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Structural evolution of a transpression zone in north central Newfoundland: Discussion

R. S. BLEWETT*

Department of Geology, Leicester University, Leicester LE1 7RH, U.K.

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IN THE recent paper by Lafrance (1989), the Boones Point Complex (Helwig 1967, Nelson 1981) was interpreted to be of entirely tectonic origin, and transected folds as the function of an overprinting relationship.

The first point of this discussion concerns the interpretation that the Boones Point Complex was entirely the product of early to late Silurian tectonic deformation (Lafrance 1989), or whether it represents a tectonically deformed late Ordovician olistostromal melange (Nelson 1981, Blewett 1989). The study area of Lafrance (1989), in western Notre Dame Bay is small compared to the along-strike equivalents (to the west), and interpretation of this complex should really take these other areas into account.

The Boones Point Complex to the west of Lafrance's (1989) study area crops out in and around Sops Arm, is locally known as the Sops Head Complex, and is correlated with the Boones Point Complex (Nelson 1981). The Sops Arm exposures are less deformed than the Exploits Bay exposures, which enabled Nelson (1981) to interpret the Boones Point Complex as deformed debris-flow deposits or olistostromes. The Boones Point Complex in this area comprises extremely poorly sorted, but rounded, polymict clasts set in an argillaceous matrix. These olistostromes developed adjacent to active S-directed thrusts and were the proximal equivalents of the more 'normal' Sansom Formation turbidites (Nelson 1981). The Sansom Formation is equivalent to Lafrance's (1989) late Ordovician marginal basin sediments. Nelson (1981) also recognized a tectonic overprinting of these late Ordovician olistostromes that developed foreland of the thrusting event. The heterogeneous nature of later deformational events meant that much of the early history (i.e. sedimentary disruption) was destroyed: e.g. at Woody and Green Islands and at the type location at Boones Point. Further, the Boones Point Complex defines the trace of the Red Indian Line in central Notre Dame Bay (Swinden 1987, Williams *et al.* 1988) over which detritus was shed, coeval with faulting, in the late Ordovician (Nelson 1979, 1981, Nelson & Casey 1981, Arnott 1983) and was deposited into equivalents of the 'marginal-basin terrane' of Lafrance (1989).

Lafrance (1989) favours a tectonic mode of disruption, and it may be that the intensity of deformation in the Notre Dame Bay exposures may have precluded the recognition of Ordovician 'wet-sediment' deformation (i.e. deformation active with sedimentation not necessarily surficial slide mechanisms), a point that Lafrance (1989) admits. The recognition of a late Ordovician marginal basin terrane separated by the lineament defined by the Boones Point Complex would imply that Notre Dame Bay was an evolving Ordovician accretionary system (cf. van der Pluijm 1986, 1987) or foreland basin (Pickering 1987a) rather than a passive margin unaffected by tectonics.

Early (F_1) structures in Notre Dame Bay have, as Lafrance (1989) pointed out, been interpreted in terms of: (1) early thrusting (Nelson 1981, van der Pluijm 1984, 1986, Elliott 1985, Pickering 1987a,b); or (2) surficial sliding of wet sediment (Helwig 1967, 1970, Horne 1968, Eastler 1971, Arnott 1983, Pickering 1987b). Many of these workers, however, do not see deformation in these end-member processes and interpret the deformation history as progressive, often commencing in unlithified sediments (cf. Arnott 1983, Pickering 1987a).

