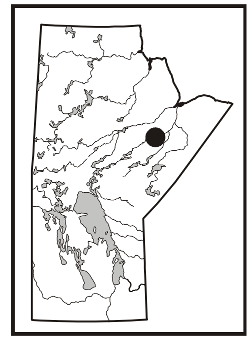
VOLCANIC STRATIGRAPHY OF SELECTED SECTIONS ON THE FOX AND STUPART RIVERS, FOX RIVER BELT (PARTS OF NTS 53M/16 AND 53N/13)

by E.C. Syme, D.C. Peck and C. Wegleitner[1]



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SUMMARY

Preliminary work conducted on volcanic stratigraphy and flow morphology in the Paleoproterozoic Fox River Belt capitalized on previous careful work by Scoates (1981) and extremely low water conditions in 1999 that provided important new bedrock exposure in river sections. This work shows that there is significant variation in flow morphology between and within the two major volcanic formations in the belt. These variations hint that systematic changes in eruptive style and conditions took place during the marine emplacement of the komatiitic to basaltic flows. Mapping of flows in the second (along-strike) dimension also revealed that the volcanic stratigraphy is considerably more complex than previously suspected. These observations have implications for the geometry of any potential intra-flow magmatic sulphide deposits. Newly discovered discordant alteration zones and stratiform sulphide occurrences within both volcanic formations indicate that hydrothermal processes were active on the sea floor synchronous with volcanism, adding a new dimension to the better known magmatic Ni potential in the belt and providing an alternative source for the external sulphur that is believed to be critical in the development of magmatic Ni sulphide deposits.

INTRODUCTION

In 1999 the Geological Services Branch began renewed study of the Fox River Belt (see Peck et al., GS-12, this volume; Fig. GS-14-1), 22 years after the last field work was conducted in the area (reported in Scoates, 1981, 1990). One component of the new work involves mapping, sampling and characterizing the volcanic rocks, with emphasis on those parts of the section that were newly exposed due to the low water conditions experienced in the summer of 1999.

The Fox River Belt (FRB) forms part of the Paleoproterozoic Circum-Superior Belt, composed of rocks of similar age, stratigraphy and lithology, that occurs around the margin of the Archean Superior craton (Baragar and Scoates, 1980). The FRB borders the northern edge of the Superior craton in Manitoba for some 300 km, although much of the belt is very poorly exposed and its extent is known largely from its aeromagnetic signature (Scoates, 1981, 1990).

The FRB consists of a north-facing, homoclinal succession of ultramafic to mafic volcanic rocks, sedimentary rocks and large differentiated sills divided stratigraphically (base to top; from Scoates, 1981) into: Lower sedimentary formation (4.0-4.5 km), Lower volcanic formation (2.0-2.5 km), Middle sedimentary formation (0.3-0.8 km), Upper volcanic formation (2.5-3.4 km) and Upper sedimentary formation (1.0-2.0 km). The Lower differentiated intrusions (0.8 km) are emplaced into the Lower sedimentary formation. The Fox River Sill (2.0 km) is intrusive into Middle sedimentary formation rocks and is interpreted to be time equivalent to the Upper volcanic formation lavas (Scoates, 1981).

The volcanic successions are overwhelmingly composed of komatiitic basalt to basalt lava flows, interpreted to have been the products of fissure eruptions (Scoates, 1981). The flows were emplaced in a marine environment and are dominated by pillowed, massive and compound flow types. Primary volcanic structures and textures are

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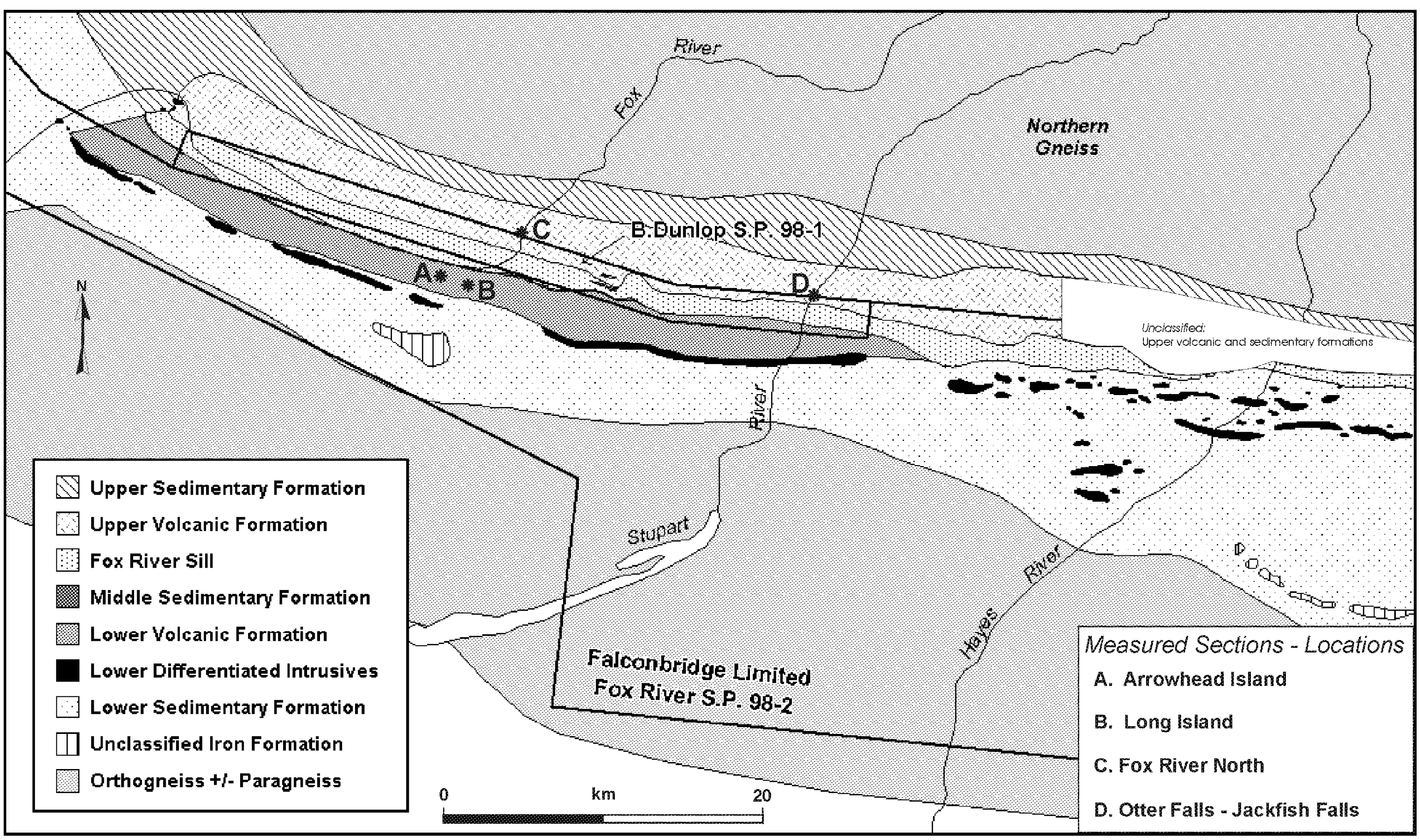


Figure GS-14-1: Major geological features of the exposed (western) part of the Fox River Belt (modified from Scoates, 1981; digital compilation by Falconbridge Ltd., Winnipeg), with locations of sections examined in 1999.

exceptionally well preserved in most of the FRB because metamorphic grade is low (prehnite-pumpellyite to lower greenschist), primary mineralogy is largely preserved, and deformation is virtually non-existent at outcrop scale (Scoates, 1981).

