocks. Whole-rock lithogeochemical samples have been collected of the volcanics and results are pending.

GROUP II: VMS MINERALIZATION WEST OF THE BURNT POND SEDIMENTS, BUT NOT ASSOCIATED WITH QUARTZ-PHYRIC VOLCANIC ROCKS

These occurrences are not known to be genetically linked to a single mineralizing event, and are grouped mainly because they are not known to be associated with quartz-phyric volcanic rocks, and because they occur within a single Cambrian volcanic terrane west of the Burnt Pond sediments (Figure 2).

Rogerson Lake Showing

The Rogerson Lake 'showing' (it is actually several mineralized zones) occurs at the north end of Rogerson Lake (Figures 2 and 7) and consists of several drill intersections of semi-massive (<50 percent) pyrite and/or pyrrhotite over a wide area, and a reported subcropping area of banded massive pyrite (A. Keats, personal communication, 1987; sample seen by G.C.S.) on the northeast end of the zone. Massive pyrite and base-metal float is noted in the area. This mineralization is hosted in non-quartz porphyritic felsic volcanic rocks that are flanked to the northwest by sheared graphitic argillites and to the southeast by mafic volcanic rocks. Semi-massive pyrite and stringer concentrations are reported from both sides of the felsic volcanic rocks, though the most intense chloritization is documented on the northwest side, suggesting that stratigraphic tops may be in that direction. Assays are generally low grade. The best recorded mineralization appears to be a 0.5-m drill intersection of massive pyrrhotite crosscut by an estimated 2 to 4% stringer sphalerite (ddh 372-11, Noranda Exploration Company Ltd., 1991). This mineralization is hosted in a VMS-style alteration zone at least 2.5 km long by up to 500 m wide, that has Hg and Ba enrichment, and Na and Sr depletion alteration signatures (Noranda Exploration Company Ltd., 1991). The current stratigraphic relationship with the other zones of alteration and mineralization within the Tally Pond volcanic belt is unknown.

Higher Levels Prospect

This prospect subcrops 14 km southwest of the Duck Pond deposit (Figures 2 and 8). It is a VMS-style, banded pyritic (with local graphite) massive sulphide lens, with pyritic stockwork in the footwall mafic and felsic flows. Hole HL-91-1 showed the lens to be at least 18.5 m thick (hole collared in massive sulphides). Assays averaged 0.2% Zn over 12.0 m (Collins, 1992). The mineralization is currently interpreted to occur in the core of a syncline (Squires and Hussey, 2001). Drill core was inspected this past season (previously relogged by G.C.S.) to evaluate whether or not the massive sulphides could have been truncated by faulting either to the north or south. No evidence was found to support this concept, but the banded sulphides were noted to be frequently folded, thus supporting the syncline model.

The 500-m-long conductor that is associated with the mineralization has only been drilled on one cross-section and several flanking conductors remain untested. Results of whole-rock sampling are pending.

North Moose Pond Showing

The North Moose Pond showing is located 6 km north–northeast of the Boundary deposit (Figure 2). It was originally recognized as an area containing intensely chloritized, stringer chalcopyrite-bearing ‘feeder pipe’-style float and base-metal till anomalies. Ground geophysics (almost no exposure) inferred these features to be near a sediment–volcanic contact, at a structural break. Drilling (Squires *et al*., 2002a) has discovered the sediment–volcanic contact to be a major fault zone (referred to as the Trout Brook fault), containing local deformed blocks of banded massive pyrite associated with strongly sericitized and chloritized felsic volcanics, and weak Na-depletion anomalies. Volcanic stratigraphy southeast of the fault is interpreted to dip sub-vertically, and to be undercut by the moderately southeast-dipping Trout Brook fault. The lack of exposure or suitable units for stratigraphic dip information in drill core, leaves room for other interpretations. The mineralized float and base-metal anomalies indicate a near-surface source that has not been located.

South Moose Pond Showing

The South Moose Pond showing consists of stringer and disseminated pyrite, sphalerite, chalcopyrite and galena on the northwest flank of an approximately 2 by 1 km VMS-style alteration zone, located 4 km northeast of the Boundary deposit (Figure 2). The best mineralization generally occurs around a contact between both mafic and felsic volcanic rocks. The alteration (carbonate, sericite, silicification and chlorite) is more widespread and occurs within all rock types (Squires *et al.*, 2002b). Although relatively well exposed, the area is virtually devoid of well-stratified units, and interpreted dips are tenuous. One outcrop in the northeast part of the alteration zone displays folded cherty sediments or tuffite, suggesting that the area is likely to be structurally complex. The large size of the associated alteration zone is encouraging from an exploration perspective, as it is comparable in size to the Boundary deposit and Duck Pond deposit alteration zones. It is open along strike and down dip.

GROUP III: VMS MINERALIZATION LOCATED EAST OF THE BURNT POND SEDIMENTS

No genetic relationship is yet evident between the three VMS properties discussed in this section, especially since volcanic rocks of Precambrian, Cambrian and Silurian ages are all inferred to be present east of the Burnt Pond sediments, and stratigraphic control is lacking. Recent laser ablation-ICP-MS dating at the Burnt Pond prospect (D.H.C. Wilton, personal communication, 2004) has forced reconsideration of the relationship between the rocks that host these occurrences, and the remainder of the TPV, as currently defined.

Burnt Pond Prospect

The Burnt Pond prospect is located 13 km northeast of the Duck Pond deposit (Figure 2). It hosts an approximately 500-m-long by 150-m-deep VMS-style base-metal-rich stringer zone with local narrow massive sulphides (Dimmell, 1986; Collins, 1991). No resource estimate has been published on the prospect. Recent drilling (Figure 9) inter-

