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Three-Dimensional Size-Analysis of Folds of Quartz Veins in the Psammitic Schist of the Oboke District, Shikoku

By

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with 7 Text-figures and 3 Plates

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Abstract: Three-dimensional size-analysis of folds of quartz veins in the psammitic schist of the Oboke district, Shikoku, has been performed. Many of fold-forms observed on the facies of quartz veins show lens-like form elongated along the fold axis, associating bifurcation of folds. A linear relationship is found between layer-thickness (T) and arc-length (L_a) as measured on a given joint surface normal to the fold axis and L_a increases with increase of T. The mode value of L_a/T ratios is 8–8.5. The L_a values on individual folds are not always constant as measured on several sections normal to the fold axis, because the folds show commonly lens-like form elongated along the fold axis. The ratios between axial length of fold (L_{fa}) and T (L_{fa}/T) appear to show a bimodal distribution, through L_{fa} tends to increase with increase of T. One of the mode values of L_{fa}/T ratios is 35 and the other is 65. The small values of L_{fa}/T ratio tend to be more frequently found on the folds with larger interlimb angles rather than on those with smaller interlimb angles. During the process of growing of amplitude of fold appears to occur frequently the phenomenon that adjacent folds approximately oriented on a straight line are combined with each other into one fold, associating change of L_a value.

Contents

I. Introduction

The size-analysis of natural folds has been so far performed only on the profile plane normal to the fold axis. That has clarified relationship between layer-thickness (T) and arc-length (L_a) for the folds of competent layers embedded in incompetent layer. Namely, it has been shown that there is a linear relationship between L_a and T and L_a increases with increase of T, and that the L_a/T ratio increases with increase of competency difference between competent layers and incompetent layers (Sherwin *et al.*, 1968; Hara *et al.*, 1968; Hara *et al.*, 1973; Hara, 1974). The variation in the L_a/T ratio on individual folds as measured on several sections normal to the fold axis would be examined in this paper. The size-analysis of folds could be also done by measurement of their axial length (L_{fa}). However, relationship between L_{fa} and T has not been so far reported in any literature. The facies of quartz veins in the psammitic schist of the Oboke district, Shikoku, Southwest Japan, which are parallel to the bedding schistosity and folded in various intensity, are frequently clearly exposed in domains each of which is wider than 900 cm^2. Therefore, in this district can be measured L_{fa}/T ratios, as well as L_a/T ratios, for the folds of quartz veins. The relationship between T and L_{fa} for the folds of quartz veins will be also examined in this paper, in order to understand three-dimensionally forms of natural folds.

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II. SIZE-ANALYSIS OF FOLDS

The size-analysis of the folds of quartz veins in the Oboke psammitic schist has been performed in five outcrops (outcrops A to E in Fig. 1). The major structure of the psammitic schist of the Oboke district is characterized by an anticlinorium, Oboke anticlinorium (Fig. 1). The outcrops A and E are placed in the crest of an anticline, Oboke anticline, developed in the southern margin of this anticlinorium and in the trough of a syncline, Koboke syncline, developed in the central zone of it respectively. And the outcrops B, C and D are placed between the crest of the Oboke anticline and the trough of the Koboke syncline. In the Oboke psammitic schist develop strain-slip cleavages referred to as the axial plane cleavage of the Oboke anticlinorium. The folds of quartz veins in the psammitic schist, whose size-analysis will be done in the following paragraphs, are of the same generation as the strain-slip cleavages (cf. HARA *et al.*, 1968).

In the psammitic schist of the outcrop E are randomly oriented many quartz veins. Based on the variation in intensity of folding between those randomly oriented quartz veins and on RAMBERG's (1959), FLINN's (1962) and TALBOT's (1970) theoretical works on folding and boudinage, the shape of the strain ellipsoid of mean longitudinal strain

