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An Anomalous Bedding/Cleavage Relationship

Abstract

In a major fold in the Kootenay arc belt in N.E. Washington, the F_1 fold geometry can be mapped from the bedding/cleavage relationships, even though the fold has been refolded by later crenulation folds. The early cleavage, S_1, is preserved in the psammitic units of the Lower Cambrian Maitlen Phyllite. However, anomalous bedding/cleavage relationships are recognized in some outcrops in which the later folding has locally reversed the angular relationship between the S_1 cleavage and the bedding. The S_1 cleavage appears to have been the dominant anisotropic control on the F_2 folding, rather than the bedding, which appears to have behaved as a relatively passive marker.

One of the most important relationships used by structural geologists to map fold structures is the angular relationship between bedding and axial plane cleavage which allows one to determine the position of an outcrop in a fold (e.g., Wilson, 1961; Ramsay, 1967, fig. 7-77). In a hinge zone, the cleavage will be at a high angle to the bedding, whereas in the limb zones, the cleavage will be at a low angle to the bedding. There will be a different sense of the cleavage crossing the bedding on opposite limbs of the fold.

Even in areas that have been refolded, the general sense of the early bedding/cleavage relationships is often maintained. The angular relationships of the early bedding/cleavage may be modified by the later deformation (e.g., Ramsay, 1967, figs. 9-16, 9-32); but usually the general position within the early fold can still be delineated.

However, during the course of detailed mapping in the Kootenay Arc in N.E. Washington, we have come across examples of anomalous bedding/cleavage relationships. The structure of the Lower Cambrian Quartzite (Gypsy) and Maitlen Phyllite just south of Northport (Stevens County, N.E. Washington) consists of a large over-turned anticline facing towards the northwest and plunging to the southwest (Mills and Nordstrom, 1973). The fold and associated minor parasitic folds have a pervasive axial plane cleavage. Later folds, F_2, also plunging southwesterly, have refolded the early folds and have formed a crenulation axial plane cleavage in the more phyllitic units. In most outcrops of the quartzitic units, the position within the early fold can be discerned because the early cleavage is preserved within the bedding. The sense of the bedding/cleavage is largely unaffected by the later crenulation. An example is shown in Figure 1 of a quartzitic unit within a phyllite matrix. The phyllite is crenulated and has an incipient crenulation cleavage, axial planar to the minor fold. The minor fold affects both the bedding and the early axial plane cleavage, which cuts through the bedding at a very low angle. The sense of the S_1 cleavage crossing the bedding is maintained around the later fold, and shows the early fold to be closing anticlinally to the southeast.

In contrast, Figure 2a shows a quartzitic unit within a quartzitic phyllite matrix. It

Figure 1. Minor F_2 fold in a quartzite layer, viewed down plunge, towards the southwest. First cleavage, S_1, is folded with bedding, S_0, but retains the original bedding/cleavage sense around the fold. Cleavage crosses bedding from upper left to lower right indicating an anticlinal closure to the southeast.

