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The Red Head Aeolian Sandstones of the Upper Triassic Fundy Basin, Nova Scotia, Canada

K.T. Martyns-Yellowe[1*], G.D Wach[1], R.I. Silva[1, 2], D.E Brown[1], D.E. O'connor[1], T.B. Kelly[1] & Y. A. Kettanah[1]

ABSTRACT

Triassic aeolian sandstone formations in various parts of the world have been reported to be prolific hydrocarbon reservoirs from which oil and gas have been produced (e.g Ormskirk Sandstone Formation, Sherwood Sandstone Group). In the Fundy Group of the Newark Supergroup, aeolian sandstones of the Fundy Basin comprises well sorted, red, quartzose aeolian sandstone characterized by very large to small scale sedimentary features. In the Minas subbasin, Nova Scotia, the Late Triassic Red Head Sandstone (RHS) is a remarkably well preserved section of aeolian strata in the Northern Segment of the Eastern North American Margin, at the type section at Red Head Point. The aeolian sandstone was deposited in an arid to semi-arid environment with its sediments sourced from a combination of alluvial and fluvial depositional means.

In this study, we integrate a combination of outcrop sedimentological descriptions with petrographic and geochemical data to examine the stratigraphy, sedimentology, provenance and reservoir characteristics of the RHS.

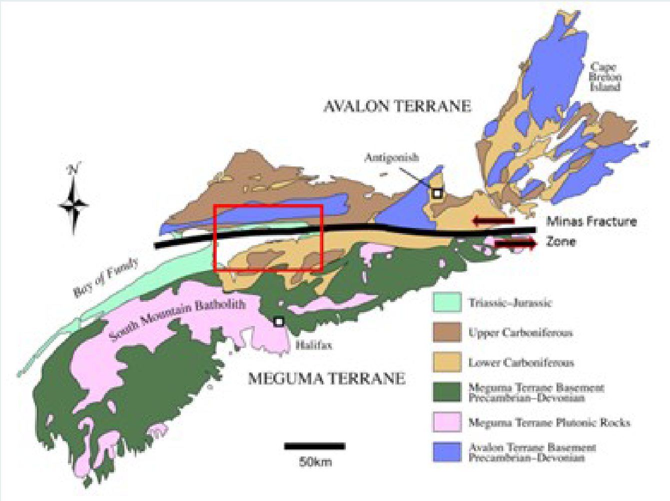

Figure 1: Geologic map of Nova Scotia showing our study area of the Minas Subbasin (Red box). Also, the Avalon and Meguma terranes are juxtaposed along the Minas Fracture Zone, a zone of movement along pre-existing basement structure with arrows showing the major sinistral strike slip trend (figure modified from Keppie, 2000).

1. INTRODUCTION

The Late Triassic Red Head Sandstone (RHS) is a well sorted, red, quartzitic sandstone characterized by very large to small scale sedimentary features. At its type section located on the northern shore of the Minas subbasin, Nova Scotia, at Red Head Point (Figure 1; Figure 2), the aeolian sandstone comprises approximately 33 m of red sandstones interpreted as deposited under primarily aeolian conditions within arid to semi-arid environments (Hubbert & Mertz, 1980, 1984; Mertz,1980; Mertz Jr. & Karl A., 1980; Olsen & Hubert, 1981; Nadon & Middleton, 1984; Martyns-Yellowe, 2015). The study location is unique as the outcrop presents a three-walled amphitheatre that allows for a near complete internal 3D visualization of the sandstone unit.

Similar to the trend recorded in Mesozoic rift basins along the Eastern North American Margin (Withjack et al., 1995, 1998, 2009, 2012), the deposition of aeolian sandstones at Five Islands (Figure 2) marks the transition between Carnian-age alluvial and fluvial sedimentation of the Wolfville Formation and Norian to Rhaetian-age lacustrine sedimentation of the Blomidon Formation in the Fundy Basin, Nova scotia (Fowell & Traverse 1995; Olsen et al. 1989). The aeolian sandstones are interbedded with fluvial sandstones and playa redbeds (Olsen & Et-Touhami, 2008; O'Connor, 2016; Leleu et al., 2009, 2016; Leleu & Hartley, 2010) and represents the Upper Triassic transition between the fluvial/alluvial Wolfville Formation and playa lacustrine Blomidon Formation.

