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# Recrystallization at grain contacts in a sandy siltstone

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**Abstract**—The microstructures of a sandy siltstone show evidence for recrystallization of quartz localized at Hertzian stress contacts. This recrystallization was driven not by an elastic stress field, but by plastic strain energy induced prior to recrystallization so that new grains were randomly oriented with respect to the principal stress axes. New grains were preferentially oriented with *c*-axes ~55° from those of their host grains.

## INTRODUCTION

CONTACT stresses between grains commonly induce pressure solution or cracking, deformation modes dominant at low pressures and temperatures. Less well studied is intragranular plasticity at sites of grain impingement. This note describes an example of recrystallization driven by strain at grain–grain contacts in a sandy argillite.

The sample was collected, unoriented, from a sequence of argillaceous sediments in the upper part of the Johnnie Formation at Areane Meadows, between Rogers Peak and Bennett Peak in the Panamint Range (Telescope Peak 15″ Quadrangle), California, by Wayne Dollase. At this locality, the rocks have undergone very low grade metamorphism (biotite grade) and the layering (bedding) dips uniformly at 30° to ENE. The locality is approximately 4 km northwest of the boundary of the Tertiary Little Chief granite porphyry stock (McDowell 1974). A subsequent attempt to locate beds of similar sandy lithology for collection of oriented specimens was unsuccessful.

## GENERAL PETROLOGY

Two perpendicular thin sections cut normal to the layering (bedding) were examined by flat- and universal-stage optical microscopy. The sample is a siltstone (sandy argillite) containing a layer of quartz sand grains (~1 mm diameter) in a fine-grained ($\leq 30\,\mu$m) matrix of quartz, iron oxides (mostly hematite) and micas (biotite and chlorite) (Fig. 1a). Almost all sand grains show strongly undulatory extinction, with up to 10° rotation of the *c*-axis, are generally equant, and are often corroded at the edges (Fig. 1b). Some quartz grains are apparently of hydrothermal origin, with needle-shaped inclusions at ~72° to *c*. Deformation lamellae and (mostly healed) fractures are abundant. Mica is prominent between and around grains, especially at regions of grain dissolution. Corroded areas not uncommonly present a quartz crystal face (rhomb or prism) flush against a mica flake. The matrix is variable in coloring from grey to black.

## RECRYSTALLIZATION

The striking feature of the quartz microstructure is that sand grains are locally recrystallized, with roughly hemispherical new regions of recrystallization growing into their hosts at contacts between sand grains (Fig. 2). From one to more than 10 recrystallized grains replace a single host. Moreover, the projections of grain–grain contacts at which crystallization occurred are oriented nearly parallel to the bedding (Fig. 3a); contacts lacking recrystallization are oriented normal to bedding (Fig. 3b). Thus, the regions of recrystallization correspond to theoretical stressed areas at Hertzian spherical contacts (Fig. 3c), with $\sigma_1$ normal to the bedding plane. In a few cases, recrystallization occurs where grains do not quite touch; presumably, the actual grain contacts lie out of the thin section.

The *c*-axis subfabrics of original (host) and recrystallized grains are essentially random (Fig. 4) although a weak girdle fabric about the normal to bedding may exist, and dynamic analysis of *c*–*c*′ pairs between host and recrystallized grains shows no clear pattern. However, *c*-axes in host and recrystallized grains had a definite preferred angular separation centered at ~55°. This preferred separation was the same for host grains replaced by one or by multiple grains.

## OTHER MODES OF DEFORMATION

Quartz sand grains underwent dislocation flow as evidenced by deformation lamellae. These are present both in host sand grains and their replacements. Crystallographically, they show a broad peak with poles 30° from *c* (Fig. 5), similar to lamellae at the nearby Papoose

*The Editors regret reporting the death of Andy Gratz on 7 June 1993, and that he was unable to see the publication of his joint work with John Christie.

