# Structural Origin of the Claremont Anticline, Nova Scotia: Has new seismic solved an old problem?

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## ABSTRACT

### Introduction

High quality 2D seismic shot by Devon Canada and its predecessor Northstar Energy during 2001 and 2002 has revealed for the first time a clear subsurface picture of the Claremont Anticline.
In this paper we review several models that may account for the structural origin of the Claremont Anticline and discuss their applicability in the light of the new seismic evidence. We suggest that a transpressional model for the origin of the Claremont Anticline is better supported by the data, and is more consistent with the tectonic development of the Maritimes Basin as a whole.

### Location of the Claremont Anticline

The Claremont Anticline is located in Cumberland county, northern Nova Scotia (Figure 1). It has a surface expression of some 70km, extending from Claremont Hill in the vicinity of Springhill, Nova Scotia to Malagash Point on Nova Scotia's North Shore, where it passes into the offshore of the Northumberland Strait.

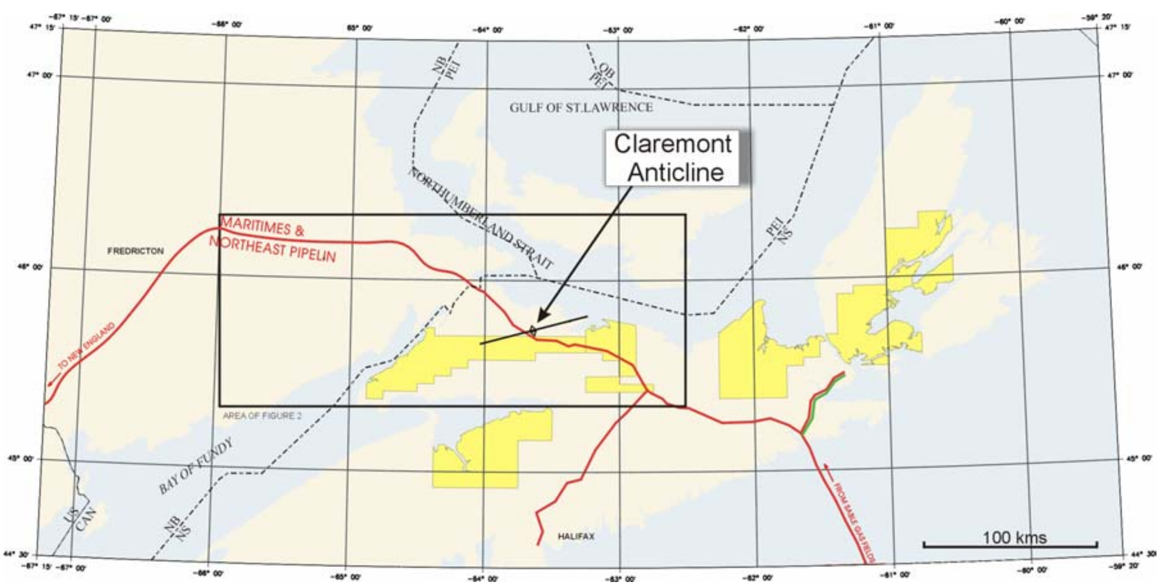


*Fig. 1: Location Map*

## Surface Geology

A compilation of regional geology from published sources (Keppie, 2000 and St. Peter, 2002) shows a series of fault-controlled sub-basins trending NE and ENE (Figure 2). These basins plunge in a north-easterly direction under progressively thicker cover sediments towards the depocenter of the Maritimes Basin in the offshore Gulf of St. Lawrence. Note the position of the Claremont Anticline within the Cumberland Basin between the Athol and Tatamagouche Synclines. Note also the position of the Minudie Anticline, subparallel to the Claremont Anticline, north of the Athol Syncline. Both anticlines exhibit close similarities in their surface expression, revealing Windsor/Mabou Group sediments in their core and younger Cumberland Group sediments on their flanks.

The complex local stratigraphy has been simplified into five units, ranging in age from late Devonian to early Permian. We believe that each of these units is separated from the others by an unconformable surface. Surface erosion has therefore generally resulted in a broad transition from older to younger section from SW to NE, but locally some units are missing at the surface due to depositional overstep. Note in particular that the Horton Group does not outcrop in the Cumberland Basin.

