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Pressure solution deformation of conglomerates in shear zones, Narragansett Basin, Rhode Island

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Abstract—Pressure solution deformation in shear zones in a Pennsylvanian quartzite conglomerate from Narragansett Basin, Rhode Island, has resulted in 51–58% cobble volume reduction. Only 16–27% of this volume reduction is due to shearing; the rest is the result of an earlier constriction during folding. In the shear zones it is possible to demonstrate the effects of flattening and shearing. Pressure solution has had a flattening effect, whereas inter-cobble rotation has aligned the planes containing the long and intermediate axes of the cobbles parallel to the shear plane. The magnitude of the flattening and the degree of alignment increases with the intensity of shearing. In one shear zone internal penetrative deformation of the cobbles has occurred in addition to pressure solution and inter-cobble rotation. The magnitude of the additional strain produced by this internal penetrative deformation can be estimated, but the amounts of strain caused by flattening and shearing cannot be separated.

INTRODUCTION

THREE main types of conglomerate deformation mechanisms have been previously proposed. One of the most commonly reported mechanisms is ductile flow affecting the internal fabrics of conglomerate clasts (see, for example, Flinn 1962, Hossack 1968). Ductile flow is an internal penetrative deformation of the clasts and may be expressed as an elongation or flattening. A second mechanism, which often acts in conjunction with the internal penetrative deformation mechanism, is intercobble rotation (Fairbairn 1936, Tavener-Smith 1962). Individual clasts rotate relative to one another and align their long, intermediate, and short axes parallel to the major, intermediate, and minor axes of the strain ellipsoid, respectively. Viscosity experiments (Gay 1968) show simultaneous internal penetrative deformation and rotation toward the direction of elongation during pure shear and toward the direction of shearing during simple shear. In nature, the direction of elongation is very frequently parallel to fold axes, and the direction of shearing is often equivalent to the direction of tectonic transport in a shear zone.

A third mechanism, pressure solution, results in dissolution of the outer portions of the conglomerate clasts, which changes the clast shapes without affecting the internal fabric. Substantial deformation by this mechanism along with inter-cobble rotation has been recently recognized in the Pennsylvanian-age Purgatory conglomerate from Rhode Island (Mosher 1976, 1978a). Pressure solution deformation has also been observed in conglomerates which have undergone internal penetrative deformation (Mosher 1978b). Moreover, pressure solution has been found to be an important deformation mechanism in general (Durney 1972, McClay 1977) and in the formation of cleavages (Plessman 1964, Geiser 1974, Wood 1974, Gray 1978). This paper examines the effects of all three deformation mechanisms on a conglomerate in shear zones.

FIELD RELATIONS

The Purgatory conglomerate forms the lower portion of the Pennsylvanian stratigraphy of the southern Narragansett Basin, Rhode Island. The conglomerate occurs in elongate lenses which vary from a few metres to nearly 100 m in thickness. The predominantly quartzite clasts range from 1 m to 1.8 m in length with the majority being cobbles in size. In most lenses there is very little sand-size matrix between the closely packed clasts.

The main conglomerate unit forms a series of upright and overturned folds with differing vergences. Shear zones, generally 1 – 2 metres wide, are found on the limbs of the overturned folds. Within these zones discrete faults are often observed but the amounts of displacement cannot be measured. These faults are assumed to be parallel to the shear plane, strike at an angle of 15° from the fold axes, and indicate a direction of tectonic transport concordant with the associated folds. Within shear zones, the planes containing the long and intermediate cobble axes are extremely well aligned relative to one another (Fig. 1) and are parallel to the fault planes. Where only folding has occurred, the planes containing the two longest axes are roughly axial planar; in flat-lying, relatively undeformed areas, this alignment is poorly expressed and approximately parallels bedding. At all localities studied the long axes of the cobbles parallel the fold axes, and fibrous quartz pressure shadows are found at the long axis terminations of cobbles (Fig. 2). In addition, adjacent cobbles show evidence of mutual interpenetration, and indentations are observed in all directions approximately perpendicular to the long dimension (Fig. 1).

In this paper two shear zones will be discussed. One is typical of most shear zones in the area studied and is on the right-side-up limb of an overturned fold. It will be referred to as locality C. The other shear zone is approximately 25 m wide, has a 2 m wide intensely sheared central core, and is on the overturned limb of a fold. The outer portion and central core of this zone will be discussed separately and designated as localities B and D, respectively. When quantitative comparisons are made with areas only involved in folding, the limb of an upright fold, locality A, will be used. The amount of deformation of the cobbles appears to increase in a qualitative manner from locality A to D.

