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FOLD CLASSIFICATION BY USING THE HINGE AND INFLECTION POINTS

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Abstract

The present paper describes a new technique to classify the folds having differential orthogonal thickness. Hitherto, most of structural geologists have considered the area of maximum curvature and its surroundings in fold profile section to classify the folds. In present study, first time the inter-arc angles (angles made by the line segments joining hinge point to inflection points) have been considered to classify the folds having differential orthogonal thicknesses. This method is based on comparison of the inter-arch angle of the two quarter wave sector of the fold profile section.

Keywords: Fold Classification, Inter-Arc Angle, Hinge Point, Inflection Point

1. Introduction

Fold classifications proposed by different workers are based mainly on fold geometry (Fleuty 1964; Ramsay 1967; Twiss 1988; Bastida 1999). Chapple (1968), Stabler (1968), Hudelston (1973), and Stowe (1988) used Fourier analysis for comparing the fold profiles with curves corresponding to mathematical functions. Hudleston (1973) indicated the relevance of inflexion points for fold classification using Fourier series analysis. Bastida et al.(1999) have suggested a mathematical power function for fitting fold shapes. Aller et al. (1999) classified the fold shapes on the basis of eccentricity and aspect ratio of conic sections. Hudleston and Lan (1994) proposed a curvature index, ki, for comparison and classification of folds. Ramsay (1967) described how the true profile shape varies with variation in curvature. He used tangents on profile curves and dip isogons between consecutive profile curves to classify the fold geometries. Hudleston (1973) modified Ramsay's classification by applying a new parameter $\varphi\alpha$, defined as the angle between normal to the tangents drawn to either fold surfaces at the angle of dip α, and the isogons.

Nevertheless, Ramsay's (1967) classification based on tangent and isogons patterns, is most popular and widely used. This classification provides an excellent tool for analyzing the geometry of folded layers. Another problem with Ramsay's classification is the difficulty in obtaining the best location of the reference thickness (t_o) to determine $t\alpha'$, as pointed out by

Bastida (1993). Bastida et al. (2005) emphasized the importance of geometrical information obtained from the folds. According to them, the quantitative methods based on fold geometry can be used to analyze the kinematical folding mechanisms.

Hitherto, most of the workers have considered the area of maximum curvature and its surroundings in fold profile section to classify the folds (Chapple 1968; Stabler 1968; Ramsay 1967; Hudleston and Lan 1994; Allert 1999).The present paper describes an alternative method to classify the folds having differential orthogonal thicknesses. In the present study, the point of maximum curvature (i.e. hinge point) and point of minimum curvature (i.e. inflection point) have been considered as base points to classify the folds. The proposed method is based on the comparison of angular relation of the two curves of the quarter wave sectors of a fold profile section. Since the method incorporates point of maximum curvature as well as point of minimum curvature of the fold profile section of a fold, it gives more relevant information to workout fold mechanics such as detail ductile behavior of folded strata. The method of classification is very simple, precise and free from any complicated geometrical construction or mathematical calculation. It can be done manually or by computer.

2. Method

Inter arc angle is the angle made by the line segments joining two inflection points to the hinge point in a fold profile section. This inter arc angle may be equated with curvature of the fold. In case of folds two quarter wave sectors can be chosen as two curves. To define angular relationship of two curves, their chords may be a suitable parameter because the slope of the chord is controlled by the curvature of the arc. In fold profile section this chord is obtained by joining hinge point to the inflection point. The present method of fold classification may proceed in the following steps (Figs 1-5):

(1) Begin with a profile curve of inner most layer of the fold having differential orthogonal thickness.