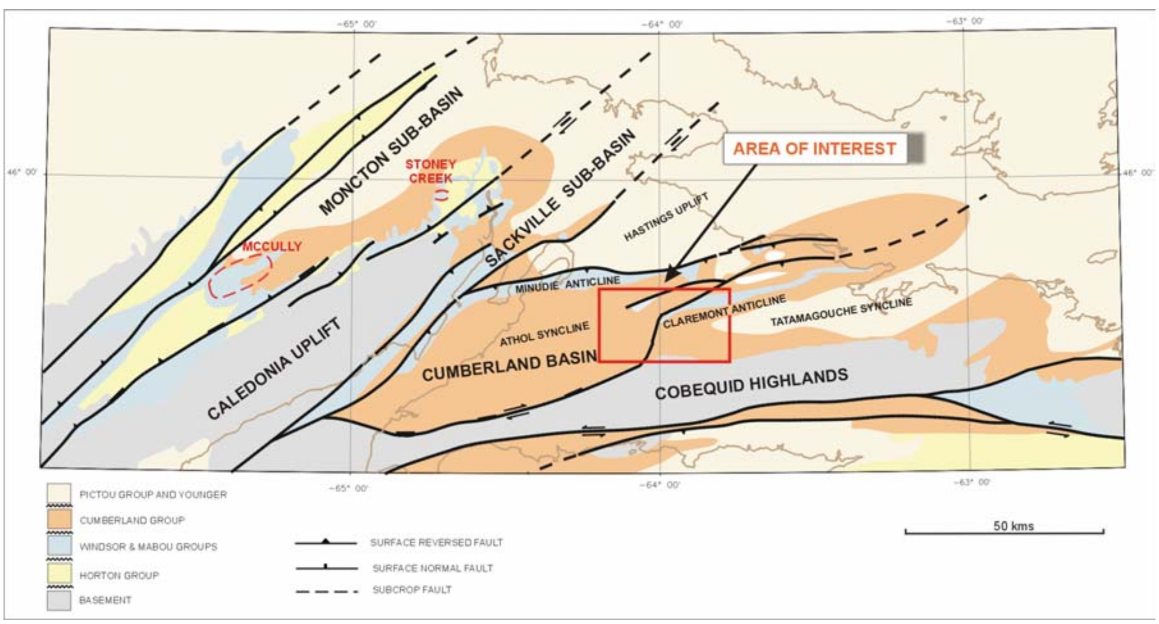


*Fig. 2: Regional Surface Geology (after Keppie, 2000 and St. Peter, 2002.)*

Other authors have described the local stratigraphy (Ryan and Boehner, 1994; Keppie, 2000; St. Peter, 2002). We present a highly simplified version derived from these sources (Figure 3). Note that the depositional environment of all groups is continental to paralic with the exception of a restricted marine environment for most of the Windsor Group. There is a significant development of halite and anhydrite within the lower Windsor Group, some of which has been mobilised into diapiric features.

| AGE | GROUP | Depositional Environment and Lithology |
|---|---|---|
| CARBONIFEROUS | PICTOU | **FLUVIAL (ABOVE BASE LEVEL)** Multiple stacked channel sands with interfluvial red mudrocks |
| | CUMBERLAND | **BRAIDPLAIN, FLUVIAL, SWAMP** Multiple stacked channel sands with interfluvial red-grey mudrocks and occasional coal seams |
| | MABOU | **PARALIC, LACUSTRINE** Fine-grained sands with interbedded red/green, grey and black shales |
| | WINDSOR | **RESTRICTED MARINE** Cyclic carbonate grainstone facies overlie an anhydrite/salt sequence of varying thickness. Common bioherms in basal carbonate facies |
| | HORTON | **INTER-MONTANE / LACUSTRINE** Heterogeneous braided stream deposits of mixed crystalline and lithic origin. Local organic-rich black shales |

*Fig. 3: Stratigraphic Column*

The Claremont Anticline itself has been defined from surface geology. Although outcrops in the area are few, surprisingly detailed maps (Figure 4) have been made from stream sections, air photos and surface geomorphology (Ryan and Boehner, 1994). The area is characterised by abrupt changes in dip angle between sediments of the Windsor/ Mabou and Cumberland Groups. Windsor salt outcrops result in low-lying marshy areas where the salt has been dissolved by surface solution.

