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Vergence boundaries: an extension of the vergence concept

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Abstract—The difficulty in distinguishing between vergence changes on adjacent limbs of tight primary folds and the similar effects produced by non-coaxial refolding of primary folds by larger-scale folds is outlined. It is suggested that a distinction should be made between typical and atypical vergence boundaries. Atypical vergence boundaries falsely suggest the presence of congruent major folds whereas major folds attributed to typical vergence boundaries are real. Practical rules are formulated that should be applied to vergence boundaries in non-coaxially refolded regions in order to recognize atypical vergence boundaries.

INTRODUCTION

THE PRINCIPAL use of mapping minor fold and cleavage vergence is to locate major fold closures. Bell (1981, p. 198) has briefly mentioned that refolding may complicate application of the vergence concept: "Generally, refolded folds in which early fold axes pitch steeply relative to late fold axes (frequently type 1 interference patterns, Ramsay 1967) show these atypical vergence relationships." He concludes that in some geometries both facing and vergence should be applied to unravel the complex structure. However, facing cannot be determined in refolded rocks entirely devoid of sedimentological way-up criteria, and one is restricted to the vergence concept. This paper outlines how the vergence concept can be applied in non-coaxially refolded regions to interpret ambiguous structural relationships. In the account that follows the use of the term vergence is taken to imply both fold vergence and cleavage vergence, though in the illustrations only fold vergence is depicted.

TYPICAL AND ATYPICAL VERGENCE BOUNDARIES

In areas of single-generation folds adjacent fold limbs bear parasitic folds of opposite vergence. The position of a large-scale fold closure follows directly from the change in the mapped vergence direction and the trace of its axial plane will correspond on a structural map to the vergence boundary (Fig. 1a). Where folds have been coaxially refolded the mapped vergence pattern on one limb of the large-scale fold is not changed by the superposition of the younger folds (Fig. 1b). If, however, folds are non-coaxially refolded it may become difficult to establish whether the change in mapped vergence directions is due to a large-scale fold closure fitting these vergences (Fig. 1c), or whether it is due to refolding (Fig. 1d). Generally the problem only arises where the major folds are tight to isoclinal, elsewhere dip and strike difference between major fold limbs and between surfaces of minor folds will be sufficiently different to prevent confusion.

I suggest the use of the adjectives typical and atypical to distinguish the two types of vergence boundaries. A typical vergence boundary defines the position of the axial plane of a major fold that is synchronous with the minor structures from which the vergence is determined (Fig. 1c). An atypical vergence boundary coincides with a major fold closure that is younger than the minor structures from which it is determined (Fig. 1d). It should be noted that the vergence patterns for congruent minor folds (e.g. Fig. 1c) and for refolded folds (e.g. Fig. 1d) may be virtually identical. The pattern of the vergences does not help in distinguishing between typical and atypical vergence boundaries. However, these terms have a genetic implication that can be established by applying additional tests to a vergence boundary. Such tests will be formulated later in this paper.

RECOGNITION OF ATYPICAL VERGENCE BOUNDARIES

It is important to consider the geometrical relationships between major folds and refolded minor folds which may give rise to atypical vergence boundaries. Theoretically, the *F*2-axial plane of every non-coaxially refolded primary fold is a potential atypical vergence boundary. However, due to the method of mapping fold asymmetries as vergences, there are some geometric configurations that are more likely to be interpreted as atypical vergence boundaries than others. The dependence of the angle α_2 between vergence symbols on the map, on the orientation of the interlimb angle α_1 in space, is shown in Figs. 2 (a–c). Clearly, the configuration in Fig. 2 (c) is most likely to be interpreted as a vergence boundary. In this particular case, however, a congruous