TEXTURAL RELATIONS WITHIN SHEAR ZONES

In all localities where shearing has occurred, microscopic pressure shadows are found at the intermediate and long axis terminations of the cobbles. Pressure shadows at the intermediate axis terminations are not observed at localities only affected by folding. Subparallel to the long axis of the cobbles, fractures which offset the cobble margins and contain concentrations of kinked and sheared micas and heavy minerals are occasionally observed.

Thin selvages between cobbles on surfaces parallel to the shear plane are highly sheared and often contain recumbent, isoclinal folds. These selvages are comprised of a residual seam of insoluble minerals left behind after the dissolution of quartz from the outer portion of the cobbles.

In shear zone localities B and C, a large number of cobble textures are present. There is an extreme variation of elongation fabrics relative to cobble axes, and in places a complete lack of any planar or linear fabric within a cobble. Fibrous pressure shadows are composed of long, rectangular quartz grains which lack any evidence of deformation.

In the centre of the widest shear zone (locality D), the quartz in the cobbles and pressure shadows at the long axis terminations is usually equidimensional and approximately equigranular with curved grain boundaries. The internal cobble quartz textures are often similar to one another. Immediately adjacent to the cobble margins, at the long axis terminations of the cobbles, pressure shadows are pods of coarse-grained quartz. These pods abruptly change into wedges of very-fine-grained quartz which taper away from the cobble. The quartz in the pressure shadows at the intermediate axis terminations is similar to that at the other shear zone localities but exhibits minor undulatory extinction. At interlocking cobble–cobble boundaries on surfaces parallel to the shear plane, most cobbles contain intra-cobble extension fractures filled by fibrous quartz. The fractures trend parallel to the long axes of the cobbles and are subperpendicular to the interlocking cobble–cobble boundaries. Due to the orientation and location of these fractures, they are believed to have formed during shearing.

DISCUSSION OF TEXTURES

The presence of pressure shadows at the intermediate axis terminations of the cobbles in shear zones and their absence at other localities suggests that quartz was in solution during shearing. At locality D this suggestion is further supported by the existence of fibrous quartz-filled extension fractures. Dissolution of quartz concurrent with shearing is indicated by the concentrations of micas and heavy minerals in shear fractures offsetting cobble margins.

In shear zone localities B and C, the extreme differences between cobble textures, the lack of consistency between cobble fabrics and the cobble axes, and the absence of deformational features in the pressure shadows, all indicate that only pressure solution affected the cobble shapes. In shear zone locality D, internal penetrative intracrystalline deformation has apparently occurred in addition, as indicated by the recrystallization textures observable in cobbles and in the pressure shadows at the long axis terminations. The coarse grained pods in these pressure shadows may represent more protected regions, whereas the very fine grained wedges further from the cobble margins reflect continuous deformation during recrystallization. That such textures are not observed in the quartz filling the extension fractures and the pressure shadows at the intermediate axis terminations indicates that the growth of this quartz was either concurrent with or postdates the internal penetrative deformation.

VOLUME LOSS

Previous work (Mosher 1978a), has shown that cobble shape changes are caused solely by pressure solution deformation at folded localities and shear zone localities B and C. Further, it was demonstrated that the shape changes are the result of cobble volume reductions of 51% at locality C and 58% at locality B.

Most of the pressure solution deformation occurred during folding and caused the long axes of cobbles to parallel the fold axes (Mosher 1978a). However, some of the volume reduction occurred during shearing as evidenced by the microscopic textural relations observed in shear zones. If the shear zone localities B and C are compared with unsheared localities in similar positions on folds, the amount of volume reduction during folding can be estimated. When this volume reduction is removed, the volume loss during shearing is 16% for locality B and 27% for locality C. It should be noted that this is cobble, not whole rock, volume loss. Most of the removed quartz is locally redeposited.