In 1999, clean exposures in river channels provided lithologic and stratigraphic information not available to Scoates (1981), who experienced 'normal' water levels during his work in the late 1960's to mid-1970's. The river exposures commonly are continuous over tens to hundreds of metres, affording an unparalleled opportunity to map considerable thicknesses of volcanic stratigraphy. Our work was conducted in the middle portion of the Lower volcanic formation on the Fox River (Long Island and "Arrowhead Island"), the lower half of the Upper volcanic formation on the Stupart River (Otter Falls to Jackfish Falls), and the sporadically exposed Upper volcanic formation on the Fox River. In this preliminary report we present detailed measured sections in the Long Island and Otter Falls - Jackfish Falls areas, as well as general descriptions from "Arrowhead Island" (Fox River) and Fox River North. We conducted geochemical sampling of the measured flow sections concomitant with the mapping (Peck, GS-12, this volume). Note that all thicknesses reported are "true stratigraphic thickness", i.e., the measured section corrected for 1) cases in which the line of section was oblique to stratigraphy, and 2) dip of flows.

LONG ISLAND, FOX RIVER

Long Island is located on the Fox River, approximately 1 km downstream (northeast) from its confluence with the Sipanigo River (Fig. GS-14-1). The 400 m long island exposes on its southeastern shore a virtually complete section through 238 m of lavas in the middle portion of the Lower volcanic formation. The twenty-one flows that comprise the section range in thickness from 1.1 to more than 21 m and average 11.4 m (Fig. GS-14-2). The flows top to the north and have an average strike of 287° and dip of 82°N. Flow types include massive (aggregate thickness 27% of the section), pillowed (32%), and compound (massive and pillowed; 41%). In total, massive lava (in both massive and compound flows) makes up 39% of the section. Flow top breccia and inter-flow hyaloclastite are rare.

Pillows in the Long Island section are bun-shaped to elongate and range in size up to several metres long by 2 m wide. Commonly there is no organization in pillow size through the flows, i.e., pillow size does not decrease upwards (Fig. GS-14-3). Pillow mounds with relief of up to 1 m occur at the tops of some pillowed or compound flows. Flow top breccias are absent; flow 15 has a 50 cm thick pillow breccia (flow-foot breccia?) at its base (Fig. GS-14-4). Pillow selvages are black and ca. 5 mm thick; interpillow material (carbonate, quartz) is recessive-weathered (Fig. GS-14-5). Coarse vuggy quartz fills the larger voids between pillows. Some pillows have sporadic carbonate-filled amygdales (weathered pits on outcrop surfaces) up to 1 cm in diameter, locally concentrated in the upper pillow margin. Stacked pillow shelves (Fig. GS-14-6), formed during successive episodes of lava drain-back, occur in many pillows in the Long Island section, generally in the upper half of pillows. Many pillows have 1-15 mm diameter devitrification structures (spherulites), either isolated or

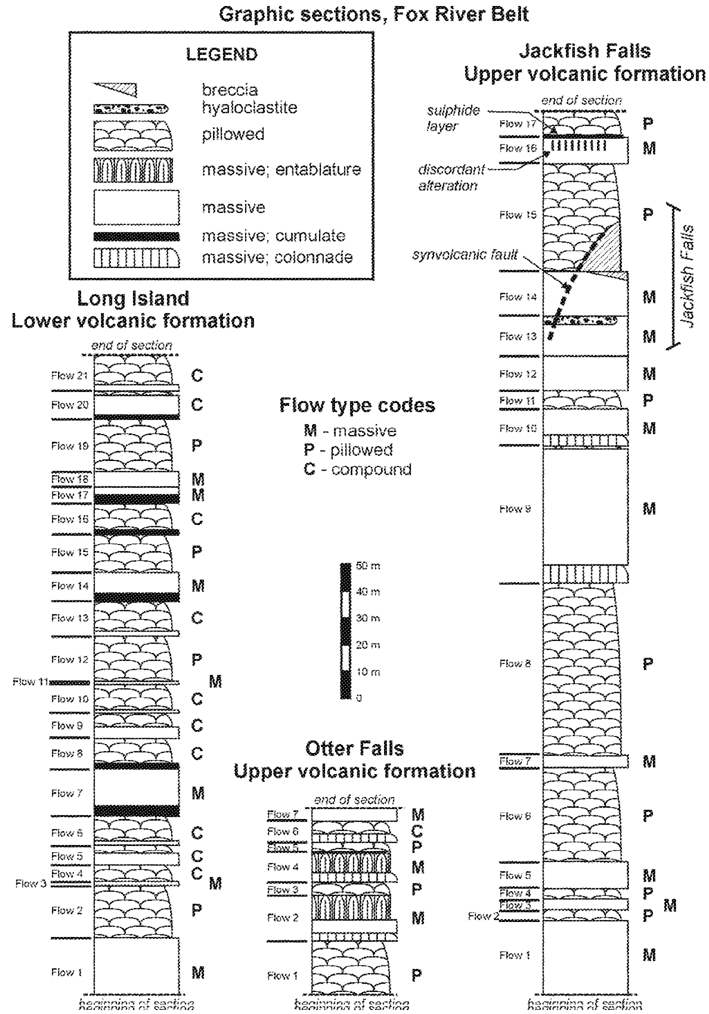


Figure GS-14-2: Graphic logs of the volcanic stratigraphy in the Long Island, Otter Falls and Jackfish Falls areas (see Fig. GS-14-1 for locations). Flows at the beginning and end of measured sections are incomplete in all sections. All thicknesses are "true", i.e., corrected for flow dip, etc.

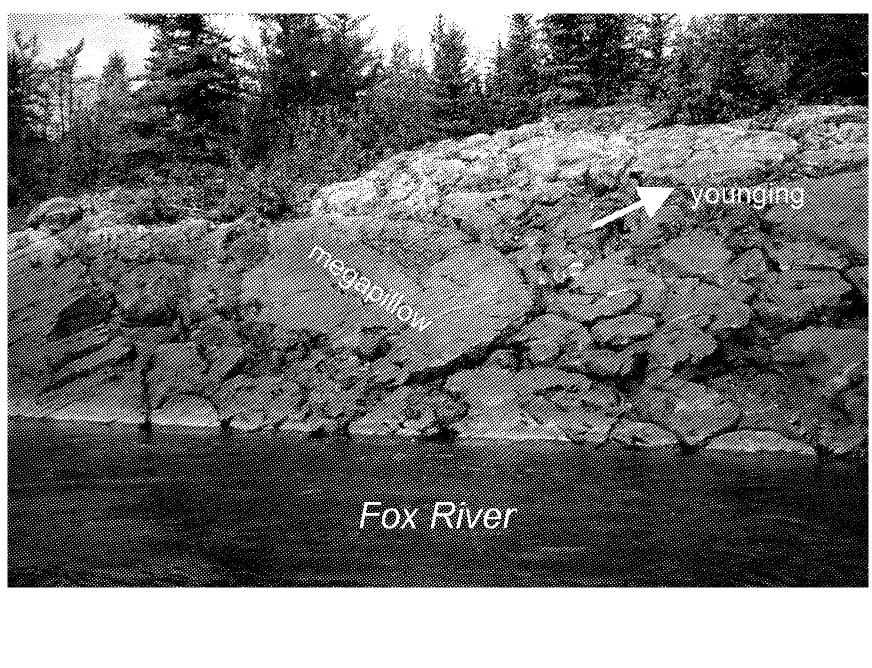


Figure GS-14-3: Pillowed flow, Long Island, Lower volcanic formation. Note mix of megapillows and smaller pillows, with no distinct pillow size organization through the flow. The lava flows trend parallel to the long axis of the megapillow and dip 82° north (to the upper right of this photograph). Stratigraphic tops are to the right. Stacked pillow shelves are in the upper portion of labeled megapillow.