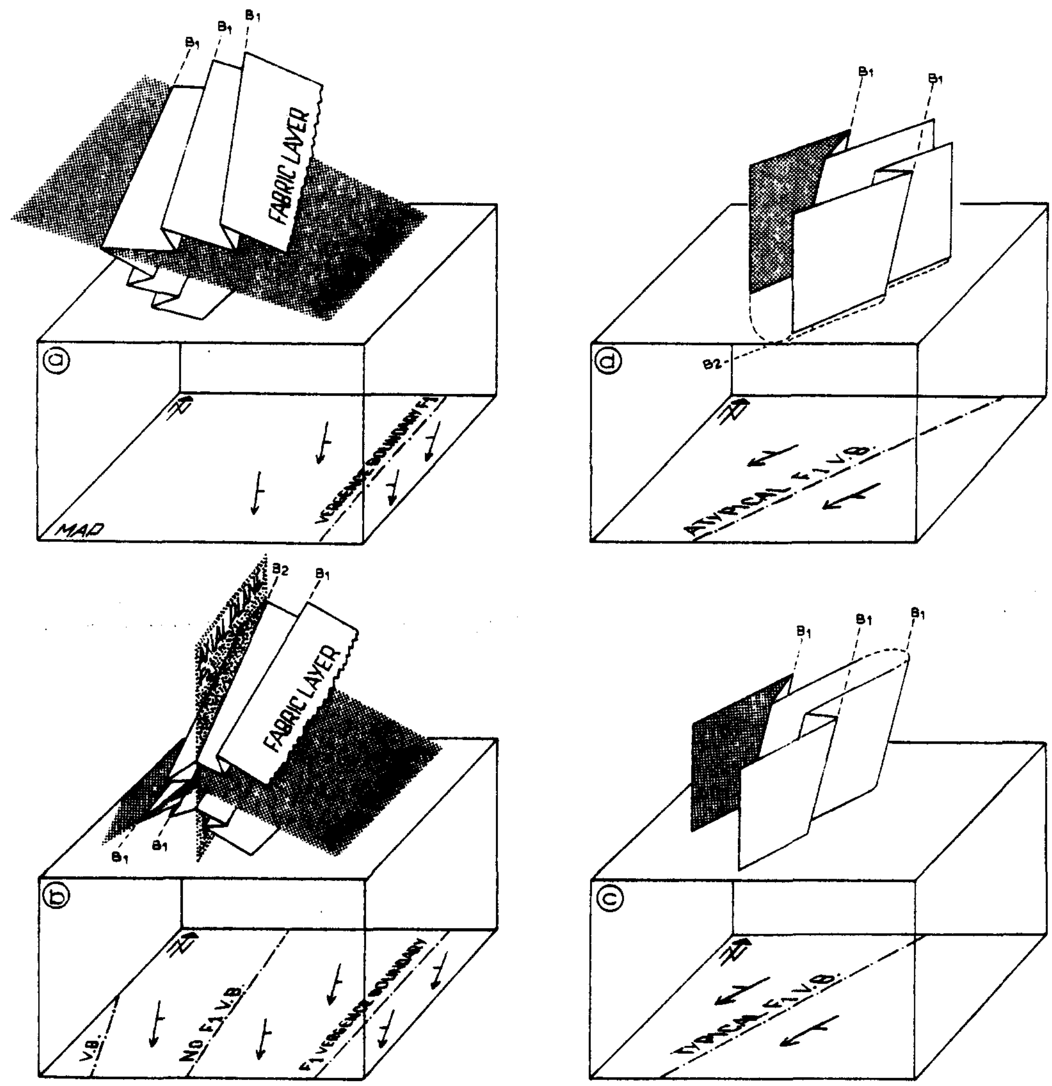

Fig. 1. (a) The position of a large-scale fold closure is marked on a structural map by a vergence boundary. (b) Where folds are coaxially refolded, the mapped vergence pattern on one limb of the large-scale fold is not changed by the superposition of the younger folds. A distinction can be made between typical vergence boundaries (c) and atypical vergence boundaries (d). The direction of vergence is indicated by the short line at the appropriate side of the fold axis symbol.

major fold does not exist. It is an apparent congruous fold because the vergence changes are atypical.

It is impossible to define a maximum value for the angle α_2 below which an atypical vergence boundary is determinable. Considerable regional variation in the orientation of primary fold axes on either side of a vergence boundary might mean that a geologist would not recognize the presence of a vergence boundary (Fig. 2f), unless α_2 becomes very small (Figs. 2d & g–k). On the other hand, the presence of an angle between vergence symbols on either side of the vergence boundary does not necessarily imply the presence of an atypical vergence boundary, because similar effects may occur at typical vergence boundaries due to differences in plunge between minor folds and the major fold to which they are related (Borradaile 1972, Berthé & Brun 1980, Cobbold & Quinquis 1980).

Where a vergence boundary is defined on the basis of an arbitrary small α_2 angle, two end members of a continuum of geometries that are most likely to give atypical vergence boundaries can be distinguished.

Type A. *F2* is a recumbent or overturned refolding with *B2* horizontally oriented at a large angle to *B1* (Fig. 2d).

Type B. *F2* is a tight non-coaxial refolding with a vertical fold axis *B2* oriented at any angle to *B1*, but non-coaxial (Figs. 2g–k).

Apart from a qualitative understanding of the geometric relationships outlined above, field geologists may need to use the following practical rules to test whether a vergence boundary in non-coaxially refolded terrains is typical or atypical.

(i) At atypical vergence boundaries, primary-generation structures that are being refolded, do not and cannot show neutral vergence.