The amount of volume loss and strain at locality D, the central core of the widest shear zone, cannot be uniquely determined. If it is assumed that all deformation was due to pressure solution, and there has been no strain due to internal penetrative deformation; then 24% of the cobble volume was removed during shearing. Alternatively if pressure solution is assumed to stop when intense shearing commenced, the cobbles would have suffered the same volume loss (16%) as those in the outer portion of the same major shear zone; the additional penetrative strain would appear to be $e_X = 25\%$, $e_Y = 12\%$, and $e_Z = 28\%$ (X is the long axis,

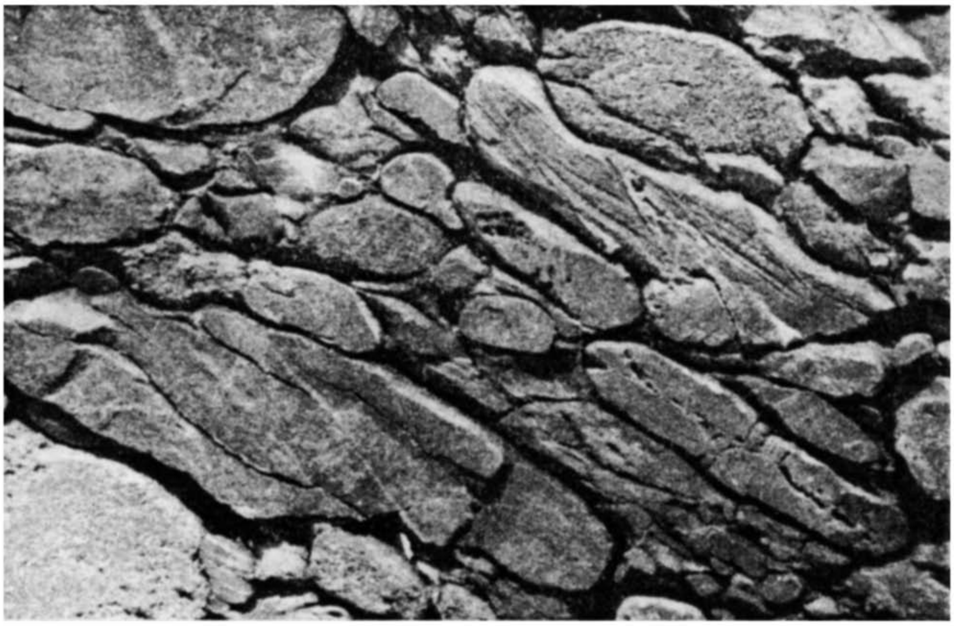

Fig. 1. Indentation relationships of adjacent quartzite cobbles at shear zone locality C; viewed on a joint face perpendicular to the long axes of the cobbles. Note the parallel alignment of the intermediate axes. Most indentations are on the flat surfaces which are parallel to nearby shear planes. Photograph is 28 cm wide.