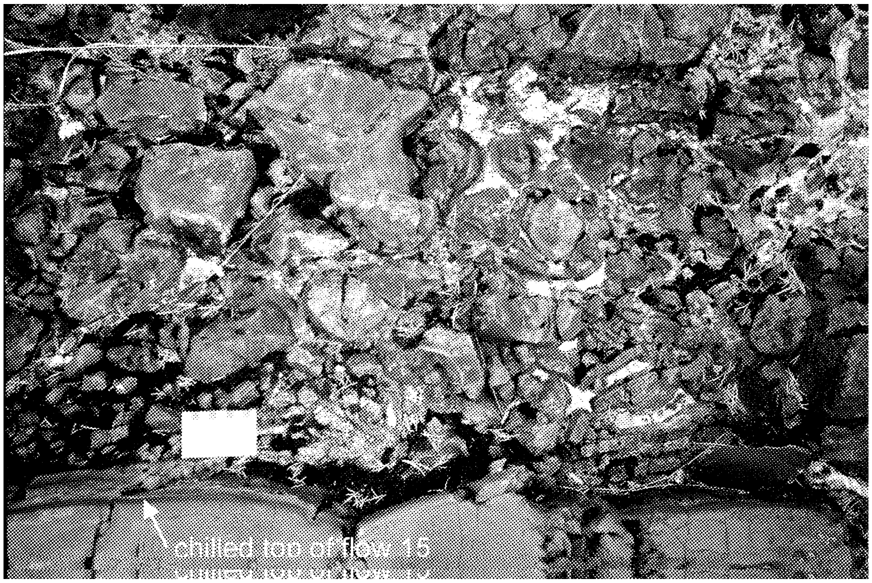


Figure GS-14-4: Undulatory flow top of massive flow 15, overlain by 50 cm thick flow-foot breccia of flow 16, Long Island, Lower volcanic formation. The top of the massive flow is chilled and has a selvage. Fragments in the breccia are angular pieces of pillows, in a matrix of vuggy quartz.

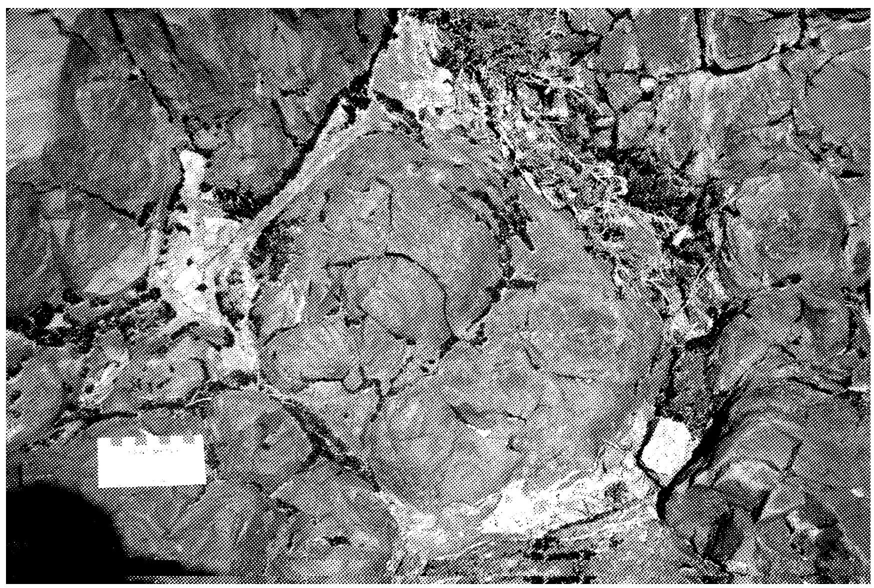


Figure GS-14-5: Interpillow voids filled with carbonate (light grey, at void margins) and white quartz (white; cores), flow 8, Long Island, Lower volcanic formation.

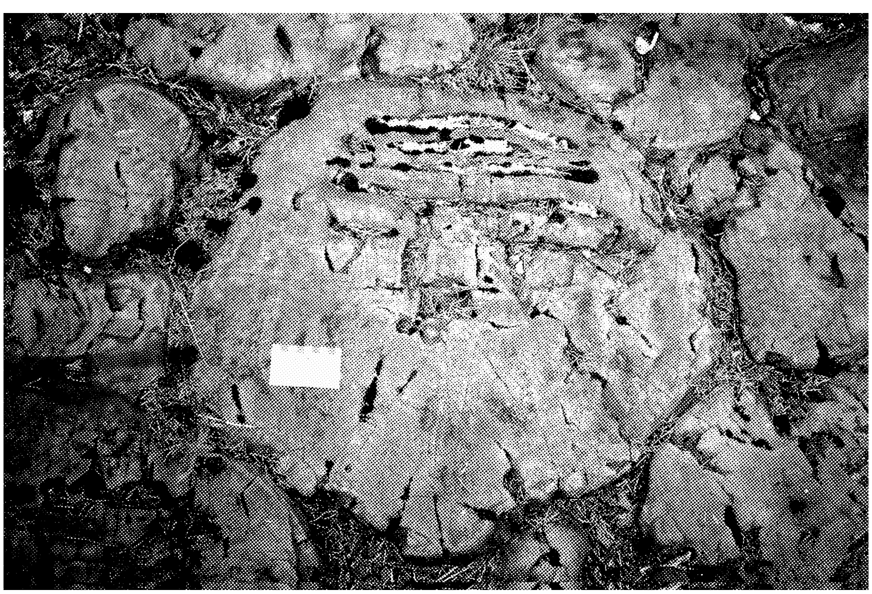


Figure GS-14-6: Stacked pillow shelves filled with vuggy quartz, in an equidimensional pillow. Upper volcanic formation, Fox River N 2 section. Note radial cooling joints perpendicular to pillow selvage.

Figure GS-14-7: Isolated and coalesced spherulites in the margin of a megapillow, flow 19, Long Island, Lower volcanic formation. These features, interpreted as devitrification structures, are particularly prominent in the Long Island section. Carbonate-filled amygdale (pit; dark) occurs to the right of the scale card.

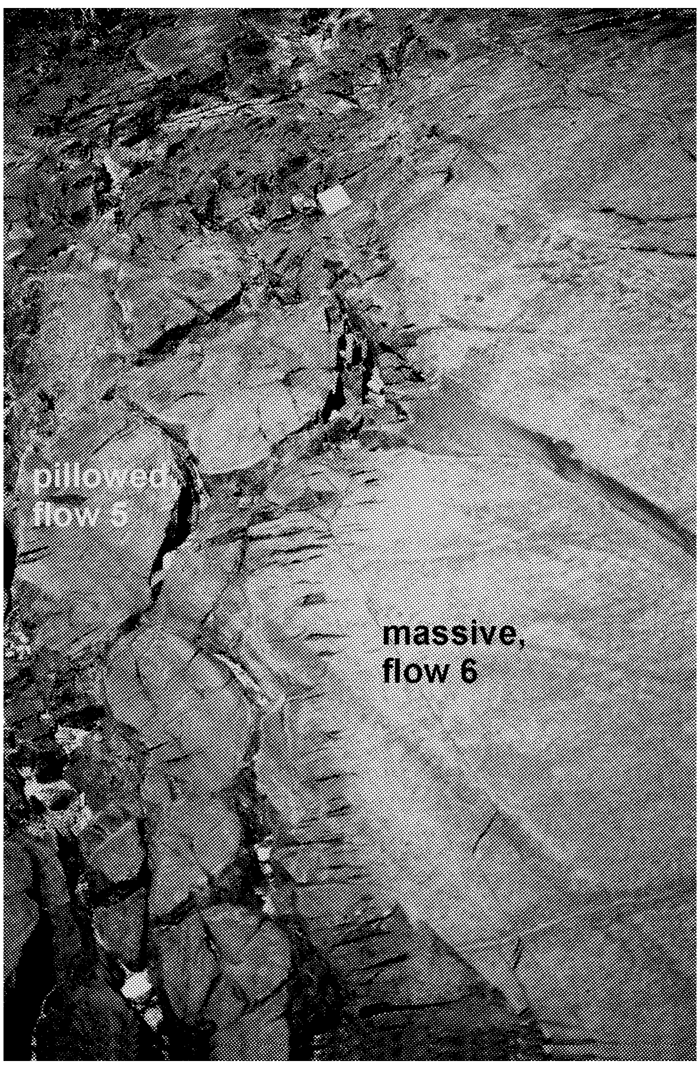


Figure GS-14-8: Contact between small pillows of flow 5 (left) and megapillow or massive zone of flow 6, Long Island, Lower volcanic formation. Note that the massive material is molded into the irregular top of the underlying pillowed flow. Cooling joints occur at the base of the massive flow.

