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The kink-band triangle: a triangular plot for paleostress analysis from kink-bands

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Abstract A kink-band can be graphically represented as a point on an equilateral triangle whose vertices define the angles between external foliation and kink plane, between internal foliation and kink plane, and between internal- and external-foliations. Four typical deformation paths that correspond to the four modes of kink-band growth can be discerned on this triangle. The three linear relationships between each of the kink-band angles and the inclination of the σ_1-axis with respect to the unrotated layering can be transformed into a straight line on the triangular plot. Application of this plot in paleostress analysis is demonstrated by several examples. The method, however, yields best results when a large number of data on the kink-band angles are plotted and contoured on the triangular graph.

INTRODUCTION

Kink-bands assume geometrical characteristics according to their mode of growth (Twiss and Moores, 1992; Table 1). Of special significance here are the three angular parameters (kink-band angles) that constrain the geometry of a kink-band (Fig. 1). These are the angles between: (i) external foliation and kink plane (ϕ), (ii) internal foliation and kink plane (ϕ_k) and (iii) internal foliation and external foliation (ψ). The relationship between ϕ and ϕ_k angles has often been used as a criterion for deciphering the mode of kink-band growth (Ramsay, 1967; Anderson, 1968; Hobson, 1973; Gay and Weiss, 1974; Verbeek, 1978; Stewart and Alvarez, 1991).

Kink-bands are commonly used as paleostress indicators in rocks and their dynamic significance has been tested in several well constrained experimental studies (Paterson and Weiss, 1966; Donath, 1968; Anderson, 1974; Gay and Weiss, 1974). One common method of paleostress analysis from kink-bands involves bisecting the dihedral angles between the conjugate pairs of kink planes (Ramsay and Huber, 1987). The other method involves application of the experimentally determined relationships between each of the kink-band angles (ϕ, ϕ_k and ψ) and the inclination of the maximum compressive stress (σ_1-axis) with respect to the unrotated layering (Gay and Weiss, 1974). In this paper, we propose a new triangular plot as an improvement in the application of the second method and discuss its suitability in the paleostress analysis from contractional kink-bands (Ramsay and Huber, 1987).

TRIANGULAR PLOT

Geometry

By definition, the three kink-band angles (ϕ, ϕ_k and ψ) are related by an equation

$$\phi + \phi_k + \psi = 180^\circ,$$

that implies the possibility of their representation on an equilateral triangle (Fig. 2). The angles ϕ, ϕ_k

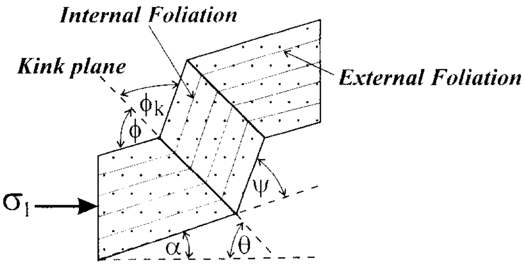

Fig. 1. Definition of the angular parameters in a kink-band (after Gay and Weiss. 1974).

and ψ are equal to 180° at the vertices of this triangle and they decrease progressively down to 0° along the normals dropped from the vertices onto the opposite sides (Fig. 2). Along the three sides of the triangle, namely, $\phi_{k(180)}$–ψ_{180}, ϕ_{180}–ψ_{180} and ϕ_{180}–$\phi_{k(180)}$, the angles ϕ, ϕ_k and ψ are equal to zero, respectively. This triangle comprises four equilateral sub-triangles, (ϕ_0, $\phi_{k(180)}$, ψ_0), (ϕ_0, $\phi_{k(0)}$, ψ_0), (ϕ_{180}, $\phi_{k(0)}$, ψ_0) and (ϕ_0, $\phi_{k(0)}$, ψ_{180}). Of these, the sub-triangle (ϕ_0, $\phi_{k(0)}$, ψ_0) is named as the kink-band triangle on account of the fact that the natural kink-bands usually plot within this sub-triangle (shaded in Fig. 2).

Most contractional kink-bands nucleate at a point on the line ϕ_{180}–$\phi_{k(180)}$ and evolve according to the geometrical constraints that characterise their respective mode of growth (Table 1). Four different modes of kink-band growth can be represented by schematic but distinct deformation paths on the triangular plot (Fig. 2). Many natural kink-bands, however, may grow by a combination of two or more modes (Verbeek, 1978; Weiss, 1980).

A linear segment and a point maximum on the altitude (normal dropped from the vertex ψ_0 onto the ϕ_0–$\phi_{k(0)}$ side) of the kink-band triangle are the characteristic deformation paths for the type-I and type-II kink-bands, respectively (Table 1 & Fig. 2). One of the several possible deformation paths for the type-III and type-IV kink-bands is a line parallel to the $\phi_{k(0)}$–ψ_0 side of the kink-band triangle. As the type-III kink-bands can continue to form in the field $\phi_k < \phi$, their deformation path may extend across the line $\phi = \phi_k$. The evolution of the type-IV kink-bands ceases once the deformation path touches the line $\phi = \phi_k$ and the condition of locking is achieved with respect to the rotation of the internal foliation (Table 1 & Fig. 2).