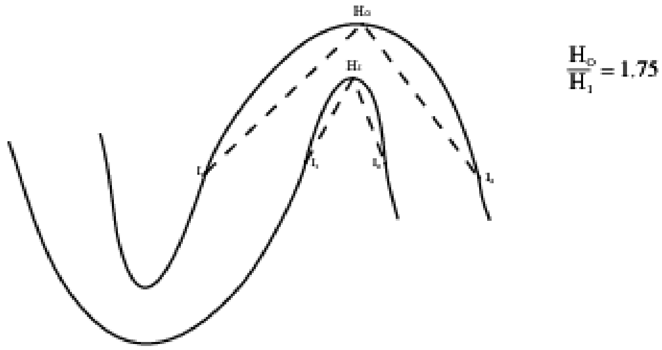

Fig.1 The inter-arc angle ratio characteristic of the Type Ia fold.

(2) Mark the points of maximum curvature and minimum curvature. Locate them as Hi and I_1 and I_2 respectively. Hi is hinge point of the inner layer.

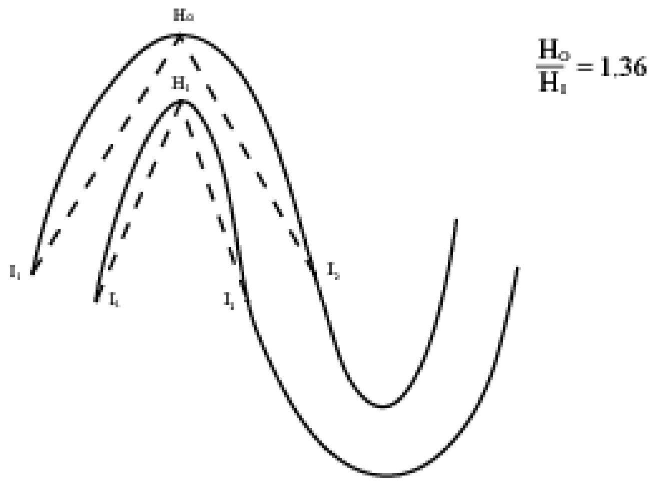

Fig. 2. The inter-arc angle ratio characteristic of the Type Ib fold.

(3) Join I_1 and I_2 with Hi. Line segment Hi I_1 is chord of first quarter sector and line segment Hi I_2 is the chord of second quarter sector.

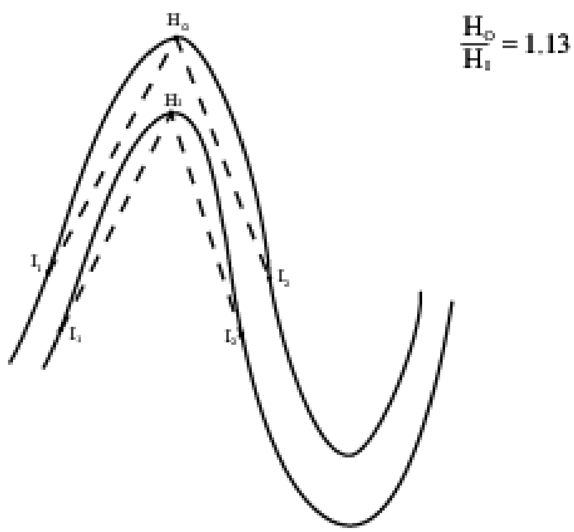

Fig. 3. The inter-arc angle ratio characteristic of the Type Ic fold.

(4) Measure the angle between these two chords and record them as “angle Hi”.

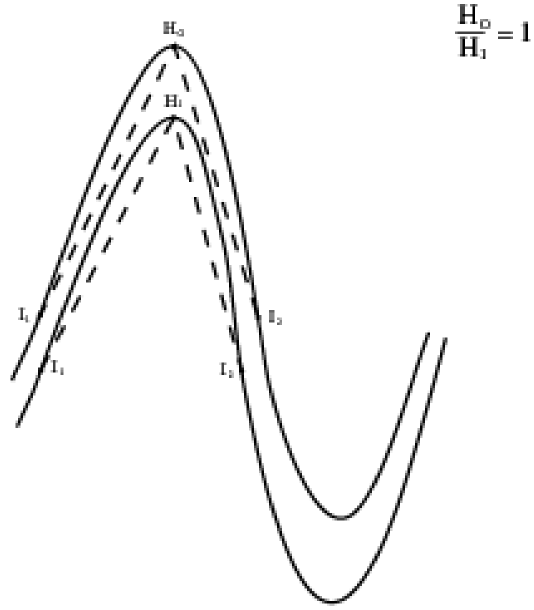

Fig. 4. The inter-arc angle ratio characteristic of the Type II fold.