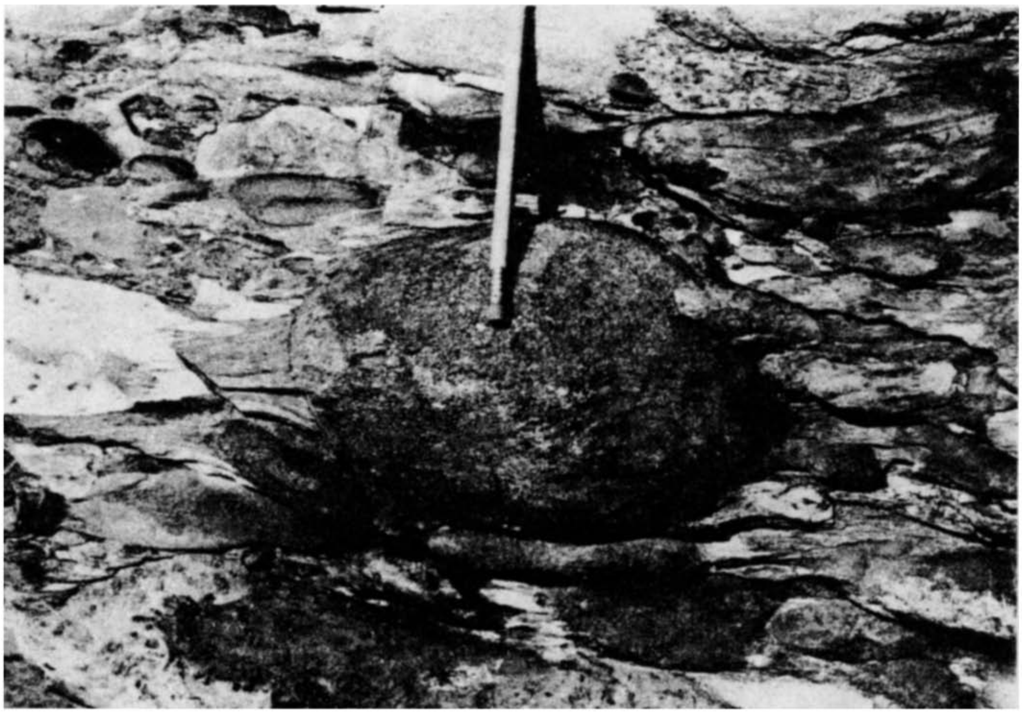

Fig. 2. Fibrous quartz pressure shadows at the long axis terminations of cobbles at shear zone locality C; viewed on a surface parallel to the fold axes. Note the parallel alignment of the long axes. A 7 mm wide pencil is used for scale.

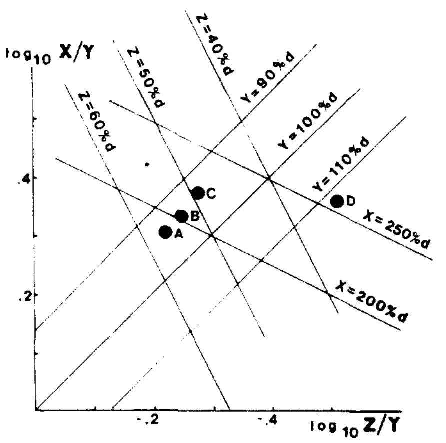

Fig. 3. Standard deformation plot of the mean axial ratios of 100 cobble measurements for four localities: a folded locality (A); the outer portion of the widest shear zone (B); a typical shear zone (C); the central core of the widest shear zone (D). Shown are the percent changes in axial lengths from the initial diameter (d) assuming no volume change has occurred. Note only locality D has an overall oblate shape because both X and Y have been lengthened. Localities A, B and C have similar prolate shapes.

Y is the intermediate, and Z is the short axis). However pressure solution was concurrent with the internal penetrative deformation. Therefore the above estimates of the amount of volume loss and concurrent penetrative strain set the upper and lower limits on the amount of deformation by the two mechanisms. It is interesting to note that on the limbs of the overturned fold, more volume loss without internal penetrative strain occurs on the upper limb than on the lower limb.

COBBLE SHAPES, ALIGNMENTS, AND INDENTATION ORIENTATIONS

In folded areas and in shear zones localities B and C, the mean cobble shapes are prolate (Fig. 3). Differences in shapes are minor and are largely attributable to the positions of the localities on folds. Only in shear zone locality D, where internal penetrative deformation has occurred, are most cobbles oblate (Fig. 3).

At all localities cobbles are aligned with their long axes parallel to the fold axes, and in shear zones the planes containing the long and intermediate axes parallel the shear plane. The long axes of the cobbles have an azimuthal fluctuation of less than 10° and no plunge. Therefore it is sufficient to discuss the orientation of the plane containing the long and intermediate axes in terms of the fluctuation of the intermediate axis from horizontal. A plot of the axial ratio of the intermediate and short axes ($\log_{10} Y/Z$) against the degree of fluctuation of the intermediate axis from horizontal illustrates the cross-sectional shapes of the cobbles and the degree of alignment of the intermediate axes. Plots for the folded areas at locality A (Fig. 4), the outer portion of the widest shear zone at locality B (Fig. 5), and the typical shear zone at locality C show the cross-sectional cobble shapes are similar with most axial ratios less than 0.4. At locality D, the central core of the widest shear zone (Fig. 6), over half of the cobbles have ratios over 0.4 indicating a significant shape change from the

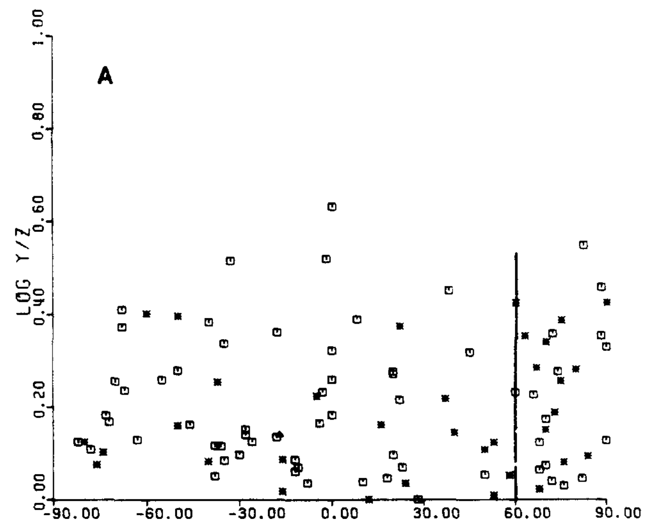

Fig. 4. Shape factor plot for folded locality A showing the variation in orientation of the intermediate axis (major axis) relative to horizontal (0°). Solid line is dip of bedding.