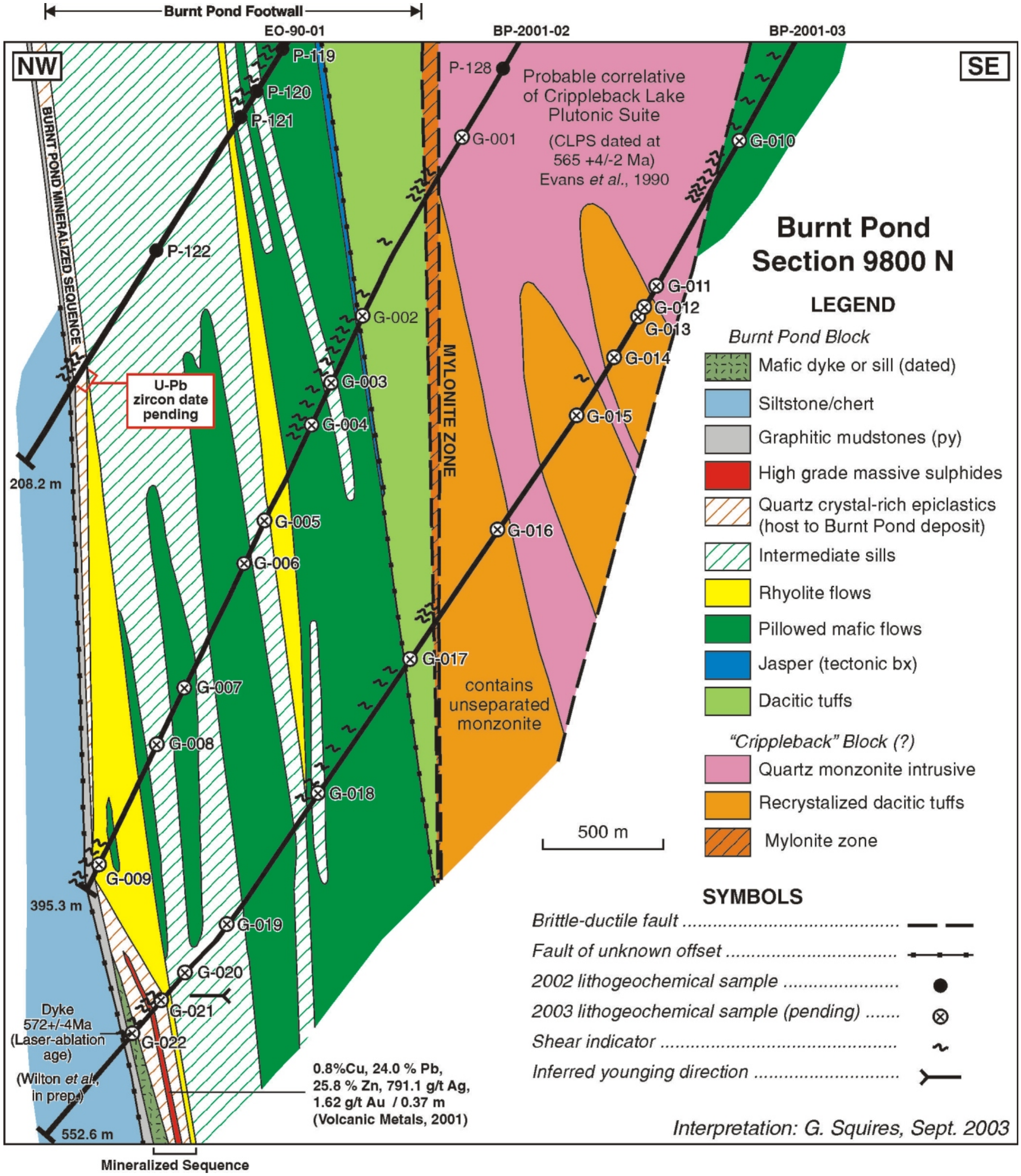

Figure 9. *Cross-section in the Burnt Pond area, illustrating the overturned, altered and mineralized Burnt Pond block volcanics and sills west of the mylonite zone, and the quartz monzonite and recrystallized tuffs east of this structure.* See *text for details.*

sected a tectonized massive sulphide zone approximately 400 m along strike to the southwest of the original prospect. This returned impressive assays of 0.79% Cu, 24.0% Pb, 25.8% Zn, 791.1 g/t Ag and 1.6 g/t Au over 0.37 m at a vertical depth of 405 m, in hole BP-2001-03 (Volcanic Metals Exploration Inc., April 6, 2001 press release). This intersection is at the same stratigraphic level as the original prospect, but represents a separate lens of high-grade massive sulphides, richer in grade than the original showing, which is open along strike and down dip. This discovery is considered to be important for exploration potential in the area, especially considering the close proximity to the Duck Pond deposit.

Three holes on one cross-section near this newly discovered mineralization were relogged. This cross-section is also interesting as it contains quartz monzonite, possibly correlative with the nearby Crippleback Lake quartz monzonite, dated at 565 +4/-2 Ma (Evans *et al.*, 1990). A mafic dyke interpreted to intrude the host rocks to the Burnt Pond mineralization has recently been dated at 572 ± 4 Ma (D.H.C. Wilton, personal communication, 2004) using laser-ablation ICP-MS methods. If this result and its interpretation are correct, the volcanic host rocks at Burnt Pond are of Precambrian age, and should therefore be excluded from the TPV.

Previous observations (Dimmell, 1986; Collins, 1991) indicated that the mineralization at the Burnt Pond prospect consists of stratiform stringer to massive sulphides hosted by a steeply east-dipping, west-facing, overturned sequence of fine-grained, graphitic, and volcanogenic ("felsic tuff") epiclastic sediments. This is referred to here as the 'mineralized sequence'. This sequence was suggested to be conformably underlain by mafic to felsic volcanics, and to be conformably overlain by fine-grained, grey-green tuff/siltstone, and an upper sequence of deep-water marine sediments and lesser intercalated mafic volcanics that are marked at the base by a distinctive mauve-red siltstone (Collins, 1991).

Relogging of drill core (Moore, 2003) confirms most of the above, but with some important modifications. First, the strongly sheared nature of the mineralized horizon precludes the confirmation of its being conformable with 'hanging-wall' units to the west, and second, the mineralized sequence has recently been recognized to contain volcanogenic quartz phenocrysts, in contrast to its footwall.

From inferred stratigraphic bottom to top in hole BP-2001-03 (i.e., progressing down the hole) the host mineralized sequence comprises chloritized rhyolite breccia passing into chloritized and graphitic, sandy quartz-phyric volcanogenic epiclastic sediments and then passing into locally mineralized graphitic mudstone. These rock types, particularly the graphitic mudstone, are generally strongly tectonized. D.H.C. Wilton (personal communication, 2004) sampled a gabbro sill (49% SiO_2, 318ppm Cr) that was interpreted to intrude the mineralized sequence. The sill returned a Precambrian age of 572 ±4 Ma. D.H.C. Wilton (personal communication, 2004) pointed out that, i) the age is comparable to that of the Crippleback Lake plutonic suite, ii) it implies the existence of Precambrian graphitic sediments and volcanics in the Victoria Lake supergroup, and that iii) a galena inclusion in one of the zircons may indicate the Precambrian age of the Burnt Pond mineralization. Because this unit is within a deformation zone, it was carefully examined to assess its contact relationships. The only evidence for deformation within the gabbro unit is a <1cm foliation zone on the stratigraphically lower contact (higher in the hole). The piece of (rubbly) core containing the opposite contact is missing, though what is preserved is not deformed. The wallrock on both sides of the gabbro sill returned elevated base-metal values, while sporadic sampling within the sill returned no anomalous values. This is consistent with emplacement of the dyke following mineralization. The age from the sill may be valid for constraining the minimum age of the Burnt Pond volcanism and mineralization, but the equivocal contacts in sheared wall rocks leave room for uncertainty.

The interpreted footwall volcanic rocks consist of (from stratigraphic top) amygdaloidal mafic flows cut by feldspar-phyric 'dacitic' sills ('andesitic', *see* lithogeochemistry section below), and subordinate 'rhyolite', underlain by dacitic ash to feldspar crystal lithic tuffs and possible flows. A narrow horizon of tectonically brecciated jasper tuffite (this contains rare quartz pseudomorphs after feldspar laths, which indicate its tuffaceous origin) at the immediate stratigraphic base of the main mafic flow sequence likely marks a hiatus between the earlier dacitic tuff and later mafic volcanism. No quartz-phyric volcanic rocks were noted in the footwall. All of these rock types contain variable VMS-style alteration (silicification, chloritization, sericitization and carbonatization) and are mineralized with up to 15 percent pyrite and local base metals. Commonly, the mafic units and the altered felsic units have developed steeply dipping shears subparallel to stratigraphy.

To the east, the stratigraphic base of the footwall dacitic volcanic rocks is marked by a steeply east-dipping, mylonitic shear zone, about 5 m wide. This structure separates the definite Burnt Pond footwall rocks in the west from a discrete structural panel containing recrystallized dacitic ash to feldspar crystal lithic tuffs, and medium- to coarse-grained quartz monzonite correlated with the Crippleback Lake plutonic suite. Contacts between the quartz monzonite and recrystallized tuffs are sharp and possibly intrusive. The tuffs east of the structure are almost ubiquitously altered (usually silicified), while the quartz monzonite is also ubiquitously saussuritized and locally silicified and pyritized. This alteration tends to mask contacts between the two rock types. The local occurrence of disseminated and stringer pyrite in both units, coupled with the observed alteration, indicates that they also may have been affected by a VMS-style alteration event. If this event is the same one responsible for the Burnt Pond mineralization, then the quartz monzonite could be the synvolcanic intrusion that provided the heat flow responsible for that alteration system. This possibility is supported by recent dating of volcanic rocks adjacent to the Crippleback Lake quartz monzonite, that has returned an age of ca. 563 Ma (Figure 1; V.L. McNicoll and D. Rogers, unpublished data, 2003), independently demonstrating the existence of Precambrian volcanic rocks. In the extreme east of the interpreted section, the east contact of the quartz monzonite is strongly sheared and cataclastically deformed over a 10-m core width (shearing oblique to core axis), where it is structurally juxtaposed with sheared mafic flows that resemble the mafic volcanic rocks in the Burnt Pond prospect footwall to the west.

