Bird's feather lineation – discovery of a new type of linear structure in calc-silicate rocks of Sheopura–Kesarpura mine area near Beawar, Rajasthan, India

The present correspondence reports an unusual type of lineation[1] recently discovered in complexly deformed calc-silicate rocks in the eastern part of Sheopura–Kesarpura limestone mine near Beawar, Rajasthan (Figure 1). The linear structure[1] resembles a bird's feather spread in a well-oriented fashion with the longest dimension aligned strictly parallel to the lineation (Figure 2), particularly mullions parallel to the axis of a set of folds in the area. The linear structure observed in the study area can be compared in shape and genesis with the lineation formed by the elongate mineral aggregates[1].

Geologically, in the Sheopura–Kesarpura area the linear bands of medium-grained calc-silicate and dolomitic marble are enclosed in the muscovite–biotite schist of Beawar Formation of the Kumbhalgarh Group[2]/Raialo Series[3]/ Raialo Group[4] of the Mesoproterozoic Delhi Supergroup of rocks resting unconformably on the Archaean basement, i.e. the Banded Gneissic Complex. The rocks of the area are intruded by small bodies, i.e. dykes, veins and veinlets of pegmatite, possibly of the Erinpura age (~850 Ma). With respect to deformation the Delhi Supergroup of rocks exhibit four phases of folding episodes[4].

The bird's feather lineation has developed in a mechanism much similar to the formation of sedimentary structures known as dendritic markings on bedding planes, except that these structures have developed in the tectonic environment of high pressure and shearing forming a lineation parallel to the fold axis. Here a number of small patches of pegmatitic solution have accumulated along the bedding planes/cleavage associated with the earliest deformation. The source of these compressed elongated small patches of solution is through closely spaced sub-vertical crenulation cleavage planes associated with the second phase of folding episode in the Delhi Supergroup. As a result small dykes, veins and veinlets have intruded, preferably along these sub-vertical crenulation cleavage planes. Especially, along the tips of these intrusive pegmatitic bodies, solution penetrated along the cleavage planes and

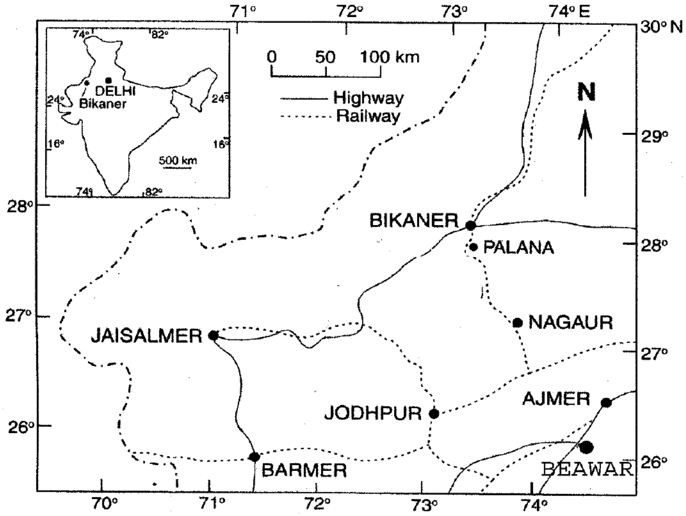

Figure 1. Northwestern Rajasthan showing location of the area.

Figure 2. Bird's feather lineation on bedding plane and S1 cleavage parallel to it.

Figure 3. Bird's feather lineation showing cuspate and lobate types of margins (coin size 2.3 cm). Mullions are also visible on the bedding plane/S1 cleavage.

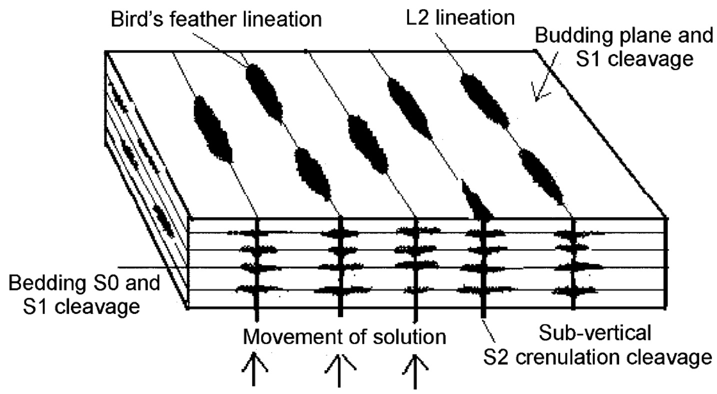

Figure 4. Formation of Bird's feather lineation.