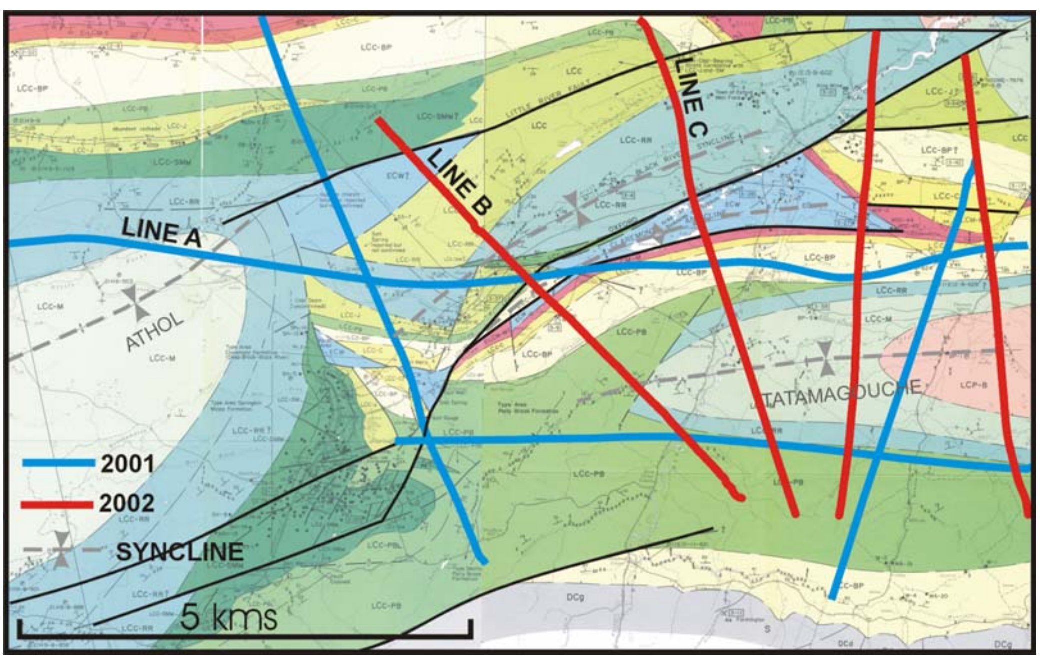


*Fig. 4: Local Surface Geology (from Ryan and Boehner, 1994) showing location of Seismic Program*

**Devon Seismic Program**

Devon Canada and its predecessor Northstar Energy shot 2D seismic programs in 2001 and 2002 that covered the SW up-plunge end of the Claremont Anticline (Figure 4). Acquisition parameters for both programs were the same (Figure 5), and prestack time migration resulted in very good images of the subsurface profile, clearly revealing distinct sequences.

| | | | |
|---|---|---|---|
| Source: | Dynamite, 1kg @ 6m | Gr Interval: | 20m |
| Channels: | 300 | Far Offset: | 3000m |
| SP Interval: | 100m | Fold: | 3000% |

*Fig. 5: 2001/2002 Seismic Acquisition Parameters*

The program layout is shown superimposed on the surface geology map (Figure 4). We present three lines from the program (Figures 6, 7 and 8).
Line A is a W-E profile, which obliquely crosses the Claremont Anticline (Figure 6). The adjacent Athol and Tatamagouche synclines are well defined but structural complexity in the core is difficult to interpret. Lines B and C were shot perpendicular to the interpreted axis of the feature (Figures 7 and 8). The data quality of these two lines is particularly good and confirms the existence of a major sub-vertical fault that we had first interpreted on Line A. A prominent syncline (extension of the Athol Syncline?) is seen on the northern downthrown side of the fault. Using only line A, we might not have interpreted this region in the same way.