coalesced, in pillow margins (Fig. GS-14-7). In massive flows, curvilinear zones of these structures outline incipient pillows. Some pillows within flows have radial cooling joints (commonly polygonal) oriented perpendicular to pillow margins. Pillows at the top of pillowed flows also commonly show polygonal joints.

Massive flows have sharp, chilled, planar to undulatory basal and top contacts (Fig. GS-14-4). About half of the massive flows have a cumulate zone at the base, characterized by a distinctly coarser texture with serpentinized olivines to 1 mm. The cumulate zone typically fines upward and is replaced by an acicular pyroxene zone in which clinopyroxene crystals are up to 1 cm long. Some of the massive flows have polygonal cooling joints developed in the base or top 50-100 cm, but the well developed colonnade and entablature zones that characterize massive flows in the Jackfish Falls section (below) are not developed. One flow has V-shaped brecciated fissures that extend up to 1 m into the flow top.

Compound flows have a massive base and a pillowed top. The 'contact' between zones is gradational in that the topmost part of the massive zone often has incipient, incomplete pillows or megapillows, defined by bits of selvage, lines of amygdales or curvilinear zones of spherulites. This internal 'contact' is in some instances bulbous and the first pillows in the pillowed portion of the flow are molded over the bulbous protuberances at the top of the massive zone. Typically, the pillows at the base of the pillowed zone are elongate megapillows. Some compound flows with very narrow (e.g., 1 m) massive zones may in fact be pillowed flows with large, elongate megapillows at the base, which in limited exposure look like a massive part of the flow (Fig. GS-14-8).

"ARROWHEAD ISLAND", FOX RIVER

The informally named "Arrowhead Island" is located on the Fox River, approximately 1 km upstream (north) of its confluence with the Sipanigo River (Fig. GS-14-1). The lavas exposed on the island and river channels are part of the Lower volcanic formation, only a few tens of metres higher in the section than the flows on Long Island.

Mapping in the "Arrowhead Island" area revealed a dominantly pillowed section (Fig. GS-14-9) containing seven distinct flows. The pillowed flows are considerably thicker than those on Long Island. The possibility exists that cryptic flow contacts, not marked by mesoscopic lithologic changes, were missed. Indeed, the contact between pillowed flows 5 and 7 is distinguished by a layer of reworked hyaloclastite only 10-15 cm thick (Fig. GS-14-10).

Apart from the thickness of the pillowed sections, the "Arrowhead Island" section provides important information about the second (along strike) dimension of the flows. Continuous exposure on both sides of a 30 m wide island reveal distinctly different stratigraphic sections (Fig. GS-14-9). The absence of folding and faulting requires that these distinct sections be stratigraphically equivalent. The thick massive unit in

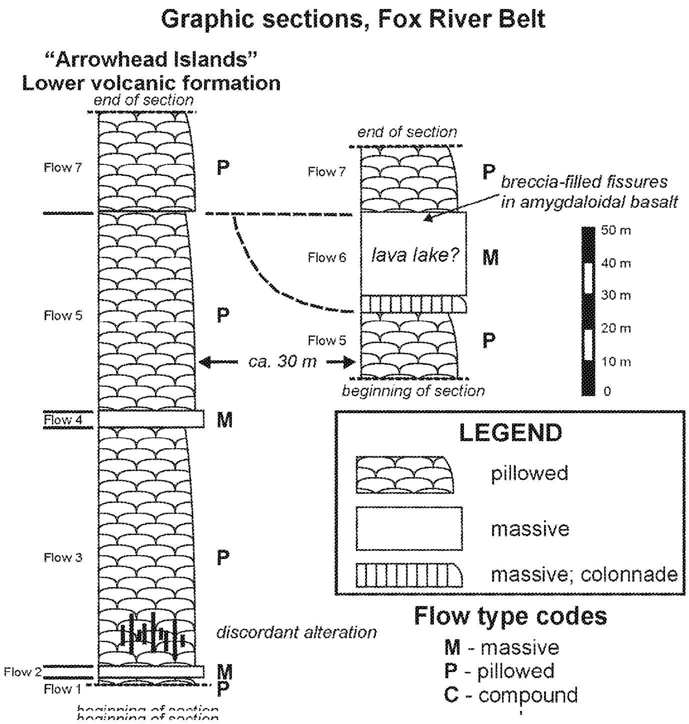


Figure GS-14-9: Graphic logs of the volcanic stratigraphy in the "Arrowhead Islands" area (see Fig. GS-14-1 for location).

the eastern section could be one of a number of features: 1) a lava lake ponded within the upper part of flow 5, 2) the termination of a massive flow, or 3) the massive core facies of a compound pillowed and massive flow. Our preferred interpretation, based on what we know about flow morphology in the Long Island section, is that the massive material represents a ponded lava lake. It has a sharp basal contact with pillowed flow 5, a lower colonnade 5 m thick with polygonal columns 30-40 cm in diameter, and a relatively coarse texture with 1 mm olivines and acicular sprays of clinopyroxene. The basalt at the top of the 'lava lake' contains 10% 5 mm carbonate-filled amygdales and has a breccia zone up to 1 m thick in which fissures are filled with rubbly basalt.

Many of the thick massive flows or lava lakes in the "Arrowhead Island" area display prominent columnar jointing, on a scale that could be readily mapped from the air. One massive flow contains columns up to 2 m across (Fig. GS-14-11). The common presence of a lower colonnade in massive flows allows ready identification of lower parts of flows in areas where outcrop density is poor.

Hydrothermal alteration pipes are exposed in thick (ca. 70 m) pillowed flow 3 at the downstream end of rapids at the south end of "Arrowhead Island". These discordant features consist of grey, fine grained, possibly carbonate-rich material (Fig. GS-14-12). On surface exposures they have selvages of white calcrete derived from the chemical reaction between the alteration zone mineralogy and carbonate-rich surface water run-off. The discordant alteration veins are relatively thin where they cut through thick megapillows (Fig. GS-14-13) and widen in parts of the flow composed of smaller pillows. This alteration is similar to localized hydrothermal alteration observed, for example, in VMS camps like Snow Lake or Flin Flon. We observed similar alteration in a number of localities in both the Lower and Upper volcanic formations, suggesting to us that the phenomenon is not rare or unusual in the Fox River Belt. Association of some hydrothermal alteration zones with sulphide-rich layers (see below) suggests that synvolcanic hydrothermal activity might be an important source of sulphide in the volcanic section.

OTTER FALLS-JACKFISH FALLS, STUPART RIVER

Otter Falls and Jackfish Falls occur 800 m apart on the Stupart River, 27 km east of the Long Island section (Fig. GS-14-1). Bedrock exposure of the lower part of the Upper volcanic formation is excellent in the vicinity of both falls.