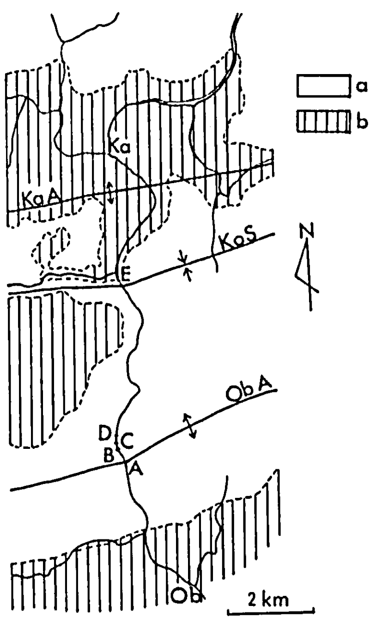

FIG. 1. Diagram showing the location of the outcrops A, B, C, D and E in which the size-analysis of the folds of quartz veins has been done.
a: psammitic schist. b: pelitic schist with basic schist. ObA: Oboke anticline. KoS: Koboke syncline. KaA: Kawaguchi anticline. Ob: Oboke. Ka: Kawaguchi.

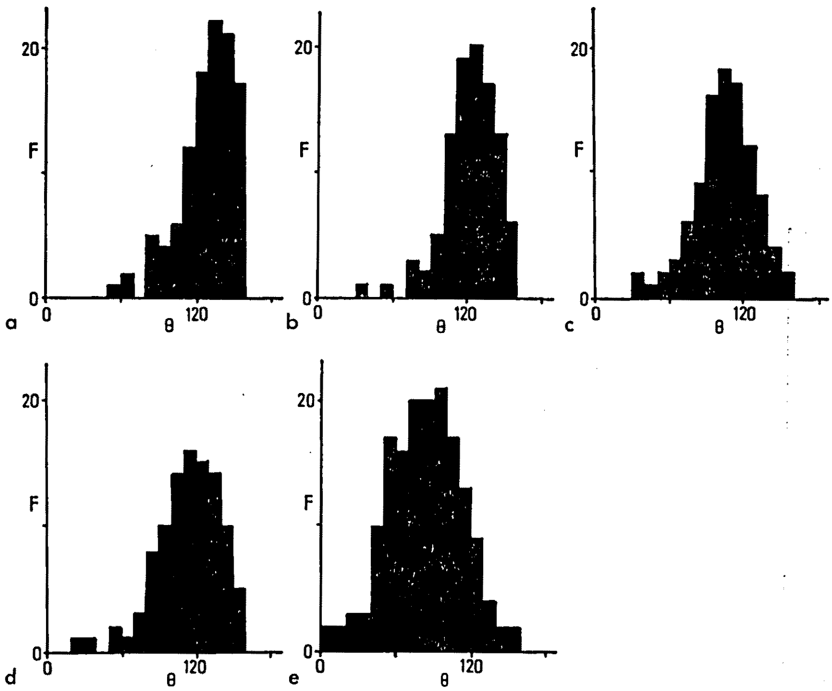

FIG. 2. Diagrams showing the variation in the interlimb angle θ between the folds of quartz veins in the outcrops A (a), B (b), C (c), D (d) and E (e).
The frequency (F) is given by number of measured folds.

of the psammitic schist in the outcrop E has been determined (HARA *et al.*, 1968; HARA, 1974). Namely, the strain state of the psammitic schist in the outcrop E has been described in term of $k=0.3$. And the intermediate principal axis (Y) of the strain ellipsoid is parallel to the axis of the Koboke syncline (=the axis of the Oboke anticlinorium), while the shortest principal axis (Z) is parallel to the general trend of the bedding schistosity and normal to the strain-slip cleavages. Judging from the orientational relation of the strain-slip cleavages to the bedding schistosity, the Y-axis and the Z-axis for the mean longitudinal strain of the psammitic schist in the outcrops A to D, which was induced by the deformation related to the formation of the folds of quartz veins in question, are also oriented in a direction parallel to the axis of the Oboke anticlinorium and in a direction parallel or subparallel to the bedding schistosity and normal to the strain-slip cleavages respectively. The size-analysis has been done on the folds of quartz veins in the outcrops A to E which are parallel to the bedding schistosity and so parallel or subparallel to the ZY-plane.

The variation in the interlimb angle θ between the folds of quartz veins in the outcrops A to e, which are oriented parallel to the bedding schistosity and so parallel or subparallel to the ZY-plane, has been examined. The results are shown in Fig. 2–a to e, though θ larger than 160° is not plotted in them. The figures all are characterized by a marked maximum: In the outcrop A the folds with θ of 121° to 150° are 61%, in the outcrop B those with θ of 111° to 140° 56%, in the outcrop C those with θ of

91° to 130° 63%, in the outcrop D those with θ of 101° to 140° 59% and in the outcrop E those with θ of 71° to 110° 48%. Of as an approximation to each of the histograms of Fig. 2–a to e can be thought the normal frequency curve.

