New Insights for the Regional Geology of the Kennetcook Basin, Meguma Terrane, Nova Scotia

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Introduction

The geologic context for the formation and evolution of the Kennetcook Basin is reviewed in detail by Waldron *et al*. (2010) and Keppie (2011). The focus herein is on a new, albeit preliminary, interpretation of the surface map pattern of the bedrock geology of the Kennetcook Basin, Meguma Terrane, Nova Scotia. This new interpretation is based on the collection of new field data during the summer of 2011. Following a brief explanation of the new interpretation, discussion will be on the key questions that remain to be addressed. Specifically, there are several outstanding data compilation steps that must be incorporated in this analysis. Also, a more final map interpretation will follow integration of this preliminary interpretation with sub-surface data from drill core, seismic reflection data, and other geophysical information.

Geographic Setting

The map area comprises parts of NTS map sheets 11E/03 (northwestern-most part), 11E/04 (central and northern parts), 11E/05 (southern part), and 11E/06 (southwestern-most part), as illustrated in Figure 1. Broadly, Devono-Carboniferous rocks of the Kennetcook Basin are exposed along a SW-NE trend parallel to the Minas Basin coastline (Fig. 2). Directly adjacent to the Minas Basin, Fundy Group rocks of Mesozoic age, which unconformably overlie the Devono-Carboniferous stratigraphy, are exposed. In contrast, to the southwest Halifax and Goldenville group rocks of early Paleozoic age, unconformably covered by the Devono-Carboniferous strata, are exposed. In the Windsor Basin to the west, the Shubenacadie Basin to the southeast, and the Saint Mary's Basin to the northeast, Devono-Carboniferous strata are laterally continuous and equivalent to those exposed in the Kennetcook Basin. Geographic or geological boundaries between the Windsor, Kennetcook, Shubenacadie and Saint Mary's Basins appear to be approximate and loosely defined, although major faults, rivers, geological variation, and/or the boundaries of NTS map sheets provide logical borders for naming distinctions. Field mapping during 2011 focused on the area between Walton in the west and Maitland in the east, and between Noel in the north and Rawdon in the south (Fig. 1). Field stations visited during the 2011 mapping season are illustrated in Figure 2.

Geological Interpretation: a Working Model

As reviewed by Keppie (2011) and references therein, the bedrock map pattern in the Kennetcook Basin likely reflects, to varying degrees, (1) deposition of the Devono-Carboniferous stratigraphy comprising the successive formation of the Horton, Windsor, Mabou and Cumberland groups; (2) folding and/or thrusting of the Devono-Carboniferous stratigraphy during Alleghenian shortening; (3) rifting and/or faulting related to the opening of the Bay of Fundy (and Minas Basin) during the Late Triassic-Early Jurassic; and (4) asynchronous migrations of salt vertically and/or laterally, due either to gravitational instabilities or tectonic forcing at various times after salt deposition.

The working model proposed here was adopted for interpreting the actual bedrock map patterns (Fig. 3). Essentially, it is hypothesized that the majority of the map pattern can be attributed to folding of the Devono-Carboniferous stratigraphy during Alleghenian shortening – if this folding produced SW-NE, doubly plunging, relatively upright regional folds. There seems little doubt that the Windsor and Kennetcook Basins together form a