In most sections on the Fox and Stupart rivers there is limited opportunity to observe lateral variation in flow morphology: exposures trend more or less across strike of the lavas and are only a few metres wide at best. Where additional strike length of exposure is available, immediately in the vicinity of both Otter Falls and Jackfish Falls, we can gain some appreciation for the types of lateral facies changes that can occur in the sequence.

Otter Falls

At Otter Falls the lavas include massive, pillowed and subordinate compound flows. Massive material predominates (Fig. GS-14-2) and the flows are substantially thinner than those in the Jackfish Falls section (below).

Directly at Otter Falls a thick pillowed flow displays spectacular development of polygonal jointing within individual pillows (Fig. GS-14-14). These polygonal columns do not propagate through pillow selvages and have orientations perpendicular to pillow margins; as a result, columns on the ends of elongate pillows fan through 180°.

The basal 2-3 m of massive flows at Otter Falls have a "lower colonnade", with well developed polygonal columns 20-30 cm in diameter. These are succeeded vertically by an "entablature" containing straight to curvilinear polygonal columns 10-15 cm in diameter. In some flows a second set of cooling joints is developed, parallel to the flow contacts.

One flow has a 50 cm thick amoeboid pillow flow top breccia (Fig. GS-14-15). Amoeboid pillows are up to 30 cm long, irregularly-shaped, non-vesicular, and with a 2-3 mm thick black selvage. Some of the amoeboid pillows have clearly budded from the top of the

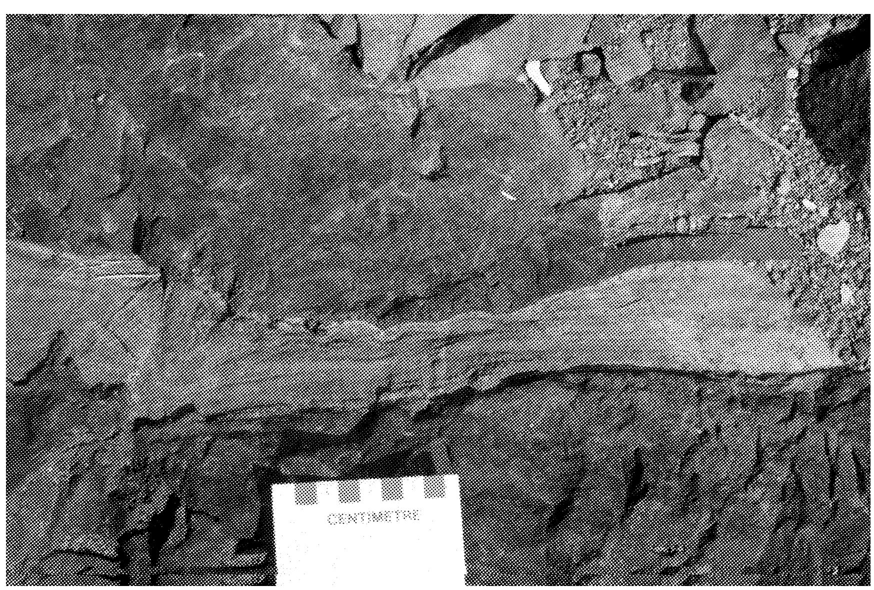


Figure GS-14-10: Thin layer of reworked hyaloclastite marking the contact between pillowed flows 5 and 7, "Arrowhead Island", Lower volcanic formation.

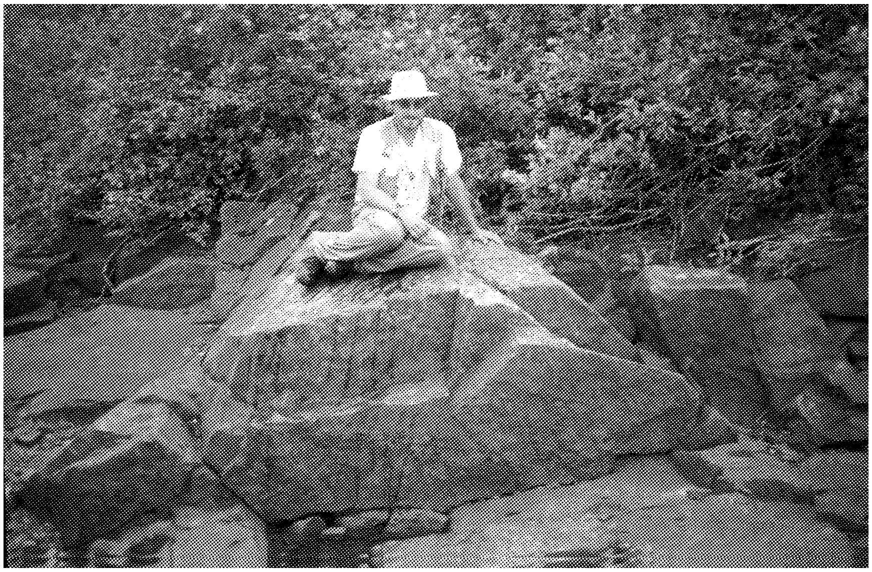
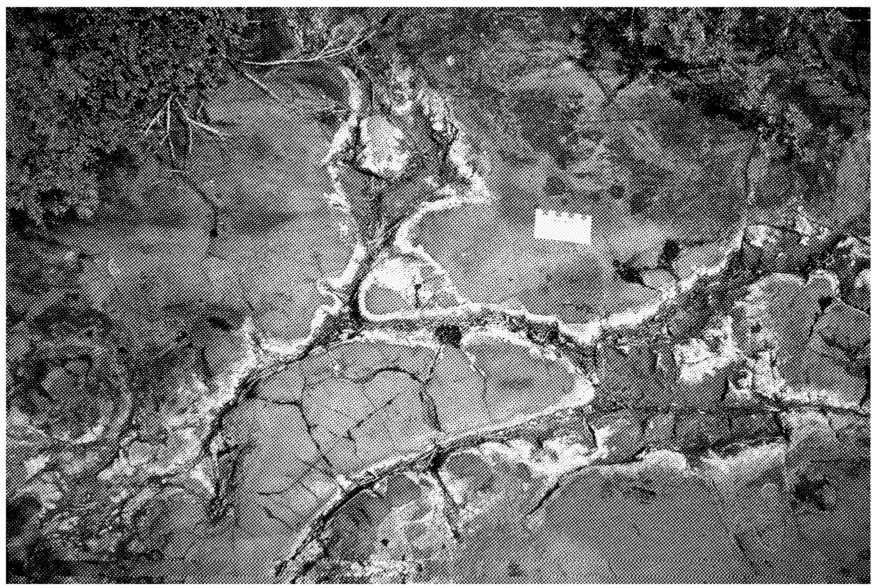


Figure GS-14-11: 2 m wide polygonal joint column (in cross section), massive flow north of "Arrowhead Island", Lower volcanic formation. These columns are part of the upper colonnade of a thick massive flow (photo from 3 m from top of flow). Note that because the flows dip steeply to the north, these originally-upright columns are now lying on their sides.

Figure GS-14-12: Interpillow alteration, flow 3, "Arrowhead Island", Lower volcanic formation. This anastomosing alteration system is part of a larger, discordant alteration zone. White selvages on grey alteration are surface phenomena (calcrete) precipitated from surface water run-off. Stratigraphic tops are towards the top of the photograph.



