Structure of the Minas Passage, Bay of Fundy: A Preliminary Report*

DONALD J. P. SWIFT
Duke University, Durham, N. C.

FRANK L. JAGODITS
Huntec Limited, Toronto, Ont.

BERNARD L. MANISTRE
Lockwood Survey Corporation Limited, Toronto, Ont.

NORMAN R. PATERSON
Huntec Limited, Toronto, Ont.

Introduction

From July, 1965 to March, 1966, a joint geological-geophysical study of the Minas Passage, Bay of Fundy, was undertaken by Huntec Limited of Toronto for the Atlantic Development Board of Canada. The purpose of the project was to test the feasibility of a tidal power station in the Passage. This paper presents a portion of the study, namely the structure of the geologically critical Minas Passage area and its bearing on regional structure.

The Bay of Fundy is a funnel-shaped body of water lying between Nova Scotia and New Brunswick (Fig. 1). Fundy proper is 144 kilometers long, 100 kilometers wide at the base, and averages 75 meters in depth. The northeast end bifurcates into northeast-trending Chignecto Bay, and the east-trending Minas Basin. Three distinct bodies of water are included within the latter; the Minas Basin proper; the Minas Channel, separated from the basin by the great curved peninsula of Cape Blomidon-Cape Split; and the Minas Passage, connecting the Channel and the Basin (Fig. 2).

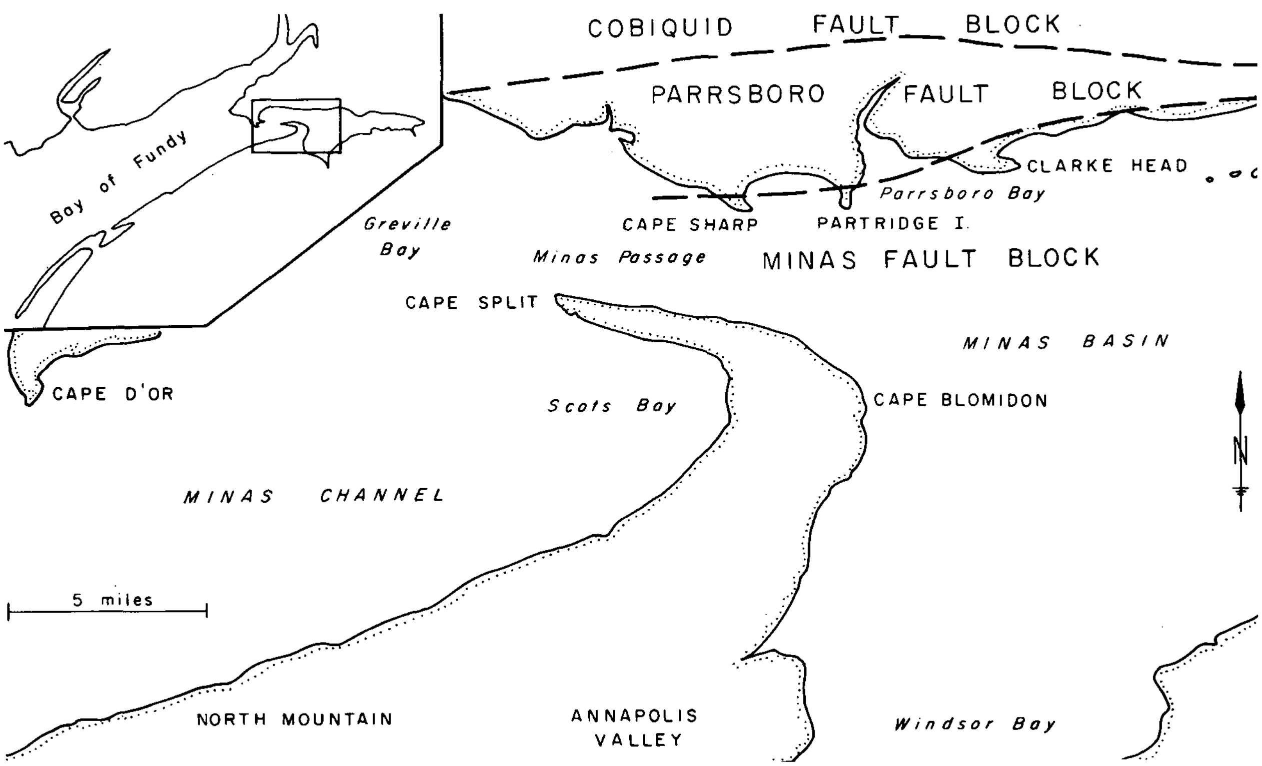

Figure 1 - Topographic names, fault blocks, and location of the study area.