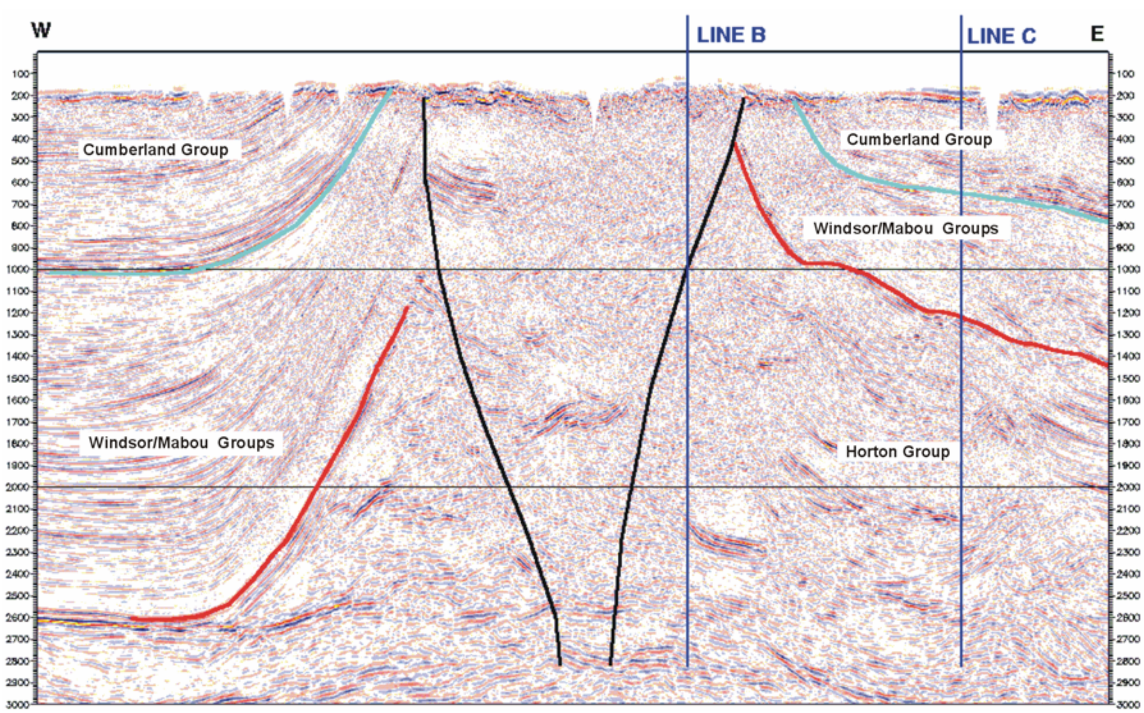


*Fig. 6: Line A*

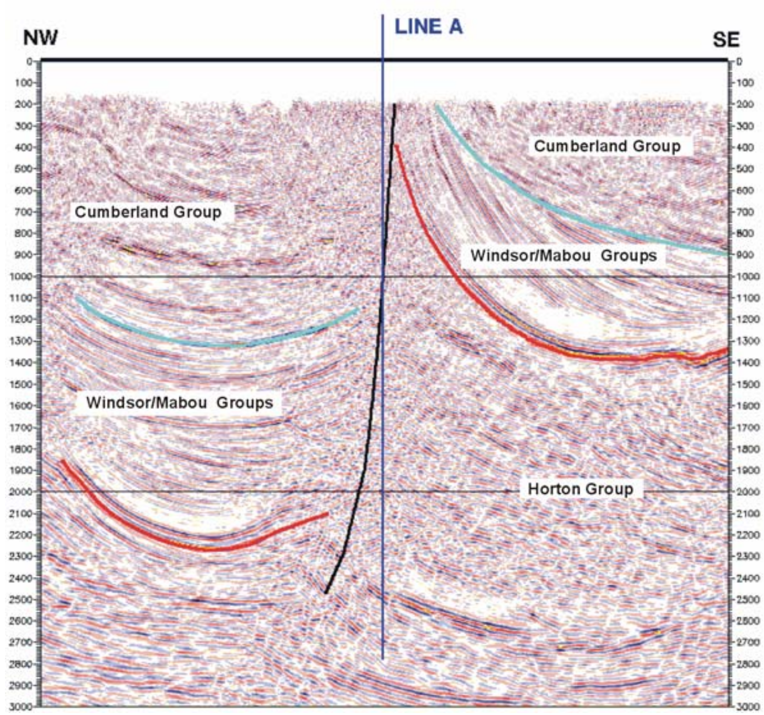


*Fig. 7: Line B*

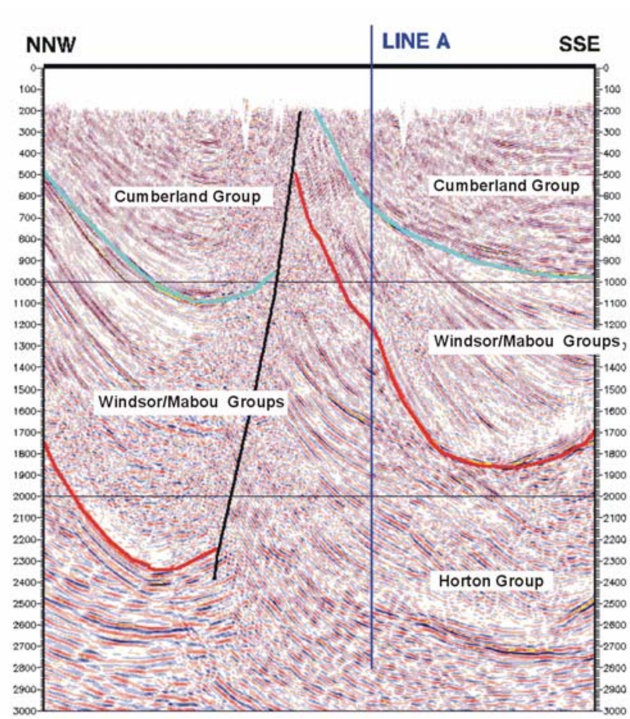


*Fig. 8: Line C*

**Previous models for the origin of the Claremont Anticline**

Strong similarities exist between the surface expression of the Claremont and Minudie Anticlines. In this section we review previous models for these two features. Windsor Group evaporites play a key role in these models, which were based on surface geology, early seismic, and limited well control.
Boehner (1991) proposed a whole range of processes from gravity slides to simple diapirism as instrumental in the origin of structural features in Nova Scotia Carboniferous basins. He suggests “the extent to which the structural configuration of post-evaporite strata is coincident with the structure beneath the evaporite is not well defined”. His interpretation of the Claremont Anticline (Figure 9) shows two fault-controlled diapiric salt bodies penetrating moderately folded Mabou-Pictou Group sediments. Between them, a Basement high is indicated, covered by thinning younger sediments. Salt evacuation is suggested on the SE flank by structural rollover of Mabou-Pictou sediments.
Our Line A (Figure 6) shows clearly that the Windsor Group sediments are bedded: the narrow surface outcrops of Windsor are a result of steep structural dip. Faulting seen at surface is supported by the data but seems to be originating from a central Basement core rather than bounding the flanks of a Basement high as suggested by Boehner. There is the suggestion of a synform above the core; based on the surface geology we would suggest that this contains Cumberland Group sediments, somewhat in keeping with Boehner’s model.