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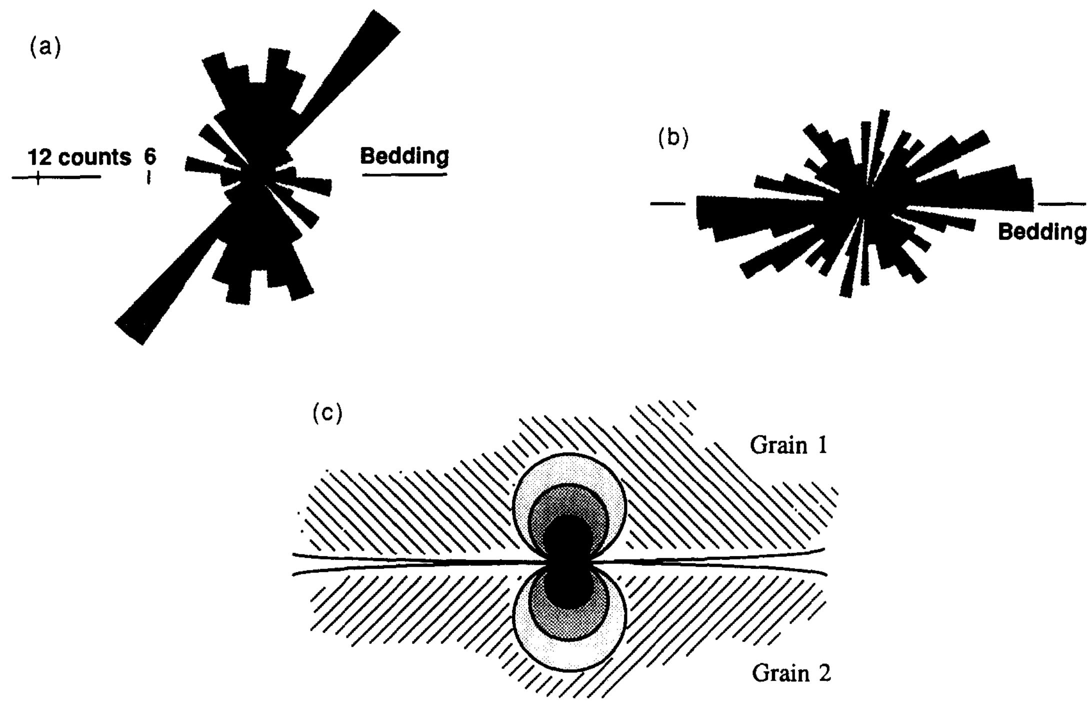


Fig. 3. Polar diagram of normals to grain–grain contacts. (a) Contacts at which recrystallization occurs; most contacts lie near the bedding plane (poles normal to bedding). (b) Contacts without recrystallization have orientations complementary to (a), i.e. they are normal to bedding. (c) Diagram of a Hertzian stress contact. Contours are of shear stress, increasing with the shading density.

Flat aureole (Sylvester 1969). Grains contained up to four sets of lamellae each, although between zero and two were typical. The lamellae subfabric showed two maxima (Fig. 6). From this subfabric, the locations of principal stress axes for this deformation episode were inferred using the acute–obtuse angle method (Sylvester 1969). The $\sigma_1$-axis is normal to bedding.

Many sand grains are also fractured. Fractures are generally long (>100 $\mu$m) and run across grains, in places are healed, and have no clear-cut crystallographic control. However, the fracture-pole subfabric (measured on throughgoing fractures, Fig. 7) has a planar distribution with its pole in the bedding plane. We take this direction to be $\sigma_1$, parallel to $\sigma_3$ for the lamellae subfabric.

## DISCUSSION AND CONCLUSIONS

Syntectonic recrystallization (hot working) invariably produces strongly textured aggregates (Griggs *et al.* 1960, Carter *et al.* 1964, Raleigh, 1965, Barrett & Massalski 1980). In contrast, annealing of deformed materials can either enhance or diminish the degree of preferred orientation (Griggs *et al.* 1960, Hobbs 1968, Gladman 1990). Because our specimen lacks preferred orientation in recrystallized grains, we conclude that annealing post-dated deformation; the strain driving recrystallization thus must have been plastic rather than elastic. It may well be that the failure to develop texture following annealing was aided by the limited extent of deformation (no grain flattening is noted).

We believe this is the first reported case of grain contact stresses driving recrystallization. Upon impingement, the sand grains did not act as rigid bodies, but took up strain by deforming plastically. This strain was localized at the sand grain–sand grain contacts, and led to localized recrystallization. Other recrystallized assemblages, notably aggregates containing porphyroblasts in a fine-grained matrix, may well behave similarly. In this regard, it is important that recrystallized regions correspond to Hertzian stress contours rather than forming patterns indicating replacement of kink bands of deformation lamellae. The recrystallization pattern is thus more like the gradation in deformation seen from the ends to the center of a piston-cylinder experiment than to the selective replacement of individual deformation features.