(5) Repeat the same process for the outer profile curve and record the angle as “angle Ho”. Ho is the hinge point of the next outer layer.

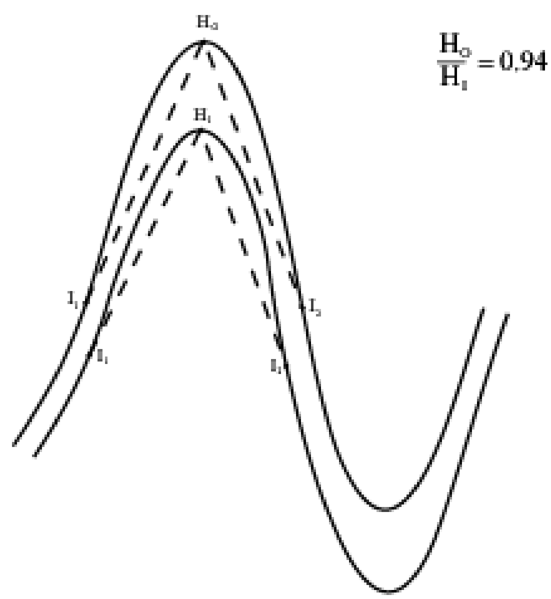

Fig. 5. The inter-arc angle ratio characteristic of the Type III fold.

6) The ratio of these two angles Ho and Hi (Ho as numerator and Hi as denominator) may be useful to classify the fold in different categories as shown in Table 1.

Table 1. Classification of layered fold shapes based on ratio of inter-arc angle (Ho/Hi)

Fold types	Sub-types	Ho/Hi ratio
Type I (Ho/Hi)>1	Type Ia	> 1.5
	Type Ib	1.25-1.50
	Type Ic	1.01-1.25
Type II (Ho/Hi)=1	-	approx. 1
Type III (Ho/Hi)<1	-	< 1.0

3. Classification of Folds (Table 1)

Based on Ho/Hi ratio following categories and sub-categories of folds may be suggested:

(1) Type I: Ho/Hi ratio is greater then 1.

Type I, is further subdivided into three subclasses as fallow-

Type Ia : In this class the ratio Ho/Hi is more than 1.5 (Fig 1).

Type Ib: In this class the ratio Ho/Hi ranges from 1.25-1.50 (Fig. 2).

Type Ic: In this class the ratio Ho/Hi ranges from 1.0-1.25 (Fig. 3).

(2) Type II: Ho/Hi ratio is equal to 1 (Fig. 4).

(3) Type III: Ho/Hi ratio is less than 1 (Fig. 5).

There is no further subdivision of Type II and Type III folds.

4. Application of the method

This method has been applied on different fold profile sections. One set of example shown in fig. 1 to fig. 5. In the figures, the I_1 and I_2 have been taken as inflection points on each profile curve, while Ho and Hi are taken as hinge points of outer and inner profile sections respectively. The results show that the ratio of angle Ho/Hi gradually changes from more than 1(Type I fold) to 1 (Type II fold) and to less than 1 (Type III fold) (Table 2). It is found that folds classified by this method may be tied with the fold classification of Ramsay (1967). There is a corresponding fold category for each fold category of Ramsay (1967) (Table 2). Comparison reveals that the present method promises a simplified implementation of Ramsay's classification.

Table 2. Application of proposed method on different profile section of the fold and comparison with Ramsay's classification.