The size-analysis of the folds of quartz veins in the outcrops A and E has been done on the profile plane normal to the fold axis (HARA *et al.*, 1968; HARA, 1974). In the outcrop A were measured the L_a/T ratios for the folds with θ of 121° to 150°. The

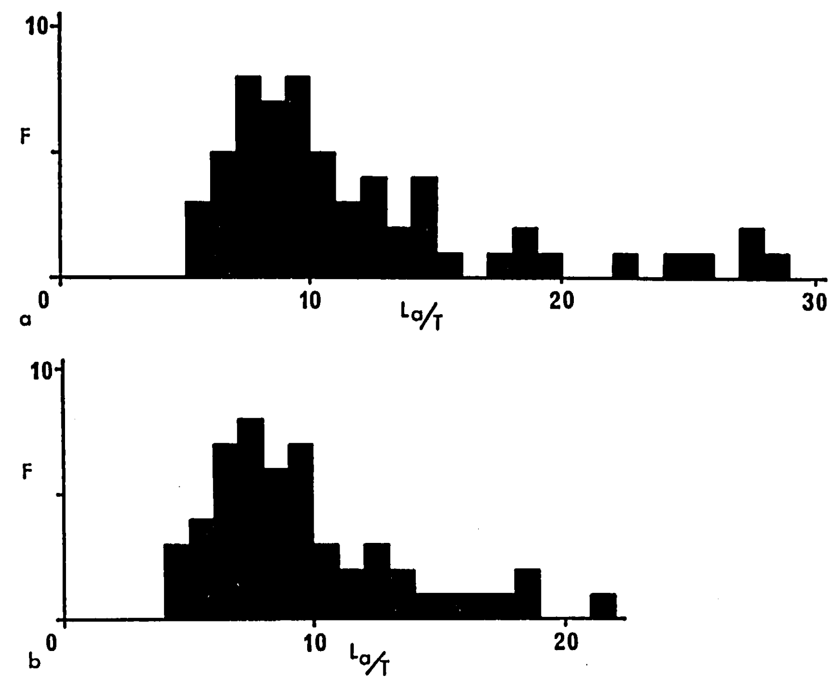

FIG. 3. Diagrams showing the variation in the L_a/T ratio between the folds of quartz veins.
a: Data from the outcrop A. b: Data from the outcrop E.
The frequency (F) is given by number of measured folds.

result is reproduced in Fig. 3–a. In this figure there is a wide spread of the L_a/T ratios ranging from 5.1 to 28.7, showing a marked maximum between 7.1 and 10.0. The mode value and the mean value of the L_a/T ratios are 8.5 and 12.1 respectively. In the outcrop E were measured the L_a/T ratios for the folds with θ of 71° to 100°, as shown in Fig. 3–b. This figure indicates that the L_a/T ratios are in the range of 4.2 to 21.5 and a marked maximum is between 6.1 and 10.0. The mode value and the mean value of the L_a/T ratios are 8.0 and 9.8 respectively. It can be pointed out that, for the folds of quartz veins, L_a depends upon T and the former increases with incresase of the latter and that the frequency distribution of L_a/T ratios is skewed to the right with smaller mode value and larger mean value but not regarded as the normal frequency distrbution (HARA *et al.*, 1968; HARA, 1974).

From Fig. 2–a and e, it could be said that the mean longitudinal strain, which was produced in the psammitic schist by the deformation related to the formation of the folds of quartz veins in question, is greater in the outcrop E than in the outcrop A and that the folds of quartz veins in the outcrop E are of the more advanced stage of folding than those in the outcrop A (HARA, 1974). Therefore, the fact that the degree of the variation in the L_a/T ratio (Fig. 3–a and b) is much smaller for the folds in the outcrop E than for those in the outcrop A might suggest a possibility that, also in the middle stages of growing of amplitude of fold, L_a changes by migration of position of fold hinge on quartz veins, probably giving rise to wavelength selection. This inference does not appears to be harmonic with HUDLESTON's (1973, p. 209) opinion, "The final distribution of L_a/T ratios, and therefore selectivity, is probably " fixed" at or before the 10–20° limb dip stage,...."

