

Geophysical Investigation of Salt Tectonics and Deeper Structure in the Eastern Magdalen Basin, Atlantic Canada.

Nathan Hayward, Alan Grant, Sonya A. Dehler*
Geological Survey of Canada (Atlantic).
Bedford Institute of Oceanography,
P.O. Box 1006, Dartmouth,
Nova Scotia. B2Y 4A2.
E-mail: dehler@agc.bio.ns.ca

Paul Durling
Corridor Resources Incorporated.
301 Cornwallis House, 5475 Spring Garden Road,
Halifax, Nova Scotia. B3J 3T2.

EXTENDED ABSTRACT

Investigation of the eastern Magdalen Basin, located in the southern Gulf of St. Lawrence (Fig. 1), has revealed an area of intense salt tectonism, above a fault-bounded sub-salt high. The basin was initiated during the waning stages of the Acadian Orogeny, with formation in an extensional setting with periods of dextral transpression (Williams 1995). The basin contains up to 18 km of Paleozoic sedimentary rocks resting on the crystalline basement of the Acadian Orogeny.

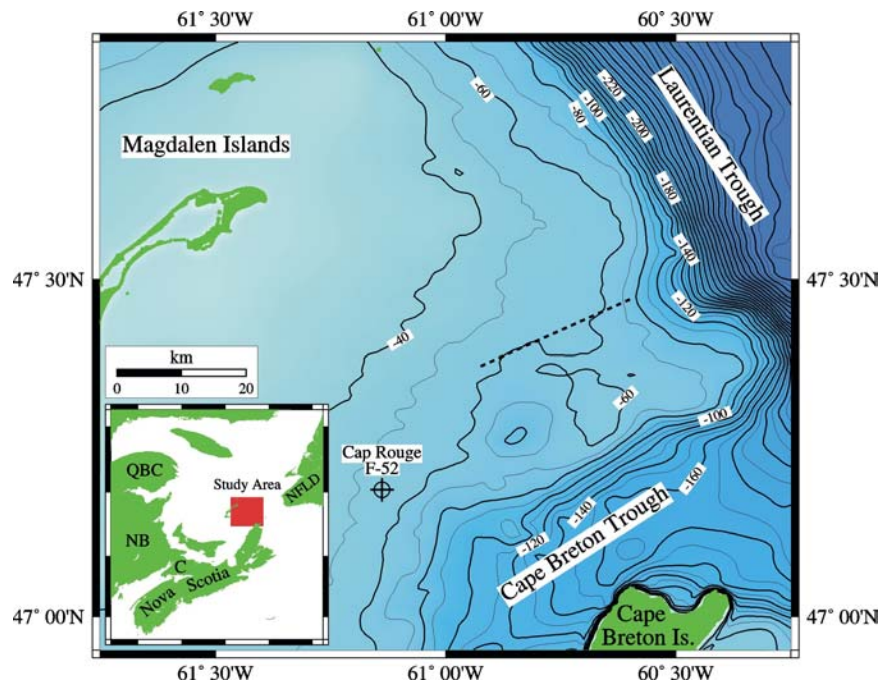


Fig. 1. Bathymetry of the eastern Magdalen Basin. Contour interval is 10 m. Dash line shows bathymetric lineation associated with faulting. Crossed circle = Cap Rouge well. On inset map, "C" shows the Cumberland area of northern Nova Scotia. QBC=Quebec, NB=New Brunswick, NFLD=Newfoundland.

Carboniferous rocks, although regionally exhibiting minor deformation, are intensely deformed to the southeast of the Magdalen Islands, due to faulting and evaporite tectonism of the Viséan Windsor Group. The distribution of near surface salt structures has been defined by a new map (Fig. 2) based on seismic reflection and gravity data. The salt structures exhibit elongate shapes along NNE and ENE trending axes.