The preserved stratigraphic architecture and depositional mechanism of the sandstone unit are attributed to winds similar to those of ancient and modern desert environments (Hubbert & Mertz, 1980, 1984; Mertz,1980; Mertz Jr. & Karl A., 1980; Olsen & Hubert, 1981; Leleu et al., 2009, 2016; Leleu & Hartley, 2010; Martyns-Yellowe, 2015; O'Connor, 2016). Outcrop observations

1 Basin and Reservoir Lab, Earth and Environmental Science Department, Dalhousie University, Halifax, Nova Scotia, Canada.
2 Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba, Canada.

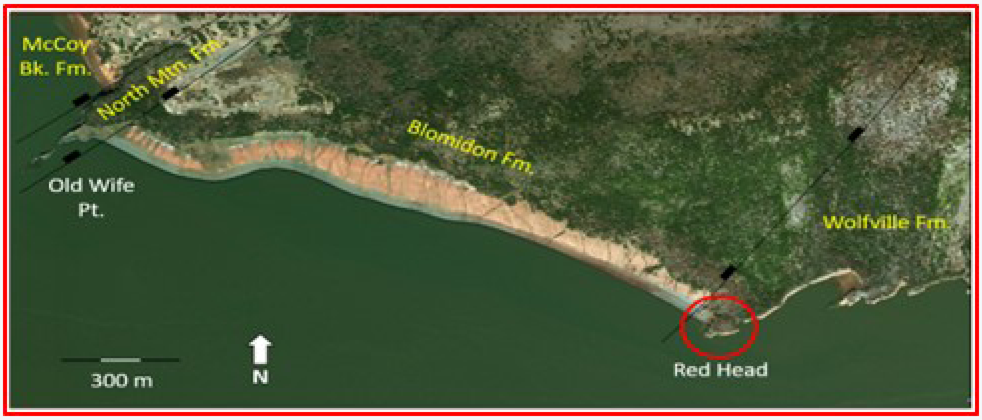

Figure 2: An aerial photograph showing the distribution of the key formations in the area along the northern shore of the Minas Subbasin. The red oval represents the location of our study section at Five Islands.

of the RHS type section shows a generally complex cross-strata configuration comprising facies associations including sand sheets, dune and interdune deposits with cross bed orientations consistent with deposition by prevailing north easterly winds (Mertz,1980; Hubbert & Mertz, 1980, 1984; Mertz Jr. & Karl A., 1980; Olsen & Hubert, 1981; Martyns-Yellowe, 2015).

2. BACKGROUND AND GEOLOGIC SETTING

Located on the northern part of the central rift segment, the Fundy Basin is one of the rift basins of the eastern North American rift system that resulted from Mesozoic extension and break-up of the Pangaea supercontinent in the Middle Triassic (Withjack et al. 1995; Olsen 1997). The basin covers an area of approximately 16500 km2, containing about 6 -12 Km of non-marine clastic sediments of Anisian to basal Hettangian-age and theolitic basalt flows of Middle Triassic to Early Jurassic age within the Newark Supergroup (Klein, 1962; Withjack et al., 1995; Wade et al.1996; Olsen 1997). The Fundy Basin comprises three contiguous structural components (Fundy, Minas, and Chignecto subbasins) all bounded by faults south of the Minas Fracture Zone (Olsen et al., 1989; Figure 1 and Figure 3). The large-scale segmentation of the border fault zone was responsible for the formation of these structural components (Olsen & Schlishe, 1990; Schlische, 1993) with the NE-striking border normal faults bounding the Chignecto and Fundy subbasins to the northwest.

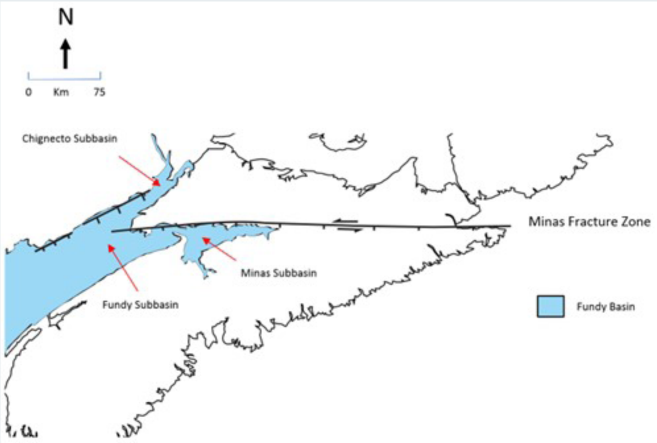

Figure 3: Map of the Fundy Basin showing the three contiguous components (Fundy Subbasin, Minas Subbasin and the Chignecto Subbasin). The major bounding Minas Fracture Zone shows a sinistral strike-slip motion (Modified from Schlische, 1993).

