Provenance from mafic and ultramafic rocks for the sedimentary succession of the southern Grand Banks, offshore Newfoundland

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Summary

Following the completion of an extensive study of heavy mineral assemblages from Triassic, Jurassic and Cretaceous sandstones from the Grand Banks the occurrence of heavy minerals such as Cr-spinel and pyroxene – indicative of mafic and ultramafic sources – has been highlighted for further provenance investigation. Firstly, we introduce possible source areas in western Newfoundland, where mafic and ultramafic rocks are widespread. Furthermore, the impact of Upper Triassic and Lower Cretaceous volcanism of the Central Atlantic Magmatic Province (CAMP) and the Scotian Basin, respectively, are considered as both are possible sources of mafic and ultramafic materials. Secondly, the possible association of Cr-spinel and metamorphic heavy minerals in some Cretaceous sandstones of the western Jeanne d'Arc Basin is discussed, as well as the provenance of these sandstones. The sedimentary succession deposited further south (within the Southern Jeanne d'Arc Basin and in the Carson Basin) is interpreted to be derived from the erosion of volcanic material (e.g. basalt flows).

Introduction

During the last two years heavy mineral analysis – via Raman spectroscopy – has been performed on a large number of cuttings and core samples (> 250 samples) from the Orphan, Flemish Pass, Jeanne d'Arc and Carson basins and the Outer Ridge Complex of the Grand Banks. Although most of the heavy mineral assemblages are composed of ultrastable minerals (zircon, tourmaline, rutile; Figure 1), some samples show relatively high concentrations of minerals with a metamorphic and / or mafic to ultramafic provenance. The aim of this study was to determine the origin of these heavy minerals. The study's focus on heavy mineral analysis is warranted because detrital zircon U-Pb geochronology cannot identify mafic to ultramafic components because these components typically have low zircon fertility.

Mafic to ultramafic rocks outcrop extensively in western Newfoundland. To the east of the Baie Verte Line, in the Notre Dame Bay Sub-zone of the Dunnage Zone, Cambrian to Ordovician mafic intrusions, mafic volcanic rocks and ultramafic rocks of ophiolite complexes (e.g., the Betts Cove Ophiolite Complex) are associated with Cambrian to Devonian felsic plutonic rocks (Colman-Sadd *et al.*, 1990).

To the west of the Baie Verte Line, the Bay of Islands and St. Anthony ophiolite complexes are associated with a "metamorphic sole" (Dewey and Casey, 2013), therefore heavy mineral assemblages derived from these areas of western Newfoundland should contain ultramafic minerals as well as metamorphic minerals. In particular, a pyroxene-garnet granulite, garnet amphibolite, epidote amphibolite metamorphic sole occurs at the base of all the main massifs of the Ordovician Bay of Islands Ophiolite Complex, with most of the mafic metamorphic portions of the sole having probably formed synchronously with the formation of the ophiolite complex (*op. cit.*). The present spatial extent of this sole is relatively limited and a large area of the Humber Zone, the Long Range Massif, is currently occupied by the Mesoproterozoic Grenville basement, mainly composed of orthogneisses, intruded by Neoproterozoic mafic dikes (Colman-Sadd *et al.*, 1990).

As documented via a study of modern sediment, obducted ophiolite belts supply pyroxene, associated with olivine and minor chrome spinel (Garzanti and Andò, 2007). Olivine rapidly disappears from the sedimentary record due to its chemical unstability, whereas chrome-spinel typically occurs in relatively high concentrations only in sediments derived from very-extensively serpentinized peridotites (*op. cit.*), or as a consequence of processes such as weathering and sediment recycling (due to its chemical stability) and hydraulic sorting (due to its high density).

Tsikouras *et al.* (2011) interpreted geochemical similarities of chrome-spinel grains collected in the Scotian Basin to represent sediment recycling and they consider the ophiolites of the Humber Zone to be the ultimate source of the ultramafic heavy minerals deposited in the Scotian Basin.

Cretaceous volcanic rocks are widespread in the south-western area of the Grand Banks, in the eastern Scotian Basin and within seamounts, named Fogo and Newfoundland, which were mapped to the south and the east of the Grand Banks, respectively (Pe-Piper *et al.,* 1994, and references therein). Early Cretaceous mafic and felsic volcanic rocks were encountered by wells Brant P-87 and Mallard M-45 and therefore bimodal volcanism was interpreted by Pe-Piper *et al*. (1994). Well Brant P-87 intersected basaltic rocks and minor pyroclastic rocks and well Mallard M-45 encountered basalt flows intercalated with tuffaceous beds and volcaniclastic strata and cuttings from both wells contain rock-chips of felsic rocks (*op. cit.*). A 15 m thick porphyritic diabase was encountered by well Twillick G-49.