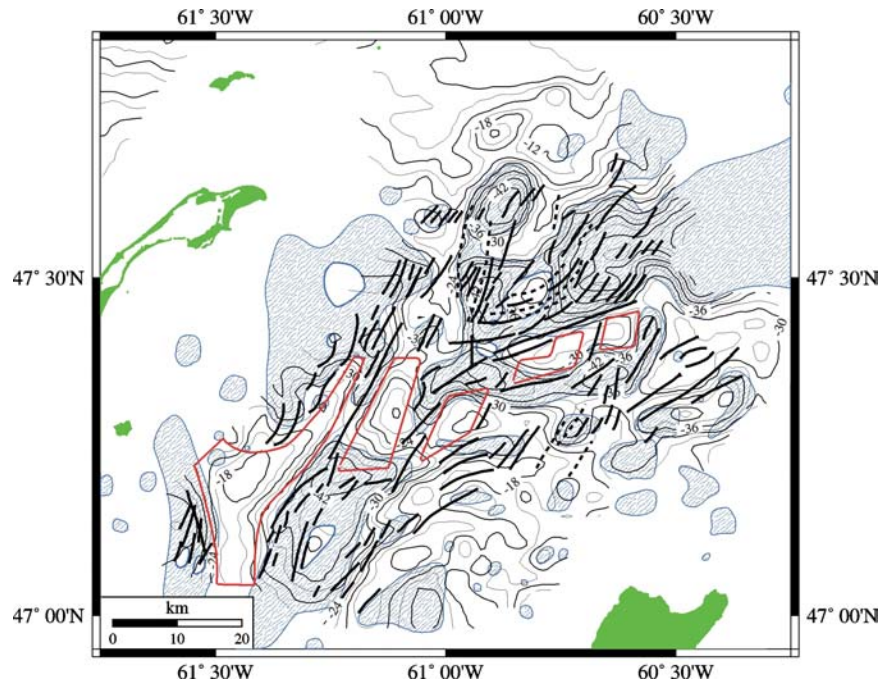


Fig. 2. Comparison of near surface salt structures in the eastern Magdalen Basin with magnetic lineations. Blue pattern filled areas show salt structures defined by seismic reflection and gravity data. Black contours show the Bouguer gravity anomalies. Heavy black lines show magnetic lineations, and zones of very low amplitude magnetic anomalies are shown by red lines.

Magnetic anomalies (Fig. 3) to the east of the Magdalen Islands show broad-wavelength highs and lows which are transected by clusters of NNE and ENE trending short wavelength ($\sim 2 - 5$ km), lower amplitude ($\sim 10 - 50$ nT) magnetic anomaly lineations. These lineations primarily occur towards the edges of salt structures, but are occasionally associated with crests or the contact between salt structures and the surrounding sedimentary rocks (Fig. 2). Zones of low magnetic amplitude correspond to salt free areas (Figs. 2 and 3) showing relatively undeformed sedimentary rocks on seismic reflection profiles. Euler deconvolution (Thompson 1982) solutions, calculated in order to estimate magnetic source types and depths for the magnetic lineations, indicate mainly shallow (< 400 m) fault type magnetic sources close to the top of the salt structures and overlying sedimentary rocks.