The Burnt Pond prospect appears to have formed in a typical VMS- style depositional environment and contains a footwall stratigraphy of altered and mineralized submarine volcanic rocks. Four samples of these volcanic rocks have mafic to intermediate compositions (*see* later discussion) that contrast with the generally more bimodal nature of the main TPV. These volcanic rocks are overlain by a fragmental tuffaceous/epiclastic horizon that appears to have provided a porous medium for deposition of the sulphides on or just beneath the ocean bottom. Heat flow may have been contributed by an intermediate to felsic subvolcanic intrusion (Crippleback Lake quartz monzonite?), which perhaps also contributed quartz phenocrysts to the host horizon to the massive sulphides. The sulphide deposition at that horizon may also have been enhanced by the formation of a fine-grained graphitic mud 'caprock'. This caprock would presumably have restricted dispersal of the mineral-laden hydrothermal fluids into the open water column and confined them to lateral flow within the sub-sea sediments, thus facilitating sulphide precipitation within the Burnt Pond mineralized sequence.

The general features of the host stratigraphy to the Burnt Pond mineralization invites direct correlation with the depositional environment at the Duck Pond deposit (e.g., Moore, 2003). However, if the data and interpretation of D.H.C. Wilton (personal communication, 2004) are correct, this cannot be the case, because the mineralization and its host rocks then must be Precambrian. The most obvious test of this hypothesis is to date the quartz crystal-rich epiclastic/tuffaceous host horizon to the massive sulphide mineralization, which is in progress.

Pittman's Pond Showing

This occurrence is located 9 km east-northeast of the Boundary deposit (Figure 2). The area is underlain by intercalated mafic and aphyric felsic volcanic rocks, and flanked to the east by a formational conductor, which consists of graphitic argillites and volcanics, with local fine-grained sulphide muds. Noranda hole PP-96-01 drilled the weak end of an isolated surface EM conductor at a geophysically indicated structural break in the stratigraphy. It intersected significant pyrite mineralization in fragmental felsic volcanic rocks, from 9.1 to 55.2 m, with the best mineralization comprising 3% to 10% disseminated and stringer pyrite between 25 and 35 m. The best intersection reportedly returned 0.5% Zn over 1.8 m at 27.3 m to 29.1 m depth (Sheppard, 1996).

The adjacent formational conductor was drilled by the Canadian Nickel Company Ltd, with hole 51589 drilling to 84.12 m and encountering sediments and intermediate flows, but also intersecting "…two bands of graphitic argillite and fine grained massive pyrite…" and saying that "The band of massive pyrite drilled from 70.4 to 78.94 m (8.54 m), caused only a small gravity peak." (Pesalj, 1982).

Pittman's Pond is one of the few mineralized horizons east of the Burnt Pond sediments. Geological extrapolation along strike, and the application of facing and structural criteria from the Burnt Pond area, suggest the Pittman's Pond horizon may be stratigraphically lower than the Burnt Pond horizon. However, the structural complexity at Burnt Pond indicates that such a direct extrapolation may not be valid.

Old Sandy Road Showing

The Old Sandy Road showing (Figure 1) is described as a zone of massive to semi-massive banded pyrite and minor chalcopyrite in grey-green pillow lava of the Sandy Lake sequence of the Tally Pond volcanics (D.T.W. Evans, personal communication, 1990, MODS data). Nothing else appears to be known about the prospect. It stands out however as one of only three significant sulphide occurrences east of the Burnt Pond sediments. It also lies along the east flank of the Precambrian Crippleback Lake quartz monzonite, very close to a sample site that recently returned a ca. 563 Ma U–Pb zircon age from volcanic rocks (V.L. McNicoll and D. Rogers, personal communication, 2004) that are intruded by the quartz monzonite (van Staal, personal communication, 2003).

LITHOGEOCHEMISTRY

Lithogeochemical studies were undertaken to further characterize the volcanic types associated with mineralization, and to establish a workable volcanic stratigraphy for the TPV, as current geochronological and palaeontological controls are inadequate. Analyses were conducted at the Newfoundland Department of Mines and Energy analytical lab utilizing ICP-ES (Inductively Coupled Plasma - Emission Spectrometry) for major- and trace-element analyses and following the methods outlined in Finch (1998). Rare-earth-element (REE) and additional trace-element analyses were conducted at the Department of Earth Sciences analytical lab, Memorial University of Newfoundland, utilizing ICP-MS (Inductively Coupled Plasma - Mass Spectrometry) and following the methods outlined in Jenner *et al.* (1990) and Longerich *et al.* (1990). The following study emphasizes so-called 'immobile' trace elements (*see* Kean *et al*., 1995 for a review), and uses discrimination diagrams to help indicate the affinities of the rocks. The use of immobile element variation diagrams for the study of altered and metamorphosed volcanic rocks is now a standard practice in lithogeochemical studies.

The Winchester and Floyd (1977) Nb/Y vs Zr/TiO_2 plot in Figure 10 depicts the variety of volcanic and intrusive rocks in the area. Although there appears to be a continuum from mafic to felsic compositions, it is important to note that three of the samples plotting in the andesite field (label a), are of altered 'dacitic' sills intruding the Burnt Pond prospect footwall. One intermediate sample (label b) is an evolved sample that was collected within the Harpoon Hill intrusion of Kean and Jayasinge (1980). This body has previously returned within-plate basalt chemistry (Pollock *et al*., 2002a) but sample (b) has returned an arc-andesitic signature. This suggests that the Harpoon Hill intrusion as mapped, actually consists of two unrelated intrusions. Also plotting in the andesite field is a relatively unaltered (in thin section), feldspar-rich intermediate sill with accessory free quartz (label c) from the Lemarchant prospect. This sample, possibly representing another intrusive phase, does not chemically match the other sills sampled at the prospect. If the samples discussed above are removed from consideration, the TPV and associated rocks are more obviously bimodal in character, as suggested by others (e.g., C.J. Collins, 1989; Pollock and Wilton, 2001). Other samples of interest are two of quartz monzonite (label d) believed to be related to the Precambrian Crippleback Lake plutonic suite, and one lone sample of the Burnt Pond footwall basalt flows (label e). A third main grouping of samples plots in the 'non-arc/within-plate' alkali basalt field (Figure 10), and represents later sills that intrude the Upper Block and Mineralized Block stratigraphy at Duck Pond, including the Upper Duck lens massive sulphides. As previously noted, similar dykes have been interpreted by Swinden (1987) to represent later back-arc/arc-rift magmatism. Also plotting with this group, and therefore suggesting that they might be related, is the single sample of Harpoon Dam gabbro (label f), which outcrops within (contacts not exposed) the Ordovician sediments north of the TPV. An additional sample (label

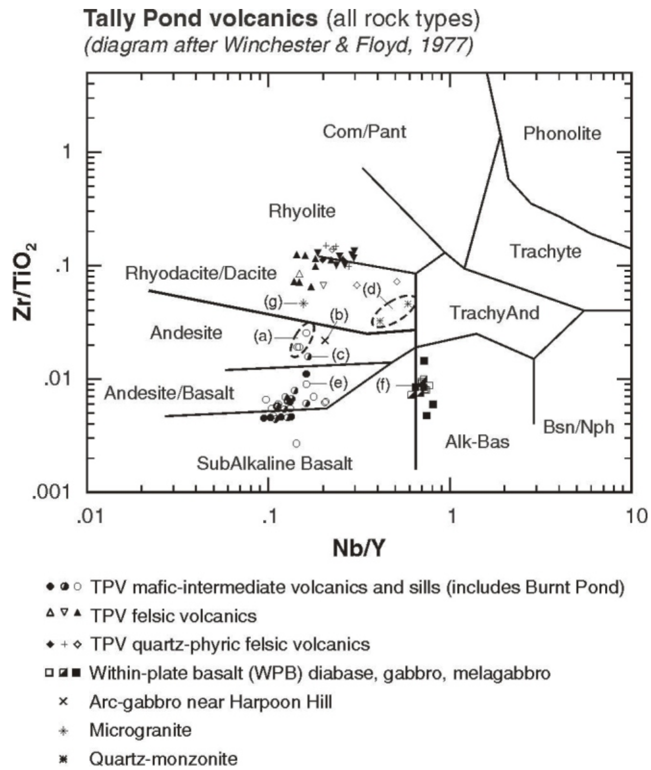

Figure 10. *Study-area rock types indicated by alteration-resistant Nb/Y vs Zr/TiO2 'immobile' element variation diagram (Winchester and Floyd, 1977).* See *text for discussion.*

g) is of the Lemarchant area microgranite body that occurs (contacts not observed) adjacent to the Lemarchant prospect alteration zone and could possibly be a synvolcanic intrusion.