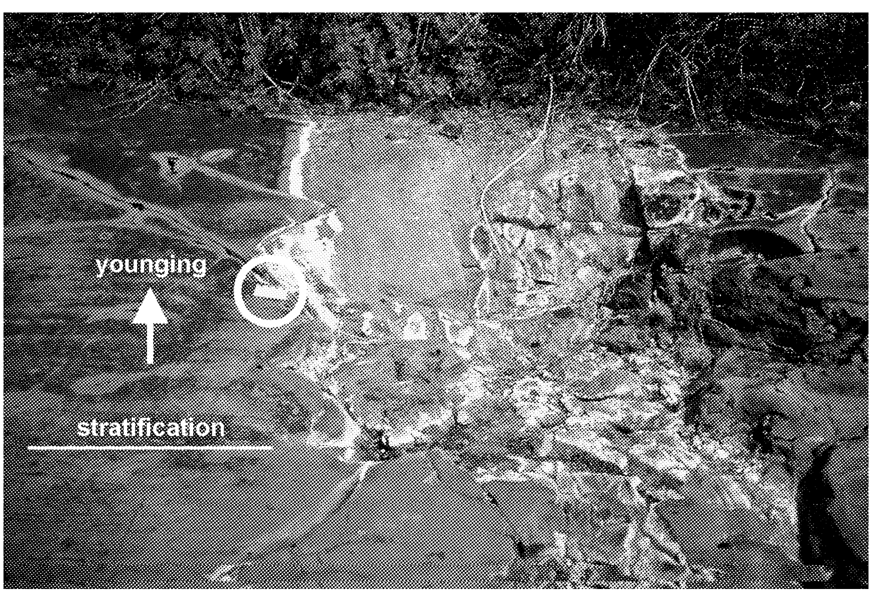


Figure GS-14-13: Anastomosing, irregular alteration vein system contained within a singe megapillow, flow 3, "Arrowhead Island", Lower volcanic formation. Card (9 cm; circled) for scale. The lava flows here trend parallel to the length of the photograph and dip subvertically to the north; the stratigraphic younging direction is towards the top of the photograph. The alteration vein system therefore cuts stratigraphy at a high angle, perpendicular to the paleo-seafloor.

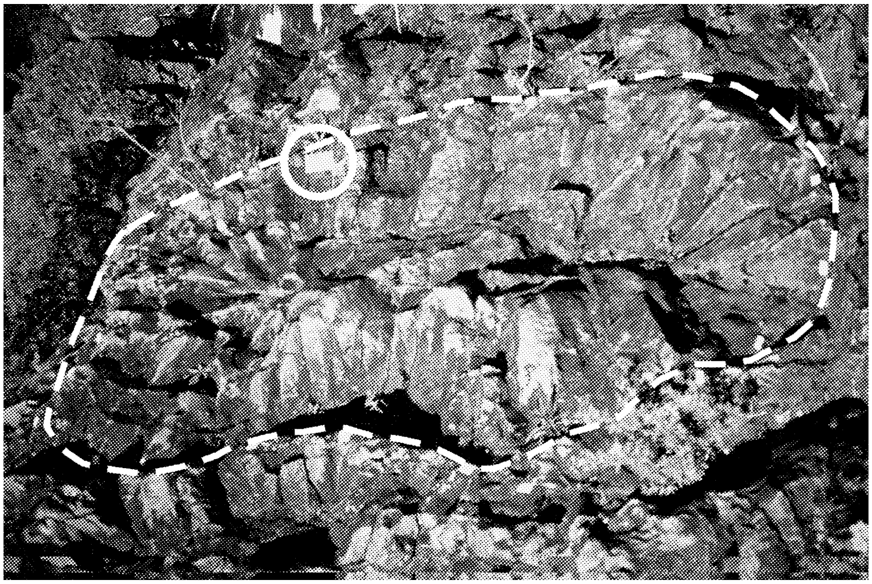


Figure GS-14-14: Polygonal jointing within a pillow, Otter Falls, Upper volcanic formation. The pillow, 2.5 m long, is outlined by a white dashed line. Card (9 cm; circled) for scale. Polygonal joints fan around the margin the pillow, normal to the cooling surfaces, and meet in the core of the pillow.

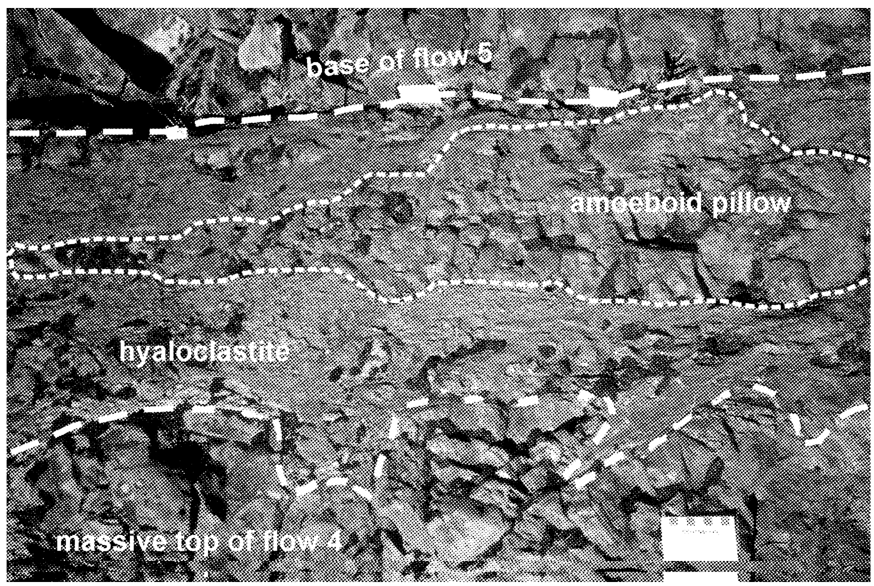


Figure GS-14-15: Flow top amoeboid pillow breccia about 50 cm thick, flow 4, Otter Falls, Upper volcanic formation. The irregular contact between the massive portion of flow 4 and its amoeboid pillow breccia is outlined with a thick dashed white line (bottom). The planar contact between amoeboid pillow breccia and the base of flow 5 is also marked by a dashed white line (top). The breccia itself is composed of elongate amoeboid pillows (fine-dashed outline) and a matrix of hyaloclastite.

massive flow. The matrix of the breccia is composed of black, glassy hyaloclastite granules (1-15 mm) and interstitial whitish siliceous material.

Along the western shoreline of the Stupart River at Otter Falls, a thick massive flow drapes over another massive flow and thickens to the east. The western boundary of the younger flow truncates the flow top breccia and colonnade of the older, massive flow unit. Immediately to the east of the unconformable contact between these two massive flows, the younger massive flow is draped by a pillowed flow unit that thickens to the west. The upper contact of the younger massive flow has a strike of 260° whereas the base of the unit, which is conformable with elongate pillows of the underlying flow, has a strike of 285°. The observed, irregular flow contacts are interpreted to reflect variations in the original flow surface topography. The lateral thickening of flows may have led to the formation of flow channels and lava lakes. These channels appear to represent simple drape structures rather than products of magmatic scouring and thermal-mechanical erosion.

Jackfish Falls

The Jackfish Falls section consists of approximately 310 m of section comprising subequal aggregate thicknesses of pillowed and massive flows (Fig. GS-14-2). No compound flows were observed. The average flow thickness is 18.3 m. This section differs significantly in flow morphology and thickness from both the Otter Falls and the Long Island sections (Fig. GS-14-2), hinting at the internal variability to be expected in both the Lower and Upper volcanic formations.

Pillows in the Jackfish Falls section are bun-shaped to elongate and range in size from 50 cm to megapillows several metres long by up to 2 m wide. Selvages are black and 1 cm thick. Interpillow material is recessive-weathering and composed of hyaloclastite granules set in a matrix if carbonate. Vuggy quartz typically occurs in interpillow voids. Pillow shelves such as those that are so prominent in the Long Island section are not in evidence; however, "eyebrow" structures (single shelf-like voids in the upper parts of pillows, either oval or with flat bottoms and cupola tops) do occur. Some of these are filled with brown, zoned chalcedony (Fig. GS-14-16). Most flow contacts are undulatory with up to 50-60 cm of relief.