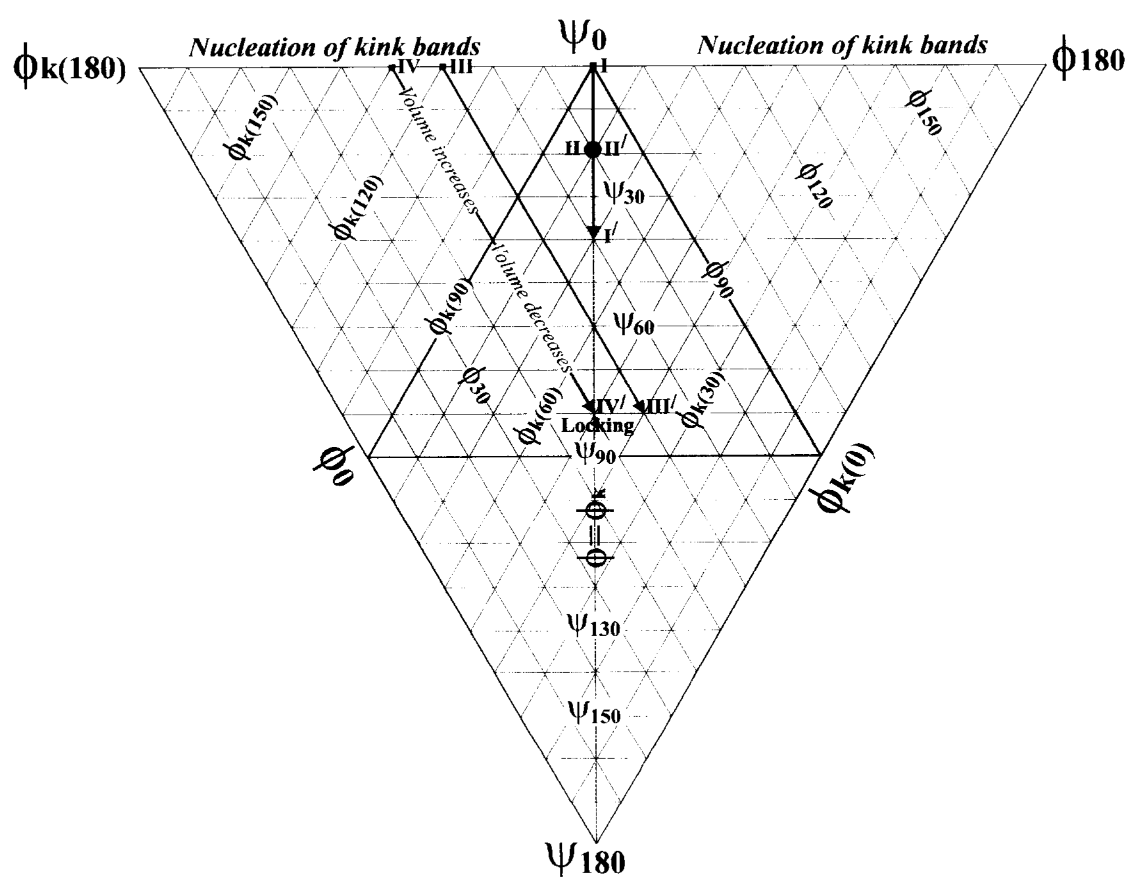

Fig. 2. The triangular graph ($\phi_{k(180)}$, ϕ_{180}, ψ_{180}) for plotting the kink-band angles. Plots for most natural kink-bands fall within the kink-band triangle ϕ_0, $\phi_{k(0)}$, ψ_0 (shaded). I–I′, II–II′, III–III′ and IV–IV′ represent the schematic deformation paths for the four modes of kink-band growth, respectively (characteristics of different modes of growth are outlined in Table 1; volume changes shown on line IV–IV′ are the changes in total or bulk volume).