The Zr vs Ti basalt discrimination diagram of Alabaster *et al*. (1982), in Figure 11, illustrates that most mafic samples plot along the pre-Fe–Ti oxide crystallization portion of the basaltic fractionation trend (dashed curved arrow), within the overlap area of the arc lava and MORB fields. Felsic samples plot in the lower part of the arc lava field. The 'dacitic' sills from the Burnt Pond deposit footwall (label a), and the most evolved Lemarchant sill (label c), again plot as intermediate compositions. The one Burnt Pond flow sample (label b), groups near the main field of basic arc-volcanics.

Figure 11 also separates the non-arc sills (all squares on this figure) into two populations that have correspondingly different field occurrences. Nine samples of the relatively fresh composite coarse-grained sill in the Upper Block structural panel immediately above the Duck Pond deposit (Figure 3, samples PJM-02-22 to 029 and 111) have higher Ti and Zr contents. Three carbonatized samples (label d) are from sills that intrude the Upper Duck massive sulphide lens in the Mineralized Block immediately below the Duck Pond

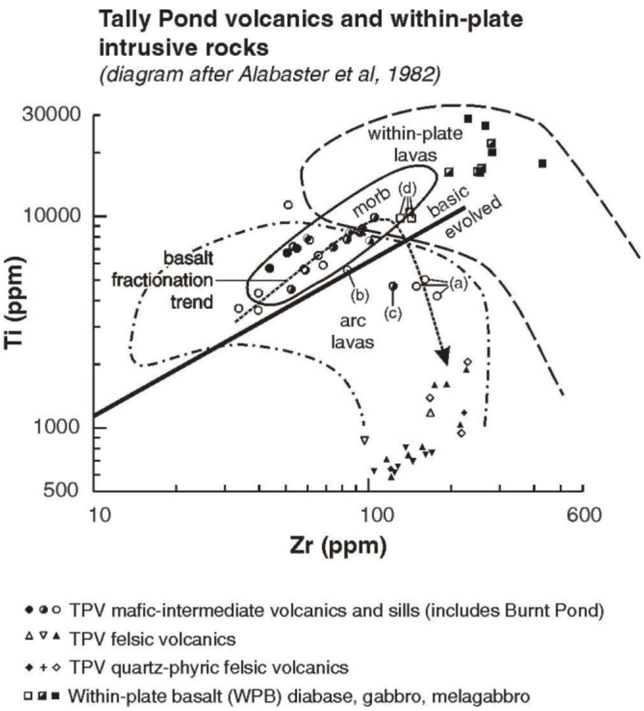

Figure 11. *Study-area arc volcanics and non-arc sills plotted on a Zr/Ti tectonic discrimination diagram.* See *text for discussion.*

thrust zone (Figure 3, samples 054 to 056), and exhibit lower total Ti and Zr contents. The latter samples are also fine grained and pervasively carbonatized (60 to 80 percent carbonate in thin section), but it is difficult to say with this diagram whether the grouping into two Ti–Zr fields is a function of original, or alteration-induced differences in composition.

At 'face value' the pervasive carbonate alteration suggests that these sills were emplaced while the VMS hydrothermal system was still active, i.e. contemporaneous with the deposition of the mineralized sequence volcanic rocks. Disseminations and marginal veins of pyrite and chalcopyrite also support this inference. However, the Duck Pond sills and the mineralized sequence volcanic rocks respectively have within-plate and arc-signatures, these rock types being generally accepted to erupt in distinct tectonic environments (e.g., Swinden, 1987). It is, however, possible for both to erupt simultaneously together (*see* Hughes, 1982, p. 400 for a rare modern example), so the best approach would be to date one of the Duck Pond sills. Assuming that the traditionally accepted diachronous eruption of these lava types is correct, a post-VMS alteration event would be needed to affect the later sills, and such an event has been empirically documented at Duck Pond. It has been observed (Squires, 1988) that strong carbonatization of Upper Block mafic flows is spatially associated with their proximity to (within about 75 m of) the Duck Pond thrust (Figure 3). Since the carbonatized sills are within that distance beneath the thrust, this inferred Silurian to Cambrian structural event could be used to explain post-VMS alteration of the sills. In support of this interpreted sequence of events, recent dating of the Harpoon Hill intrusion has been determined as 465 ± 1 Ma (Pollock, 2004). This intrusion also returned non-arc, within-plate chemistry (*op. cit.*; Pollock *et al*., 2002a) and is directly along strike from the Duck Pond deposit, coming to within one kilometre of the Duck Pond sills. It is here proposed that the similar chemistry, geographic proximity, and age constraints suggested by field relationships, indicate the Duck Pond sills are directly related to the Middle Ordovician Harpoon Hill intrusion. This reasoning also suggests that the Duck Pond thrust, which truncates the sills, is Middle Ordovician or younger.

The Ti–Zr–Y basalt discrimination diagram of Pearce and Cann (1973) clearly distinguishes the Duck Pond sills as within-plate rocks, from the other arc-related mafic volcanic rocks (Figure 12). Other samples of interest are (a) the Burnt Pond footwall basalt flow, which seems to have calc-alkaline tendencies on this plot, (b) the arc-related gabbro, near the within-plate Harpoon Hill intrusion, which appears to have a slight within-plate component on this plot, and (c) the Harpoon Dam non-arc gabbro, which again plots within the non-arc field.

Figure 13 displays primitive mantle-normalized (normalizing values from Hoffman, 1988) extended REE plots of mafic flows and sills from various parts of the TPV. Compared to the wider variations of such profiles throughout central Newfoundland (e.g., Swinden *et al.*, 1989), the Tally Pond mafic rocks are relatively uniform, primitive to slightly calc-alkaline island-arc tholeiites (latter suggested by 'enrichments' of Th and the LREEs). These profiles show that mafic flow units from the deep footwall of the Boundary deposit (in the Mineralized Block), and several levels of the Upper Block structurally above the Duck Pond deposit, as well as Lemarchant sills and Burnt Pond flows, are essentially indistinguishable. This indicates the homogeneity of the sampled mafic volcanic rocks in the belt. It also indicates that with this particular dataset, these trace elements do not provide useful stratigraphic information with this type of variation diagram.

Some of the 'Enrichments' in Th and LREE indicated in Figure 13 can probably be attributed to alteration. For example, the enriched samples PJM-02-021, 02-040, 02-041 and 02-119 (Figure 13, panels c, d and f), show intense carbonatization in thin section. The first three samples are within the structural carbonatization zone (Figure 3) of the Upper Block adjacent to the Duck Pond thrust (*see* Figure 11 discussion above). By inspecting the locations of the depicted samples and the structural alteration front on Figure 3, it is