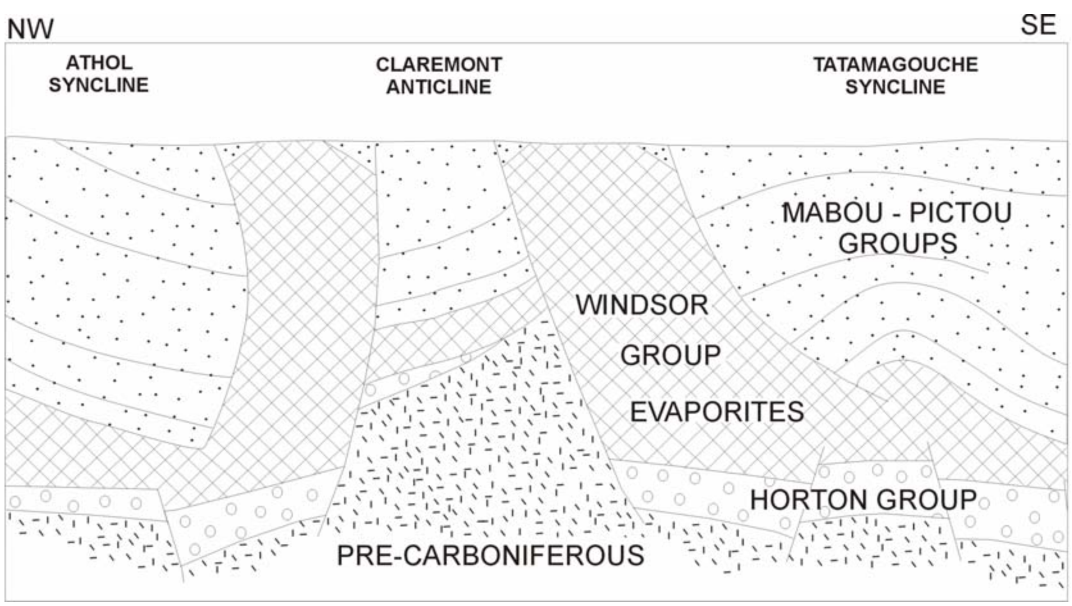


*Fig. 9: Claremont Anticline (after Boehner, 1991)*

We also reproduce part of Boehner’s cross-section illustrating the Minudie Anticline (Figure 10). Surface outcrop of the Windsor Group is more extensive here than at the up-plunge end of the Claremont Anticline. Although there is the suggestion of a low-angle fault (thrust?) Boehner interprets the feature as a “salt diapir”.