The east trending Minas subbasin is bounded by a series of normal, strike-slip, and oblique slip faults of the Minas Fracture Zone to the north (Keppie, 1982; Olsen & Schlishe, 1990; Withjack et al., 1995). According to Withjack et al. (1995, 1998), the Minas Fracture Zone played a role in the deposition of continental sediments at various stages of the evolution of the Minas subbasin. With a sedimentary thickness of 1050 m, a two-stage stratigraphic relationship exists in the Minas subbasin comprising upto 800 m of the Wolfville Formation and 250 m thick of the Blomidon Formation (Leleu & Hartley, 2010; Figure 4).

Alluvial plain deposits of Carnian to Norian age make up the main body of the Wolfville Formation (Hubert & Florenza, 1988; Olsen, 1988; Figure 4), which are the oldest sediments in the Fundy Basin. The formation rests unconformably on Paleozoic metasedimentary strata of the Horton Bluff Formation (Hubert & Florenza, 1988). The Wolfville Formation comprises red to brown, coarse to fine grained sandstone, orange pebbly sandstone, conglomerates, and a few shale interbeds typical of alluvial, braided river deposits in a semi-arid climate (Klein 1962; Hubbert & Florenza 1988; Leleu et al. 2009; Wach et al. 2011). The formation is exposed on both sides of the Minas subbasin.

The Blomidon Formation occurs stratigraphically above RHS and the Wolfville Formation (Figure 4) and is approximately 220m thick comprising over 100 thin lacustrine cycles of red laminated to massive mudstone (Ackermann et al. 1995). The formation comprises laterally continuous graded mudstone beds that range between 5 and 30 cm in thickness (Mertz & Hubert, 1990). The formation outcrops mostly on the northern shore of the Minas subbasin. According to Mertz & Hubert (1990), the age of the formation spans the Norian, Rhaetian and Hettangian age based on palynomorph assemblages.

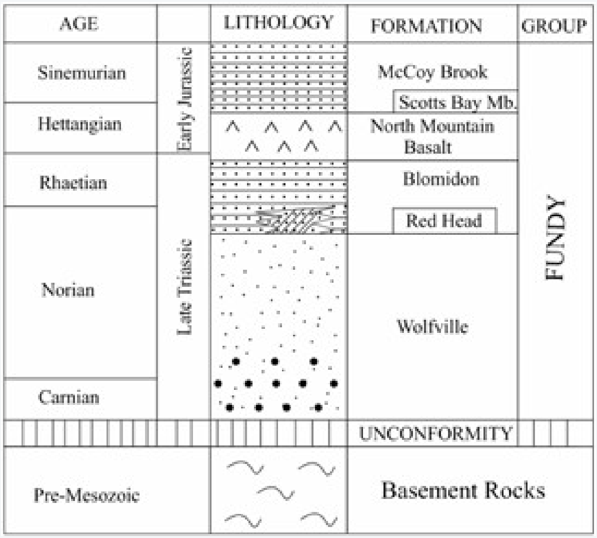

Figure 4: Stratigraphic chart of the Mesozoic Fundy Group and corresponding age of each of the four main formations. From oldest to youngest are the Wolfville, Blomidon, North Mountain Basalt, and the McCoy Brook formations.

3. METHOD

Integrated analysis of outcrop samples (Figure 5), petrographic thin section analysis (including point counts) geochemical (XRF) and scintillometer) data were used to characterize the sediments. The texture and elemental composition of the RHS from thin section and geochemical analysis respectively were compared against samples from the overlying playa- lacustrine mudstones of the Blomidon Formation.

4. RESULTS

Outcrop and petrographic analysis of sandstone samples from the RHS supports aeolian transport with thin section and point count analysis revealing mature, sub to well-rounded grains with enhanced levels of primary porosity (Figure 6; Figure 7b). Mudstone samples from the Blomidon Formation show reduced matrix porosity and exhibit a predominance of matrix supported quartz, mica, and significant amounts of iron oxides (Figure 7a). The RHS plots between subarkose and sublithic arenites in the QtFL classification of Folk (1968) in Figure 8 and in the recycled orogenic field of the QtFL provenance indicator plot in Figure 9 with recalculated parameters after Ingersoll & Suczek (1979), and Dickinson (1985). Mapping geochemical analysis results from the sandclass plot (Herron, 1998; Figure 10) to petrographic analysis result of the RHS indicates that the RHS is mainly subarkosic. Thus, implying an abundance of quartz and lesser amounts of feldspars in the aeolian sandstone.