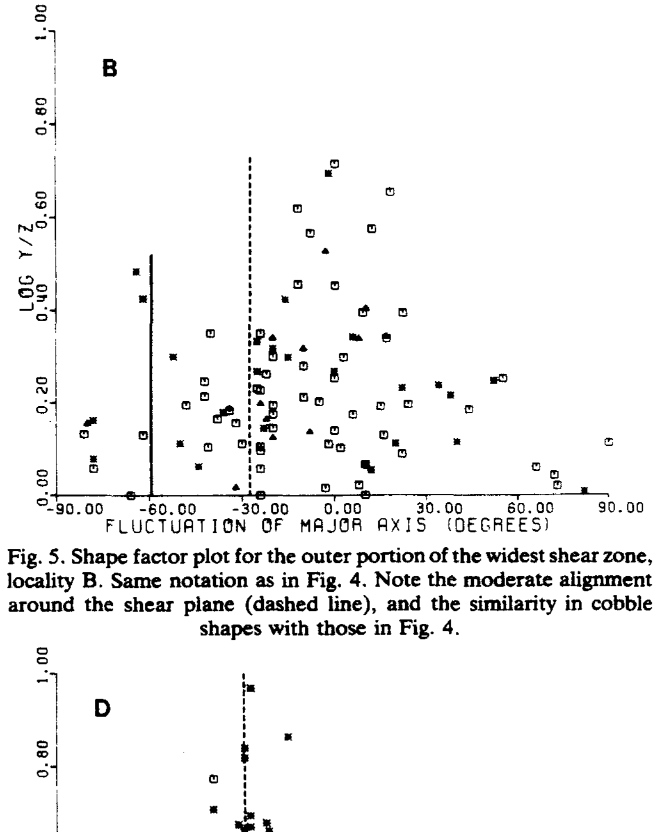

Fig. 5. Shape factor plot for the outer portion of the widest shear zone, locality B. Same notation as in Fig. 4. Note the moderate alignment around the shear plane (dashed line), and the similarity in cobble shapes with those in Fig. 4.

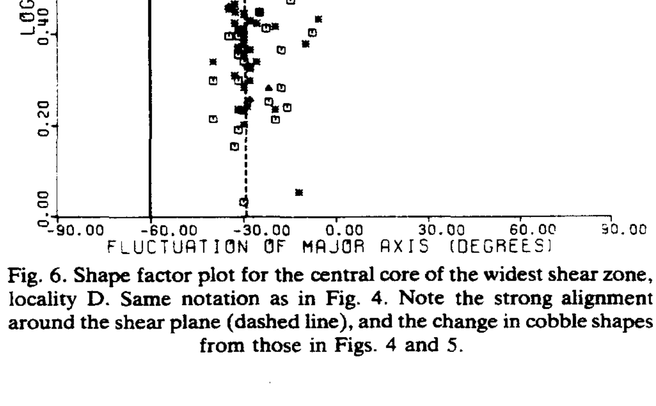

Fig. 6. Shape factor plot for the central core of the widest shear zone, locality D. Same notation as in Fig. 4. Note the strong alignment around the shear plane (dashed line), and the change in cobble shapes from those in Figs. 4 and 5.

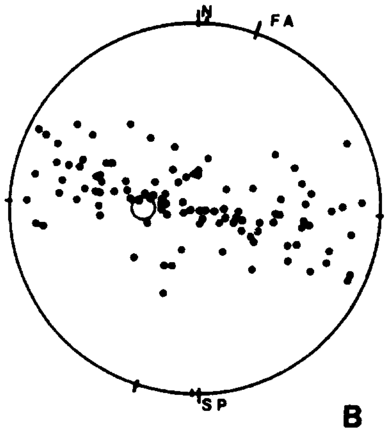

Fig. 7. Poles to indentations for the outer portion of the widest shear zone (locality B). The open circle is the pole to the shear plane; SP is the strike of the shear plane; FA is the fold axes. The axis to the broad girdle of points is parallel to the fold axis.

