DISCUSSION

PROVENANCE AND PLATE TECTONIC INDEXING OF LOWER PALEOZOIC SANDSTONES, QUEBEC AND MAINE

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INTRODUCTION

In a recent paper, Schwab (1994) tested two plate tectonic models for the Northern Appalachians to determine whether a conventional Wilson cycle model or a collage model of far-traveled, unrelated terrains was the best fit as indicated by the framework mineralogy of sandstones. Schwab's samples were collected from several uppermost Precambrian to lower Paleozoic units across the Québec-Maine orogen. These units are exposed in apparently distinct terranes across Québec and Maine. The results of his reconnaissance work led him to propose an alternative and new tectonic model for the Northern Appalachians. In his model, the Northern Appalachians are viewed as the result of the "distension of a broad continental crustal block which generated a simple series of down-dropped basins separated by uplifted continental block sources" (p. 421).

This conclusion partly confirms the results published by several researchers in recent years (DeBroucker, 1987; Cousineau, 1990). Namely, crustal blocks were of greater importance in the building of the Taconian orogen than had been previously appreciated. However, Schwab's proposed model does not account for the existence of oceanic crusts, several volcanic arcs, and melange belts in the Northern Appalachians. It is our opinion that petrographic studies of numerous sandstones in Québec and northern Maine do confirm the past existence of both oceanic-type crusts and volcanic arcs, at least for the Dunnage-Boundary Mountain terranes. Our comment is mostly, but not exclusively, centered on the following points: (1) the lack of sampling of both fore-arc basin and melange sandstones, (2) the absence of alternative views for arkosic and quartzose sandstones in accretionary complexes, and (3) the absence of supporting data based on other petrographic constituents, such as heavy minerals. The absence of these data has introduced a bias leading to the tectonic model proposed by Schwab (1994).

FORE-ARC BASIN AND MELANGE SANDSTONES

Sampling of a large area in a reconnaissance study is difficult. Often the stratigraphic, structural, and geographic distribution of the samples is uneven, and the number of samples is small. Hence, the selection of samples is neither systematic nor is it a random sampling of units (Krumbein and Graybill, 1965). Commonly such studies do not permit the formulation of strong conclusions. Also, Schwab does not use conven-

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tional tectonic divisions for the northern Appalachians (William and Hatcher, 1983; St-Julien and others, 1983; Boone and Boudette, 1989). The basis for the use of these peculiar divisions has not been addressed by Schwab in his paper.

The entire Dunnage terrane in Québec is represented by only one sample. This sample comes from the Saint-Daniel Melange, a chaotic unit with a complicated history interpreted as an accretionary complex (Cousineau and St-Julien, 1992; Pollock, 1989, 1993). The Saint-Daniel Mélange is a major unit, much of which is olistostromal in origin. Furthermore, the sole Saint-Daniel sample used by Schwab was collected in the southwesternmost part of the Québec Appalachians where deformations are more intense and where stratigraphic relationships between the olistostromes of the Saint-Daniel and adjacent units are blurred by transcurrent movement along bounding faults. The Saint-Daniel in Québec contains a variety of sedimentary, igneous, and metamorphic rock-types. Several sandstone-rich units are present. Cousineau and St Julien (1992) conclude that the oldest units are often quartz-rich, but that the olistoliths exhibit a wide range in composition. Units considered to be younger contain volcanogenic sandstones similar to sandstones of the Frontière Formation of the Magog Group (see below). The youngest olistostromes are interpreted to have been derived from a Caldwell-type unit that was up-thrust, disrupted and emplaced on the melange following the arc-continent collision. Olistoliths from this uppermost unit have an arkosic composition, but in no way can this composition be related to the evolution of an Ordovician arc where arc-related intrusive complexes became exposed to erosion. Hence the Saint-Daniel records changes in provenance broadly related to changing tectonic environments.

Schwab discarded all samples from the Caldwell Group because they appeared to be too recrystallized. Recrystallization is a feature common in the southwesternmost part of the Québec Appalachians, but it is not a major feature further to the northeast. In the Beauce area, Tawadros (1977) has made a detailed sedimentological study of the Caldwell Group. These sandstones are described as arkosic and feldspathic wackes which contain up to 8 percent basaltic rock fragments. Tawadros (1977) interpreted the entire Caldwell Group as a turbidite sequence derived from a northern source and deposited in a continental rift-related basin. Roy and others (1991) also describe feldspathic Caldwell equivalents in northern Maine.