Table 1. Summary of the changes in geometrical characteristics in the four types of kink-bands during their progressive evolution by the four idealized modes of growth (after Twiss and Moores, 1992). The angles ϕ, ϕ_k and ψ are defined in Fig. 1

Geometrical characteristics	Type-I (Mode-I)	Type-II (Mode-II)	Type-III (Mode-III)	Type-IV (Mode-IV)
Variation in ϕ and ϕ_k during the growth of kink-band	Both ϕ and ϕ_k decrease progressively in such a manner that the condition $\phi = \phi_k$, is always satisfied.	The condition $\phi = \phi_k$ = constant, is satisfied throughout the growth of kink-band.	$\phi \neq \phi_k$. ϕ remains constant but ϕ_k decreases progressively.	ϕ remains constant but ϕ_k decreases progressively until the condition $\phi = \phi_k$, is achieved.
ψ	Increases progressively.	Remains constant.	Increases progressively.	Increases progressively.
Two kink-band boundaries	Migrate by rotating about fixed hinges. The amount of rotation for the two kink-band boundaries is equal but their sense of rotation is opposite to each other.	Migrate away from each other by moving parallel to themselves.	Remain fixed during the growth.	Remain fixed during the growth.
Bulk or total volume	Remains constant.	Remains constant.	Remains constant.	First increases and then decreases.
Width of kink-band	Increases.	Increases.	Remains constant.	Variable.
Length of internal foliation	Remains constant during the growth.	Remains constant during the growth.	Variable	Remains constant during the growth.

PALEOSTRESS

Experimental deformation of card decks and slate (Gay and Weiss, 1974) shows a systematic variation in geometry of the kink-bands with progressive increase in the angle α (between maximum compressive stress and the original anisotropy) from 0° to 30°. These experiments reveal three important linear relationships between each of the kink-band angles (ϕ, ϕ_k and ψ) and the angle α (defined in Fig. 1). As the angles, ϕ, ϕ_k and ψ, are readily measurable in natural kink-bands, the three experimentally obtained linear plots (ϕ–α, ϕ_k–α and ψ–α; fig. 6 in Gay and Weiss, 1974) provide three alternative ways for estimating the angle α and hence the orientation of the maximum compressive stress (σ_1-axis).

The three best-fit lines through the experimental data in ϕ–α, ϕ_k–α and ψ–α plots of Gay and Weiss (1974) can be transformed into a straight line (referred below as the 'paleostress line') inside the kink-band triangle (Fig. 3). Co-ordinates (ϕ, ϕ_k and ψ), required to plot the different values of α on the kink-band triangle, are determined from the experimentally established relationships between ϕ and α, and ϕ_k and α, and ψ and α (Gay and Weiss, 1974). A paleostress line is then constructed by joining the points that represent

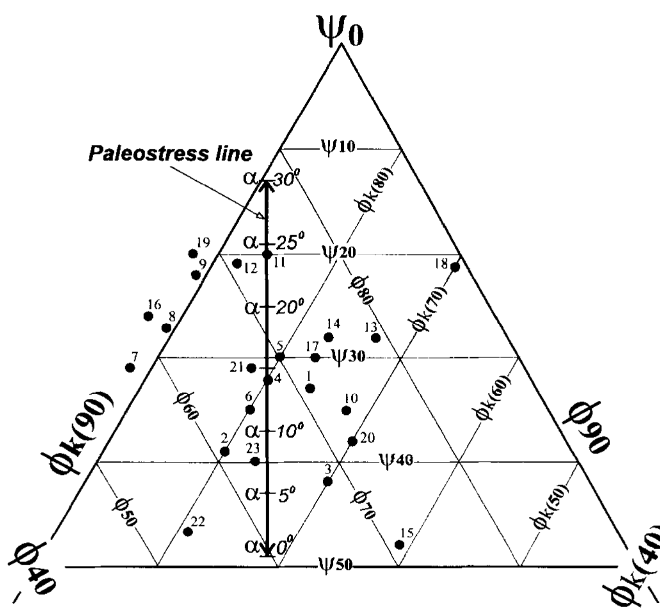

Fig. 3. The part ϕ_{40}, $\phi_{k(40)}$, ψ_0 of the kink-band triangle (shaded in Fig. 2) that contains the plots of the individual kink-bands (1–23). Angular data for plotting these kink-bands are taken directly from the table 1 in Gay and Weiss (1974). The paleostress line (barbed) is calibrated for the angle α (from 0° to 30°) on the basis of the experimental results in Gay and Weiss (1974).

different α values on the triangular plot. The uncertainty in constructing the paleostress line from the three best fit lines through the experimental data is less than 1 .

For the kink-bands that plot on the paleostress line (plots 4 and 11 in Fig. 3), all the three kink-band angles (ϕ, ϕ_k and ψ) yield the same value of α. For those kink-bands that plot off the paleostress line, three possible values of α are given by the intersections of the paleostress line with the projections of the plot parallel to the three sides of the kink-band triangle (Table 2). It is noteworthy that the projections parallel to the ϕ-, ϕ_k- and ψ-lines give, respectively, the same α as those obtained independently from the ϕ–α, ϕ_k–α and ψ–α graphs in Gay and Weiss (1974). The triangular graph, therefore, obviates the need for using three separate linear graphs. Furthermore, on account of the equilateral geometry of the kink-band triangle, the angle α obtained from the projection of the kink-band plot parallel to the ψ-line (equivalent to α from ψ–α graph) is, in fact, the arithmetic mean of the α angles obtained from the projections parallel to the ϕ- and ϕ_k-lines (equivalent to the α from ϕ–α and ϕ_k–α graphs, respectively).