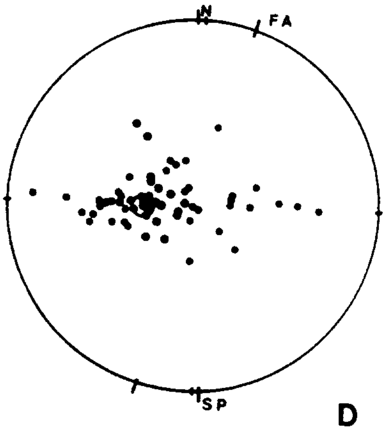

Fig. 8. Poles to indentations for the centre of the widest shear zone (locality D). The notation is the same as in Fig. 7. Note the cluster of poles around the pole to the shear plane; the axis to this narrow girdle is parallel to the strike of the shear plane.

other localities. No alignment of the intermediate axes is observed for locality A (Fig. 4), but a reorientation of cobbles parallel to the shear plane is observed at locality B (Fig. 5). This reorientation is even more pronounced at locality C and is a maximum at locality D (Fig. 6).

All cobble surfaces approximately perpendicular to the long axes are covered with identations containing concentrations of micas. The orientations of the poles to the indentations indicate the direction of the local stresses during deformation. Inspection of joint faces perpendicular to the long axes shows that in shear zones, most indentations are on the flat surfaces parallel to the shear planes. This is illustrated for locality C in Fig. 1. At locality A and the shear zone locality B (Fig. 7), the poles to indentations form a broad girdle with an even point distribution around the fold axis. At locality C most poles fall on a narrow girdle at angles of ±60° to 90° from the shear plane, and the girdle axis lies between the fold axis and the strike of the shear plane. At locality D, most poles cluster around the pole to the shear plane, and the narrow girdle has an axis parallel to the strike of the shear plane (Fig. 8).

DISCUSSION

During folding the cobbles in this conglomerate had material removed from all directions perpendicular to the fold axes which made the cobbles elongate parallel to these axes (Mosher 1976, 1978a). During the subsequent shearing, the intermediate axes became aligned parallel to the shear plane. In shear zone localities B and C this alignment occurs without any significant change in cross-sectional shapes or internal penetrative deformation. In addition the micas on surfaces parallel to the shear planes are recumbently folded and sheared. Apparently the cobbles rotated into alignment parallel to the shear plane rather than undergoing substantial shape changes.

The shape changes which do occur in localities B and C are due to pressure solution which had a fundamentally flattening effect. This is shown by the poles to resulting identations which are at high angles to the shear planes and lie on narrow girdles with axes that shift from the trend of the fold axis to the strike of the shear plane as the intensity of shearing increases.

The amount of strain in the conglomerate unit as a whole is due to both the cobble shape changes and the reorientation of the cobbles during both folding and shearing. During folding the conglomerate underwent intercobble rotation and large scale pressure solution causing cobble volume reduction. The resultant constrictional strain is expressed by prolate cobbles aligned with their long axes parallel to fold axes. During shearing, pressure solution removed cobble volume from surfaces parallel to shear planes, producing a flattening strain of cobbles and of the conglomerate unit as a whole. The rotation of the intermediate axes of the cobbles toward the shearing direction also caused a shear strain of the conglomerate unit. The net result of these three strains is prolate cobbles aligned with their long axes parallel to the fold axes and their intermediate axes parallel to the shearing direction. In the central core of the widest shear zone at locality D, where internal penetrative deformation has lengthened the intermediate axes making the cobbles oblate, the additional strain produced by this mechanism is presumably both one of flattening and shearing.

CONCLUSIONS

Pressure solution deformation of a quartzite conglomerate resulted in cobble volume reduction of 16 – 27% during shearing. This deformation produced a flattening strain which was superimposed on a previous constrictional strain caused by the same mechanism during folding. In addition, inter-cobble rotation aligned the long axes of the cobbles parallel to the fold axes during folding, and the plane containing the long and intermediate axes of the cobbles parallel to the shear plane during shearing. Therefore, during shearing the conglomerate unit as a whole was affected by both a shearing and a flattening strain.

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