Our observation of a preferred orientation for recrystallized grain *c*-axes near 55° from host *c*-axes is quite different from past observations of 10–40° misorientations in laboratory experiments and natural samples (Hobbs 1968, Ransom 1971, Bell & Etheridge 1976). The reason for this is not clear, but it may indicate that the misorientation of recrystallized grains varies with annealing conditions. Studies in metals show that the rate of heating is of crucial importance in development of annealing textures in metals (Gladman 1990). This may well be true in minerals as well, so that textures in an area of contact metamorphism (as for this sample, near the Little Chief stock) could differ considerably from those produced by regional metamorphism.

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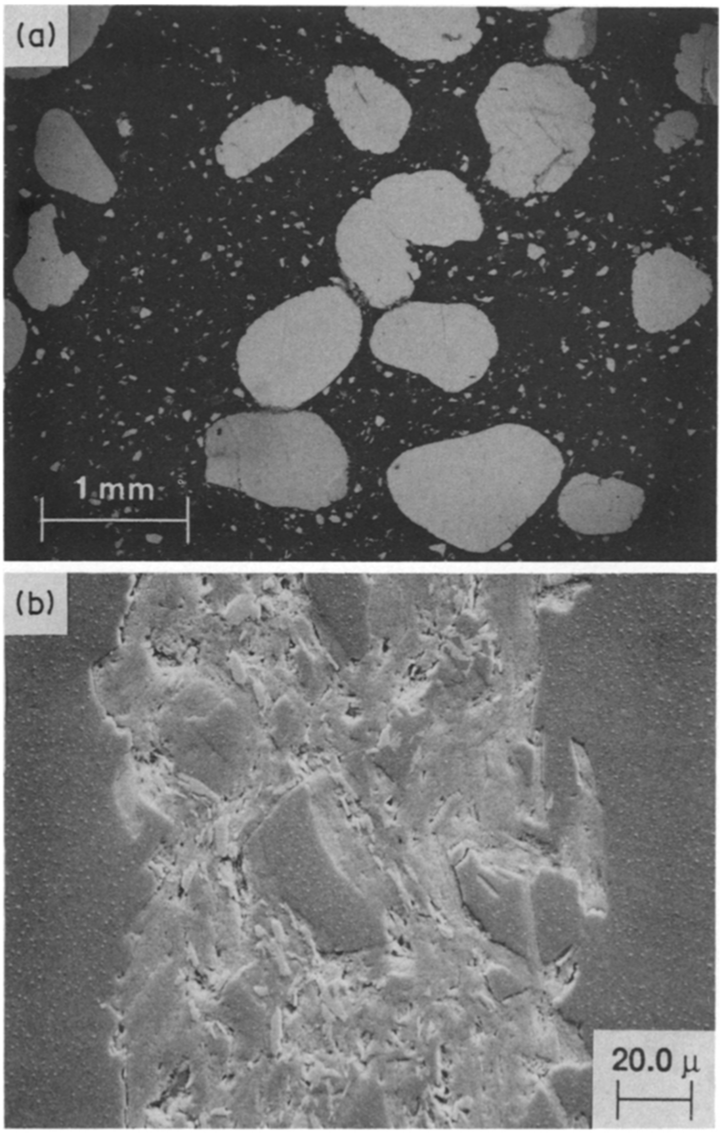


Fig. 1. (a) Crossed-polars optical micrograph of general sample appearance showing a sandy quartz layer in an opaque-rich siltstone. (b) Scanning electron micrograph shows corrosion of sand grains (dark) and infilling of micas (bright).