spread along the bedding planes/first-generation slaty cleavage (which are almost parallel to the bedding except in the hinge zones of the first-generation folds) in an elongated pattern forming an unusual type of lineation in the rock[1]. On close examination in each bird's feather-like structure, the solution starts spreading from the centre and spreads outward forming a corona-like structure at the margin (Figure 3). Viscosity contrast between calc-silicate and the pegmatitic material seems to have given rise to the development of lobate and cuspate types of margins[5] (Figures 2 and 3). The patches are sporadically distributed on the surface. They vary from 0.5 to 1 mm in thickness. These structures range from 5 to 12 cm in length and from 1 to 3.5 cm in width. When slightly thicker they give a pseudo impression of highly compressed and elongated pebbles of a conglomerate similar to the one exposed near Barr[3].

The linear structure appears to be unique in its mechanism of formation. Its significance in the structural analysis of complexly deformed rocks is likely to contribute significantly in establishing a relationship between the particular phase of deformation and the time of emplacement of pegmatite in the region. In the present case, the bird's feather lineation has developed due to penetration of pegmatitic solution along the sub-vertical crenulation cleavage planes (Figure 4) associated with the second deformation in the Delhi Supergroup and the structures are oriented parallel to the axis of the second-generation folds. Therefore, the emplacement of pegmatite bodies in the region has taken place during the second deformation in the Delhi Supergroup of rocks.

1. Hobbs, B. E., Means, W. D. and Williams, P. F., *An Outline of Structural Geology*, John Wiley, London, 1976, p. 267, 273.
2. Gupta, S. N. *et al.*, *Mem. Geol. Surv. India*, 1997, **123**, 67–78.
3. Heron, A. M., *Rec. Geol. Surv. India*, 1953, **79**, 339.
4. Gupta, S. N. *et al.*, Lothostratigraphic Map of Aravalli Region, Geological Survey of India, Hyderabad, 1980.
5. Ramsay, J. G. and Huber, M. I., *The Techniques of Modern Structural Geology, Volume 2: Folds and Fractures*, Academic Press, London, 1987, pp. 491–501.

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Nonlinear electrical conductivity response of shaly-sand reservoir

I would like to draw the attention of the readers to a number of errors in the scientific paper[1]. These errors, taken together, are sufficiently important to make all four of the paper's conclusions invalid.

The paper[1] contains a review of three different approaches to the modelling of electrical conductivity of reservoir rocks composed of two conducting phases. The three approaches are (i) Bussian's model[2], (ii) a model that they call the Mixing model, but which in fact would be better attributed to Korvin[3] or Tenchov[4], and (iii) the model of Glover *et al.*[5]. According to Sri Niwas *et al.*[1], all these equations are nonlinear. A nonlinear system is one in which the variable(s) to be solved for cannot be written as a linear combination of independent components, i.e. it is a system which does not satisfy the superposition principle. Only the Bussian equation fulfils this criterion. Both the Korvin[3] and Glover *et al.*[5] models are linear and can be solved exactly, without recourse to numerical solution.

In their figure 1, Sri Niwas *et al.*[1] purport to show the calculation errors when using the three models. By this they mean the errors induced in using their nonlinear inversion code, which uses the bisection method. The figure correctly shows that the error in the Bussian nonlinear inversion is low (10^{-4} to 10^{-8} S/m). However, it shows the errors for the Glover[5] and Korvin[3] models to be in the range 100–10^{-2} S/m (i.e. much higher). As I have already discussed, the Korvin[3] and Glover[5] models are not nonlinear. They can be solved analytically and exactly using a calculator or a computer. In other words, the error associated with their computation is the same as a computer (i.e. about 10^{-499} S/m) and is independent of the other parameters in the model. It is not clear from the paper how the authors have generated the curves in figure 1 for the Korvin[3] and Glover[5] models. It is possible that the large error values are caused by instabilities in their numerical routines when applied to linear models.