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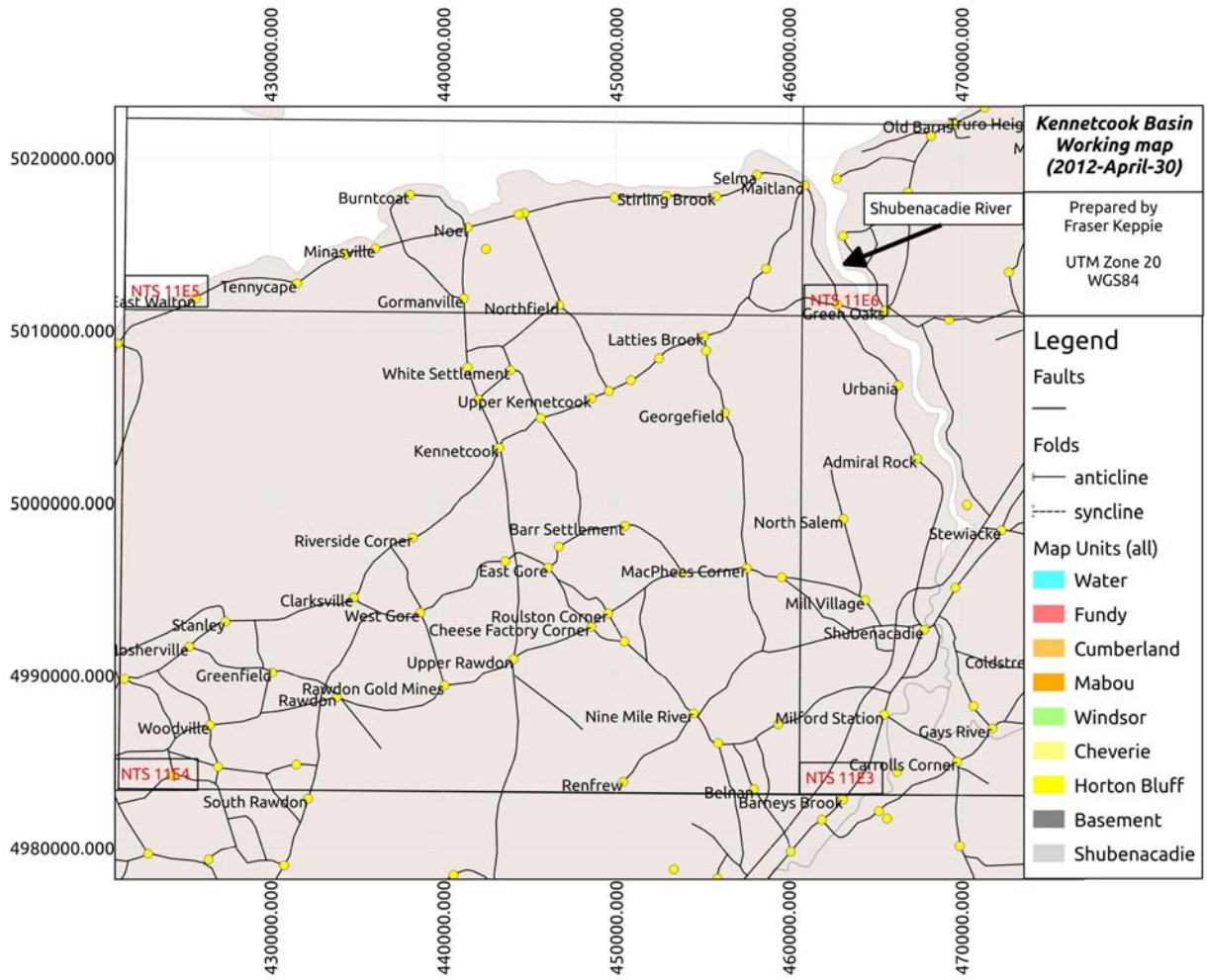

Figure 1. Geographic area re-interpreted for bedrock geology as a consequence of new mapping data acquired by the author in the summer of 2011. Note that none of the map units are identified on this location map.

regional scale, doubly plunging syncline, so the hypothesis that this map pattern is reflected at a finer scale, in a parasitic fashion, seems reasonable. Further justifications for supposing that Alleghenian deformation has produced doubly plunging folds in the Devono-Carboniferous stratigraphy within the Kennetcook Basin are as follows. First, a single phase of folding can produce doubly plunging folds because folds nucleate at points and subsequently grow due to propagation parallel to their hinge lines (Keppie *et al*., 2002). This can also happen where two horizontal directions of principal stress are compressive (Twiss and Moores, 2007). Second, Neoacadian and Alleghenian deformation phases likely shared, or had modestly oblique, principal shortening axes within the Meguma Terrane as a whole (Keppie, 2011). If principal shortening axes were modestly oblique, these two phases of folding could have produced the doubly plunging map pattern observed in the Paleozoic rocks of the Goldenville, Halifax and Rockville Notch groups (Culshaw and Liesa, 1997; Keppie *et al*., 2002; White and Barr, 2010), at least in part. The overlying Horton, Windsor, Mabou and Cumberland groups in the Kennetcook Basin may have inherited the basement deformation style during the Alleghenian deformation phase.