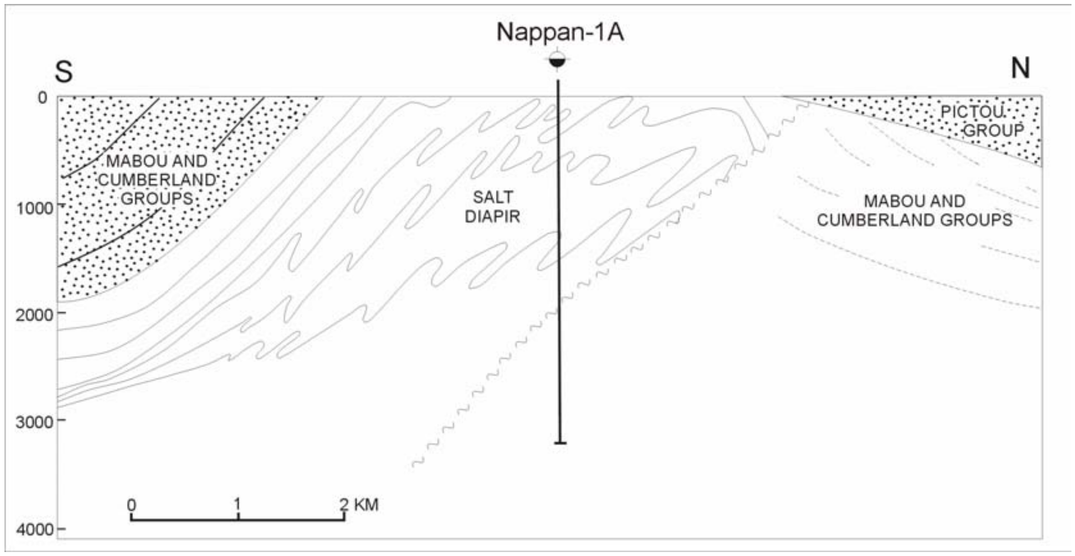


*Fig. 10: Minudie Anticline (after Boehner, 1991)*

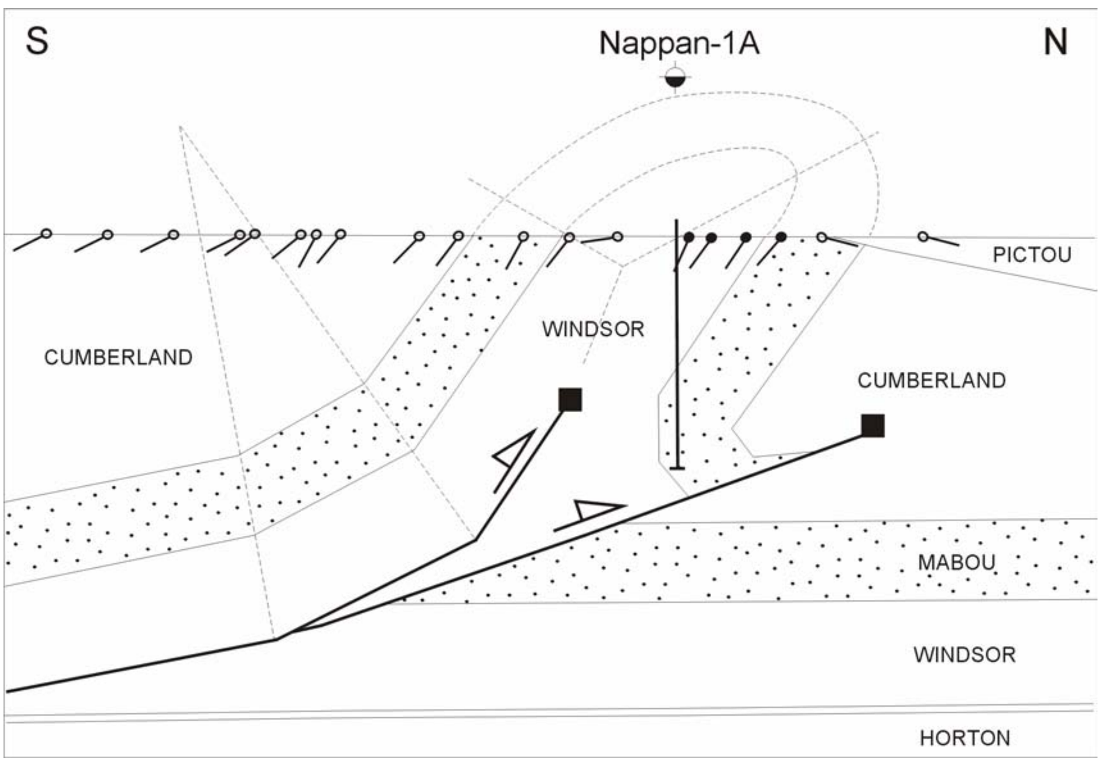


*Fig. 11: Minudie Anticline (after Lynch and Keller, 1998)*

Lynch and Keller (1998) also conclude that salt mobilisation is the primary driver of structural development. They elaborate on the concept of the Ainslie Detachment as a regional bedding-parallel salt-lubricated fault over which the Windsor, Mabou and Cumberland Groups were transported as a gravity slide in a generally SE to NW direction (Lynch and Tremblay, 1994; Lynch and Giles, 1996). We reproduce and reverse Lynch and Keller's interpretation of the

Minudie Anticline (Figure 11) for comparison with Boehner's interpretation (Figure 10). Boehner's suggestion of low-angle fault (thrust?) is displayed with greater confidence as a toe-thrust of a gravity slide. Lynch and Keller suggest that the Minudie Anticline is of a structural origin but formed by gravity as opposed to structural compression.

If the Minudie and Claremont Anticlines have the same origin (and their similar orientation suggests this is likely), then Lynch and Keller's model could apply to the Claremont Anticline. We do see strong evidence of truncation at the base of the Windsor Group that could be interpreted as a blind thrust cutting up from a Base Windsor detachment. The truncation could, however, equally well be interpreted as simple erosional truncation under a Base Windsor unconformity. Also on Lines B and C, we see evidence of growth in the Windsor Group. Clearly there has been structuring going on at this time, which has resulted in a migration of the Tatamagouche syncline depocenter towards the SE. Although the cause of this migration could be salt diapirism, it could also have resulted from incipient structural growth of the Claremont Anticline unrelated to salt movement.

**A Transpressional Model**

We believe that the Maritimes Basin was created by transtension (and local transpression) in a right-lateral regime formed originally during the Appalachian/Caledonian orogeny. Renewed movement on these faults during the Hercynian orogeny created progressively larger depocenters, which were infilled by sediments of the Horton, Windsor/Mabou, Cumberland and Pictou Groups. A snapshot of this process is shown in a simplified reconstruction of the basin during Visean-Westphalian time (Figure 12), when the Windsor/Mabou and Cumberland Groups were deposited.