Remnants of extensive, contemporaneous basalt flows were penetrated by well Hesper I-52 and by wells located to the north-west. These basalt flows extended from basement highs with strong magnetic anomalies interpreted as Hauterivian to Barremian volcanic centres (Bowman *et al.,* 2012). Abundant detrital material deposited in the Scotian Basin was probably eroded from Aptian basalt flows and Albian pyroclastic deposits (*op. cit.*), which could also have provided material to the southern Grand Banks.

Further to the south, in the Central Atlantic Magmatic Province (CAMP), products of the Triassic rift system are widespread (e.g., Ziegler, 1988). The CAMP, which is currently interpreted as Rhaetian, includes great volumes of mafic volcanic successions (Ogg et al., 2008, Cirilli et al., 2009, Deenen et al., 2011, Dal Corso et al., 2014). Therefore, not only Western Newfoundland but also Upper Triassic and Lower Cretaceous volcanic rocks located in the Scotian Basin and the CAMP could have been the source of mafic material to the Grand Banks basins.

Methods

Cuttings and core samples of sedimentary rocks were disaggregated and sieved to isolate the 40 to 250 µm grain-size window. After carbonate digestion, ‘light’ and ‘heavy’ grains were separated using a lithium metatungstate solution (density 2.89 g/cm^3), using the funnel separation technique as indicated in Mange and Maurer (1992). HM grains were mounted on a glass slide and each slide was analyzed with a Horiba LabRam Raman Microscope, using a 532nm green laser.

A Frantz magnetic separator was employed to further concentrate zircon grains. To determine the U-Pb age of each grain we used a laser ablation inductively coupled plasma mass spectrometer (ICP-MS). The Plesovice zircon standard (Sláma et al., 2008) was used to correct for downhole U-Pb fractionation, mass bias and instrument drift. Any age data that was more than ± 10 % discordant was filtered from the dataset.

Currently, the provenance database for the Grand Banks includes more than 250 samples analyzed via Raman spectroscopy. Detrital zircon U-Pb geochronology was performed on more than 300 samples. Additional samples are being processed.

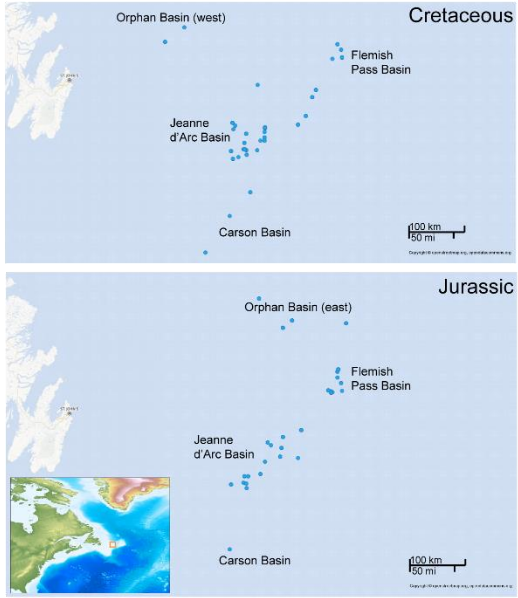

Figure 1. Wells having ZTR maturity index (sum of the percentages of ultrastable heavy minerals zircon, tourmaline, rutile; Hubert, 1962) higher than 70 in their Jurassic (bottom map) and Cretaceous (top map) successions.

Results and Discussion

In the St. Anthony Basin, relatively high amounts of chrome-spinel are observed in the Carboniferous metasedimentary rocks which form the 'economic basement'. This basin is located to the north-east of the St. Anthony Ophiolite Complex, the probable source the chrome-spinel. Notably, most of the Jurassic to Cretaceous succession deposited in the Grand Banks does not contain this mineral. However, locally relatively high proportions of Cr-spinel occur in some Cretaceous sandstones deposited in the western area of the Jeanne d'Arc Basin. As expected due to its chemical unstability, olivine is rarely reported and if present only in trace amounts. Garnet grains (and less frequently andalusite, kyanite and staurolite) are observed in relatively high percentages in a number of wells, such as Outer Ridge Complex well North Dana I-43, Jeanne d'Arc Basin well Fortune G-57 and other wells located further to the southwest.

In most cases, metamorphic minerals do not appear to be correlated with ultramafic minerals. However, both groups of minerals occur in sandstones intersected by wells Hibernia K-18 and Egret K-36. In well Hibernia K-18, Cretaceous sedimentary rocks (Catalina Member) have garnet and chrome-spinel. In well Egret K-36, Upper Cretaceous sedimentary rocks (Petrel Member and Fox Harbour Member) have garnet, andalusite, kyanite, chrome-spinel and traces of staurolite and occassionally olivine. Additionally, the Upper Cretaceous Dawson Canyon Formation drilled by well Terra Nova I-97 has relatively high percentages of chrome-spinel and the correlative sandstones in well Riverhead N-18 have some garnet and staurolite.