The second point of discussion concerns the relative chronology of deformation and the interpretation of transected folds in terms of an overprinting relationship. The 'F_3' fold generation of Lafrance (1989, cf. table 1) is the penetrative late Silurian 'Acadian' deformation considered by most workers in the Dunnage Terrane as F_2 (cf. Nelson 1979, 1981, Karlstrom *et al.* 1982, Arnott 1983, van der Pluijm 1984, Elliott 1985, Pickering 1987b, Blewett & Pickering 1988, 1989, Blewett 1989). The most striking features of Lafrance's stereonets (fig. 3) is the maintenance of cylindricity despite four phases of deformation, especially if one bears in mind the interpreted structural evolution (Lafrance 1989, cf. fig. 8). Further, the stereonets (fig. 3) do not match the schematic diagrams of fig. 8. The interpretation for overprinting relationships, rather than an essentially contemporaneous transecting fold–cleavage relationship (as reported by Blewett & Pickering 1988), hinges on the recognition of an F_3 overprint on F_2 folds. There appears to be little to distinguish between F_2 and F_3 in table 1 apart from cleavage intensity which is often variable and lithology-dependent (Blewett 1989), and so I am left unconvinced by this division.

Clarification of the statement that "overprinting of F_3 on F_2 at the mesoscopic scale is observed" is needed,

*Present adress: Bureau of Mineral Resources, Geology and Geophysics, G.P.O. Box 378, Canberra 2601, Australia.

especially if this refers to a cleavage–fold relationship (i.e. figs. 5c & d) in the light of transected folds. Unequivocal overprinting would be established with the recognition of a convincing F_2–F_3 fold interference and an associated S_2 overprint of S_3. The synoptic stereonets (cf. fig. 3) show 'F_2' fold axes and "rotated axial surfaces" (although not shown by Lafrance 1989) to lie on a girdle interpreted as a "large-scale fold". Surely this girdle represents the axial surface of the folds about which the mesoscopic axes pitch, rather than a large-scale fold. The 'F_3' axes also lie on this girdle, and by the same token, are they considered to have been refolded by this same event? The macroscopic overprint of 'F_3' on 'F_2' is therefore, not unequivocally demonstrated by Lafrance (1989). The cylindricity of the girdle of the poles to bedding surely would preclude these complicated refolding events. The 'F_2' folds therefore seem indistinguishable from 'F_3' folds on the basis of the stereonets shown in fig. 3.

The mesoscopic evidence of a cleavage (interpreted as S_3) 'overprinting' folds (interpreted as F_2) should be reconsidered as evidence for transected folds. This is particularly relevant when "on Swan Island, S_2 was completely obliterated by an overprinting cleavage". It may be that 'S_2' (as defined by Lafrance 1989) never occurred and therefore, was never 'obliterated', and the relationships are more akin to the common cleavage transected folds of the British Caledonides (cf. Soper 1986 and references therein) and the Newfoundland Appalachians (Blewett & Pickering 1988, Blewett 1989). Also, the disparity between the number of measurements of regional 'F_3' folds (22) and their associated regional penetrative slaty cleavage (of which there are 134 readings) and 'earlier' folds ('F_2' = 169) is unusual. Again, on the evidence presented by Lafrance (1989), it is difficult clearly to separate 'F_2' from 'F_3'. Surely 'F_3' folds, as they are allegedly associated with the regional cleavage, would be more numerous than folds without associated regional cleavage.

In the New, Seal and Badger Bay areas to the west and south of Exploits Bay (Lafrance's study area), a regional penetrative (Acadian) cleavage variably transects the dominant NE–SW-trending F_2 Acadian folds (Blewett & Pickering 1988, 1989, Blewett 1989). Acadian folds (regarded by most workers as F_2) show fold–cleavage relationships similar to those displayed in Lafrance (1989, cf. figs. 5c & d), where a cleavage is parallel to the axial trace or fans symmetrically about this, while the bedding–cleavage intersections are at oblique angles (transect) the hinge line. Further, the recognition of transected Acadian folds is chiefly confined to argillaceous beds while complementary folds in more competent, or psammatic beds, commonly show approximately axial planar relationships between the folds and cleavage. This has important implications as a single cleavage cannot be both axial planar (and therefore related to the folds) and still overprint, in the manner suggested by Lafrance (1989), while complementary fold pairs have the same cleavage transecting the hinge line.