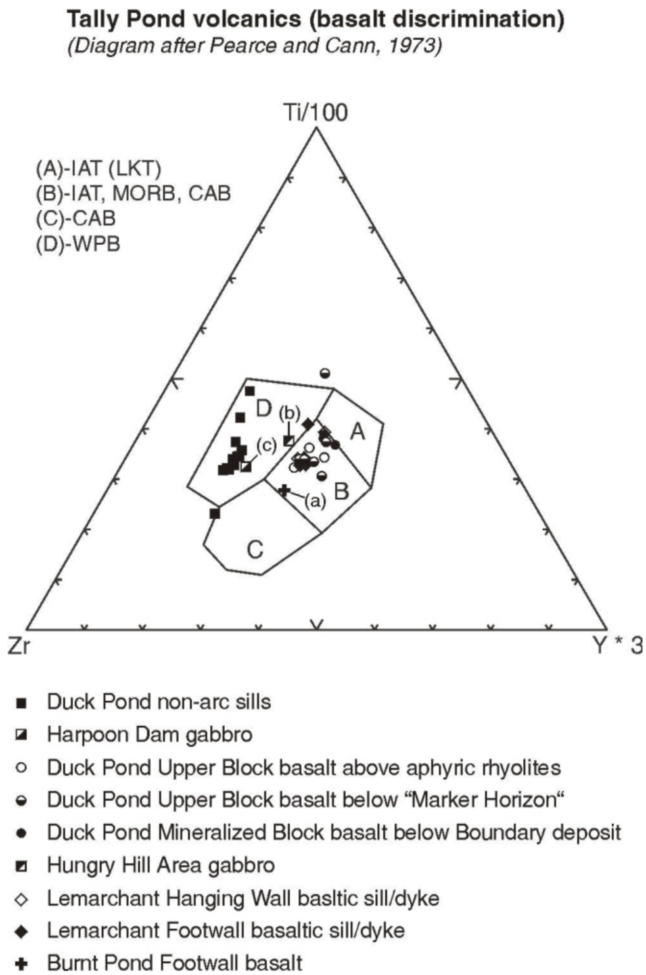

Figure 12. *Ti-Zr-Y discrimination diagram (Pearce and Cann, 1973) of basaltic samples from the Tally Pond volcanics. [Symbols as indicated].* See *text for discussion.*

apparent that some of the most enriched samples are adjacent to the thrust, whereas their more distal counterparts within the same mafic flows depict flatter extended REE profiles. The fourth enriched sample noted is of the Burnt Pond footwall mafic flow unit (PJM-02-119, panel f). Besides being intensely carbonatized in thin-section the unit is also sheared, so by applying the above rationale, it can be inferred that its enriched profile may also be due to alteration, though more sampling at Burnt Pond (in progress) is required to substantiate this. Sample PJM-02-118 (panel b) from the Lemarchant prospect area is intensely chlorite–carbonate altered in thin section, so its unusual pattern may again reflect alteration effects. Therefore, it appears that 'enrichments' in immobile elements may be due to element mobility in the presence of structurally induced carbonate alteration. The recognition of this mobility is important in assessing analytical results, as extended REE plots of affected samples can resemble transitional to calc-alkaline primary compositions, and lead to incorrect interpretations of the paleotectonic environment.

Figure 14 illustrates primitive mantle-normalized extended REE plots for all of the sampled within-plate mafic sills (as defined above), and demonstrates their virtually identical profile shapes, suggesting that they are genetically related. The Duck Pond deposit diabase sills comprise the three coincident samples with the lowest normalized values on the diagram. The remaining broad group of profiles is from the single composite (including its core melagabbro phase) Upper Block gabbro sill. The single Harpoon Dam gabbro has a perfect overlap with the Upper Block gabbro samples, thus strongly suggesting its genetic relationship to the Duck Pond within-plate sills. The identical pattern of the intensely carbonatized Duck Pond sills, to those of the other samples, implies that the 'immobile' elements in these sills were not affected by this alteration.

Figure 15 shows primitive mantle-normalized (normalizing values from Hoffman, 1988) extended REE plots for felsic volcanic and intrusive rocks. In Figure 15a, all aphyric felsic volcanic rocks for the Duck Pond Upper Block structural hanging wall and Duck Pond Mineralized Block stratigraphic footwall are depicted. Note the identical patterns for all samples, suggesting that units on both sides of the Duck Pond thrust are likely related. Mineralized sequence quartz crystal tuffs, for both the Duck Pond and Boundary deposits, as well as one Upper Block quartz-phyric tuff, produced the same patterns and ranges, but for clarity are not plotted. In Figure 15b, profiles of selected evolved volcanic and intrusive rocks – the Stony Lake volcanics (Silurian), the Lemarchant microgranite (Cambrian?) and Burnt Pond area quartz monzonite (Precambrian Crippleback Lake equivalent?) – are plotted against the range of all sampled Tally Pond (felsic) volcanics. The profiles illustrate that only the Lemarchant microgranite sample falls entirely within the range of the Tally Pond (felsic) volcanics. The microgranite unit flanks the Lemarchant prospect alteration zone, and the noted chemical equivalence (when contrasted with the discordance of the other selected samples), suggests that it may be a synvolcanic intrusion related to the genesis of the Lemarchant prospect alteration and mineralization. Furthermore, the discordance of the Burnt Pond quartz monzonite sample indicates it is not related to the TPV sampled.

Immobile trace-element discrimination plots Zr *vs* Th and Zr *vs* Nb (Figure 16a and b respectively) of aphyric felsic volcanics in the Upper Block and in the Mineralized Block footwall at the Duck Pond deposit portray a clear separation of these two units. Similar discrimination success was found with Nb/Y and Ta/Y plots, suggesting these elements may be useful for resolving stratigraphy. The few samples of quartz-phyric tuffs from both sides of the Duck

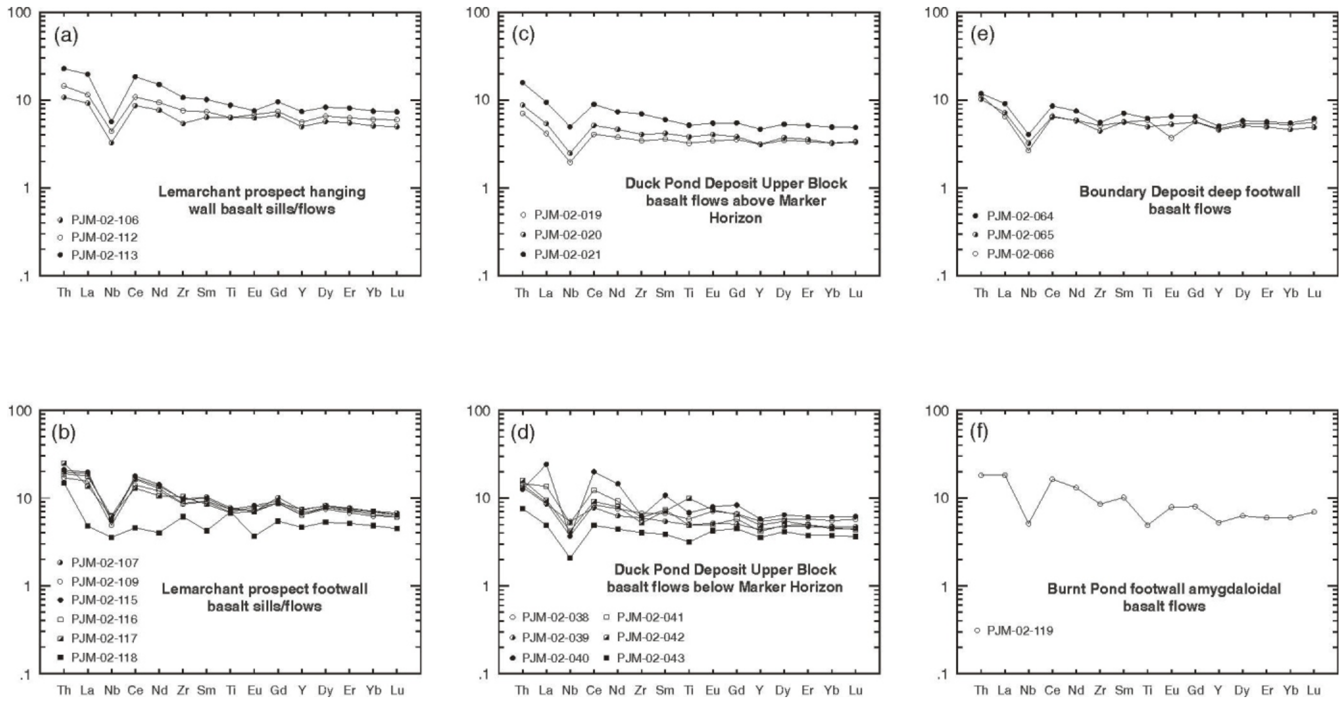

Figure 13. *Primitive mantle-normalized extended REE diagrams for each of the basaltic volcanic rock units, grouped by area. Normalization factors after Hoffman (1988).* See *text for discussion.*