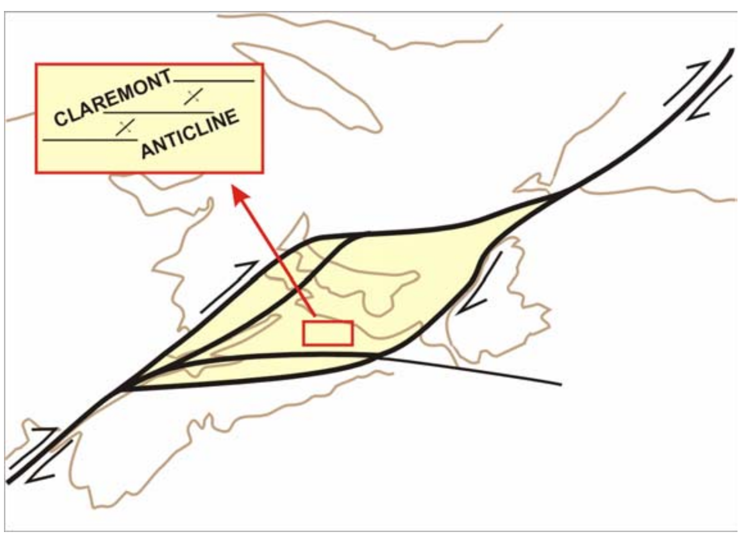


*Fig. 12: Reconstruction of the Maritimes Basin during Visean-Westphalian time. The Claremont Anticline is seen north of a major zone of right-lateral fault movement.*

Within this regional context, we see the local applicability of theoretical models (Wilcox et al, 1973; Rodgers, 1980) that indicate the growth of anticlines trending at 45 degrees to the orientation of deep-seated faults (Figure 13). The up-plunge end of the Claremont Anticline delineated by Devon's seismic would seem to have such an orientation when compared to the Cumberland Basin as a whole. In a left-stepping regime as defined by Rodgers (1980), there could be several similar *en echelon* features within the whole length of the Claremont Anticline as currently defined from surface geology.

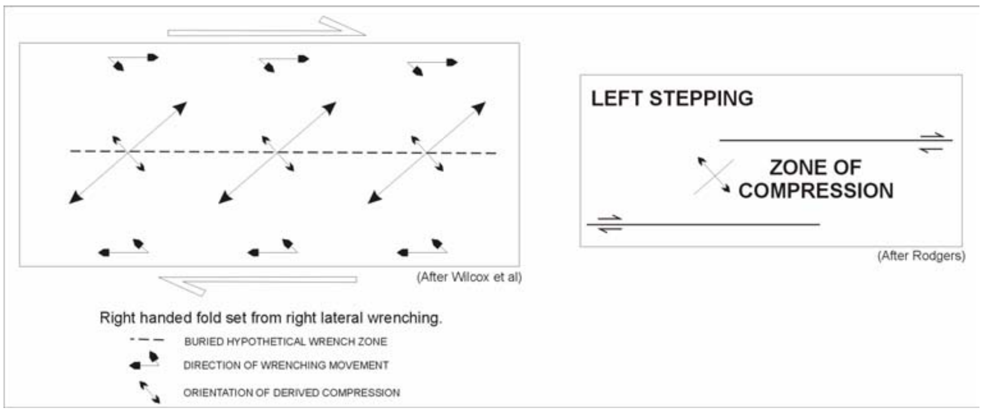


*Fig.13: Right-lateral Transpressional Models (after Wilcox et al, 1973, and Rodgers, 1980)*

An examination of the seismic data shows prominent faulting, most of a sub-vertical nature, and originating from a central position under the Claremont Anticline (Figures 6, 7 and 8). We believe that the fault style and the dramatic difference in thickness of section across the fault are strongly indicative of strike-slip movement. Furthermore, in such a domain, we consider that the existence of a fault-controlled low immediately over a fault-controlled high (Figure 6) is not outside the realm of possibility.

Although there is salt diapirism along the length of the Claremont Anticline, this diapirism could have been triggered by instability caused by sporadic right-lateral fault movement throughout the period of time represented by the Windsor/Mabou and Cumberland Groups. In other words, we see salt diapirism as an affect rather than the root cause of the anticline's tectonic development.

## Conclusions

- New seismic data has significantly improved our knowledge of the subsurface of the Claremont Anticline
- Salt mobilisation is less prevalent than might have been expected based on surface geology and earlier seismic data
- There is significant faulting that is of a probable strike-slip origin

- The data may not necessarily have *solved* "an old problem" but does suggest that the Claremont Anticline is more likely to have been formed by structural transpression than by salt diapirism

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