Figure 5: The RHS aeolian type section at Five Islands (study area) with numbers showing sample locations.

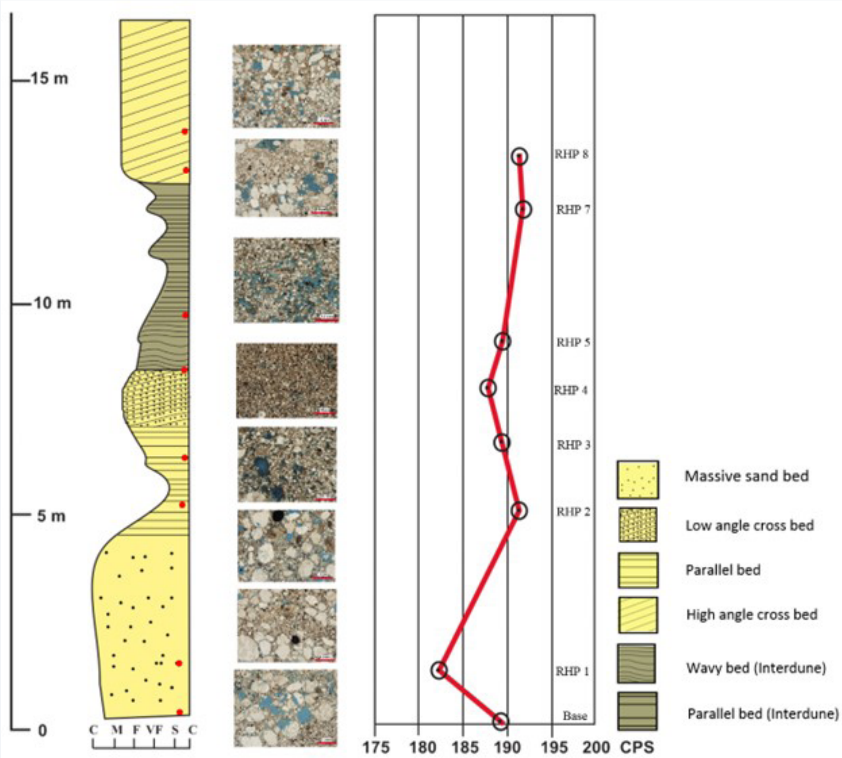

Figure 6: A measured section of the Red Head Member aeolian sandstone, Five Islands, NS with corresponding pseudo gamma-ray (scintillometer) plot of the section. The red dots represent where samples were collected in the outcrop, with thin section images displaying their respective textures. The corresponding sample identification numbers are to the right of the gamma plot.

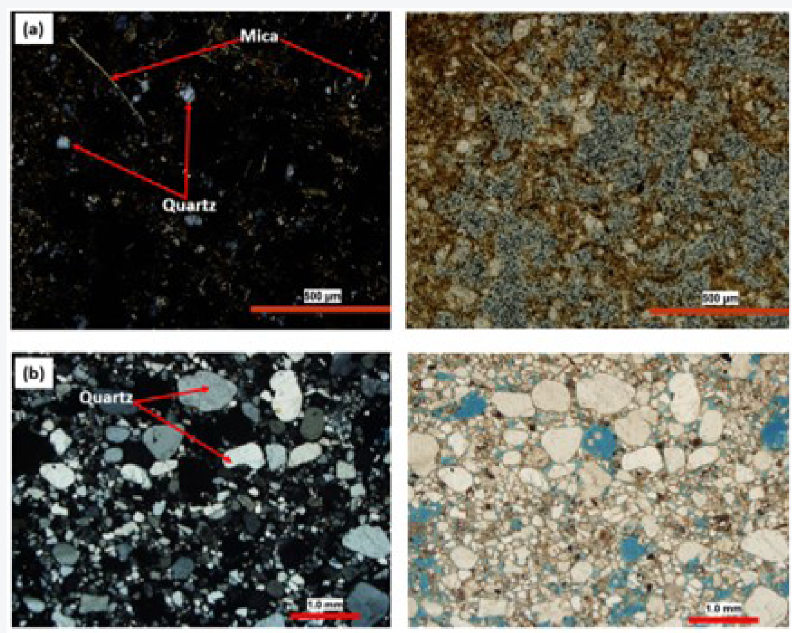

Figure 7: Photomicrograph comparing the grain size variation, mineralogical distribution with a poorly sorted, bimodal distribution and layering in the (a) Blomidon Formation mudstones (b) RHS.