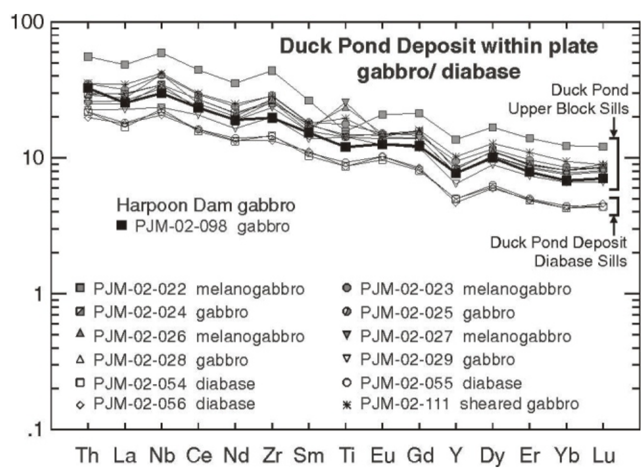

Figure 14. *Primitive mantle-normalized extended REE plot for all of the within-plate, non-arc mafic sills. Normalization factors after Hoffman (1988).* See *text for discussion.*

Pond thrust and the Boundary deposit show variations with some of these elements, but the small sample population and suspected tendancy for these variably epiclastic rocks to be inhomogeneous (winnowing effects, physical mixing of foreign material, alteration), presently precludes any meaningful interpretation of the data. It is likely that the non-tuffaceous volcanic and intrusive rocks will offer the best chance at deriving original compositions for the purpose of stratigraphic mapping. The syn-mineralization (synvolcanic) Burnt Pond intermediate sills also plot separately from all sampled TPV, again hinting at their having a possible distinct origin, as suggested by the Precambrian gabbro dyke of D.H.C. Wilton (personal communication, 2004).

To summarize, lithogeochemical studies broadly confirm conclusions of previous workers that the TPV are a bimodal primitive to possibly mildly calc-alkaline oceanic-arc assemblage, cut by younger within-plate intrusive rocks, probably representative of the arc-rift phase of arc evolution. The presently small database indicates that mafic and felsic volcanic rocks have uniform REE patterns, suggesting that there is little systematic variation linked to stratigraphic position. Lithogeochemical characterization of the mineralized sequence and other quartz-phyric tuffs is currently equivocal, sample density currently being too small to make meaningful inferences. However, some preliminary success has been had in differentiating aphyric Mineralized Block and Upper Block felsic units. The chemical similarities of within-plate intrusives in the Duck Pond Upper Block and Mineralized Block, as well as at Harpoon Dam (and possibly Harpoon Hill, now dated as middle Ordovician by others) indicate that they are related to the same magmatic event. Some variation in extended REE profiles of the mafic volcanics appears to be due to structurally induced carbonatization near the Duck Pond thrust and possibly at other sites. Carbonatization of the late within-plate sills within the Duck Pond VMS-alteration halo also appears to be related to this post-mineralization carbonatization (which does not affect their immobile elemant contents), rather than Cambri-

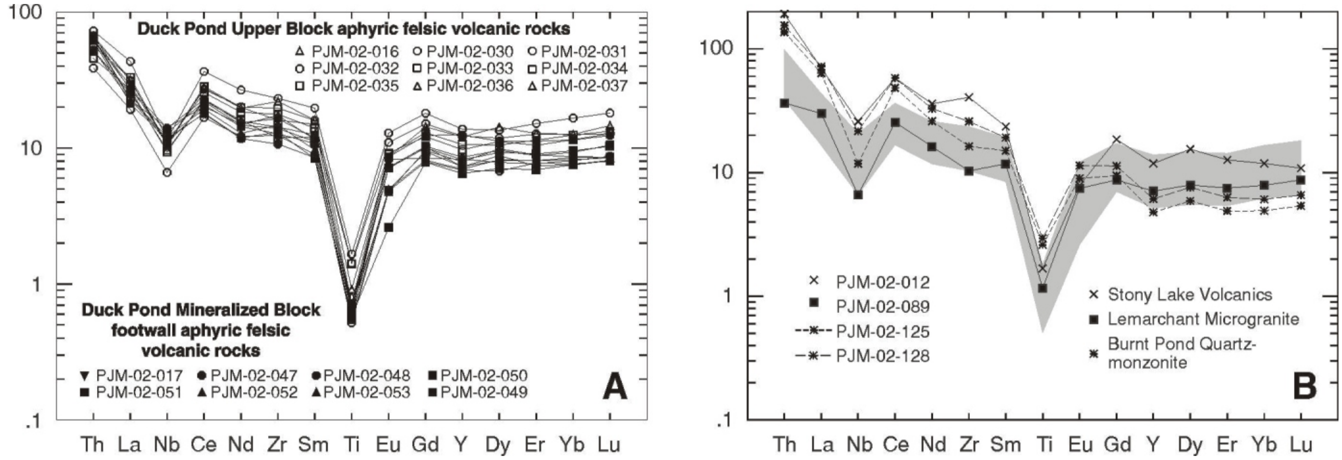

Figure 15. *Primitive mantle-normalized extended REE plots for felsic volcanics and intrusives: (a) all TPV aphyric felsic volcanics (b) other selected volcanic and intrusive rocks (shaded area is sample range from(a)). Normalization factors after Hoffman (1988).* See *text for discussion.*

an VMS alteration. Intermediate compositions appear to be mainly confined to syn-mineralization sills at Burnt Pond, possibly indicating their distinct origin from the TPV (as suggested by recent dating). Extended REE profiles of the Lemarchant microgranite suggest it is a synvolcanic intrusion of the TPV. An extended REE profile of the previously presumed TPV east of Sandy Lake does not match those of the sampled Tally Pond (felsic) volcanics from this study. Extended REE profiles of a quartz monzonite intrusive in the Burnt Pond area, of probable Crippleback Lake plutonic suite affinity, do not match the profiles of the sampled TPV, supporting their distinct origin as previously interpreted.

CONCLUSIONS

Industry geologists have long commented on the empirical link between VMS mineralization in the Tally Pond volcanics and quartz-phyric tuffaceous rocks. Work conducted during this study confirms and expands this observation beyond the Duck Pond area. Geochronology suggests that these quartz-phyric tuffs have a common age, and these rocks are important for stratigraphic correlation and mineral exploration. It is suggested that the quartz-phyric nature of the mineralized sequences and their widespread alteration and mineralization indicate sub-volcanic magma chambers that provided heat for hydrothermal systems and suitable host rocks for mainly sub-seafloor deposition of sulphides. The geochemical similarity of the Lemarchant microgranite to that of the TPV, suggests that it may be an example of such a sub-volcanic intrusion, in this case probably related to the genesis of the Lemarchant prospect.

The recovery of ‘inherited’ Precambrian (573 ± 4 Ma) zircons from the TPV (McNicoll, 2003), is considered the first direct evidence of the incorporation of Gondwanan continental crust during Cambrian Tally Pond magmatism. This data suggests that the TPV and the late Precambrian plutonic rocks were physically associated in the Cambrian, and that their original contact relationship may have been unconformable.

The TPV mostly comprise a bimodal, primitive island-arc assemblage, but are locally transitional to calc-alkaline in composition. Younger sills and dykes of within-plate affinity from Duck Pond, Harpoon Dam and possibly Harpoon Hill, are suggested to be genetically related, with the Harpoon Hill example recently being dated at 465 ± 1 Ma (Pollock, 2004), but further dating is required. Mafic and felsic volcanic rocks of the TPV have very uniform geochemical signatures, throughout the TPV as sampled. Some ‘enrichments’ in LREE are not primary, but are caused by local areas of structurally induced carbonatization. Thus, some of the apparent calc-alkaline tendencies of the volcanic rocks may not be truly indicative of magma compositions.