*Manuscript received 12 January, 1968.

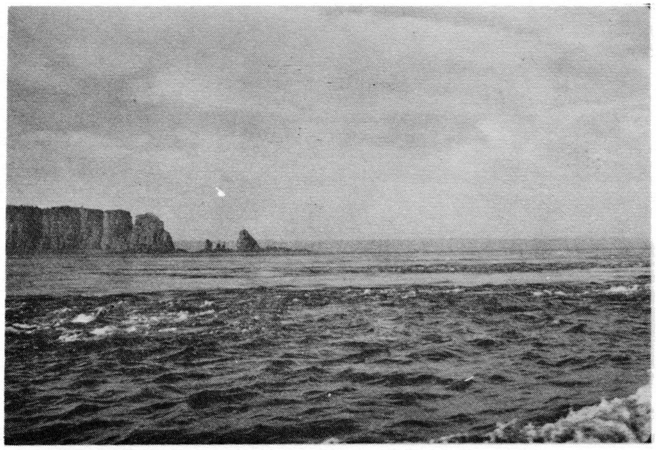

Figure 2 - The Minas Passage with Cape Split in the background.

Stratigraphy

Three well-defined bedrock sequences occur in the Minas Passage area. The Cobequid Complex is a lower Paleozoic metamorphic and igneous complex comprising the upraised Cobequid Fault Block (Fig. 1, 3) near the northern margin of the study area. This Complex forms a basement for younger rocks throughout the rest of the area. Carboniferous clastic and chemical sediments rest with profound angular unconformity on the lower Paleozoic rocks of the Parrsboro Fault Block. In the study area, the thickness of the Carboniferous System reaches a maximum of approximately 3, 300 meters (Howie and Cumming, 1963). A third major sequence consists of the gently dipping Triassic sandstones, mudstones and basalts of the Minas Fault Block (Fig. 1).

PERIOD	STAGE	GROUP	FORMATION		LITHOLOGY	REFERENCE
TRIASSIC		FUNDY	SCOTS BAY		INTERBEDDED GRAY, PURPLE SANDSTONE, CLAYSTONE, CHERT LIMESTONE	KLEIN 1962
			NORTH MOUNTAIN		BASALT FLOWS	
			BLOMIDON		INTERBEDDED GRAY, REDDISH SANDSTONE, SILTSTONE, CLAYSTONE	
			McKAY HEAD		BASALT FLOWS, AGGLOMERATE	
			WOLFVILLE		REDDISH SANDSTONE, CONGLOMERATE	
PENNSYLVANIAN	CUMBERLANDIAN	"COURSE FLUVIAL"			REDDISH CONGLOMERATE	BELT 1965
	RIVERSDALIAN	MABOU	PARRSBORO	BOSS POINT	REDDISH CONGLOMERATE, DARK GRAY SILTSTONE AND LAMINATED SHALE, LIGHT GRAY SANDSTONE	
	CANSOAN			SHEPODY		
			WEST BAY	MARINGOUIN	REDDISH AND GRAY SILTSTONE AND SHALE, LIMESTONE, GYPSUM	
MISSISSIPPIAN	WINDSORIAN	WINDSOR				
	HORTONIAN	HORTON			SIMILAR TO PENNSYLVANIAN	
DEVONIAN, SILURIAN, ORDOVICIAN					GRANITE ROCKS, GRAY PHYLLITE AND QUARTZITE, ACID METAVOLCANICS	HOWIE AND CUMMING 1963

Figure 3 - Summary of stratigraphy.

Major Structures of the Cobequid Block

The Cobequid Fault (Fig. 4) on the south margin of the Cobequid Block is clearly the key to the tectonics of the region. Its best documented movement has been neither compressional nor tensional, but transcurrent. Fyson (1964a, p. 178) noted 19 small strike-slip faults with probable dextral displacement along the Cobequid Fault Zone in Greville Bay. North-northeast trending cross-folds in both the Cobequid and Parrsboro Blocks have been explained by him as due to dextral movements along the fault. The remarkable straightness of the scarp suggests that the Cobequid Fault has the subvertical orientation of transcurrent faults.