Modifying this underlying map pattern are two series of faults (Fig. 4): (1) a NW-SE fault series, including the Walton River Fault, for example, and (2) a SW-NE fault series, including the Kennetcook River, Rawdon and Roulston Corner faults. Both series of faults have components of motion which offset and postdate Devono-Carboniferous

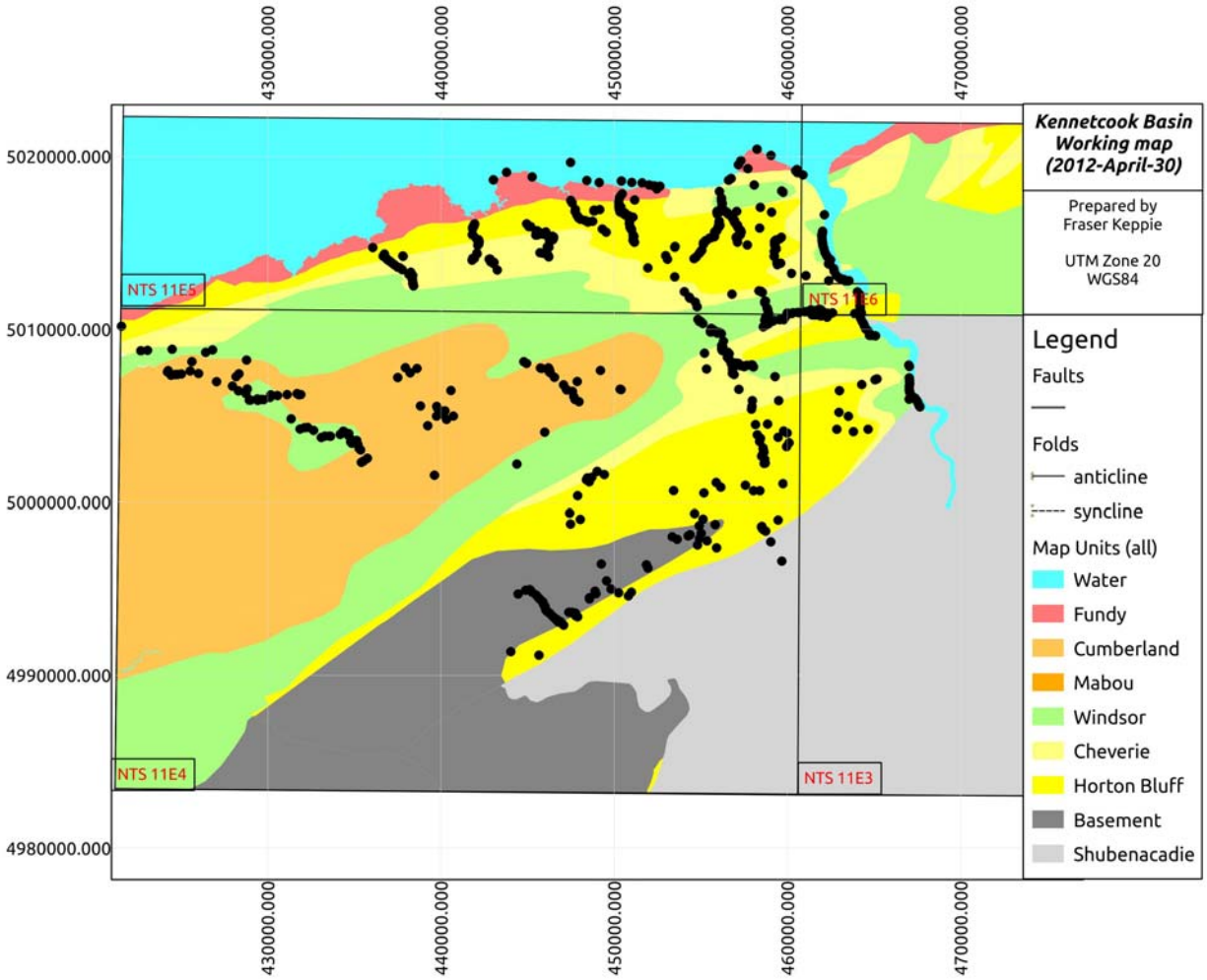

Figure 2. Field stations acquired during the 2011 field mapping season.

stratigraphy. This faulting may therefore be related to the Mesozoic opening of the Bay of Fundy (Keppie, 2011). As well, the fact that the principal stress axis during Neoacadian shortening may have been parallel to, or contained in, the fault planes of the NW-SE fault series means that these faults may record an earlier component of motion that predates the Devono-Carboniferous (Twiss and Moores, 2007). This faulting would not affect the map pattern in the Devono-Carboniferous stratigraphy, however, and is not considered further here.