APPLICATION OF THE TRIANGULAR PLOT

The three angles (ϕ, ϕ_k and ψ) required for the application of the triangular graph to natural kink-bands can be determined stereographically from the orientations of external foliation, kink plane and internal foliation. Direct measurements of ϕ, ϕ_k and ψ angles on joint planes or photographs are likely to introduce errors as these planes are often oblique to the profile sections of the kink-bands (Stewart and Alvarez, 1991). We demonstrate the application of the triangular graph with the help of published data on 23 individual kink-bands as well as data from several hundred kink-bands in three case studies.

Individual kink-bands

Triangular plots for the 23 examples cited in Gay and Weiss (1974, table 1) show that the plots for most natural kink-bands fall within a small region on the triangular graph (Figs 2 & 3). For those kink-bands that plot at or close to the paleostress line (e.g. 4, 5, 11 and 23 in Fig. 3) the α values can be read directly. For those kink-bands that plot off the paleostress line, ϕ, ϕ_k and ψ angles yield mutually inconsistent α values. Two alternative explanations are possible for such kink-bands: (i) They do not grow in accordance with the experimentally simulated two-dimensional model that requires a parallelism between kink axis and σ_2-axis. The kink-band triangle cannot be used for estimation of α from such kink-bands. (ii) Alternatively, even if the kink-bands nucleate by a mechanism simulated in the two-dimensional model, one of the angles (ϕ or ϕ_k) may change due to a relatively late deformation outside or within the kink-bands. For example, simple shear along the kink planes can modify the original ϕ_k angle without altering the ϕ angle. In these

Table 2. Results from triangular plots of the individual kink-bands. Bold numbers indicate the optimum value of the angle α (between the σ_1-axis and the unrotated layering). The examples and kink-band angles (Φ and ψ) are adopted from table 1 in Gay and Weiss (1974)

		Kink-band angles			α from intersection of paleostress line with the projections of the plot parallel to different sides of the sub-triangle (Fig. 2)		
Sl.	Source	Φ	Φ_K	ψ	$\Phi_{K(0)}$ ψ_0 side	Φ ψ_0 side	$\Phi_{K(0)}$ ϕ_0 side
1	Weiss, 1972 plate 115a	71	76	33	19	**07**	13
2	Weiss, 1972 plate 115a	61	80	39	**02**	15	8.5
3	Weiss, 1972 plate 115b	68	70	42	14	?	**06**
4	Weiss, 1972 plate 115b	68	80	32	**14**	**14**	**14**
5	Weiss, 1972 plate 116	70	80	30	18	**14**	16
6	Weiss, 1972 plate 117a	65	80	35	**09**	14	11.5
7	Weiss, 1972 plate 117a	57	92	31	?	> 30	15 (?)
8	Weiss, 1972 plate 117a	62	91	27	3.5	> 30	**18**
9	Weiss, 1972 plate 117b	67	91	22	12	> 30	**22**
10	Weiss, 1972 plate 117b	73	72	35	22	**02**	11.5
11	Weiss, 1972 plate 118	74	86	20	**24.5**	**24.5**	**24.5**
12	Weiss, 1972 plate 118	71	88	21	**19**	27	23
13	Weiss, 1972 plate 121	79	73	28	> 30	03	**17.5**
14	Weiss, 1972 plate 121	75	77	28	26	09	**17.5**
15	Weiss, 1972 plate 121	71	61	48	19	?	**01**
16	Weiss, 1972 plate 121	61	93	26	02	> 30	**19**
17	Fyson, 1968 Fig. 1(a)	73	77	30	23	**09**	16
18	Fyson, 1968 Fig. 1(b)	89	70	21	> 30	?	23 (?)
19	Fyson, 1968 Fig. 1(d)	68	92	20	14	> 30	**24.5**
20	Fyson, 1968 Fig. 1(e)	72	70	38	22	?	**09**
21	Anderson, 1968 plate 1A	67	82	31	**12**	18	15
22	Anderson, 1968 Dextral	54	79	47	?	12	**02**
23	Anderson, 1968 Sinistral	63	77	40	**05**	09	07

type of kink-bands, this is the angle that remains relatively unchanged since growth is a more reliable indicator of α. For the sake of demonstration of the method, we assume that most of the kink-bands that plot off the paleostress line in Fig. 3 have grown according to the two-dimensional model but post-growth modification in the kink-band geometry has resulted in modification of either ϕ or ϕ_k.