Eisbacher and Kelley (1966) report that the Cobequid Fault Zone along its southern margin contains slices of fractured granitic rocks brought into contact with sedimentary rocks along very gently plunging trajectories, as indicated by steeply plunging folds with right lateral drag. They state that striations on boudins and other tectonic elements point to a strong right-lateral, strike-slip component for the overall process of displacement.

Our reconnaissance suggests that after the middle Carboniferous, movement on the Cobequid fault had also an important reverse component. The following features indicate this.

1. The topographic and presumably structural crest of the Cobequid Block occurs along its south edge.
2. The nearest structure in the downthrown Parrsboro Block is a syncline parallel to the fault, and asymmetrical toward the south.
3. At the base of the Cape d'Or Peninsula, the Cobequid scarp can no longer be resolved, suggesting that as the Cobequid Fault is traced eastward, a reverse component becomes more important.

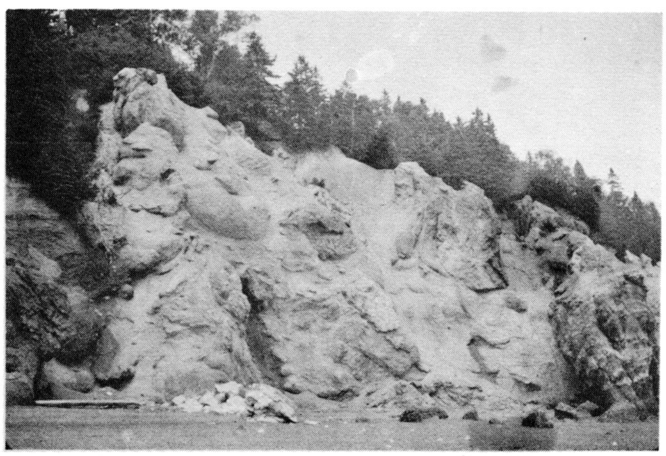

Figure 5

Brecciated zone, Clarke Head. Rounded knobs are milled boulders of tectonic origin. White mass in foreground is gypsum boulder which has fallen from breccia.

Major Structures of the Parrsboro Block

The major structures of the Parrsboro Fault Block are a series of asymmetrical, east-northeast trending folds (Fig. 4). The Bumper Brook Syncline lies immediately south of and parallel to the Cobequid Fault. The topographic expression of the Syncline may be seen along Bumper Brook on aerial photographs and topographic maps. Cuestas formed by the Syncline suggest that the north limb is steeper than the south limb, and that the Syncline plunges east. The Bumper Brook Syncline has been traced by hydrosonde profiles through Greville Bay where it is more nearly symmetrical.

The Clarke Head Anticline occupies most of the remaining Parrsboro Fault Block. The hills east and west of Parrsboro are its north limb. The axial zone is well exposed in the Windsor Group and West Bay Formation, on Clarke Head, Greenhill Beach, and Ottawa House Beach. The axial zone is quite complex. On the eastern end of Clarke Head, lenses of mylonite with possible maximum thicknesses of 50 meters are present. The mylonite resembles a semi-consolidated till (Fig. 5). A matrix of plae gray-green, pulverized rock contains milled boulders up to five meters diameter. Masses of gypsum varying to a few meters in diameter have been squeezed along this zone. At several points, a tectonic foliation in this material dips north. Zones of uncrushed rock alternate with the mylonite on the cliff face. North, vertical, and south dips are present. The north-dipping beds may include overturned beds. Small reverse faults in the uncrushed zone dip 45 degrees north.

The mylonite zone is a major reverse fault which has broken through the vertical or overturned south limb of the Clarke Head Anticline. The fault is named the Clarke Head Fault. If stratigraphic throw alone is responsible for bringing the Windsor Group to the surface, then this throw is on the order of 400 meters.

Previous studies of the Minas Carboniferous basin have lead to a variety of structural models. Bell (1929, 1944) and Belt (1965) have concluded that Carboniferous deposits accumulated in subsiding, down-folded troughs separated by rising welts from which most of the sediment was derived. Howie and Cumming (1963) have inferred subsidence of the basins by normal faults, and that "fragmentation and tilting of basement blocks during Carboniferous time would have initiated a cycle of isotatic adjustments accompanied by erosion and sedimentation". They suggest that the gentle north slope and steep south slope of the Cobequid block indicates that it was tilted northward.