Some of the massive flows have a lower colonnade up to 7 m thick (in the thickest flow in the section). Flow-top hyaloclastite deposits are rare or, if present, generally only a few centimetres thick; the exception is a flow-top amoeboid pillow breccia up to 3 m thick at the top of flow 13 (Fig. GS-14-17). Contacts between the massive portion of flow 13 and the flow-top breccia are highly irregular.

At Jackfish Falls there is a northeast-trending, curvilinear feature, interpreted as a synvolcanic fault, that cuts across at least three flows (Fig. GS-14-2). This feature is filled with brecciated basalt and contains a well-defined cleavage dipping ca. 75° northeast. Basalt wall rocks on both

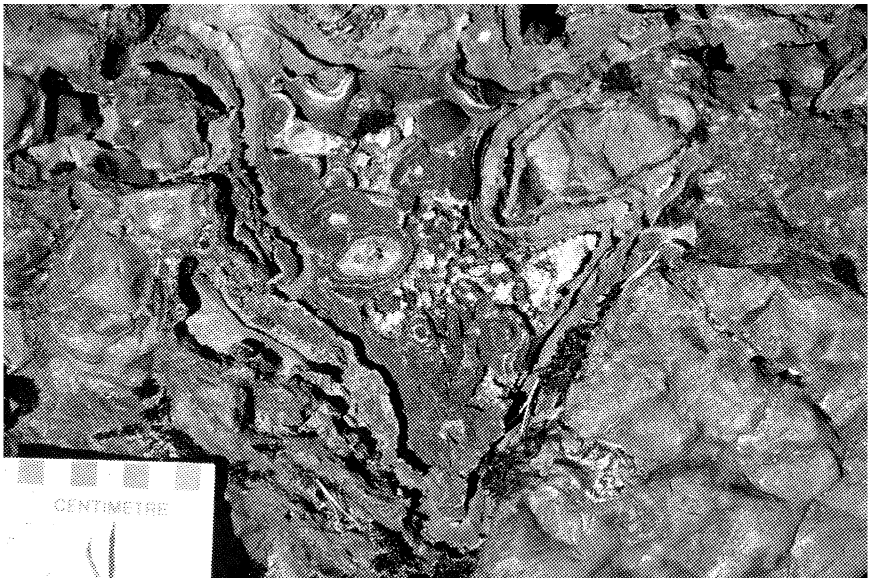


Figure GS-14-16: Interpillow chalcedony, Otter Falls, Upper volcanic formation. The chalcedony has been replaced by fine-grained quartz and carbonate but the primary botryoidal texture is preserved. Coarse vuggy quartz occurs in the core of the interpillow void.

sides of the fault contain open tension gashes. The fault does not produce significant offsets in flow contacts, apart from minor sinistral offset on the upper contact of flow 13. The fault dies out up-section and ultimately is replaced by a normal, unfaulted contact between breccia and pillows. The breccias are spatially associated with the fault and are derived from massive vesiculated material representing the top of flow 14, as well as a thicker section of pillow fragment breccia (Fig. GS-14-18). The thick pillow fragment breccia contains pillows broken in situ and totally disaggregated pillows; it is abruptly overlain by pillowed material of flow 15. The breccia may in fact not be part of flow 15, but rather the brecciated margin of another flow not exposed in the mapped section. Pillowed flow 15 in this interpretation is in part faulted against the breccia and in part overlying it.

Flow 16 is unaltered at its base but displays prominent, discordant, rusty alteration zones in its top. This flow is overlain by a metre-thick sulphide layer, presumably related to the hydrothermal alteration zones beneath it. The overlying pillowed flow is only slightly altered, but contains abundant conformable, steeply north-dipping fractures that are not present in the underlying flows.

FOX RIVER NORTH SECTION

The Fox River North Section (Scoates, 1981) is 7-8 km northeast of Long Island (Fig. GS-14-1). We examined all of the available bedrock exposure of the Upper volcanic formation on the Fox River, between the top of the Fox River Sill and the base of the Upper sedimentary formation. Very little outcrop exists in the upper half of the volcanic formation and none of the Upper sedimentary formation is exposed (Scoates, 1981).

The contact between the Upper volcanic formation and the Middle sedimentary formation is not exposed. The lowermost part of the volcanic section comprises pillowed and massive flows ranging in composition from clinopyroxenite to high-Mg basalt. Outcrops of the Fox River Sill and pillowed basalt of the Upper volcanic formation are less than 30 m apart stratigraphically, suggesting that the Middle sedimentary formation is either very thin or non-existent at this location. Furthermore, the Hybrid Roof Zone, which is the uppermost major lithostratigraphic unit recognized in the Fox River sill (Scoates, 1990), was not observed in this location. The Hybrid Roof Zone is characterized by the presence of hanging wall-derived metasedimentary xenomelts and xenoliths that occur within Si-enriched contaminated gabbroic rocks. The absence of the Hybrid Roof Zone in the Fox River north section could indicate that the top of the Fox River sill did not come into contact with low melting point sedimentary rocks in this area.

One massive flow from the lower part of the Upper volcanic formation is beautifully exposed on a small rocky island in Fox River. This particular massive flow is 8.7 m thick , overlying a pillowed flow at least 4 m thick. The top of the pillowed flow has pillow mounds producing 50 cm relief on the top of the flow. The lowermost 4 m of the overlying massive flow has a well developed colonnade comprising polygonal columns 30-40 cm wide, oriented perpendicular to the flow contact (Fig. GS-14-19). The upper 4.7 m of the flow consists of an entablature in which polygonal columns are 10-15 cm wide near the contact with the colonnade and 6-8 cm wide near the top of the flow. Columns in the entablature are

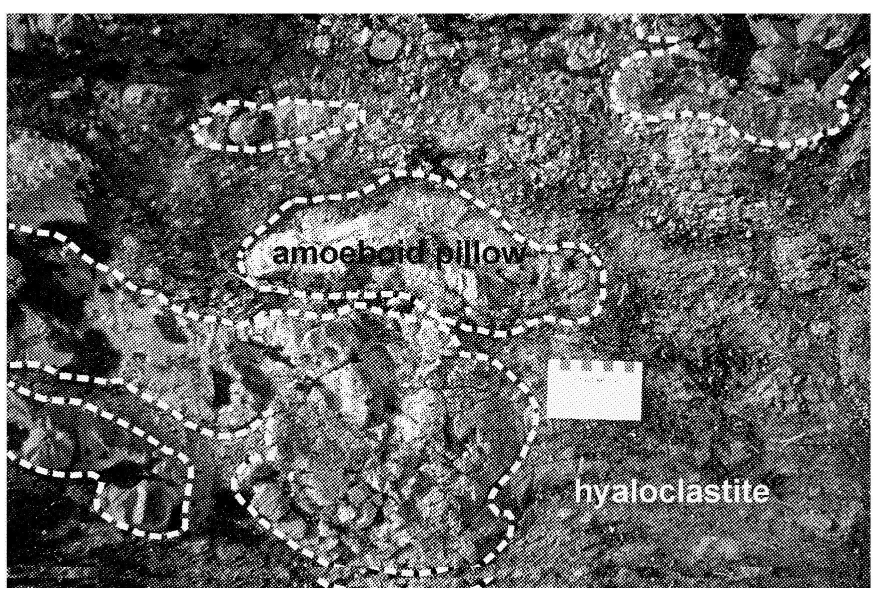


Figure GS-14-17: Amoeboid pillow breccia, flow 13, Jackfish Falls, Upper volcanic formation. This flow top breccia is locally up to 3 m thick but is irregular in distribution and is locally absent between flows 13 and 14. Irregular amoeboid pillows (outlined) and angular pillow fragments are in a matrix of hyaloclastite.