Palynological data were collected to aid the interpretation of the bedrock map pattern. Sample names, locations and age interpretations are given in Table 1 after field notes by the author and the palynological analysis of Graeme Dolby (2012). Palynological samples are also plotted on the map in Figure 3. These results establish in several key cases that stratigraphic order has not been compromised where field contacts appear to have suffered subsequent faulting or other tectonism. Note that sample kk284A comes from a clastic section along the western bank of the Shubenacadie River that has been interpreted as Cheverie Formation (Giles and Boehner, 2006), which should be Tournaisian in age, whereas the age interpretation is Visean or equivalent age to the Windsor Group. Presently, the age interpretation appears to be based on only a single spore (Dolby, 2012), therefore the field interpretation has not been discounted. However, a further sample or two from this section may help to confirm or reject the initial age estimate. There may also be a possibility that a clastic section between the Cheverie Formation and Windsor Group, missing in the type area, may be of Visean age (Giles, personal communication). This could be the equivalent of

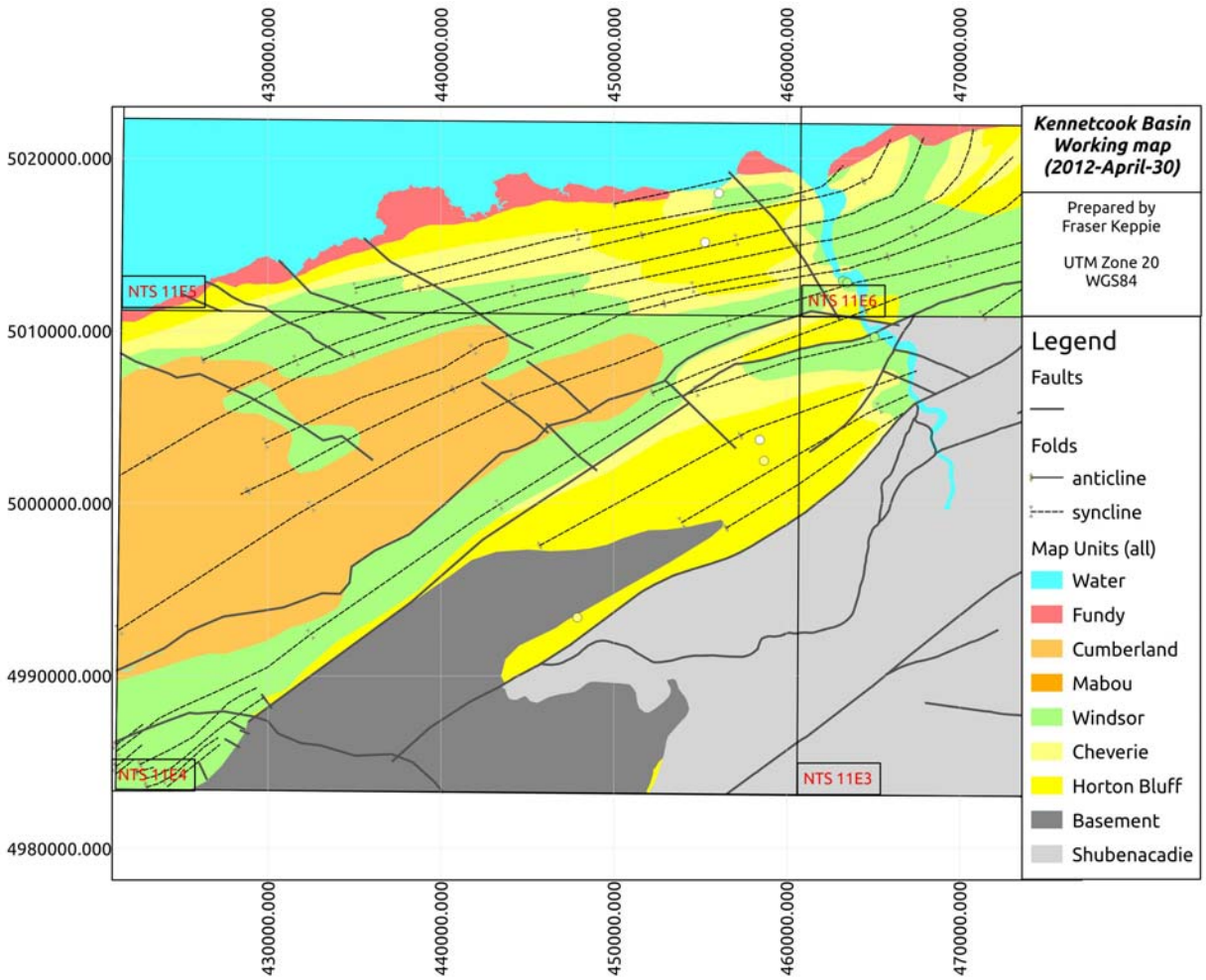

Figure 3. Working map interpretation of major stratigraphic divisions in the Kennetcook Basin. Palynological samples reported in Table 1 are plotted here for reference and colour-coded according to interpreted stratigraphic age, where possible.

