Fluid compositions in crustal-scale plumbing systems related to contrasting styles of Ordovician and Silurian orogenesis, Northern Appalachians, Newfoundland

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Introduction. During terrane accretion, significant volumes of fluid can be generated at depth and advected to higher crustal levels along terrane-bounding faults or large-scale shear zones. The chemical and isotopic characteristics of the fluids may reflect the nature of the orogenesis that produced them. Newfoundland records the destruction of a late Precambrian-Early Paleozoic ocean whereby marine volcanic and epiclastic sequences, and ophiolite complexes, that were part of Cambrian to mid-Ordovician island arc and back-arc basins (Swinden, 1991), were accreted to the Laurentian and Gondwanan continental margins. This provides a good opportunity to use geochemical and isotopic data to study the nature and scale of fluid flow in the basement and accreted terrane related to orogenic events of different ages and character on opposite sides of the accreted terrane (Fig. 1). The basement in the Mount Cormack study area (on the Gondwanan margin) is characterized by Ordovician S-type plutons and migmatites (Colman-Sadd *et al.*, 1992), whereas the Baie Verte study area (on the Laurentian margin) has eclogite preserved in the continental margin, Silurian I-type plutons and bimodal magmatism (Cawood and Dunning, 1993). Though both areas have Ordovician ophiolite complexes adjacent to continental metasedimentary terranes, these parts of the Laurentian and Gondwanan margins have very different orogenic histories and the fluids associated with them have substantially different geochemical and isotopic signatures. There is commonly a pronounced contrast in metamorphic grade across the terrane-bounding faults, and both sides preserve clear field evidence for widespread fluid migration along faults, in shear zones, and in vein systems. One prominent manifestation of large-scale fluid movement is the formation of shear-hosted, mesothermal gold mineralization in both the basement and accreted terranes.

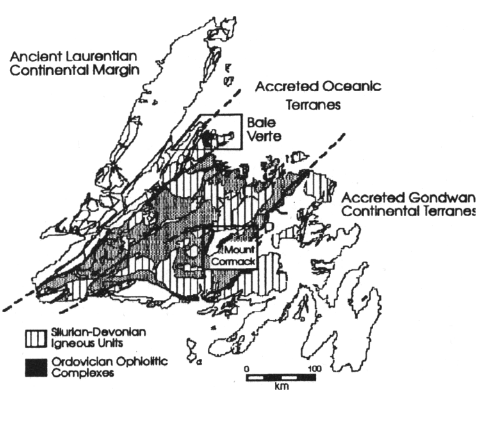

FIG. 1.

The Laurentian margin. in western Newfoundland Precambrian (Grenville) basement and shelf-facies rocks of the North American (Laurentian) continental platform are over-ridden by allochthonous sedimentary and ophiolitic rocks. In the Baie Verte area, the accreted oceanic terrane is separated from metaclastic rocks of the Laurentian margin by the Baie Verte-Brompton Line (BVBL), a narrow structural zone characterized by discontinuous ophiolitic complexes. Both sides of the terrane boundary are intruded by Silurian rocks and have widespread evidence of fluid-rock interaction, including alteration and veining in fracture networks, large scale vein systems, local and regional faults, and major shear zones. Some veins contain only quartz, but faults and shear zones have more complex hydrothermal mineral assemblages. The largest hydrothermal systems are in regional shear zones associated with several mesothermal gold occurrences.

The Gondwanan margin. Iin east-central Newfoundland, ophiolite complexes emplaced on the Gondwanan continental margin are exposed in the Mount Cormack area (Fig. 1). The basement, which is exposed in a structural window through the accreted oceanic terrane, consists of greenschist to upper amphibolite facies metasedimentary gneisses and, locally, Ordovician migmatites and granites (Colman-Sadd *et al.*, 1992). This study focused on the Coy Pond ophiolite, the margins of which are characterized by tectonic mélange zones interpreted to be major thrust surfaces that developed during obduction and imbrication of the ophiolite on the Gondwanan continental margin. The mélanges are about 1 km wide, continuous along-strike for several kilometers, and have sheared, altered and veined ultramafic blocks in a schistose matrix. Though the basement rocks and ophiolitic melanges have widespread evidence for fluid-rock interaction, unlike the Laurentian margin, they contain no gold-bearing occurrences suggesting a fundamental difference in the nature of the basement-accreted terrane interaction.