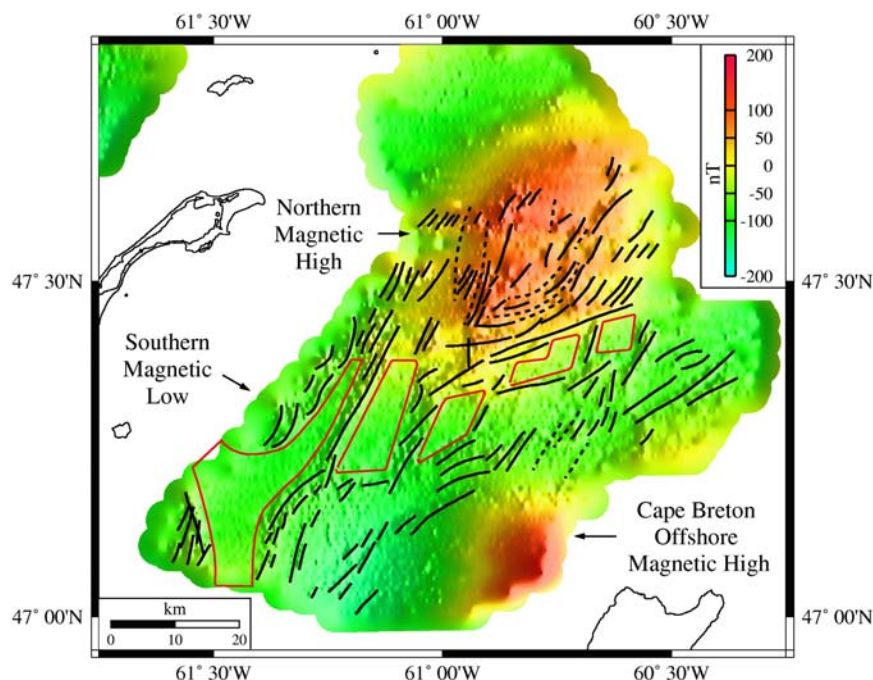


Fig. 3. Interpretation of magnetic anomalies of the eastern Magdalen Basin. Reds and oranges indicate high anomalies, greens indicate low anomalies. Illumination from the east. Magnetic lineations shown by heavy black lines, and zones of very low amplitude magnetic anomalies by red lines. Magnetic lineations derived from careful interpretation of a number of large scale maps with various illumination angles.

Salt deposits of the Cumberland area, Nova Scotia (e.g. Boehner 1986) (C; Fig. 1, inset), are similar to those of the Magdalen Basin. At Malagash geophysical survey results show low amplitude magnetic anomalies concentrated along the flanks of the gravity lows. It has been speculated that these may be due to shallow concentrations of the mineral rinneite ($\text{FeCl}_2 \cdot 3\text{KCl} \cdot \text{NaCl}$). Small quantities of possible rinneite remnants are also reported for intensely brecciated, red potash bearing, zones of the Pugwash salt deposit. Susceptibility measurements made at the old 830 foot level of the Pugwash salt mine confirm the presence of higher susceptibility brecciated carnallite-rich veins within deformed halite bodies. The mean susceptibility is 0.32×10^{-3} SI, with individual measurements as high as 0.47×10^{-3} SI. This is an order of magnitude larger than the halite and within the susceptibility range of typical sedimentary rocks and may explain the observed anomalies in the Magdalen Basin.

A magnetic forward model was developed to further investigate the character of shallow sources responsible for the anomalies. The calculated anomaly shows an excellent fit to the residual profile data and the high frequency anomaly lineations may be explained by dipping sources at less than 400 m depth, with susceptibility well within that considered typical for sedimentary rocks. Although the measured susceptibilities from the Pugwash mine are lower than those required by the model, we believe that mineralised, brecciated zones are still the likely explanation for the magnetic anomalies. The mine rocks have been exposed to the air for a long period, so decomposition of unstable magnetic

minerals, such as rinneite would have already occurred and the magnetic signature consequently lost.

Interpretations of the structure below the salt are well constrained to the west of the Magdalen Islands (Durling and Marillier 1990), but salt structures to the east obscure the deeper structure on numerous industry seismic profiles. The consistent pattern of NNE trending structures and geophysical signatures suggests deeper basin structure may have played a strong role in the development of salt structures.