Table 1. Ages (Dolby, 2012) and locations for palynology samples collected during the 2011 field season. Samples are plotted and colour-coded according to inferred formation name on Figure 1.

Sample	Age	Stratigraphic unit	Comment	utmx	utmy
kk1A	indeterminable			456077	5017976
kk57A	indeterminable			455279	5015129
kk161A	Visean	Lower Windsor	NS Zone	465083	5009620
kk284A	Visean	Windsor	Possible age and stratigraphic unit	463255	5012884
kk285A	Visean	Windsor		463495	5012798
kk298B	indeterminable			458445	5003683
kk305A	Tournaisian	Upper Horton Bluff		458692	5002467
kk358A	Tournaisian	Upper Horton Bluff		447892	4993389

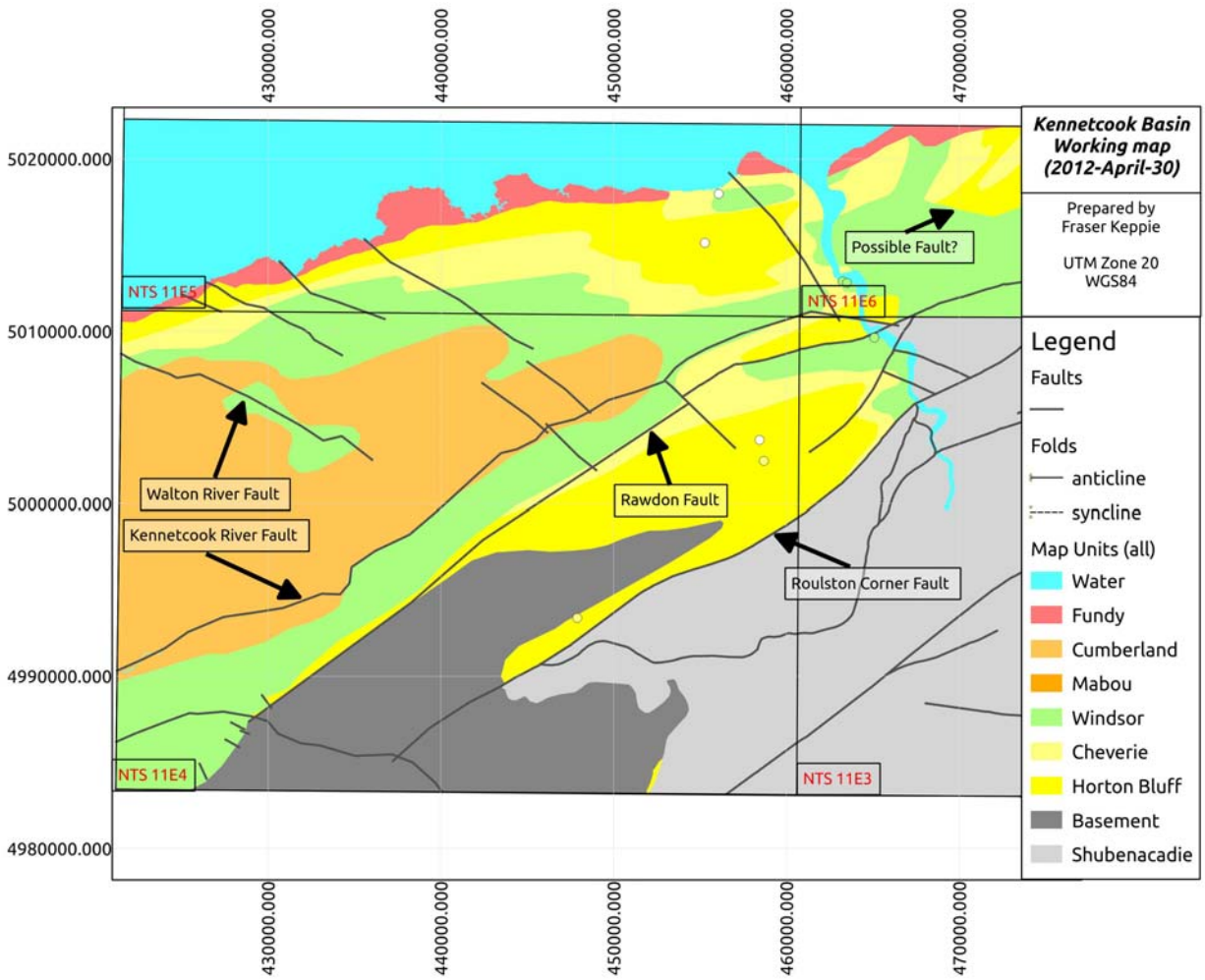

Figure 4. Map of Figure 3 shown with major faults only. Note the presence of a NW-SE fault series that includes the Walton River Fault, for example, and the presence of a SW-NE fault series that includes the Kennetcook River Fault, Rawdon Fault, and Roulston Corner Fault. Potential issues with the interpretation of these fault systems are discussed in the text. Note the presence of an implied fault in the northeast corner of the map area, which is required to make the map compilation of Brisco et al. (2006) consistent in this location. This is discussed in the text as well.

the Sussex Group identified in New Brunswick, for example. The age and stratigraphic identity of this clastic section is thus a subject of active inquiry at present.

Outstanding Issues

Windsor Group rocks exposed on the western bank of the Shubenacadie River north of Green Oaks must be considered somewhat enigmatic at present. The reason is that rocks of the Horton Bluff Formation can be traced from Noel eastward towards the Shubenacadie River, but the noted Windsor Group rocks are exposed where Horton Bluff Formation rocks might have been expected to crop out on the Shubenacadie River. This has been reconciled in Figure 3 by interpreting a section of Cheverie Formation rocks between the Horton Bluff rocks to the west and the Windsor rocks on the western bank of the Shubenacadie River. This interpretation would be the case if the inferred synclines plunge to the east in this region (Fig. 3). However, it is critical to note that no Cheverie Formation outcrop is available to ground-truth this hypothesis at present (Fig. 2). The alternative possibility is a fault contact, or that salt tectonics have produced a halo-kinetic contact between the Horton Bluff and Windsor rocks sometime after the age of deposition. Invocation of salt tectonics may be one way to explain the observation that

anhydrite-mudstone contacts of the Windsor Group rocks are recumbently folded along this segment of the western bank of the Shubenacadie River. Detailed structural analysis and mapping east of the Shubenacadie River are required.