Analytical results and discussion. Samples were collected from all major geological units that displayed widespread features of fluid–rock interaction (i.e. veins, shear zones etc) in the two field areas. To date, 275 oxygen and carbon isotope measurements, 11 strontium isotope and 30 trace element analyses have been completed at Memorial University (Table 1). In the following discussion, 'regional veins' refers to faults, shear zones and vein systems distributed over a wide area, whereas 'gold-bearing veins' refers specifically to mineralized shear zones that typically have more extensive alteration associated with them.

In the Laurentian field area, the gold-bearing veins with the largest hydrothermal systems have enrichments of up to 600% in LILE, *REE*, and some HFSE contents. This suggests that the fluids were derived in part from enriched continental crustal material as opposed to depleted ophiolitic rocks. In contrast, the highly altered ophiolitic melanges in the Gondwanan field area have little or no LILE and *REE* enrichments.

The $\delta^{18}O$ values of quartz veins vary depending on their host rock and setting. The regional veins from the basement gneisses have the highest values (Laurentian 13.2, Gondwanan 14.2) which are consistent with the somewhat higher $\delta^{18}O$ values of the host gneisses (*c.* 10.5 and 11.8) compared to the ophiolitic rocks (9.3 and 9.7). Similarly, ^{18}O-rich veins (*c.* 13.2) are also found in the highly sheared Laurentian suture zone. The regional quartz veins in the Laurentian ophiolites are isotopically indistinguishable from gold-bearing vein systems in these ophiolites (*c.* 11.5) and gold-bearing veins in the basement gneisses (*c.* 11.7). This suggests a large-scale Au-bearing hydrothermal system, distinct from that which formed the regional veins in the basement, was present in the basement and ophiolites. In comparison to the Laurentian field area, the Gondwanan regional vein systems have distinctly higher $\delta^{18}O$ values in both the basement and the ophiolite (*c.* 14.2 and 15.0). The type of fluid that produced the auriferous Laurentian veins is not present in the Gondwanan field area, and neither are any known gold occurrences. The lowest and most variable $\delta^{18}O$ values were for quartz veins in the intrusive rocks in the Laurentian field area, suggesting this fluid did not directly affect the fluid budget in the ophiolites.

Carbon and strontium isotopes are potentially useful tracers of basement-ophiolite interaction because of the distinct isotopic contrast expected for the two rock types. Regional and gold-bearing veins from the basement and ophiolite in the Laurentian area have $\delta^{13}C$ values around –5 to –7, consistent with 'average crustal' carbon (i.e. metamorphic or magmatic sources). In contrast, veins in the Laurentian suture zone and the Gondwanan ophiolite have lower $\delta^{13}C$ values (*c.* –10.3) which indicate some of the carbon was likely derived via metamorphism of graphitic metasedimentary basement. Though only a few strontium analyses have been completed, they clearly indicate that the Gondwanan ophiolite contains radiogenic basement strontium (*c.* 0.7166), whereas the gold-bearing veins in the Laurentian ophiolite do not (*c.* 0.7058). Gold-bearing veins in the Laurentian basement and suture zone also contain radiogenic strontium (0.7536 and 0.7099).

There are pronounced differences in the trace element and isotopic results for the Gondwanan and Laurentian study areas that reflect differences between the Ordovician and Silurian histories of these continental margins. The S-type plutonism in the Gondwanan basement reflects crustal thickening and melting during emplacement of allochthons, with little or no mass transfer from the mantle. This style of orogenesis produced fluids with sedimentary $\delta^{13}C$ and crustal $^{87}Sr/^{86}Sr$ values that have affected the accreted ophiolites. In contrast, Silurian I-type and bimodal plutonism in the Laurentian field area result from mechanical thinning of the mantle part of the lithosphere beneath an orogenic belt ('delamination' as defined by Nelson, 1992). The concomitant heat and mass transfer produced large-scale crustal anatexis and fluids with igneous carbon isotopic and mantle-like strontium isotopic compositions.

Colman-Sadd, S.P., Dunning, G.R. and Dec, T., (1992) *Amer. J. Sci.*, **292**, 317–55.