The regional Acadian cleavage has been shown consistently to transect the regional Acadian fold axes in a clockwise sense in areas to the south of the Boones Point Complex, while in areas approaching the E–W swing in strike (i.e. in Lafrance's study area), predominantly anticlockwise transected Acadian folds are recorded (Blewett 1989). The regional cleavage is, therefore, related to the regional folds but probably in a more complex manner than suggested by Lafrance (1989).

In the 'Discussion' of Lafrance (1989) there is confusion over correlations with previous workers' F_2 (regional Acadian) folds (cf. Karlstrom *et al.* 1982, Reusch 1983, van der Pluijm 1984, 1986, Pickering 1987b) none of whom clearly recognize two discrete phases of pre-Acadian deformation (i.e. Lafrance's 'F_1' and 'F_2'), although van der Pluijm (1984) lumps several generations into a pre-Acadian F_1 phase. Presumably Lafrance (1989) is referring to his 'F_3' as these previous workers' F_2? Further, many of these workers record NW-verging 'F_2' folds (cf. Karlstrom *et al.* 1982, cf. fig. 5, van der Pluijm 1984, 1986), not southerly verging folds as suggested by Lafrance (1989).

The paper by Lafrance (1989) makes an important contribution to the understanding of the complex area of the northern Dunnage Terrane and also proposes an interesting interpretation for the cleavage-transected folds which are clearly more common than axial planar fold–cleavage relationships. The chronology of deformation proposed by Lafrance (1989) could therefore be 'simplified' if 'F_2' folds that were recognized on the basis of small transection angles by the regional cleavage, are reinterpreted as transected Acadian folds similar to those described by Soper (1986 and references therein) rather than as an overprint. What is probably most in question is whether one is a 'splitter' and favours overprinting, or a 'lumper' and favours progressive deformation and transection!

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Structural evolution of a transpression zone in north central Newfoundland: Reply

Bruno Lafrance

Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, N.B., Canada E3B 5A3

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In his discussion, Blewett raises important questions concerning (1) the nature and origin of the Boones Point Complex and (2) the overprinting relationship between F_2 and F_3 folds. Blewett also proposes that F_2 folds with the geometry of transected folds have formed synchronously with the transecting cleavage. These points will be briefly addressed, but the reply focuses on the last question raised by Blewett which is of more general interest: should folds with the geometry of transected folds be considered as overprints?

Blewett and other workers interpret the Boones Point Complex as a tectonized belt of débris flows related to an early thrusting event. The Boones Point Complex consists of several disrupted, incompetent horizons or mélanges surrounding more competent rock units. The deformation structures seen in the mélanges are 'hard rock' structures (see Lafrance 1989 for more details); there is no convincing evidence of unlithified sediment deformation. The mélanges occur in shear zones which in certain cases clearly transpose the regional S_3 foliation indicating that they developed late in the tectonic history of the region. The Boones Point Complex therefore consists of tectonized mélanges some of which are definitely late in origin, since they overprint the regional cleavage. There is, however, some justification for Blewett's and other workers' interpretations since, in a well dated sequence on eastern New World Island, a younger olistostromal unit lies between two older units (Jacobi & Schweikert 1976, van der Pluijm 1986). I would therefore like to reinforce a statement made in the original paper (Lafrance 1989, p. 711): "There may have been in the Boones Point Complex disrupted horizons related to an early thrusting event, but the late overprinting shearing would make them indistinguishable from shear zone mélanges".

Blewett questions the interpretation concerning the overprinting of F_2 folds by a large-scale F_3 fold on Swan Island (Lafrance 1989, fig. 3). He suggests that the girdle defined by the distribution of F_2 fold axes represents the axial surface of the folds about which the mesoscopic axes pitch, rather than a large-scale fold. Since F_2 folds retain the same vergence on both limbs of the large-scale fold, they may be interpreted, on the basis of the distribution of their axes alone, to overprint the large-scale fold (as proposed by Blewett) or to be overprinted by the large-scale fold.

As mentioned in the original paper, F_2 fold axial planes are folded around the large-scale fold; outcrop exposure is continuous along the coastline and this interpretation is based not only on equal-area projec-