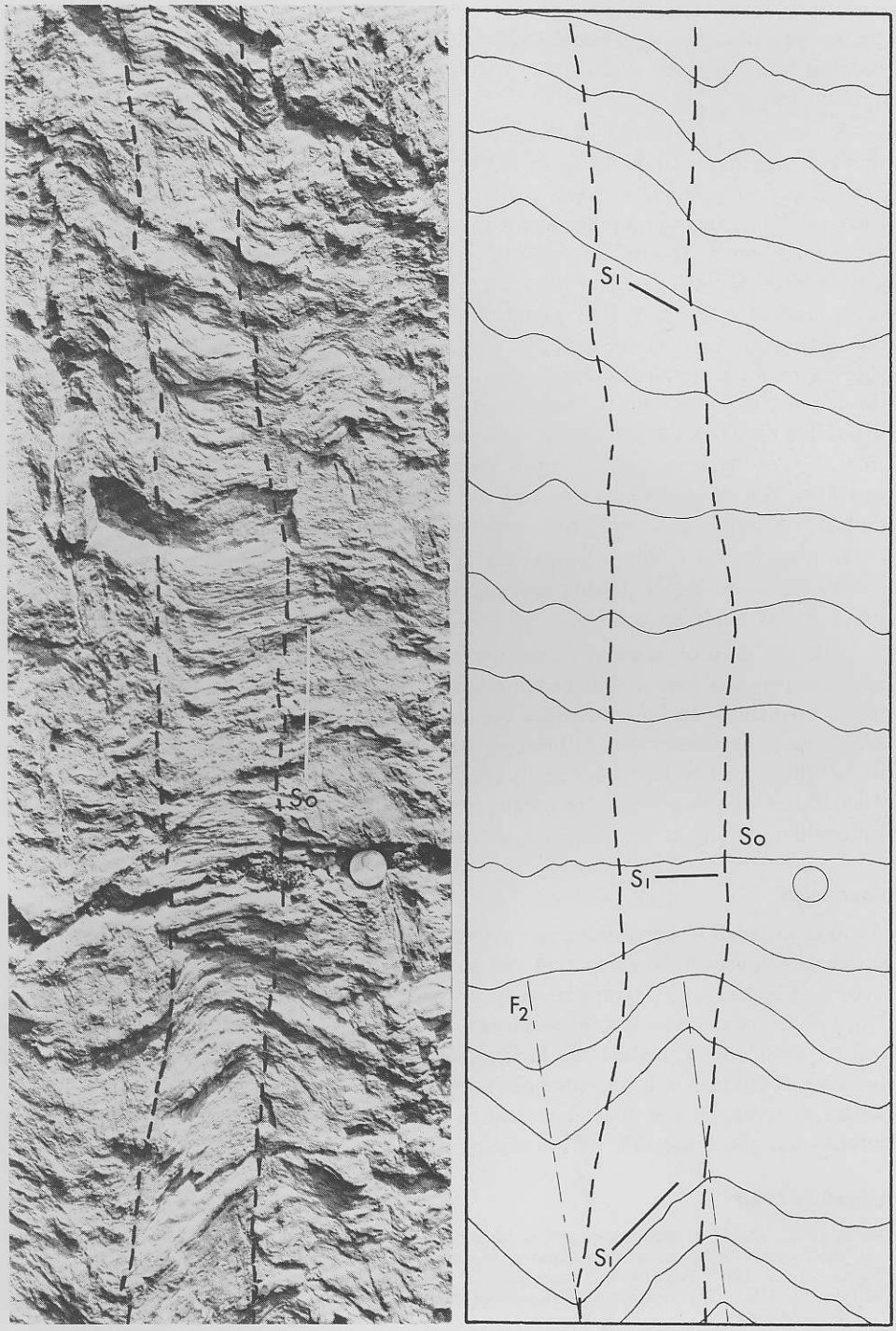

Figure 2a. Progressive change of bedding/cleavage sense along a quartzitic unit. Axial traces of F_2 folds cross bedding at a low angle. The S_1 cleavage is folded but the bedding, S_0, is largely unaffected. The folds characteristically die out along their axial traces. Figure 2b. Line drawing of Fig. 2a, showing the bedding, S_0, the first cleavage, S_1, and the F_2 fold axial surface traces.

can be seen that the angle between the bedding and the S_1 cleavage changes along the bedding from an acute angle, up to ninety degrees, then to an acute angle facing the opposite way.

A first interpretation is to suggest that this outcrop represents a minor first fold that has been flattened out or unfolded by the later deformation. However, further examination of the outcrop reveals that the cleavage is folded into a series of chevron folds, which change amplitude along their axial plane traces, locally dying out into planar S_1 surfaces. The bedding unit traverses the chevron folds at a low angle to their axial surface traces. Therefore, in places it follows one limb of the chevrons, gradually moves into a hinge zone and eventually onto the opposite limb; thus the angle of the cleavage to the bedding gradually changes. This geometry results in areas of anomalous or locally reversed bedding/S_1 cleavage relationships. It is not possible to ascertain the original angle between the bedding and the cleavage before the later folding. Nor is it possible to determine the original sense of the cleavage crossing the bedding, although from the areal context, this outcrop is known to be on the northwest limb of the major anticline. The bedding/cleavage sense in the lowermost portion of Figure 2a would then be consistent with the position of the outcrop within the major fold.

In this chevron folding example, the bedding appears to have very little mechanical control on the folding, behaving as a passive marker stripe, with the early cleavage acting as the dominant anisotropy.

It is not possible to ascertain the mechanical effect of the bedding units in the example shown in Figure 1. The bedding is at a very close angle to the cleavage and it is therefore difficult to know whether one or both controlled the folding. The thickness of the bedding presumably influenced the wavelength of the fold, as smaller wavelength folds are developed in the thinner bedding unit in the left side of the photo. The smaller wavelength may, of course, be due to there being fewer quartzitic cleavage "microlithon" units in the thinner quartzitic unit.

Conclusion

As long as careful observations are maintained, the anomalous bedding/cleavage relationships can usually be recognized and so taken into account when mapping out early structures by bedding/cleavage relationships in a refolded area. In this particular area at Northport, there is also a well established stratigraphy and therefore stratigraphic control on the mapping besides the bedding/cleavage relationships. There may, of course, be some occasional isolated outcrops in which not enough of the folding can be observed to recognize the anomalous situation and which will therefore give misleading information about the first fold geometry.

Literature Cited

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