The facies of the folded quartz veins, which are parallel to the bedding schistosity, are frequently clearly exposed in domains wider than 900 cm² for each in the outcrops B to E. Observation of fold-forms on those facies indicates that folds show generally lens-like form elongated parallel to the fold axis, associating bifurcation of folds, and the lengths of them along the fold axis (L_{fa}) can be frequently measured (Plates 12 to 14). The characteristics of fold-forms observed on the facies of quartz veins is quite similar to that shown in model experiment by GHOSH *et al.* (1968), as is obvious in comparison of Fig. 3–A of GHOSH *et al*'s paper and Plates 12 to 14. The L_a values measured on individual folds change along the fold axis. This is because folds show generally lens-like form elongated along the fold axis, as schematically sketched in Fig. 4. The

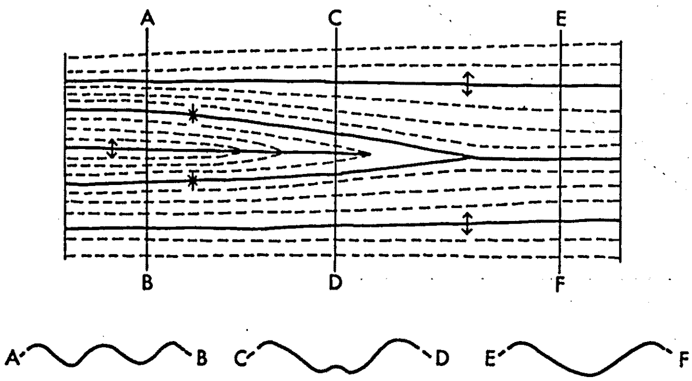

FIG. 4. Schematic sketch of the folds of quartz veins which show lens-like form and bifurcation. Dashed lines: contors. A–B, C–D and E–F: profile of fold.

authors have found that the L_a/T ratio varies from 6.1 to 12.6 on one fold as measured on several sections normal to the fold axis. The great variation in the L_a/T ratio, seen in Fig. 3–a and b, would be closely related, as well as to the initial perturbation of quartz veins, to that the L_a values are not always measured at the middle points on the axes of individual folds but at various points on them.

Fig. 5 illustrates the relationship between L_{fa} and T for the folds of quartz veins in the outcrops B to E, which have moderate to small values of θ. It may be roughly said that a linear relationship is found between L_{fa} and T, though the L_{fa}/T ratios are fairly variable in this figure: The mean value and the minimum value of the L_{fa}/T ratios are 75 and 29 respectively. When a histogram showing the variation in the L_{fa}/T ratio is

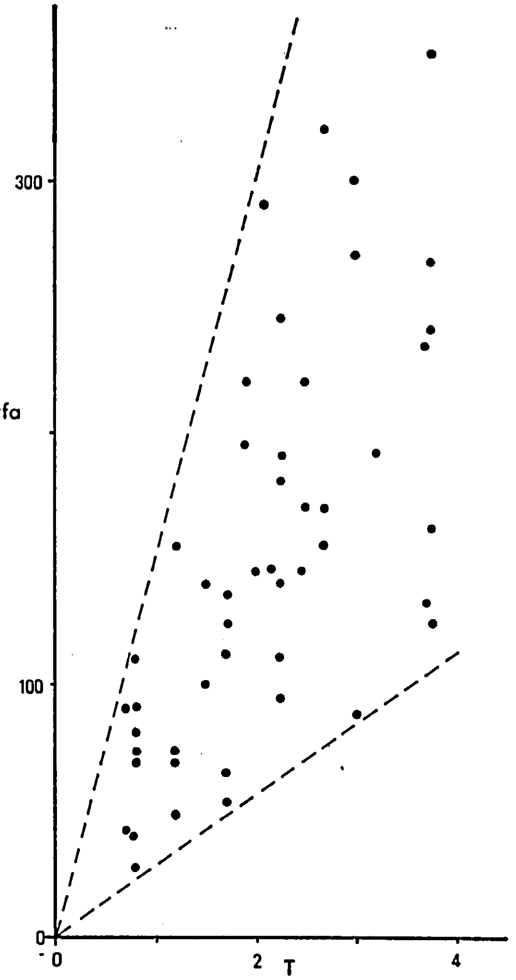

FIG. 5. Diagram showing the relationship between layer-thickness (T) and axial length (L_{fa}) for the folds of quartz veins in the outcrops B to E.