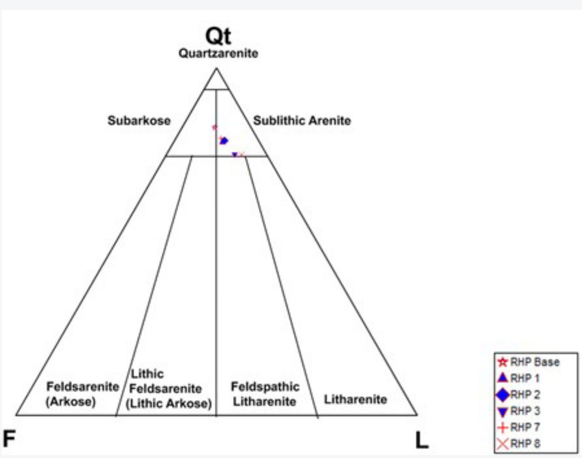

Figure 8: QtFL classification of Folk (1968) applied to the RHS. The samples plot between subarkose and sublithic arenites.

5. DISCUSSION

The occurrence of aeolian deposits in the Minas subbasin (Fundy Basin) at the transition between the Wolfville and Blomidon formations are characteristic of a semi-arid to arid domain (Hubbert & Mertz, 1980, 1984; Mertz Jr. & Karl A., 1980). The aeolian sandstones have been seen interbedded with fluvial sandstones and playa redbeds in various locations along the ramp margin to the south of the Minas subbasin and the faulted margin to the north of the Minas subbasin (Olsen & Et-Touhami, 2008; O'Connor, 2016; Leleu et al., 2009, 2016; Leleu and Hartley, 2010; Figure 11), and represents a late stage in synrift basin fill that occurs between the two major synrift phases that resulted in the deposition of the Wolfville and Blomidon formations (O'Connor, 2016; Leleu et al., 2009, 2016; Leleu & Hartley, 2010). Hence, it represents a boundary strata (Slavador & Murphy, 1998) between the two major synrift phases. The cross bed orientation at the aeolian sandstone type section along the northern margin is consistent with deposition by prevailing north easterly winds (Hubbert & Mertz, 1980, 1984; Mertz Jr. & Karl A., 1980).

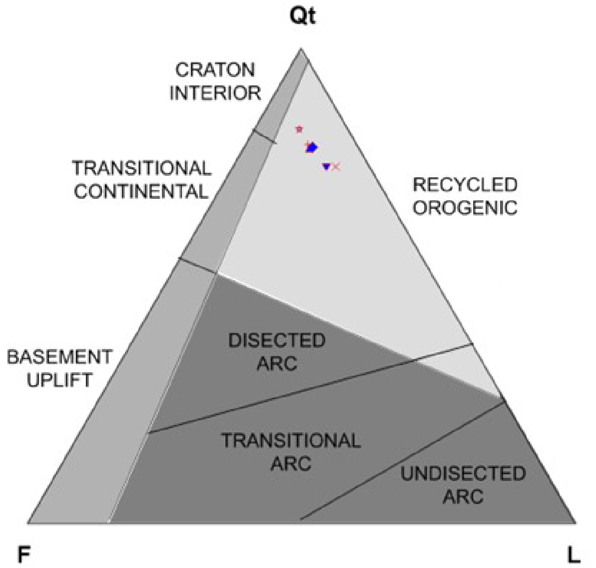

Figure 9: A provenance indicator plot after Ingersoll and Suczek (1979) and Dickinson (1985) for the RHS. The plot shows that the samples fall in the field of recycled orogenic provenance.

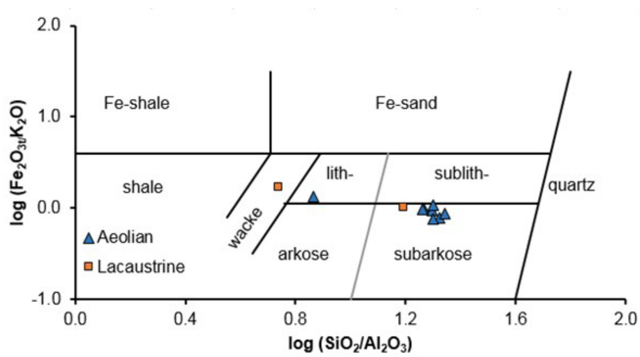

Figure 10: Red Head Point sandclass plot after Herron, (1998) for sandstone and mudstone samples. Most of the sandstone samples (blue) plot in the subarkosic field.