Some typical examples of natural kink-bands that plot to the left of the paleostress line (and close to the $\phi_{k(90)}$-side) are labelled as 8, 9, 16 and 19 in Fig. 3. The projections of these plots parallel to the ϕ_k-lines (or ϕ_0–ψ_0 side) would intersect the paleostress line at α greater than 30°. Such high values of α are improbable as 'sliding' rather than 'kinking' is more likely to occur at α greater than 30° (Gay and Weiss, 1974). As some of these kink-bands (e.g. plot 16 in Fig. 3 corresponding to kink-bands in plate 121 in Weiss, 1972) exhibit a conjugate geometry that implies low values of α, it is evident that the α values (18–24°) obtained by projecting these plots parallel to ψ-lines (or ϕ_0–$\phi_{k(0)}$ side) are also overestimates. The most realistic α values ($\leq 15°$), in these cases, are obtained by the intersections of the paleostress line with the projection of the kink-band plots parallel to the ϕ-lines (or $\phi_{k(0)}$–ψ_0 side) in the kink-band triangle.

It is possible that the data falling to the left of the paleostress line represent kink-bands in which the external foliation has maintained its orientation, whereas the internal foliation has undergone a significant rotation since the beginning of the kink-growth process. As a consequence, the angle ϕ indicates the most reasonable inclination of the σ_1-axis and the other two angles (ϕ_k and ψ) overestimate α.

For most of those kink-bands that plot to the right of the paleostress line, the angle ϕ_k (projections of the plots parallel to the ϕ_k-lines) provides the optimum value of α and both ϕ and ψ tend to overestimate this angle (e.g. plots 1, 10, 13, 14 and 17 in Fig. 3). External foliation in these kink-bands probably changes its orientation by processes such as overrotation (Verbeek, 1978; Rousell, 1980) and consequently the angle ϕ loses its significance as a paleostress indicator.

The angle α is difficult to estimate for those kink-bands that plot to the left of the paleostress line in such a manner that their projections parallel to the ϕ-lines do not intersect the paleostress line (plot 22 in Fig. 3). A similar limitation exists for the plots falling to the right of the paleostress line if their projections parallel to the ϕ_k-lines do not intersect the paleostress line (plots 3 and 15 in Fig. 3). In such cases, α can, at best, be approximated by projections of the plots parallel to the ψ-lines, though these results are likely to be overestimates.

No reliable estimates of α can be made by this method for those kink-bands that plot in such a position that neither their projections parallel to ϕ-lines nor parallel to ϕ_k-lines intersect the paleostress line between $\alpha = 0°$ and $30°$ (plots 7 and 18 in Fig. 3). Growth by mechanisms other than those simulated experimentally by Gay and Weiss (1974) and/or post-growth modifications in the geometry could be possible explanations for the inapplicability of the method in such cases.

Examples

The application of the triangular plot in studies involving a large population of dynamically compatible kink-bands requires the plotting of representative kink-band angles. Such representative angles are suggested either by 'modal statistics' in the histograms or by the contour maxima on the triangular plots. A distinct merit of contouring the plots on the triangular graph (Fig. 2) is the fact that all three angles are considered simultaneously, whereas in a histogram only one angle is considered at a time. Thus, a situation may exist where the sum of the modal values of the three angles given by three separate histograms may not be equal to 180° and the fundamental equation ($\phi + \phi_k + \psi = 180°$) constraining the geometry of a kink-band is not satisfied (Hobson, 1973). Triangular plots of kink-bands always satisfy this condition.

The case studies presented here include the new data from conjugate kink-bands in the Precambrian carbonate sequence in the Satur area, western India (Fig. 4a), published data on conjugate kink-bands in the slates and siltstones of the Ards Peninsula, N. Ireland (Anderson, 1968) and published data on monoclinal kink-bands in the Somport slate in the Pyrenees (Verbeek, 1978). The two sets belonging to the conjugate pairs of kink-bands in the Satur area and the Ards Peninsula are plotted separately (Fig. 5a–d). The monoclinal kink-bands in the Somport slates are plotted without any subdivision (Fig. 5e).

Numerous contractional mesoscopic kink-bands are developed synchronously with a macroscopic kink-fold in the vicinity of the Great Boundary Fault (Iqbaluddin *et al.*, 1978) in the Satur area (Fig. 4a). These kink-bands occur in two conjugate sets suggesting, respectively, 'top-to-the-NNW' and 'top-to-the-SSE' sense of the relative movements. The kink axes of the two sets are mostly parallel to sub-parallel and they plunge at low angles ($< 20°$) towards ENE or WSW (Fig. 4b). On the triangular plots, the 25% contour maximum for each of the sets falls on the paleostress line at α equal to 0° (Fig. 5a & b).