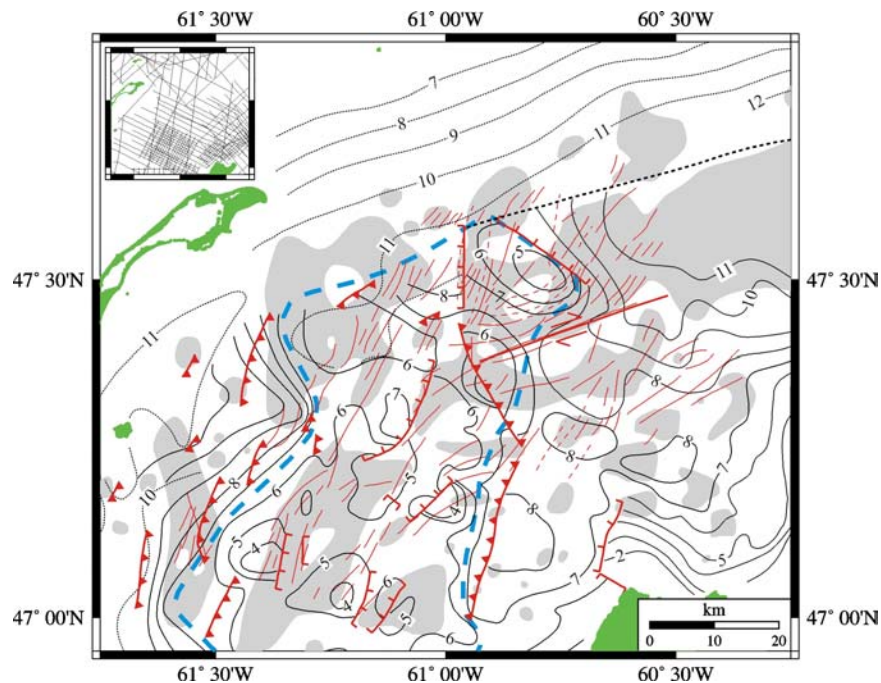


Fig. 4. Base event depth map. Contour interval 1 km. Dotted contours indicate lower footwall of thrusts in the base event. Inset shows seismic line locations. Solid red lines show strike-slip faults. Filled triangles show thrust faults. Ticked lines indicate steep faults where downthrow, but not fault style, can be established. Light grey shaded regions show salt structures. Heavy blue dash line shows the outline of the sub-salt high, a NNE trending uplifted region. Narrow red lines show magnetic lineations.

Seismic reflection data have been used to map of the base event, a bright reflection surface considered to be associated with a regional unconformity at the base of the Viséan Windsor Group in the Magdalen Basin (Fig. 4). The base event overlies in part Carboniferous Horton Group rocks and elsewhere pre-Carboniferous rocks ranging from Lower Paleozoic to Precambrian age. Structural maps of the base event show that the study area (Fig. 4) is within the most structurally complex part of this basin, where the base event surface is faulted and irregular, and obscured by overlying salt bodies. In the northwestern part of the study area the base event shows a regional planar surface dipping to the SSE down to depths of more than 11 km. To the southeast this surface shows large-scale irregularities related to faulting, including WNW and ESE

directed thrust faults. The SSE dipping base event surface is in places overlapped by these thrust sheets. To the east of these thrust faults, the base event forms a NNE trending plateau (Blue dash; Fig. 4), with depths ranging from about 3.5 to 8.0 km, which is affected by faults that trend primarily NNE to NE. Topographic highs in the base event are commonly located beneath salt structures (Fig. 4). The common NNE trend of the base event structures and overlying salt structures suggest a strong link between the deep structure and salt tectonism.