Although the Burnt Pond VMS prospect is associated with a quartz-phyric volcanogenic epiclastic horizon similar to that at the Duck Pond deposit, recent dating (D.H.C. Wilton, personal communication, 2004) implies that host volcanic rocks may be Precambrian in age. A quartz monzonite body at Burnt Pond may correlate with the Precambrian Crippleback Lake pluton. The Burnt Pond volcanic rocks and the quartz monzonite contain zones of alteration and mineralization, indicating the quartz monzonite might represent a co-genetic sub-volcanic intrusion, related to the Burnt Pond mineralization. Geochronolocical and lithogeochemical work in progress should help to clarify the ages and affinities of rocks at Burnt Pond.

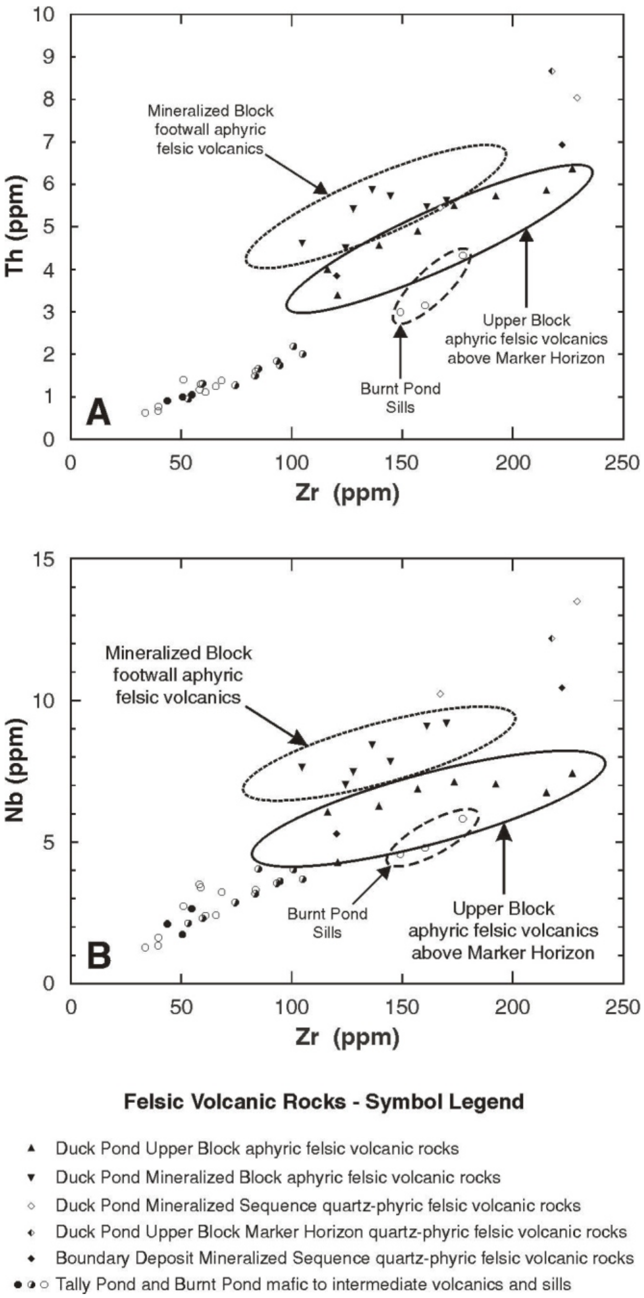

Figure 16. *Immobile trace-element discrimination plots; (a) a Zr vs Th plot and (b) a Zr vs Nb plot achieve a complete separation of Duck pond area felsic flow units.* See *text for discussion.*

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REFERENCES

Alabaster, T., Pearce, J.A. and Malpas, J.
1982: The volcanic stratigraphy and petrogenesis of the Oman ophiolite complex. Contributions to Mineralogy and Petrology, Volume 81, pages 168-183.

Brace, T.D., Hussey, A.M. and Squires, G.C.
2000: 1999 Impost report for Reid Lot 234 (line cutting, geological mapping, prospecting and diamond drilling), Tally Pond area, central Newfoundland (NTS 12A/9,10). Newfoundland and Labrador Geological Survey, Assessment File 12A/0973. Thundermin Resources Inc., 282 pages.

Collins, C.
1991: Fourth year assessment EPOCH Option (6776), licence 3000, March 1990-March 1991, NTS 12A/9. Newfoundland and Labrador Geological Survey, Assessment File 12A/09/0598. Noranda Exploration Company Limited, 125 pages.

1992: Report on 1991 assessment work over concession lands within the boundary of the Noranda-BP Resources Ltd., Tally Pond joint venture (A.N.D. Charter, Reid Lot 229, 231, 234, & 235), NTS. 12A/7, 9, 10. Newfoundland and Labrador Geological Survey, Assessment File 12A/0630. Noranda Exploration Company Limited, 835 pages.

1993: Report on 1992 assessment work over concession lands within the boundary of the Noranda-BP Resources Ltd., Tally Pond joint venture (A.N.D. Charter, Reid Lot 231, 234, & 235), NTS. 12A/7, 9, 10. Newfoundland and Labrador Geological Survey, Assessment File 12A/0643. Noranda Exploration Company Limited, 74 pages.

Collins, C.J.
1989: Report on lithogeochemical study of the Tally Pond volcanics and associated alteration and mineralization. Unpublished company report, Noranda Exploration Company Ltd., St. John's, Newfoundland.

Colman-Sadd, S.P, Dunning, G.R. and Dec, T.
1992: Dunnage-Gander relationships and Ordovician orogeny in central Newfoundland: a sediment provenance and U/Pb age study. American Journal of Science, Volume 292, pages 317-355.

Dimmell, P.M.
1986: A case history of the discovery and geophysical and geochemical signatures of the Burnt Pond sulphide prospect, Noel Paul's Brook area, central Newfoundland, NTS 12A/9. Unpublished B.Sc. thesis, University of New Brunswick, 56 pages.

Dunning, G.R.
1986: Precise U-Pb zircon geochronology applied to Newfoundland ophiolites, granitoid and felsic volcanic rocks. Program with Abstracts, Newfoundland Section, Geological Association of Canada, Annual Spring Meeting, St. John's, pages 11-12.

Dunning, G.R. Swinden, H.S., Kean, B.F., Evans, D.T.W. and Jenner, G.A.
1991: A Cambrian island arc in Iapetus: geochronology and geochemistry of the Lake Ambrose volcanic belt, Newfoundland Appalachians. Geological Magazine, Volume 128, No. 1, pages 1-17.

Evans, D.T.W. and Kean, B.F.
2002: The Victoria Lake Supergroup, central Newfoundland - Its definition, setting and volcanogenic massive sulphide mineralization. Newfoundland Department of Mines and Energy, Geological Survey, Open File NFLD/2790, 68 pages.

Evans, D.T.W., Kean, B.F. and Dunning G.R.
1990: Geological studies, Victoria Lake Group, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 131-144.

Evans, D.T.W., Kean, B.F. and Jayasinghe, N.R.
1994a: Geology and mineral occurrences of Noel Paul's Brook. Map 94-222. Scale: 1:50 000. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 012A/09/0685. Blueline paper. GS# 012A/09/0685.

Evans, D.T.W., Kean, B.F. and Mercer, N.L.
1994b: Geology and mineral occurrences of Lake Ambrose. Map 94-223. Scale: 1:50 000. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Open File 012A/10/0686. Blueline paper. GS# 012A/10/0686

Finch, C.J.
1998: Inductively coupled plasma - emission spectrometry (ICP-ES) at the geochemical laboratory. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 98-1, pages 179-194.

Hoffman, A.W.
1988: chemical differentiation of the Earth: the relationship between mantle, continental crust, and oceanic crust. Earth and Planetary Science Letters, Volume 90, pages 297-314.

Hughes, C.J.
1982: Developments in petrology 7: Igneous Petrology. Elsvier, New York. 551 pages.

Jenner, G.A, Longerich, H.P., Jackson, S.E. and Fryer, B.J.
1990: ICP-MS - a powerful tool for high precision trace element analysis in earth sciences: evidence from analysis of selected USGS reference samples. Chemical Geology, Volume 83, pages 133-148.

Kean, B.F. and Evans, D.T.W.
1988: Regional metallogeny of the Victoria Lake Group. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 88-1, pages 319-330.