In cases of layer-parallel compression ($\alpha = 0°$), such as the one in the Satur area, the angle between the external foliation and kink plane becomes equal to the angle between the σ_1-axis and the kink plane ($\phi = \theta$). The modal values of the angle ϕ ($=60°$) for both sets of kink planes, in the Satur area, imply that the σ_1-axis is sub-horizontal and directed towards SSE (Fig. 6). The σ_1-axis determined independently by

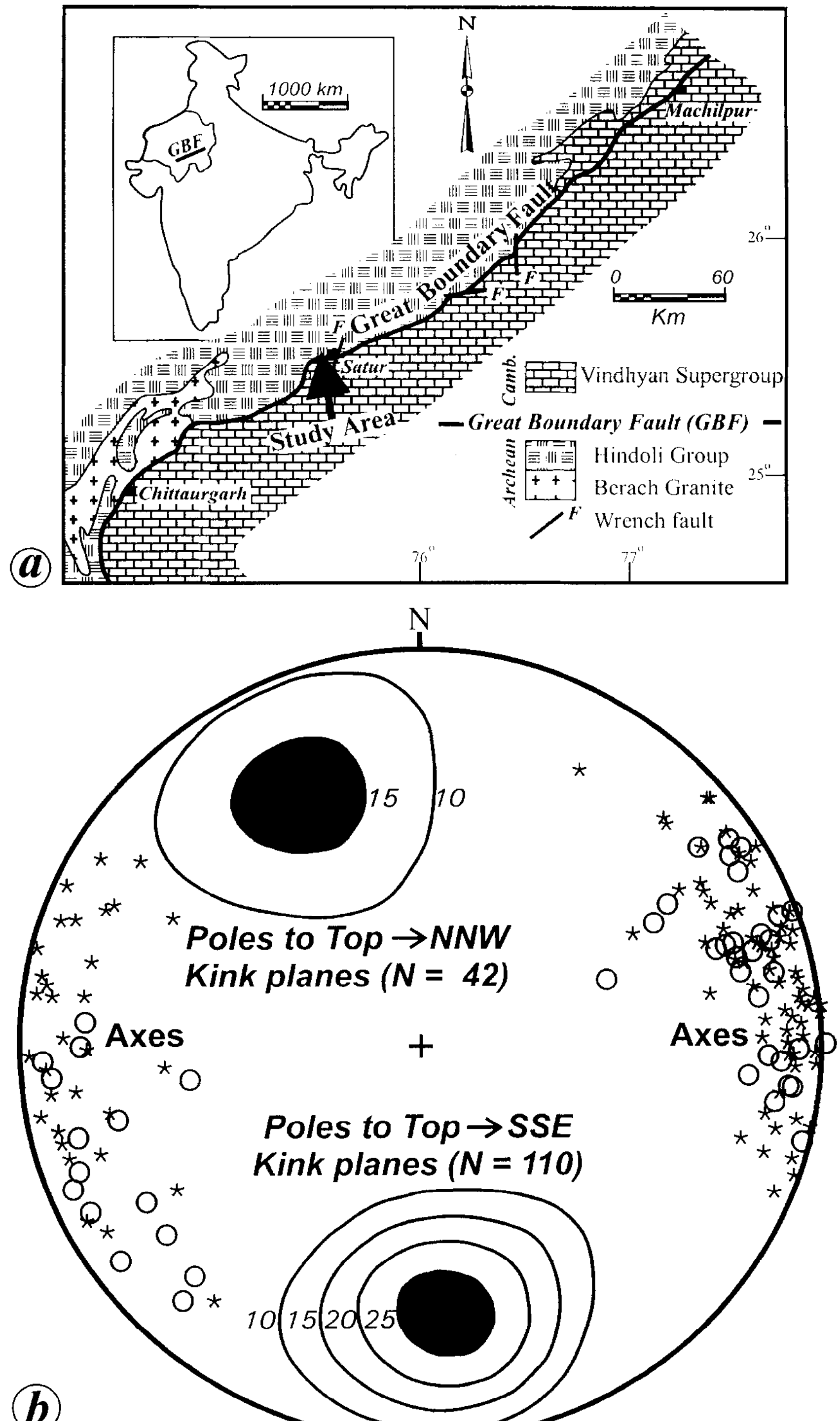

Fig. 4. (a) Geology of the Satur area (indicated by arrow). Inset shows the Great Boundary Fault (*GBF*) in India, (after Iqbaluddin *et al.*, 1978). (b) Orientation of the conjugate pairs of the kink planes and kink axes in the Satur area. Circles and stars represent 42 axes of the 'top-to-the-NNW' and 110 axes of the 'top-to-the-SSE' kink-bands, respectively. Contours at every 5σ ($\sigma = 1.2$ and 1.4 for the 'top-to-the-NNW' and 'top-to-the-SSE' kink-bands, respectively).

bisecting the obtuse angle between the two conjugate sets of kink planes is consistent with the results obtained from the triangular plots (Fig. 6).