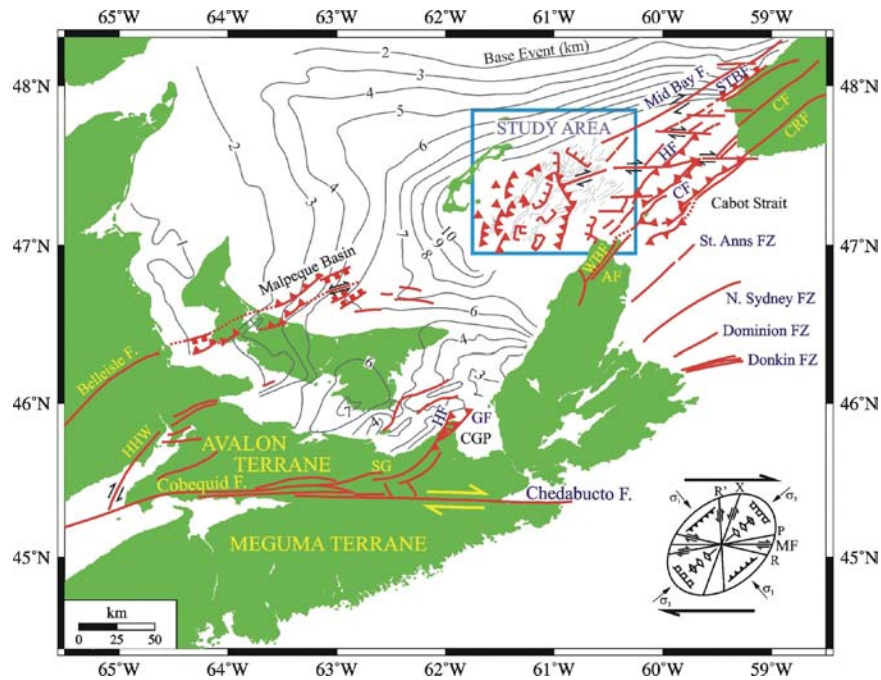


Fig. 5. Tectonic setting of the eastern Magdalen Basin. Contours show the depth and fairly smooth structure of the base event outside of the study area. Faults: HF = Hollow, CF = Cabot, CRF = Cape Ray, SGBF = St. George's Bay, AF = Aspy, WBF = Wilkie Brook, GF = Greendale, HHW = Harvey-Hopewell. Fault sources: New Brunswick and Nova Scotia (St. Jean et al. 1993); Western Magdalen Basin (Durling and Marillier 1990); Cabot Strait (Langdon and Hall 1994); Sydney Basin (Pascucci et al. 2000). CGP = Cape George Peninsula, SG = Stellarton Graben. Strain ellipse model (Christie-Blick and Biddle 1985), MF = Master Fault, P = Primary, R = Reidel Shear, R' = Antithetic Reidel Shear.

Structural observations, which include salt structures, base event faulting and magnetic lineations in the eastern Magdalen basin are consistent with a regional dextral transpressive regime associated with the Cobequid - Chedabucto fault zone (Fig. 5). This produced WNW compression and ENE dextral motion between the Late Viséan and Westphalian D (Yeo and Ruixing 1987, Keppie 1982). NNE striking base event thrusting, and ENE dextral faulting were integral in forming the observed pattern of salt deformation.

References

- Boehner, R.C. 1986. Salt and Potash Resources in Nova Scotia. Nova Scotia Department of Mines and Energy, Bulletin 5.
- Christie-Blick, N., and Biddle, K.T. 1985. Strike-slip deformation, basin formation, and sedimentation: based on a symposium sponsored by the Society of Economic Paleontologists and Mineralogists. Society of Economic Paleontologists and Mineralogists Special Publication 37.
- Durling, P., and Marillier, F. 1990. Structural trends and basement rock subdivisions in the western Gulf of St. Lawrence, Northern Appalachians. *Atlantic Geology*, **26**:79-95.
- Keppie, D.J. 1982. The Minas Geofracture. *In Major Structural Zones and Faults of the Northern Appalachians. Edited by P. St-Julien and J. Béland.* Geological Association of Canada Special Paper 24, pp. 263-280.
- Langdon, G.S., and Hall, J. 1994. Devonian-Carboniferous Tectonics and Basin Deformation in the Cabot Strait Area, Eastern Canada. *American Association of Petroleum Geologists Bulletin*, **78**:1748-1774.
- Pascucci, V., Gibling, M.R., and Williamson, M. A. 2000. Late Paleozoic to Cenozoic history of the offshore Sydney Basin, Atlantic Canada. *Canadian Journal of Earth Sciences*, **37**:1143-1165.
- St. Jean, J.A.R., Nance, R.D., and Murphy, J.B. 1993. Tectonic significance of Late Paleozoic deformation in the Cape George Peninsula, Antigonish Highlands, Nova Scotia. *Atlantic Geology*, **29**:27-42.
- Thompson, D.T. 1982. EULDPH: A new technique for making computer-assisted depth estimates from magnetic data. *Geophysics*, **47**: 31-37.
- Williams, H. 1995. Geology of the Appalachian-Caledonian Orogen in Canada and Greenland. Geological Survey of Canada, *Geology of Canada*, 6 (also Geological Society of America. *The Geology of North America*, F-1).
- Yeo, G.M., and Ruixing, G. 1987. Stellarton Graben: an Upper Carboniferous pull-apart basin in northern Nova Scotia. *In Sedimentary basins and basin-forming mechanisms. Edited by C. Beaumont and A.J. Tankard.* Canadian Society of Petroleum Geologists, Memoir 12, pp. 299-309.