Kean, B.F., Evans, D.T.W. and Jenner, G.A.
1995: Geology and mineralization of the Lush's Bight Group: Report 95-2, Department of Natural Resources, Newfoundland and Labrador, Geological Survey, 204 pages.

Kean B.F. and Jayasinghe, N.R.
1980: Geology of the Lake Ambrose (12A/10)- Noel Paul's Brook (12A/9) map areas, central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-2, 29 pages.

Longerich, H.P., Jenner, G.A., Fryer, B.J. and Jackson, S.E.
1990: Inductively coupled plasma-mass spectrometric analysis of geological samples: a critical evaluation based on case studies. Chemical Geology, Volume 83, pages 105-118.

McNicoll, V.
2003: U-Pb geochronology report for the Tally Pond project. Geological Survey of Canada unpublished contractual report to the Newfoundland Department of Mines and Energy, 15 pages.

Moore, P.J.
2003: Stratigraphic implications for mineralization: Preliminary findings of a metallogenic investigation of the Tally Pond volcanics, central Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 03-1, pages 241-257.

Mullins, W.J.
1961: Geology of the Noel Paul's Brook area, central Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 97 pages.

Neuman, R.B.
1984: Geology and paleobiology of islands in the Ordovician Iapetus Ocean: review and implications. Geological Society of America Bulletin, Volume 95, pages 1188-1201.

Noranda Exploration Company Ltd.
1988: Gander district monthly progress report, July, 1988. Noranda Mining and Exploration Ltd., St. John's Office.

1990: Gander district monthly progress report, August, 1990. Noranda Mining and Exploration Ltd., St. John's Office.

1991: Geotechnical review of the Tally Pond joint venture area. Noranda internal report by St. John's office staff.

Oneschuk, D., Tod, J. and Kilfoil, G.
2001: Red Indian Line Geophysical Compilation (Part I), central Newfoundland. Geological Survey of Canada Open File 3923, Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Open File 12A/0911. CD-ROM.

Pearce, J.A. and Cann, J.R.
1973: Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Sciences Letters, Volume 19, pages 290-300.

Pesalj, R.
1982: Geological, geophysical, geochemical and diamond drill report, Badger project, Newfoundland. Claim blocks 2966-2980, Lic. No. 2015-2026; 2042-2044, NTS 12A/9, 12A/16. Mines and Energy Open File # 12A/334.

Pollock, J.C.
2004: Geology of the Tally Pond Group, Victoria Lake Supergroup, Dunnage Zone, Newfoundland: An integrated geochemical, geochronological, isotopic and metallogenic study of a Cambrian ensimatic island arc. Unpublished M.Sc. Thesis, Memorial University of Newfoundland, 328 pages.

Pollock, J.C. and Wilton, D.H.C.
2001: Metallogenic studies of the Tally Pond belt, Victoria Lake Group: trace-element geochemistry and lead isotope data from the Exploits Subzone, Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 01-1, pages 247-266.

Pollock, J.C., Wilton, D.H.C. and van Staal, C.R.
2002a: Geological studies and definition of the Tally Pond Group, Victoria Lake supergroup, Exploits Subzone, Newfoundland Appalachians. *In* Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 02-1, pages 155-168.

Pollock, J.C., Wilton, D.H.C., van Staal, C.R. and Tubrett, M.N.
2002b: Laser ablation ICP-MS geochronology and provenance of detrital zircons from the Rogerson Lake Conglomerate, Botwood Belt, Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 02-1, pages 169-183.

Sheppard, D.
1996: Second year assessment report for Licence 4585, Pittman's Pond property, NTS 12A/9. Unpublished Noranda Mining and Exploration Inc. assessment report.

Squires, G.C.
1988: Sixth year assessment report on diamond drilling exploration for licence 2553e on claims in the Duck Pond and Tally Pond areas, Newfoundland. Newfoundland and Labrador Geological Survey, Assessment File 12A/0484. Noranda Exploration Company Limited, Chemex Labs Limited, Selco Division-BP Resources Canada Limited, and BP Resources Canada Limited, 664 pages.

1994: 12th year assessment report (Geology, drilling, geochemistry, geophysics) on extended Licence 2553E

(Duck Pond deposit area) NTS 12A/9. Newfoundland and Labrador Geological Survey, Assessment File #0688. Unpublished Noranda Exploration Co. Ltd. assessment report.

Squires, G.C., Brace, T.D. and Hussey, A.M.
2001a: JCEAP completion report to the Minister of Mines and Energy on the 2001 advanced exploration program (diamond drilling, lithogeochemistry and borehole TDEM) Old Camp Project. Government of Newfoundland and Labrador, March, 2001, 21 pages plus appendices.

2001b: Newfoundland's polymetallic Duck Pond deposit: Earliest Iapetan VMS mineralization, formed within a sub-seafloor, carbonate-rich alteration system. *In* Geology and Mineral Deposits of the Northern Dunnage Zone, Newfoundland Appalachians. *Edited by* D.T.W. Evans and A. Kerr. GAC/MAC Field Trip Guide A2 (Part 1), pages 167-187.

2002a: Assessment report (horizontal loop EM, diamond drilling, lithogeochemistry) Licences 4820M (7th yr.), and 4782M (6th yr.) North Moose Pond project Tally Pond area, central Newfoundland (NTS 12A/9) February 2002, Thundermin Resources assessment report.

2002b: 2001 Impost report Reid Lot 234 (East Pond and Boundary West Projects) A.N.D. Charter (South Moose Pond Project) (diamond drill core re-logging, diamond drilling, whole rock lithogeochemistry and borehole TEM surveys), Tally Pond area, central Newfoundland, (NTS 12A/9, 12A/10) for Thundermin Resources Inc. April 2002, Confidential company assessment report.

Squires, G.C. and Hussey, A.M.
2001: Assessment report (geological mapping and prospecting, re-logging, lithogeochemistry) covering Licence 7696M (1st and 2nd years), Higher Levels project, Lake Ambrose Area, central Newfoundland, (N.T.S. 12A/10) for Thundermin Resources Inc., November 2001.

Squires, G.C., MacKenzie, A.C. and MacInnis, D.
1990: Geology and genesis of the Duck Pond volcanogenic massive sulphide deposit. *In* Metallogenic framework of base and precious metal deposits, central and western Newfoundland. *Edited by* H.S. Swinden, D.T.W. Evans and B.F. Kean. Eight IAGOD Symposium Field Trip Guidebook. Geological Survey of Canada Open File 2156, pages 56-64.

Swinden, H.S.
1987: Ordovician volcanism and mineralization in the Wild Bight Group, central Newfoundland: a geological, petrological, geochemical and isotopic study. Unpublished Ph.D. thesis, Memorial University of Newfoundland, St. John's, 452 pages.

Swinden, H.S., Jenner, G.A., Kean, B.F. and Evans, D.T.W.
1989: Volcanic rock geochemistry as a guide for massive sulphide exploration in central Newfoundland. *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-1, pages 201-219.

Swinden, H.S. and Thorpe, R.I.
1984: variations in style of volcanism and massive sulfide deposition in Early to Middle Ordovician island arc sequences of the Newfoundland Central Mobile Belt. Economic Geology, Volume 79, pages 1596-1619.

van Staal, C.R.
1994: Brunswick subduction complex in the Canadian Appalachians; record of the late Ordovician to Late Silurian collision between Laurentia and the Gander margin of Avalon. Tectonics, Volume 13, Number 4, pages 946-962.

Wagner, D.W.
1993:Volcanic stratigraphy and hydrothermal alteration associated with the Duck Pond and Boundary volcanogenic massive sulphide deposits, central Newfoundland. Unpublished M.Sc. thesis, Carlton University, Ottawa, 197 pages.

Williams H., Colman-Sadd, S.P. and Swinden, H.S.
1988: Tectonic - stratigraphic subdivisions of central Newfoundland. *In* Current Research, Part B. Eastern and Atlantic Canada, Geological Survey of Canada, Paper 88-1B, pages 91-98. (NFLD/2022)

Winchester, J.A. and Floyd, P.A.
1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, Volume 20, pages 325-343.