The triangular plots of the sinistral kink-bands from the Ards Peninsula show that the 20% contour maximum falls on the paleostress line at $\alpha = 0°$ (Fig. 5c). Although the 25% contour maximum for the dextral set lies to the left of the paleostress line, its projection parallel to the ϕ-lines intersects the paleostress line at $\alpha = 3°$ (Fig. 5d). That these two sets were developed as conjugate pairs under the conditions of layer-parallel compression is corroborated by the

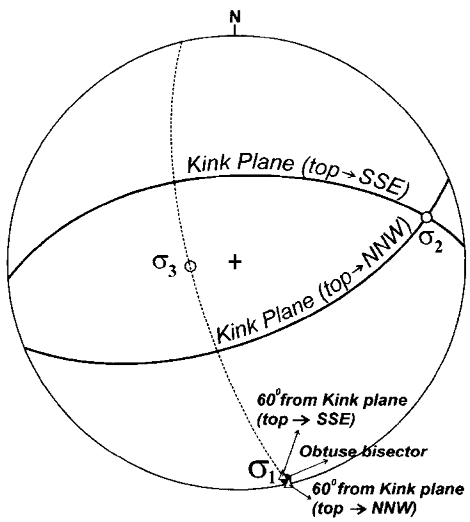

Fig. 6. Comparison of the results from the two methods. Triangle and the circle (black) represent the σ_1-axes obtained from the triangular plots and the bisection of the dihedral angle, respectively. (Continuous great circles—modal kink planes, dashed great circle—profile section.)

mutually consistent and low values of α ($\leq 3^\circ$). As the modal values of ϕ angles in both dextral and sinistral sets are equal to 60°, the angle θ ($=\phi-\alpha$, Fig. 1) between kink plane and the σ_1-axis is 57–60° for these kink-bands. By an entirely different method, Anderson (1964) found a value of θ ranging between 55–60° for these kink-bands and his results are consistent with those obtained here from the triangular plots.

The final case study includes co-zonal, monoclinal kink-bands of lenticular geometry in the Somport slates (Fig. 5e). As the 30% contour maximum for these kink-bands lies to the right of the paleostress line, its projection parallel to the ϕ_k-lines is considered for the determination of the angle α. An α value of 10° revealed by this method compares closely with the results (α = 11–15°) obtained by Verbeek (1978) from the independent stress solutions.

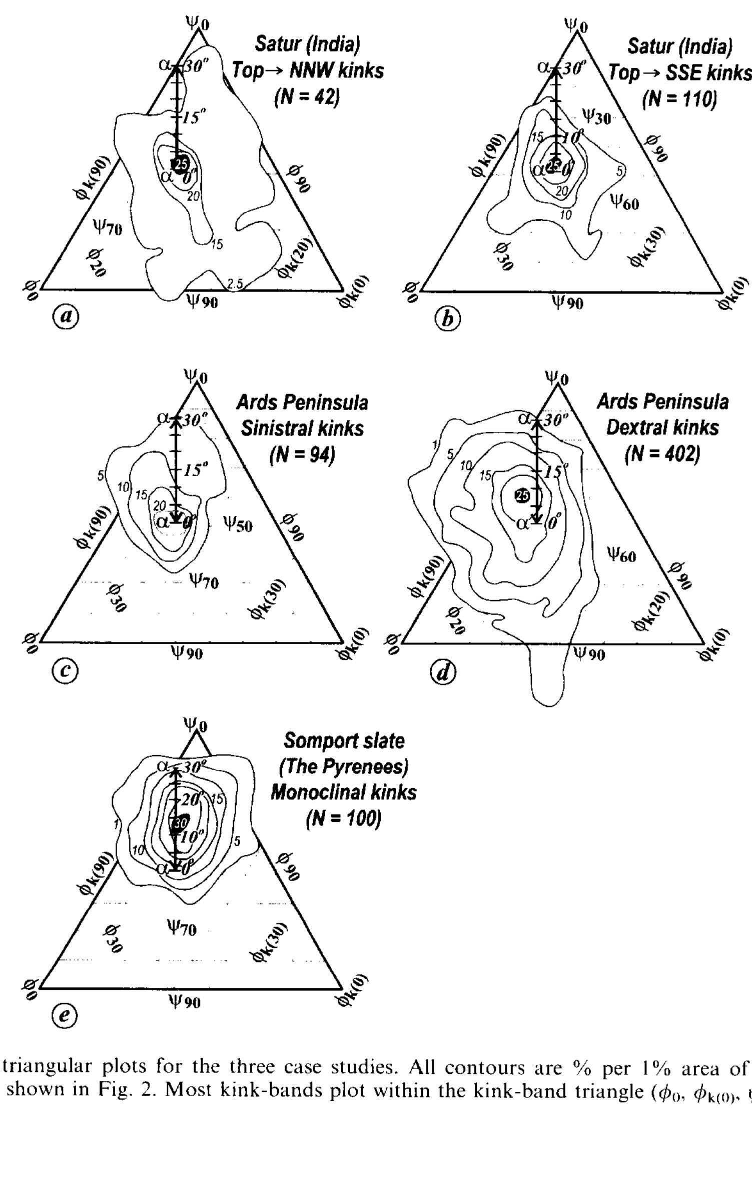

Fig. 5. Contoured triangular plots for the three case studies. All contours are % per 1% area of the triangular graph ($\phi_{k(180)}$, ϕ_{180}, ψ_{180}) shown in Fig. 2. Most kink-bands plot within the kink-band triangle (ϕ_0, $\phi_{k(0)}$, ψ_0; shaded in Fig. 2).