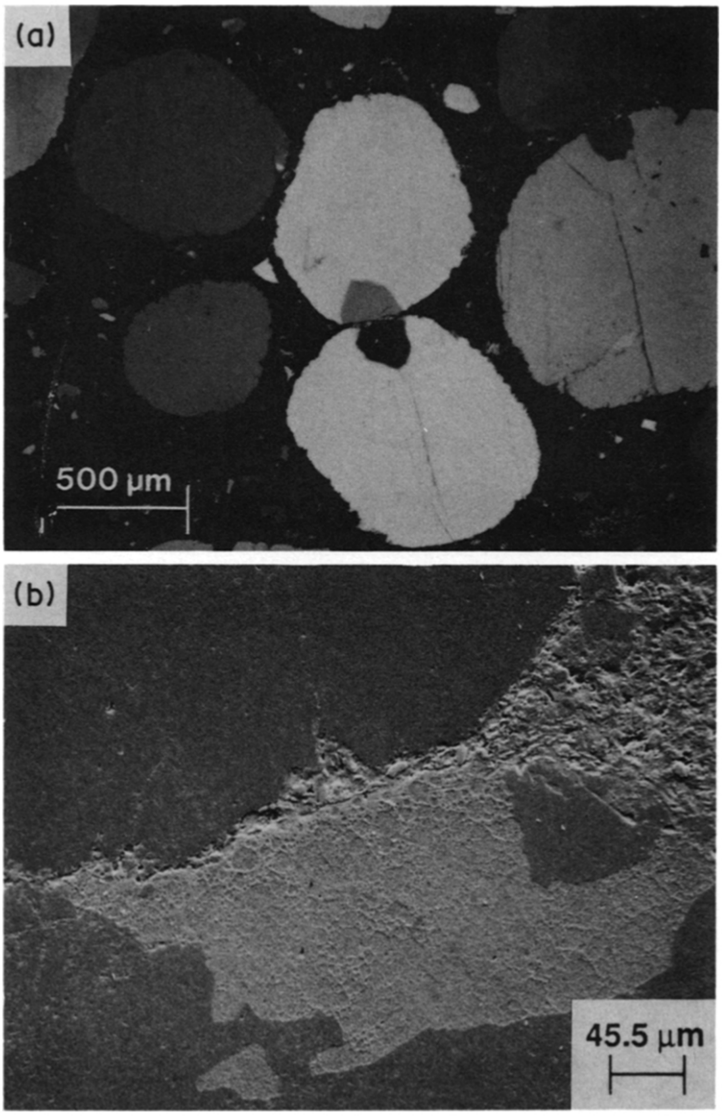


Fig. 2. (a) Crossed-polars optical micrograph shows recrystallization at a bedding-normal contact. (b) A similar contact revealed in SEM by etching; the recrystallized grains (bright) have etched differentially with respect to their hosts (dark). Note micas plating contact.