East of the Shubenacadie River, a similar problem is evident in the map compilation of Brisco *et al.* (2006) as well. Here, Brisco *et al*. (2006) report a possible fault boundary that may abruptly juxtapose Windsor and Horton Bluff rocks (Fig. 4). It is not clear what the genetic context for this fault is, however. The existence of this fault and the nature of this contact must be viewed as tentative at present; lack of outcrop may limit how well this issue can be resolved.

Another outstanding issue is the character of the SW-NE fault series. In general, both the block north of the Kennetcook River Fault and the Rawdon Hills Block, located between the Rawdon and Roulston Corner faults (Fig. 4), appear to have been upthrown (cf. King, 2001). However, these relative displacements may have been accommodated due to reverse or normal faulting depending on the dip of the bounding faults. In fact, both interpretations have been illustrated in the recent literature. For example, Horne *et al*. (2001) infer that the Rawdon and Roulston Corner faults are normal, whereas Waldron *et al*. (2010) infer that these faults are reverse. The simplest way to address this question is to inspect the available three-dimensional reflection seismic and gravity data for these regions. If these faults were primarily normal, their formation may be directly related to the opening of the Bay of Fundy. In the case of the Rawdon Fault at least, the sense of motion appears to change along strike, which may imply that it is a scissor fault (Fig. 4).

Future Work

Data from the 2011 field season are ready to be quality-controlled and filtered for display at various presentation scales (e.g. 1:250 000, 1:50 000 and 1:10 000). In conjunction with this, however, there are at least three further field datasets that should be included in the compilation effort and subsequent map interpretations. These are the historical lithology and map data extracted from the Geological Survey of Canada maps of the 1950s (Brian Fisher, personal communication), unpublished field data from the federal-provincial Targeted Geoscience Initiative-3 (Peter Giles, personal communication), and unpublished field data from John Waldron and his various students between ca. 2009 and 2012. In collaboration with the GIS section at the Department of Natural Resources and the original authors, attempts will be made to obtain, capture and compile these additional data for public release. Final map interpretations suitable for presentation at 1:50 000 scale, at least, will be developed from all compiled data, modified from the working map described here.

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