(ii) The true nature of a vergence boundary can be established by mapping secondary fold or cleavage vergence changes, if developed.

(iii) Significant differences in the direction of the plunge of *F1* minor fold axes or intersection lineations *L1*, on

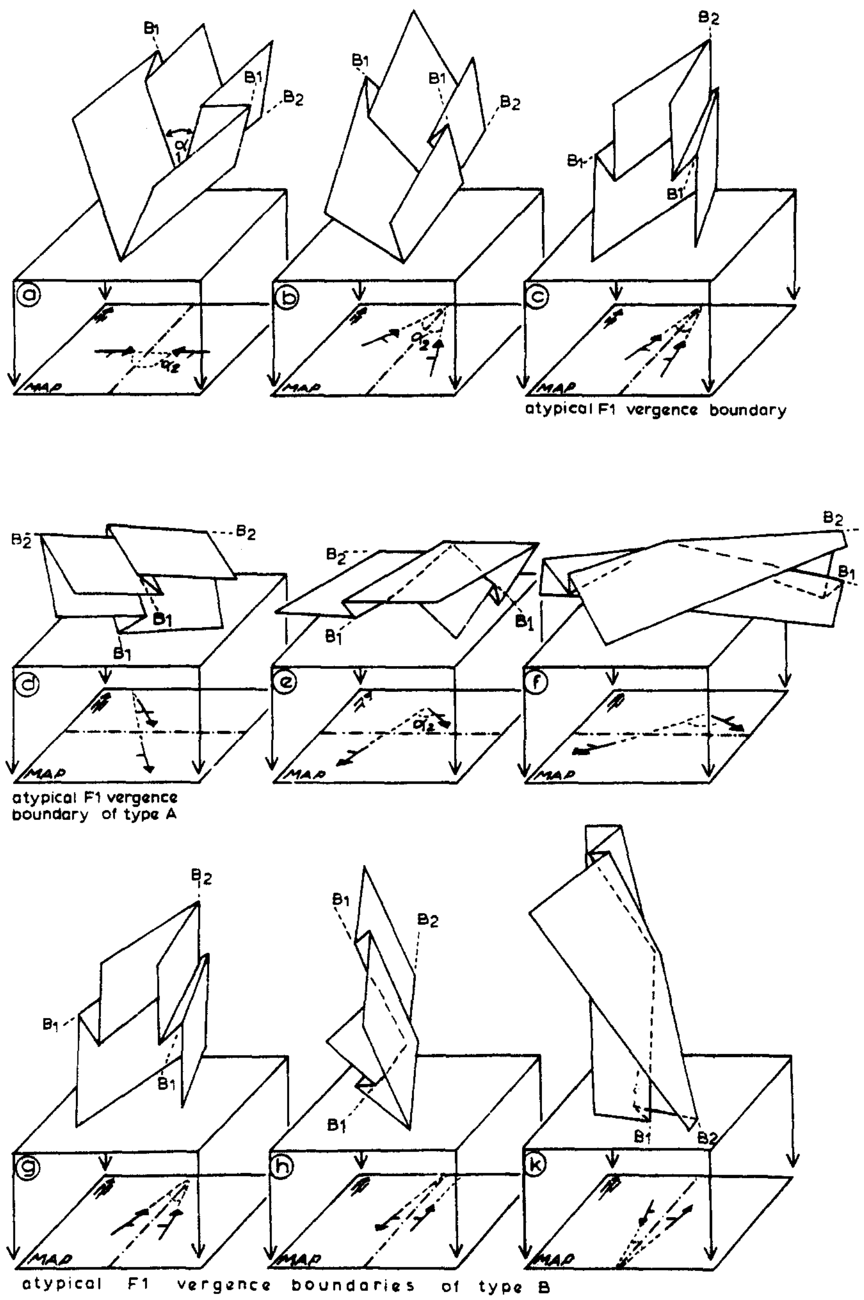

Fig. 2. Atypical vergence boundaries occur in a limited number of configurations of overprinting fold systems (for explanation see text).

either side of a vergence boundary, are possible indicators that the vergence boundary is not typical.

I have discussed atypical vergence boundaries at major fold closures of a generation younger than the minor structures from which the vergence is determined. Means (pers. comm.) has correctly remarked that an additional type of atypical vergence boundary may occur across the axial planes of earlier large-scale folds when there has been orthogonal refolding by either coaxial or non-coaxial folds (see Means 1966, fig. 5b, Ramsay 1967, fig. 10-21). In such exceptional cases, the axial planes of primary folds coincide with atypical $F2$-vergence boundaries. Neutral secondary fold and cleavage vergences cannot occur at atypical $F2$-vergence boundaries.

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