Results from the petrographic and geochemical analysis of the RHS in this study suggests that the RHS is both texturally and compositionally mature, supported by an abundance of well sorted quartz sand grains with low proportions of feldspar. Provenance indicator triangles of detrital assemblage presented in the results of our analysis indicates that the RHS was derived from a continental block provenance and by plotting in the recycled orogenic field of the triangular diagrams of Dickinson (1985) further supports the aeolian sandstone being the product of a reworking of the underlying Wolfville Formation sandstone.

6. CONCLUSIONS

The Fundy Basin is located in the northern central rift segment of eastern Canada between New Brunswick and Nova Scotia. It is one of the rift basins of the eastern North American rift system that resulted from the Mesozoic extension associated with the break-up of the Pangaea supercontinent in the mid-Triassic. The Red Head Sandstone (RHS) represents the late stage of synrift basin fill in the Minas Subbasin comprising the older/basal alluvial and fluvial phase represented by the Wolfville Formation and overlying/younger playa lacustrine phase represented by the Blomidon Formation. Hence, it represents a transitional boundary between the two major synrift phases produced by drying of the climate and abundant sediment supply.

Given the compositional and textural variation between the RHS, the overlying mudstones of the Blomidon Formation and the underlying alluvial/ fluvial Wolfville Formation sandstones, a combination of both petrographic and geochemical methods allowed for a more robust classification of the respective sedimentary units. Ensuring that finer grain sediments (very fine sandstones and mudstones) which are difficult to analyze through point count were included in the study.

Field sedimentological and lithological observation of the RHS and the Blomidon Formation at the type section indicates that the RHS possesses different sedimentary characteristics from the overlying very fine sandstone and mudstones of the Blomidon Formation. The aeolian sandstone of the RHS is distinguishable from fluvial sandstones of the underlying Wolfville Formation.

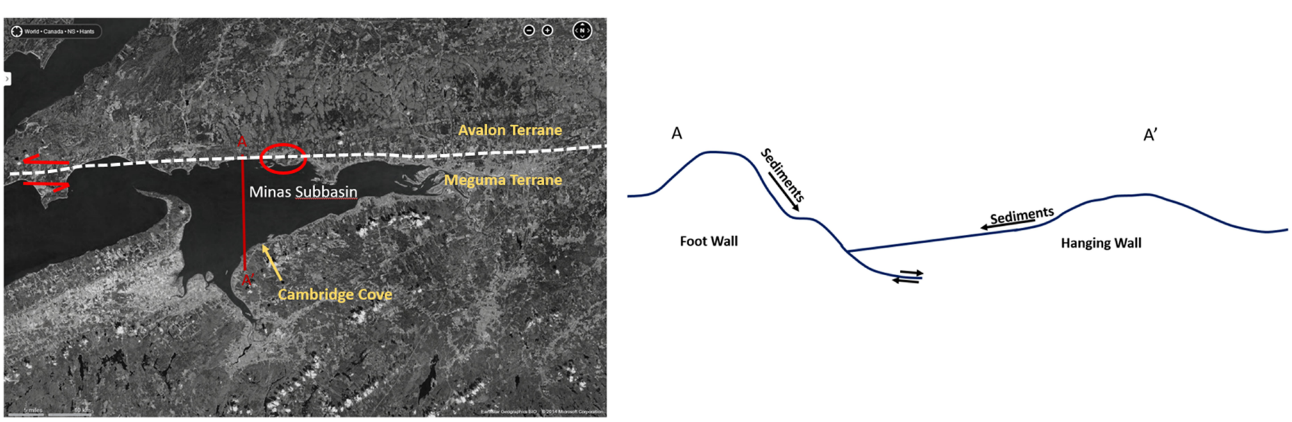

Figure 11: A Satellite image of the Minas Subbasin showing the major terranes, basin bounding fault with fault trend and a cross section of the Minas Subbasin through A-A'. The location of the Red Head study section is indicated by a red circle. To the left is an annotation of the basin fill pattern across A-A'.

Based on the evidence presented, the RHS appears to represent a discrete stratigraphic formation, separate from the Blomidon and Wolfvill formations.

The excellent reservoir quality of the RHS suggests great potential for a wide range of applications including emerging geothermal energy projects and geostorage projects.

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