Neither of these models provide an explanation for the well-defined fold system of Carboniferous rocks in the Fundy Basin. On the south side of the Minas Sub-basin, Fyson (1964a, b) has found folds overturned to the south, and following Boyle (1963) Fyson suggests that thrust movements from the north were responsible. On the north side of the Basin, however, Fyson reports folds with opposite asymmetry and attributes these to north tilting of the Minas Fault Block accompanied by gravity sliding. Since we have found that the north shore folds have the same asymmetry as the south shore folds (toward the south) we cannot accept gravity sliding, but would extend Boyle's and Fyson's "thrust movements from the north" to both sides of the basin.

Cameron (1956) has proposed a model in which the concept of thrusting is extensively developed. He considers that the Fundy basin has undergone post-Carboniferous compression resulting in the thrusting of Carboniferous sediments toward both margins. The southern thrust zone has brought the Cobequid Horst to the surface, dividing the Fundy Basin into the Cumberland and Minas Sub-basins. According to this model, the asymmetry of the Cobequid Block would reflect not northward tilting, but southward overthrusting. We do not have sufficient data to assess the regional implications of this model, but find it best explains the structures that we observed in the Minas Passage area.

However these models fail to consider the third dimension. Fyson (1964b), Eisbacher and Kelley (1966), and the authors have noted evidence for transcurrent movement on the Cobequid Fault. The Carboniferous Maritimes might resemble neither the normally faulted Basin and Range Province as suggested by Howie and Cumming's model, nor the overthrusted Rocky Mountain Basins, as suggested by Cameron's model, but rather the continental borderland off California. There, trans current faults with local reverse or normal components fragmented the basement into basins and highs.

Major Structures of the Minas Block

The Triassic rocks capping the Minas Fault Block occupy a half graben with the border fault on the north. The half graben is probably a result of the adjustment of the earth's crust to tension in the basement (Klein, 1960, p. 167; Goguel, 1952, p. 219). Triassic structures may be in part reactivated basement structures (Cameron, 1949, 1956; Klein, 1960, p. 168).

The present border fault is the Portapique Fault (Fig. 4) a south-dipping normal fault (Weeks, 1948; Klein, 1960, p. 155). Klein has inferred a displacement of 1500 meters for this fault in its type area. However, at the mouth of Wasson Brook behind Clarke Head, the West Bay Formation is exposed at the foot of an outcrop of Wolfville Sandstone (Belt, personal communication). Here the displacement must be much less, or erosion at this point has removed most of the Triassic from the Minas Fault Block.

The Cobequid Fault may be the true master fault. Cameron (1949, 1956) suggested that the Cobequid Fault Zone was reactivated during Triassic time. Presumably, normal movement occurred along the south-dipping plane. If this is true, the Triassic cover has been stripped from the Parrsboro Fault Block, leaving only an erosional remnant of Triassic over the down-dropped Minas Fault Block. The Portapique Fault would then be a second-order step fault. However, Eisbacher and Kelley (1966) have found "no pure dip-slip components anywhere along the (Cobequid) Fault Zones".

The Portapique Fault has been traced by the hydrosonde records as far west as the mouth of the Minas Passage. There, the Fault joins the Minas Passage Fault - a south-dipping normal fault separating Carboniferous rocks on the north from the Triassic rocks of the Fundy syncline to the south. The area of junction is overlain by the most turbulent portion of the Minas Passage Tide Race, and hydrosonde records here are obscured by sea noise; the area is undoubtedly of greater structural complexity than is shown in figure 4.

The Minas Passage Fault is coincident with the axis of the bedrock valley, and has provided the zone of weakness along which the Minas Passage has been eroded. The Fault trends west northwest, parallel to the north limb of the Fundy Syncline, rather than southwest, parallel to the trend of the north shore Triassic. The fault on the floor of Greville Bay between the Triassic of the Fundy Syncline and the Carboniferous rocks to the north is presumably its extension.

Triassic strata in the study area are dominated by a broad syncline which plunges 3 to 10 degrees west. Named the Fundy Syncline by Klein (1960), it is outlined by the great, curved cuesta of North Mountain-Cape Blomidon-Cape Split. Dips on its flanks are 5 to 15 degrees and up to 40 degrees near faults. Gentle second-order faults with wavelengths up to one half mile are locally abundant.