To the northeast in Maine, compositions of the olistoliths in the Saint-Daniel Mélange also demonstrate that a variety of rock types were sampled during formation of the unit. Here, the olistoliths are predominantly sedimentary in origin. Sandstone olistoliths range from a quartz arenite similar to the one described by Schwab, to lithic, feldspathic, and arkosic sandstones (Pollock, unpublished). Other olistoliths are rare in the Saint-Daniel but include radiolarian-bearing chert, and types micrite, calcarenite, rudite, and oolite limestone (Pollock, 1989). These latter lithologies are rare, comprising less than 1 percent of the olistoliths. This wide range of olistolith lithologies places constraints on the nature of the source region. However, the scale of the unit (1 km wide by more than 450 km in length) suggests this unit has substantial tectonic implications beyond the recording of sedimentation processes.

Additionally, Schwab errs in his statement that the "sedimentary rock assemblage, which includes the lowermost parts of what was once called the Magog and Formations has been redefined as the St. Daniel Formation" (p. 408). This statement leads the reader to believe that the entire Magog Group was redefined as Saint-Daniel. Schwab makes this statement without reference to source. This is not an inconsequential error. St-Julien and others (1983) clearly separated the shale olistostrome assemblage of the Saint-Daniel melange from the Magog Group. St-Julien, Slivitzky, and Feininger (1983) considered the Magog Group to consist of, in ascending order, the Beauceville and St. Victor Formations. Slivitsky and St-Julien (1987) use the term Saint-Daniel Formation and again treat the chaotic Saint-Daniel separately from the Magog Group. Slivitsky and St-Julien (1987) considered the Magog Group in the Estrie-Beauce area to contain, in ascending order, the Frontière, Etchemin, Beauceville, and Saint-Victor formations. The olistostromal Saint-Daniel has been considered a separate mappable unit for well over a decade, while the Magog Group remained as a separate mappable stratiform unit with distinct formations.

Schwab interprets the Magog Group as forearc basin fill of Middle Ordovician age (p. 408). It is difficult to understand why Schwab did not include the Magog Group in his analysis. If one wants to document the presence of an arc and its evolution, sampling of forearc basin units should be a necessity! Hence, it is difficult to understand why neither the Magog Group nor any of its correlatives (Depot Mountain Formation, northern Maine, Roy, 1989; Roy and others, 1991; Cabano Formation, Témiscouata area, David and others, 1985; Mictaw Group, southern Gaspé Peninsula, De Broucker, 1987; Honorat Group, southern Gaspé Peninsula, Malo, 1988) were not sampled. If it had been done, several samples would have fallen in the Mixed Provenance Field, near the limit with the Magmatic Arc Provenance Field.

Work by Cousineau and St-Julien (1985), Cousineau and St-Julien (1994) on the volcanogenic sandstones of the Frontière Formation in the Magog Group, and by De Broucker and St-Julien (1985) and De Broucker (1987) on the Neckwick Formation in the Mictaw Group (not sampled despite what may be suggested, Schwab's, table 1, p. 406) have proved the presence of a volcanic arc. We agree that this arc probably grew on a continental crust. Furthermore, the abundant volcaniclastic rocks in the rest of the Magog Group (even though some resedimented crystal-rich ones could be classified as arkoses) are also a proof of the lasting existence of volcanogenic input from an arc during the Ordovician. As for the youngest flysch units, they demonstrate changes in sources as the orogen matures and the basin fills.

Suite 12 of Schwab from the Hurricane Mountain and Jim Pond formations and their equivalents in the Caucomgomoc Lake inlier contain quartz-rich metawackes and quartz-rich metaarenites. Locally, these lithologies, together with interbedded slate or phyllite, occur as beds, lenses, or members within greenschist to amphibolite facies metabasalts of the Jim Pond and Caucomgomoc Lake formations. The metabasalts are overlain by a melange containing a variety of intraclast lithologies. The origin of the melanges has been discussed in detail by Boone, Doty, and Heizler (1989) and Pollock (1989). The geology, along strike changes and timing of formation of these melanges, was described in detail by Pollock (1993). These units are not inconsequential in their geological significance, and cannot be ignored in tectonic reconstructions. The quartz-rich nature of the sandstones in the metabasalt and melange sequence does suggest a source, as Schwab indicates, of continental derivation. Yet, Schwab's proposed model provides no alternative explanation to account for the distribution of the melange—ophiolite belts.