Provenance from the ophiolitic complexes and the associated metamorphic units of western Newfoundland, therefore, seems to be restricted to the Cretaceous succession intersected by well Hibernia K-18, the Upper Cretaceous succession intersected by well Egret K-36 and, possibly, by wells Terra Nova I-97 and Riverhead N-18. The recognition of mafic / ultramafic provenance is important as sands derived from such sources often have a lower reservoir quality – due to their large amount of unstable minerals at the time of sediment deposition and subsequent impact on diagenesis – compared with sediments characterized by higher percentages of recycled material.

Wells Hibernia K-18 and Egret K-36 are both located along the western margin of the Jeanne d'Arc Basin. Possibly, transport systems draining western Newfoundland initially entered the Jeanne d'Arc Basin from the Bonavista Platform and deposited material in the area of well Hibernia K-18 (in the Early / middle

Cretaceous), whereas, later in time (in the Late Cretaceous), sediment derived from western Newfoundland was deposited further to the south, i.e. in the area of well Egret K-36.

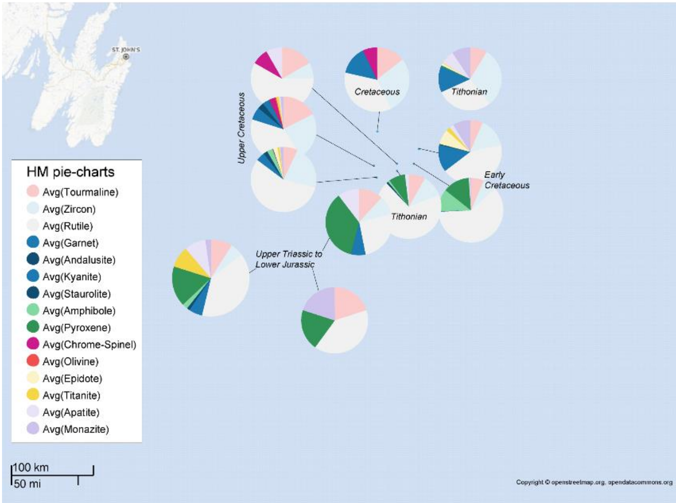

Figure 2. Pie-charts showing results of heavy mineral analysis perforemd on some sandstones of the southern Grand Banks area.

Most of the study succession shows pyroxene grains being either absent or in very in small percentages, with the exception of the Upper Triassic to Lower Jurassic succession penetrated by wells Spoonbill C-30, Osprey H-84 and Phalarope P-62 (containing c. 15 – 35 % pyroxene). In addition, pyroxene is reported in the Tithonian in well Fiddlehead D-83 and the Early Cretaceous succession in well Federation K-87, with the latter also showing relatively high percentages of amphibole. It is therefore suggested that Upper Triassic mafic volcanic rocks of the CAMP provided some detritus to the Carson and Whale basins, as well as the southern-most part of the Jeanne d'Arc Basin, during the late Triassic and Early Jurassic. The observed absence of zircon grains with ages of c. 200 Ma and the low percentages of zircon grains in the heavy mineral assemblages were to be expected, given the mafic composition of the CAMP volcanic rocks.

Pyroxene derivation from the Lower Cretaceous bimodal volcanic rocks documented in the southern Grand Banks and in the Scotian Basin is suggested for the Lower Cretaceous succession of the south-eastern part of the Jeanne d'Arc Basin (e.g., for the succession intersected by well Federation K-87) and possibly for the underlying Tithonian sandstones. Results of detrital zircon U-Pb geochronology, showing high proportions of Early Cretaceous zircon grains in samples containing pyroxene grains, give further indications to support this provenance. The contemporaneity of bimodal volcanism and sedimentation in the south-eastern area of the Jeanne d'Arc Basin is clear and therefore results of detrital zircon U-Pb geochronology can be applied to satisfactory constrain the maximum depositional age of Lower Cretaceous sandstones in this area of the Grand Banks.

Conclusion

Provenance from mafic and ultramafic rocks and associated metamorphic rocks of western Newfoundland is suggested for some of the sedimentary material contained in the Cretaceous succession of the Jeanne d'Arc Basin, mainly in the Upper Cretaceous succession intersected, for example, by well Egret K-36. Further investigation is underway to assess the impact of mafic and ultramafic sources on resevoir quality of sands in Grand Banks. Provenance from Upper Triassic mafic volcanic rocks of the CAMP is suggested for a component of the Upper Triassic to Lower Jurassic material deposited in the Carson and Whale basins and in the southernmost part of the Jeanne d'Arc Basin, whereas derivation from the Lower Cretaceous bimodal volcanism for the Lower Cretaceous succession of the south-eastern area of the Jeanne d'Arc Basin.

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