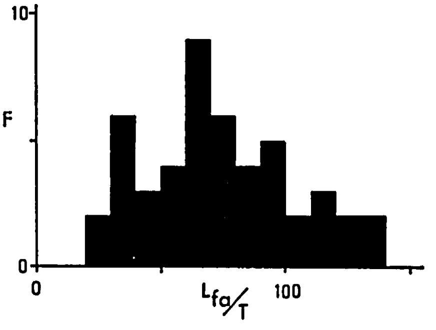

FIG. 6. Diagram showing the variation in the L_{fa}/T ratio between the folds of quartz veins in the outcrop B to E.
The frequency (F) is given by number of measured folds.

drawn on the basis of the data of Fig. 5, however, the histogram (Fig. 6) shows a character of bimodal distribution with one maximum and one submaximum. The maximum is between 61 and 70, while the submaximum is between 31 and 40.

From detailed observation of forms for the folds with θ of various values on the facies of quartz veins, it could be said that the small values of L_{fa}/T ratio are more frequently measured on the folds with θ of larger values rather than on those with θ of smaller values. Adjacent anticlinal folds, which are separated by small shallow synclinal folds in the earlier stage of folding and approximately oriented on a straight line, might be frequently combined with each other into one anticlinal fold in the more advanced stage of folding. Culminations found on one anticlinal fold with θ of small value might have been frequently "separated anticlinal folds" in the earlier stage of folding, as schematically shown in Fig. 7. Such the observations and inference, which would be harmonic with the bimodal distribution of the L_{fa}/T ratios in Fig. 6, suggest that the

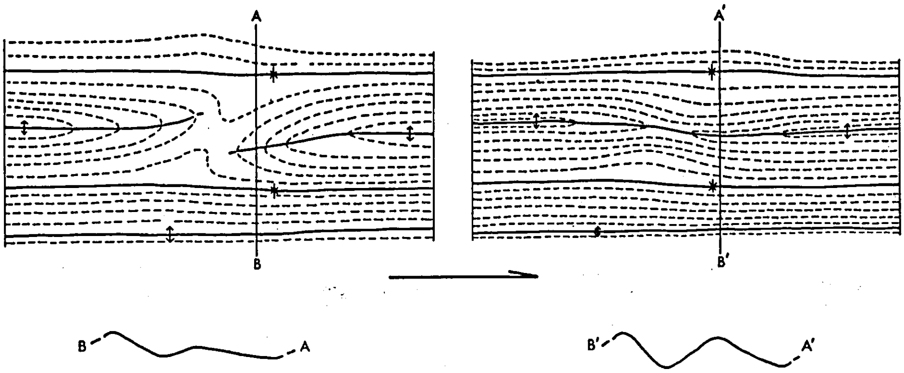

FIG. 7. Diagram showing a process in which adjacent anticlinal folds approximately oriented in a straight line are combined with each other into one anticlinal fold during the process of folding (arrow).
Dashed lines: contors. A–B and A′–B′: profile of fold.

positions of fold hinges migrate on quartz veins even in the middle stage of folding, changing L_a value. The great difference in the distribution of the L_{fa}/T ratio between the folds of the outcrop A (Fig. 3–a) and those of the outcrop E (Fig. 3–b) might be also related to the phenomenon that adjacent folds approximately oriented on a straight line are frequently combined with each other into one fold during the process of folding. Now, it would be pointed out that it is not so easy to correlate the L_a/T ratios for natural folds with BIOT's (1961) and RAMBERG's (1964) wavelength equation for buckle fold. and that equation for fold shape should be written in term of three dimensions ($=L_a$, L_{fa} and amplitud).

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EXPLANATION OF PLATE I

Photograph of fold-forms observed on the facies of one quartz vein in the outcrop D.

EXPLANATION OF PLATE II

Photograph of fold-forms observed on the facies of one quartz vein in the outcrop C.

EXPLANATION OF PLATE III

Photograph of fold-forms observed on the facies of one quartz vein in the outcrop D.