Not all melanges are part of former accretionary prisms, but this was the case for those melanges along the sutures of the Dunnage and Boundary Mountain terranes. Geographic distribution and composition of sandstone in accretionary complexes are diverse. Interpretation of sediment provenance based on framework mineralogy only is difficult (Underwood, 1986). Quartzose sandstones are not unusual (for a compilation of sandstone composition in accretionary prisms, see Critelli, 1993). They occur: (1) if sands were derived from an adjacent continent before being scraped off into the accretionary prism (Vebel, 1985), (2) through resedimentation along the inner slope of an accretionary prism, and (3) in tropical climates where fluvial first-cycle quartz arenite may form (Johnsson, Stallard, and Meade, 1988). Furthermore, if the fore-arc basin is not ponded, little volcanogenic sands may cross the trench-slope break and come to rest on the inner slope of the accretionary prism. Lastly, sediments from the continental slope and rise are added to the accretionary prism as the collision between the fore-arc region and a continent continues. This increases again the amount of sandstones with a continental provenance in these accretionary complexes. A combination of these factors probably existed during the Ordovician Taconian orogeny, thus increasing the amount of quartz arenite in the Québec-Maine stratigraphic record.

PETROGRAPHY OF HEAVY MINERAL SUITES

Framework mineralogy of sandstones is a widely used and powerful petrographic technique that helps in deciphering tectonic settings. However, as all techniques, it has its limitations. For example, some rock types produce more readily resistant sand-size particles than others in a given compound source area. In a source area with granitoids and slates—schists, sand-size particles originating from the granitoid rocks are 14 to 20 times more abundant than those from the slates—schists in the final sandstone deposits (Palomares and Arribas, 1993). This is readily applicable to dissected arcs in orogenic belts. The basement granitoids will generate more resistant sand-size fragments than volcanic rocks, and the final product will have a composition richer in feldspar.

Great attention must be paid to the identification of lithic fragments in a volcanic context. However, these rock fragments are very sensitive to diagenesis and can be transformed entirely into a pseudo-matrix (McBride, 1985) if subjected to subsequent deformation and metamorphism. Heavy mineral suite can complement framework mineralogy studies. For example, sandstones of the Tourelle Formation contain mafic and felsic volcanic rock fragments and abundant chromite grains (Hiscott, 1978). The only recognized source for the chromite grains is an obducted ophiolite.

Some sandstones from Taconian fore-arc basins of the Dunnage terrane in Québec contain the unusual association of felsic volcanic rock fragments and of chromite grains as in the Tourelle Formation (De Broucker, 1987; Malo, 1988; Cousineau, 1990; Cousineau and St-Julien, 1994). The abundance of felsic volcanic rock fragments is interpreted as having been derived from a volcanic edifice built on a continental crust. The chromite grains, however, indicate a nearby ophiolitic source. The source area for all these units may thus be a crustal block, but one with a volcanic cover and one originally separated from Laurentia by an oceanic crust. In Schwab's final model (his fig. 4), the only oceanic crust present lies between Laurentia and the Ascot-Weedon terrane, presumably on the basis of the framework mineralogy of the Tourelle sandstones. Even though framework mineralogy does not indicate their presence, this model ignores ophiolites and melanges spread along the southwestern limit of the Boundary Mountains-Dunnage terrane. An other ocean must, therefore, be inserted in this model. Paleogeographic maps for the Ordovician based on palinspastic reconstruction of ophiolite sequences in Newfoundland (Williams, 1980), fossil distributions (Neuman, 1984), and sedimentation rates of the Laurentian margin units (Vallières, 1984) support the existence of a large (about 2000–4000 km) ocean at that time. Consequently, a conventional Wilson cycle model in which some crustal terranes are present can explain the building of the Taconian orogen.

CONCLUSION

In summary, Schwab presents interesting data and points to a field that can contribute much to the understanding of the Northern Appalachian orogen. Framework mineralogy of sandstones can and does contribute to tectonic understandings. To date framework mineralogy of sandstones has been an under utilized tool in Northern Appalachian paleogeographic reconstructions. However, other petrographic data must be considered, and such work needs to be tied carefully to stratigraphic and structural sequences, as well as paleocurrent patterns, facies distributions, faunal provinces, and paleomagnetic data in order for the full picture and model to be developed. It is our opinion that previous Wilson cycle and terrane amalgamation models for the Northern Appalachians can not be ruled out.

References

Boone, G. M. and Boudette, E. L., 1989, Accretion of the Boundary Mountains terrane within the northern Appaplachian orthotectonic zone, in Horton, J. W., Jr., and Rast, N., editors, Melanges and olistostromes of the U.S. Appalachians: Geological Society of America Special Paper 228, p. 17–42.

Boone, G. M., Doty, D. T., and Heizler, M. T., 1989, Hurricane Mountain Formation melange: description and tectonic significance of a Penobscottian accretinary complex: Maine Geological Survey, Studies in Maine Geology, Volume 2, p. 33–83.

Cousineau, P. A., 1990, Le Groupe de Caldwell et le domaine océanique entre Saint-Joseph-de-Beauce et Saint-Sabine: Québec Ministry of Energy and Resources, Geological Report MM 87-02, 178 p.