The Hydrosonde profiles show that the Fundy syncline is not as symmetrical as its cuesta might suggest. The northern limb shows steeper dips, and minor folds within the Scots Bay Formation, reflecting the half-graben structure of the Minas Triassic Basin.

The Minas Triassic Basin is a half-graben with the Portapique Fault the present border fault. Cameron (1949, 1956) and Klein (1960) have suggested that Triassic structures are due in part to reactivation of structures in the Carboniferous Basement. North of the Minas Passage fault, where the Triassic cover is thin to absent, and bedrock control of structures should be apparent, both trends of the Portapique fault and the Clarke Head Graben parallel the east-northeast trend of Carboniferous structures. To the south of the Minas Passage Fault, where the mass of down-folded sediment is appreciable, structures are instead related to the development of this fault and the adjacent Fundy syncline, and they trend instead east-southeast.

Barrell (1915) after study of the Connecticut Triassic Basin first proposed a model for the Triassic Fault Valleys of eastern North America which involved simple rotation of the valley floor about a hinge. Bascom and Stose (1944) suggested a model based on the Newark Triassic Basin in which crustal sagging was as important or more important than rifting. The Minas Triassic Basin, with its great central syncline appears to conform more closely to the latter model.

Conclusions

The study area, then, lies athwart a Triassic basin superimposed on a larger Carboniferous basin; key structures of both are exposed on the land areas or are accessible to the sub-bottom profiler. Resolution of these structures has shed new light on the nature of the Carboniferous and Triassic structural systems. The Carboniferous basin is the product of southward thrusting combined with dextral transcurrent movements. The Triassic system in the Minas Passage is to a large extent controlled by Carboniferous structures. Subsidence and downwarping seem as important in its structural evolution as faulting.

References cited

BARRELL, J., 1915, Central Connecticut in geologic past: Connecticut Geological Survey Bull. 23, p. 14.

BASCOM, F., and STOSE, G. W., 1938, Geology and mineral resources of the Honeybrook and Phoenix quadrangles, Pennsylvania: U. S. Geol. Survey Bull. 891, 42 p.

BELL, W. A., 1929, Horton-Windsor district, Nova Scotia: Geol. Survey, Canada, Mem. 155, 268 p.

__________, 1944, Carboniferous rocks and fossil floras of northern Nova Scotia: Geol. Survey, Canada Mem. 238, 276 p.

BELT, E. S., 1965, Stratigraphy and paleogeography of Mabou Group and related middle Carboniferous facies, Nova Scotia, Canada: Geol. Soc. America Bull., v. 76, p. 777-802.

BOYLE, R. W., 1963, Geology of the barite, gypsum manganese, and lead-zinc-copper-silver deposits of the Walton-Cheverie area, Nova Scotia: Canada Geol. Survey paper 62-25, 38 p.

CAMERON, H. C., 1949, Faulting in Nova Scotia: Roy. Soc. Canada Trans., v. 43, Ser. 3, Sec. 4, p. 13-21.

______________, 1956, Tectonics of the Maritime area: Roy. Soc. Canada Trans., v. 50, Ser. 3, Sec. 4, p. 45-51.

EISBACHER, G. H., and KELLEY, D. G., 1966, Tectonic studies in the Cobequid Mountains, Nova Scotia: Maritime Sediments, v. 2, p. 180-183.

FYSON, W. K., 1964a, Repeated trends of folds and cross-folds in Paleozoic rocks, Parrsboro, Nova Scotia: Can. Jour. Sciences, v. 1, p. 167-183.

______________, 1964b, Folds in the Carboniferous rocks near Walton, Nova Scotia: American Journal of Science, v. 262, p. 513-522.

GOGUEL, J., 1952, Tectonics (English translation, 1962): San Francisco, W.H. Freeman, 384 p.

HOWIE, R. D., and CUMMING, L. M., 1963, Basement features of the Canadian Appalachians: Geol. Surv. Canada Bull. 89, 15 p.

KLEIN, G. de V., 1960, Stratigraphy, sedimentary petrology, structure of Triassic sedimentary rocks Maritime Provinces of Canada: Unpublished doctoral dissertation, Yale University, New Haven, Mass., 332 p.

WEEKS, L. J., 1948, Londonderry and Bass River mapareas, Colchester and Hants Counties, Nova Scotia: Geol. Survey Canada Mem. 245, 86 p.