CONCLUSIONS

Most natural kink-band plots fall within the kink-band triangle on account of the fact that only a limited number of growth-modes can lead to the evolution of these structures (Figs 2 & 3). For the kink-bands that plot away from the paleostress line, one of the two angles (ϕ or ϕ_k) could be a better estimator of the orientation of the maximum compressive stress, provided that these kink-bands have essentially grown by the simple two-dimensional model simulated in the experiments of Gay and Weiss (1974) and at least one of the angles (ϕ or ϕ_k) has remained unchanged since growth of the kink-bands. The third angle (ψ) has little independent dynamic significance as it yields an α value which is the arithmetic mean of the two α values suggested by ϕ and ϕ_k.

The use of the kink-band triangle is advocated for the determination of maximum compressive stress orientation from suitable kink-band structures. In practice, it is better to measure a large number of kink-bands and obtain the modal angles by the contour maximum on the triangular graph. The triangular plot suggested here is suited ideally if the kink axis is parallel to σ_2-axis, $\phi_k > \phi$ and the kink-bands show little or no concentration of the finite strain (Gay and Weiss, 1974). As these conditions are satisfied in many natural kink-bands (Anderson, 1964), the triangular plot may find a wide application.

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REFERENCES

Anderson, T. B. (1964) Kink-bands and related geological structures. *Nature* **202**, 272–274.

Anderson, T. B. (1968) The geometry of a natural orthorhombic system of kink-bands. In *Researches in Tectonics*, eds A. J. Baer and D. K. Norris, pp. 200–219. Geological Survey of Canada paper **68–52**.

Anderson, T. B. (1974) The relationship between kink-bands and shear fractures in the experimental deformation of slate. *Journal of the Geological Society of London* **130**, 367–382.

Donath, F. A. (1968) Experimental study of kink-bands in Martinsburg slate. In *Researches in Tectonics*, eds A. J. Baer and D. K. Norris, pp. 255–288. Geological Survey of Canada paper **68–52**.

Fyson, W. K. (1968) Profile variation in a kink set. In *Researches in Tectonics*, eds A. J. Baer and D. K. Norris, pp. 243–254. Geological Survey of Canada paper **68–52**.

Gay, N. C. and Weiss, L. E. (1974) The relationship between principal stress directions and the geometry of kinks in foliated rocks. *Tectonophysics* **21**, 287–300.

Hobson, D. M. (1973) The origin of kink-bands near Tintagel, North Cornwall. *Geological Magazine* **110**, 133–144.

Iqbaluddin, Prasad, B., Sharma, S. S., Mathur, R. K., Gupta, S. N. and Sahai, T. N. (1978) Genesis of Great Boundary Fault of Rajasthan, India. *Proceedings of the Third Regional Conference on Geology and Mineral Resources of South-East Asia*. Bangkok. pp. 145–149.

Paterson, M. S. and Weiss, L. E. (1966) Experimental deformation and folding in phyllite. *Geological Society of America Bulletin* **77**, 343–374.

Ramsay, J. G. (1967) *Folding and Fracturing of Rocks*. McGraw-Hill, New York.

Ramsay, J. G. and Huber, M. I. (1987) *The Techniques of Modern Structural Geology, Volume 2: Folds and Fractures*. Academic Press, London.

Rousell, D. H. (1980) Kink-bands in the Onaping Formation, Sudbury basin, Ontario. *Tectonophysics* **66**, 83–97.

Stewart, K. G. and Alvarez, W. (1991) Mobile-hinge kinking in layered rocks and models. *Journal of Structural Geology* **13**, 243–259.

Twiss, R. J. and Moores, E. M. (1992) *Structural Geology*. W. H. Freeman and Company, New York.

Verbeek, F. R. (1978) Kink-bands in the Somport slates, west-central Pyrenees, France and Spain. *Geological Society of America Bulletin* **89**, 814–824.

Weiss, L. E. (1972) *The Minor Structures of Deformed Rocks. A Photographic Atlas*. Springer Verlag, Berlin.

Weiss, L. E. (1980) The nucleation and growth of kink-bands. *Tectonophysics* **65**, 1–38.