Cousineau, P. A., and St-Julien, P., 1994, Stratigraphie et paléogéographie d'un bassin d'avant-arc ordovicien, Estrie-Beauce, Appalaches du Québec: Canadian Journal of Earth Sciences, v. 31, p. 435–446.

——— 1985, A new lithostratigraphy of the Magog Group, Southeastern Québec, Canada: Geological Society of America Northeastern Section annual meeting, Abstract with Program, v. 17, p. 13.

——— 1992, The Saint-Daniel Mélange: evolution of an accretionary complex in the Dunnage terrane of the Québec Appalachians: Tectonics, v. 11, p. 898–909.

David, J., Chabot, N., Marcotte, C., Lajoie, J., and Lesperance, P. J., 1985, Stratigraphy and sedimentology of the Cabano, Pointe aux Trembles, and Lac Raymond formations, Temiscouata and Rimouski counties, Québec: Geological Survey of Canada, Current Research Part B, Paper 85-1B, 491–497.

De Broucker, G., 1987, Stratigraphie, pétrographie et structure de la boutonnière de Maquereau—Mictaw: Québec Ministry of Energy and Resources, Geological Report MM 86-03, 170 p.

De Broucker, G., and St-Julien, P., 1985, Mictaw Group: Taconic flysch and mélange of the Québec Appalachians, evidence for a continental volcanic-arc and metamorphic terrane derivation: Geological association of Canada annual meeting, Abstract with programs, v. 10, p. A13.

Hiscott, R. H., 1978, Provenance of Ordovician deep-water sandstones, Tourelle Formation, Quebec, and implications for the initiation of the Taconic orogeny: Canadian Journal of Earth Sciences, v. 15, p. 1579–1597.

Johnsson, M. J., Stallard, R. F., and Meade, R. H., 1988, First-cycle quartz arenites in the Oronoco river basin, Venezuela and Colombia: Journal of Geology, v. 96, p. 263–277.

Krumbein, W. C., and Graybill, F. A., 1965, An introduction to statistical models in geology, McGraw-Hill Co., New York, 475 p.

Malo, M., 1988, Stratigraphie et structure de l'anticlinal d'Aroostook—Percé de l'est de la Gaspésie: Québec Ministry of Energy and Resources, Geological Report ET 87-06, 48 p.

McBride, E. F., 1985, Diagenetic processes that affect provenance determinations in andstone, in Zuffa, G. G., editor, Provenance of arenites: Riedel Publishing Company, p. 95–113.

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

Palomares, M., and Arribas, J., 1993, Modern stream sands from compound crystalline sources: composition and sand generation index, *in* Johnsson, M. J., and Basu, A., editors, Processes controling the composition of clastic sediments: Geological Society of America special Paper 284, p. 313–322.

Pollock, S. G., 1993, Terrane sutures in the Maine Appalachians, USA and adjacent areas: Geological Journal, v. 28, p. 45–67.

——— 1989, Sedimentation and deformation in an accretionary prism, northwestern Maine: Geological Society of America Programs with Abstracts, v. 21, p. 59.

Roy, D. C., 1989, The Depot Mountain Formation: transition from syn- to post-Taconian basin along the Baie Verte-Brompton line in northwestern Maine: Maine Geological Survey, Studies in Maine Geology, Volume 2, p. 85–99.

St-Julien, P. and Hubert, C., 1975, Evolution of the Taconic orogen in Quebec. American Journal of Sciences, v. 275A, p. 337–362.

St-Julien, P., Slivitzky, A., and Feininger, T., 1983, A deep structural profile across the Appalachians of southern Quebec, *in* Williams, H., Hatcher, R. D., Jr., and Zietz, I., editors, Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 103–112.

Tawadros, E., ms, 1977, Etude pétrographique des grès cambriens du Groupe de Caldwell de la région du lac Etchemin, Québec: M.S. thesis, Université de Montréal, 60 p.
Underwood, M. B., 1986, Sediment provenance within subduction complexes: an example from the Aleutian forearc: Sedimentary Geology, v. 51, p. 57–73.
Vallieres, A., ms, 1984, Stratigraphie et structure de l'orogène taconique de la région de Rivière-du-Loup, Québec: Ph.D. thesis, Universite Laval, 302 p.
Vebel, M. A., 1985, Mineralogically mature sandstones in accretionary prisms: Journal of Sedimentary Petrology, v. 55, p. 685–690.
Williams, H. 1980, Structural telescoping across the Appalachian orogen and the minimum width of the Iapetus ocean, *in* Strangway, D. W., editor, The continental crust and its mineral deposits: Geological Association of Canada Special Paper 20, p. 421–440.
Williams, H. and Hatcher, R. D., Jr., 1983, Appalachians suspect terranes, *in* Williams, H., Hatcher, R. D., Jr., and Zietz, I., editors, Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 33–53.