Figure GS-14-18: Pillow fragment breccia, flow 15, Jackfish Falls, Upper volcanic formation. Fragments are equant and angular, some preserving pillow selvages. This type of breccia is rare in the exposed volcanic section and may be related to a nearby synvolcanic fault (Fig. GS-14-2).

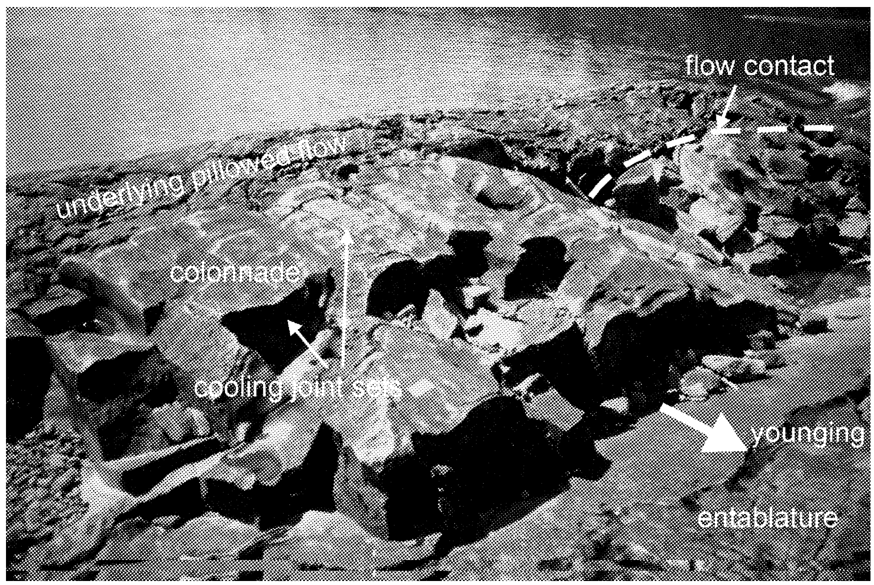


Figure GS-14-19: Oblique view of the lower colonnade in an 8.7 m thick massive flow, Fox River N 2 section, Upper volcanic formation. Polygonal columns are oriented perpendicular to the basal contact in this now vertically-dipping lava flow. Planar cross joints (vertical surfaces in shadow) cutting columns are also primary cooling joints. The underlying pillowed flow is in the background.

generally oriented perpendicular to the upper flow contact but display some curvilinear forms distinct from the ruler-straight columns in the lower colonnade. This zone has a weakly defined flow banding oriented parallel to flow contacts. The top of the flow is exposed in the third dimension: it is undulatory, with about 50 cm relief over 8 m. The top surface of the lava flow is smooth and not ropy. No hyaloclastite is present between this massive flow and the overlying pillowed flow, only about 5 cm of vuggy quartz, fine-grained grey carbonate and a few slabby granules of basaltic glass.

One of the mapped flows in the Fox River North section displays pervasive alteration possibly of a semi-conformable type. The flow is pillowed and is exposed for 46 m; the base is not exposed. The lowermost 27 m of the flow is most highly altered. It is megascopically heterogeneous with a generally intense epidotization, vein-like, anastomosing silica-epidote networks (Fig. GS-14-20), and local discordant vein-like grey alteration similar to the pipe-like alteration at "Arrowhead Island" (above). A very fine scale parallel fracture cleavage is developed parallel to flow contacts (hydrofracturing?). The interval 27-38 m has less intense alteration and the fracture cleavage has no single preferred orientation. The topmost 8 m of the flow is least altered; the fracture cleavage is still present but not as intensely developed as lower in the flow. An overlying massive flow (more than 10 m thick) displays none of the alteration features observed in the underlying pillowed flow, suggesting that the alteration is restricted to the pillowed section and is not disconformable.

The northernmost outcrop of the Upper volcanic formation is located 800 m below the projected top of the formation (Scoates, 1981). This flow is noteworthy in that the pillows (exposed in three dimensions) dip 64° north, some 20° shallower than flows to the south. This flow is basaltic in composition and contains carbonate-filled amygdales to 5 mm in pillow margins. It contains two prominent joint sets not present in the flows to the south; the strongest set, with 5-20 cm spacing, strikes 100° and dips 52° south and a weaker set strikes 186° and dips 73° west.

CONCLUSIONS

A number of first-order conclusions can be made from the limited work conducted in the Fox River Belt volcanic belt in 1999. More work is required to test some of the observations and to extend re-mapping to areas not covered in 1999. A more extensive field program is planned for the 2000 field season.

1. Systematic variation in flow composition, flow morphology and flow thickness have been documented in the Lower and Upper volcanic formations. These variations are likely related to factors such as magma composition and volatile content, proximity to volcanic vents or fissures, volume of eruption and time between eruptions.

2. Lateral facies variation observed in a number of localities indicates that the volcanic stratigraphy is not a simple layer-cake succession of flows. Ponded lava lakes, synvolcanic faults and breccia deposits mapped in the

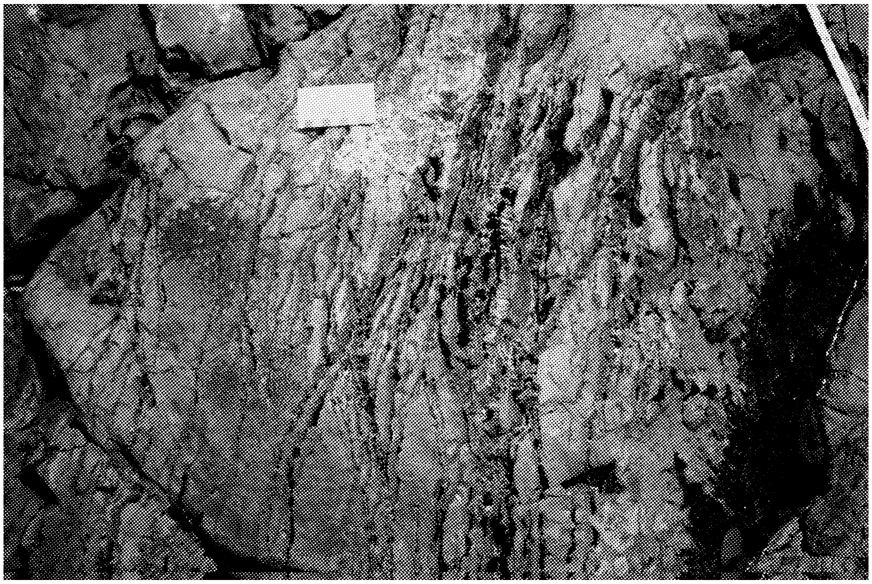


Figure GS-14-20: Alteration, possibly semi-conformable, restricted to a single pillowed flow, Fox River N 2 section, Upper volcanic formation. Epidotized pillows here contain quartz-epidote cross-fiber veins which in part occupy discordant curvilinear fractures.

Fox River Belt indicate that continuity of flows may be limited. More work is necessary to correlate mapped sections with magnetic patterns in an attempt to define lateral variation and continuity in Fox River lavas.

3. Synvolcanic hydrothermal alteration has been documented in both Lower and Upper volcanic formations, including disconformable pipe-like alteration and more pervasive perhaps semi-conformable alteration. Barren massive sulphide layers are associated with some of the alteration zones. These phenomena contribute to the total S budget in the volcanic pile and constitute a potential source of S, in addition to sulphides in the sedimentary formations. The possibility that barren exhalative sulphide deposits could have triggered the formation of magmatic sulphide deposits in or proximal to fluid-magma conduit systems requires additional investigation.

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