Fold types	Ho/Hi ratio	Present classification	Ramsay (1967) classification
Fig.1	1.75	Type Ia	Class 1A
Fig.2	1.36	Type Ib	Class 1B
Fig.3	1.13	Type Ic	Class 1C
Fig.4	1	Type II	Class 2
Fig.5	0.957	Type III	Class 3

5. Limitation of the proposed method

The proposed method requires location of hinge and inflection points and there may be errors in identifying hinge and inflection points that would lead to errors in the measurement of Ho and Hi. Therefore, careful location of hinge and inflection points is obligatory for this method. Such as, in the case of a fold in which the inner arc is very much smaller than the outer arc - as is common for folds in competent layers with small wavelength/thickness ratios - the distance between hinge and inflexion point may be small, and small errors in locating the inflection points could then lead to large differences in Hi.

Further geometrical application and analysis of different folded shapes may overcome the limitation in future.

6. Discussion

Starting from Ramsay (1967) development in the field of fold classification and fold geometries has been significant. There are many studies related to the structural significance of the fold geometry. Chapple (1969) explained that non linear viscous-plastic behaviors of rocks are responsible for dissimilarities between theoretical model and natural folds. Bayly (1974) proposed that shape of the fold is direct outcome of energy dissipation during the buckling of folded units. Woodcock (1976) analyzed the shapes of slump folds and tectonic folds and gave opinion as these two types of folds are difficult to be distinguished with respect to fold shapes. Ramsay (1982) has correlated the fold geometries with variation in viscosity contrast of the folded layers. Ridley and Casey (1989) showed that strong anisotropic properties of rock layers are responsible for concentration of maximum curvature in the hinge area. Hudleston and Lan (1994) correlated the fold shape, stress exponent and viscosity contrast with the help of numerical modeling of viscous materials. Srivastava and

Lisle (2004) classified the forms of the profile sections of the folded layers with the help of cubic-Bézier curves.

As far as geometry of folded layers is concerned, out of many, the classification of Ramsay (1967) based on tangent and isogons pattern is most convincing. Though, the problem of obtaining the best location of the reference thickness (t_o) to determine tα' is outstanding Bastida (1993, 2005). Further, possibility of error involved in selection of a single contact point between a profile curve and a tangent may be an additional problem. A straight line may touch a curve at more than one point. Many times a tangent is drawn on a curve it touches a part of the curve rather than a point. This fact is overlooked by structural geologist, but a minor mistake in selection of a point can categories the fold from convergent to divergent category and vise-versa.

To overcome these difficulties and for more accuracy and simplicity, the present method of fold classification based on inter-arc angle is proposed. The method is based on the presumption that inter-arc angle is inversely proportional to the amount of stress involved in folding. Two layers of a lithological unit, under similar set of compressive stress regime, will show the same curvature and same inter arc angle presuming that other parameters are constant. But any difference in these parameters may be reflected as a change in curvature and hence in the inter arc angle of the two layers. Therefore, the present classification based on inter arc angle has the kinematic implications as stressed by Bastida et al. (2005).

7. Advantages of the proposed method

This method is free from the difficulty in obtaining the best location of the reference thickness (t_o) to determine t_α and selection of single contact point between tangent and profile curve which have been previously mentioned by workers like Bastida (1993). In the present method, minor shift of one or two points in the fold profile curve will not affect the result because classification categories are based on range of ratios of inter-arc angles. Secondly, fold profile is not a circular curve but it is a combination of circular and elliptical curves, and angles of same segment of a circle are equal. Therefore, in the fold profile a minor shift of hinge point will not make any considerable difference in the value of inter-arc angle.

Furthermore, in the case of fold profile it is not a circular arc, but it may be presumed as a part of elliptical curve. The inter arc angle is capable to give the measurement of distortion of circular tendency of the curve by further geometrical processes. Therefore, the inter arc angle may be an important tool for morphological as well as kinematical analysis of fold.

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