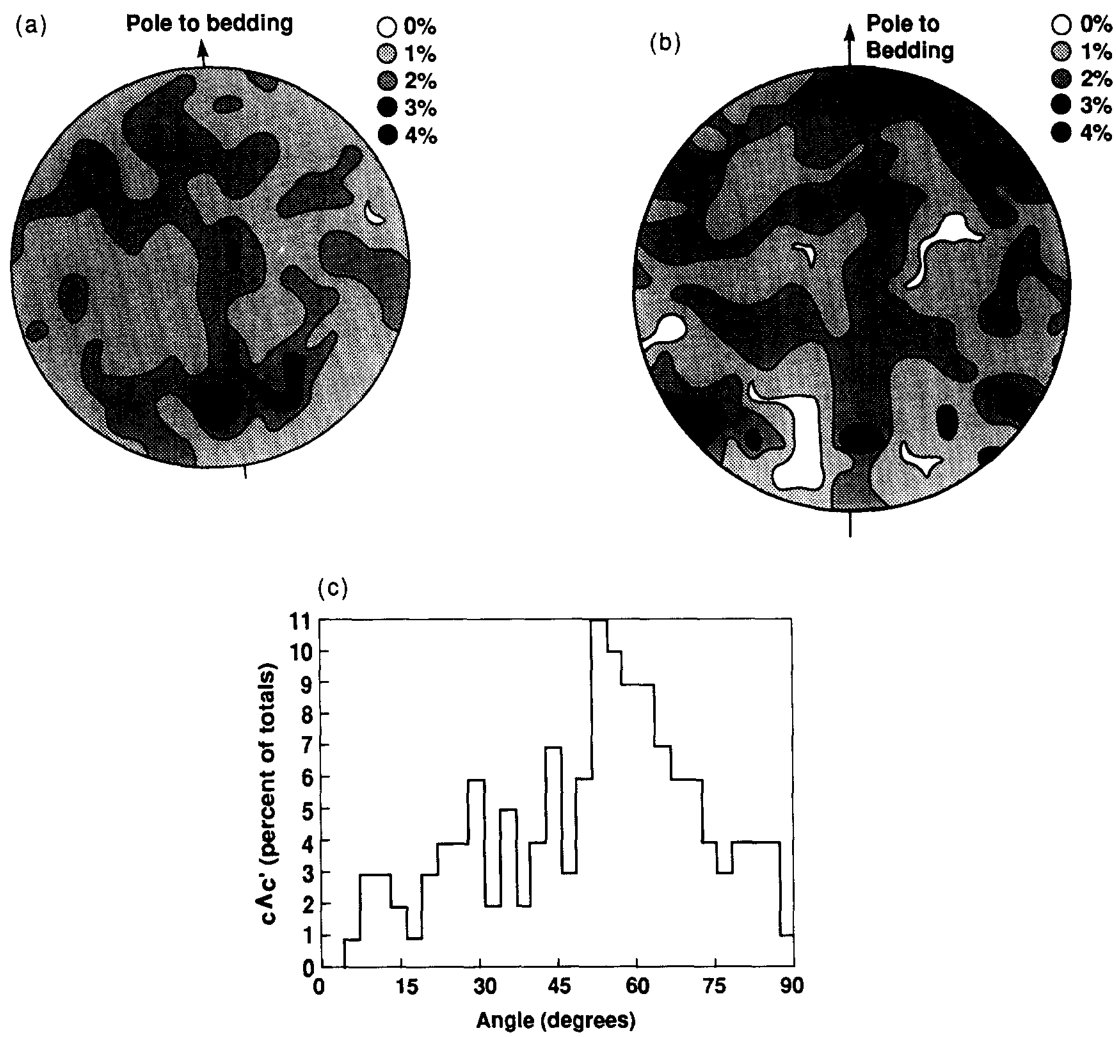


Fig. 4. (a) $c$-axis subfabric (242 counts) of original grains shows no strong preferred orientation (the bedding pole is marked for reference). (b) Same for $c$-axes of new (recrystallized) grains (160 counts). (c) Histogram of angles between host and new grains shows a peak near 55° to $c$ (134 counts).

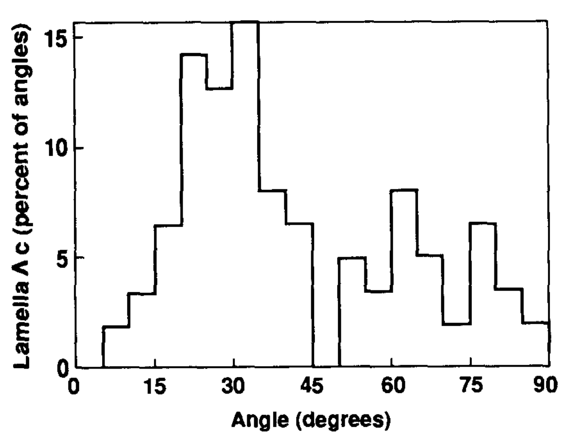


Fig. 5. Histogram of angles between lamellae and $c$-axes shows a broad peak in the 20–35° range (63 counts). In many cases, accurate determination of an angle was precluded by the rotation of the $c$-axis.

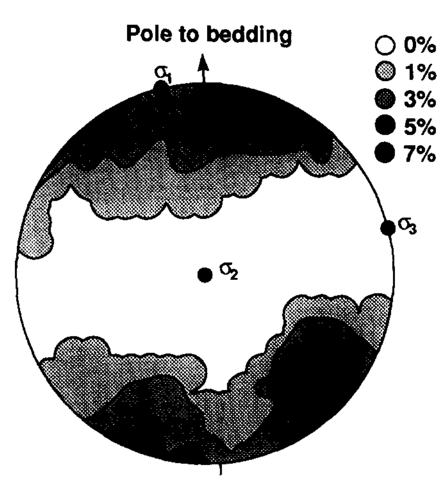


Fig. 6. Lamellae subfabric shows two strong maxima; the inferred $\sigma_1$ direction is near the pole to bedding (243 counts).

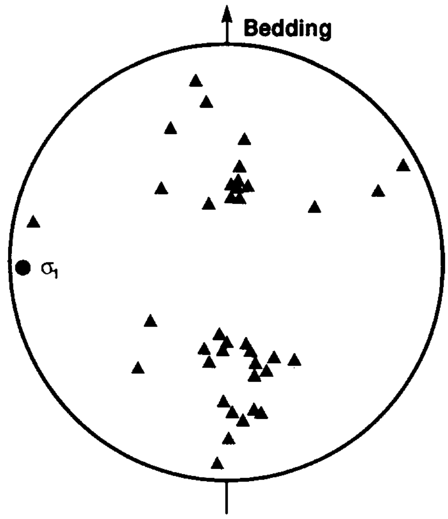


Fig. 7. Fracture subfabric (32 counts) of sand grains. The fracture poles define a great circle whose pole lies in the bedding plane, and which is inferred to parallel $\sigma_1$ for this deformation episode.

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