RIPPLE MARKS AND PSEUDO-RIppLE MARKS IN DEFORMED QUARTZITE

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ABSTRACT. Study of regionally metamorphosed Precambrian quartzites from Tasmania indicates that ripple marks may be preserved in rocks that have been sufficiently deformed to have a preferred orientation of quartz and mica. Ripple marks may be distinguished from tectonic structures of similar appearance (pseudo-ripple marks) only if sufficient diagnostic sedimentary features are retained. Petrofabric analysis is inconclusive in distinguishing ripples from pseudo-ripples because tectonic and sedimentary structures may be similar in orientation.

INTRODUCTION

Ripple marks are sufficiently distinctive (Shrock, 1948) to be recognized with certainty in undeformed or slightly deformed sediments, but distorted ripple marks in deformed rocks resemble certain linear tectonic structures referred to as pseudo-ripple marks by Ingerson (1940; Shrock, 1948). Pseudo-ripple marks originate in at least two ways:

1. Crenulation of a surface (Ingerson, 1940).
2. Intersection of various surfaces; e.g. bedding, curved fractures, cleavage and joints (Shrock, 1948; Mikkola, 1960; Kranck, 1961).

DISTINGUISHING CRITERIA FOR DISTORTED RIPPLE MARK AND PSEUDO RIPPLE MARK

1. Ripple marks are generally distinctive in plan view. They are rarely straight and commonly intersect each other, whereas most linear tectonic structures tend to be straight and parallel. Anastomosing and bifurcated ripples are common and have no close parallel in any known tectonic structure. Interference, lobate, linguloid, and rhomboid ripple marks are distinctive.

2. Ripple marks vary in cross-sectional shape, and some varieties are quite different (even when distorted) from any tectonic structure. The common ripples shown in figure 1a and 1d resemble crenulations, but the compound types (fig. 1b, 1c, and 1e) are unique to sediments (see Van Hise, 1896, figs. 141, 142; Kindle, 1917, figs. 4, 7b, pls. 24, 25a; Brown, 1912, fig. 2; Shrock, 1948, figs. 63, 66, 74).

3. Ripple marks in adjacent beds of the same composition may differ markedly in direction, wave length, amplitude, or ripple index (\(\frac{\text{wave-length}}{\text{amplitude}}\)), whereas linear tectonic structures tend to be similar, at least in orientation. Divergence of direction of ripple-like structures on adjacent bedding surfaces is strong evidence that they are of sedimentary, not tectonic, origin.

4. The concentration of heavy minerals, mica flakes, or large grains in the troughs of ripples is diagnostic of ripples.

5. The only positive criteria for pseudo-ripples is their occurrence on surfaces that are not bedding. Pseudo-ripples in quartzite (Ingerson, 1940) occur on a foliation surface, those described by Mikkola (1960) in quartzite are on joints, and the remarkable pseudo-ripples figured by Kranck (1961) are on joints in igneous rock.
Fig. 1. Typical cross sections of ripple marks in undeformed sediments: a, b, and c are symmetrical, d and e are asymmetrical. Note the secondary ripples giving compound forms in b, c, and e.

(6) Bedding surfaces in sediments are formed at separate times, and a rippled bedding surface may be separated from a planar one by a distance of much less than the wave length of the ripple, but an unfolded surface cannot be much closer to a folded one than a distance equal to the wave length. Pseudo-ripples formed by curved or intersecting fractures may, however, be closely spaced.

*Relation of ripple-like structures to tectonic structures.*—It is difficult, if not impossible, to ascertain the origin of ripple-like structures in rocks that have been strongly deformed if the diagnostic criteria discussed above are not preserved. It has been accepted (Ingerson, 1940) that, if all tectonic features in the rock are oblique to the "ripples", then they are of sedimentary origin. But it has also been accepted that, if any tectonic feature is parallel to the "ripples", then they are probably of tectonic origin. This argument is unsound.

If all structural elements are discordant to the suspected ripples, then the ripples may well be sedimentary, but, alternatively, they may be old structural relics not related in their symmetry to the latest fabric (Ramsay, 1960). If the suspected ripples are parallel or related symmetrically to certain fabric elements, the ripples may nevertheless be sedimentary for the following reasons:

(1) The orientation of both may be subject to the same basic control. The directions of currents, winds, and waves depend on the disposition of land and sea and hence on the shape of the basin; thus, sedimentary structures are commonly parallel or perpendicular to the shoreline. The orientation of structures such as folds, faults, cleavage, and lineation is commonly similar to the trend of the orogenic zone and hence the original sedimentary basin.
A. Fisher A quartzite.

C. Specimen adjacent to Fisher B.
B. Fisher B quartzite. Arrow shows lineation.

D. Mount Mullens quartzite.
(2) In the early stages of deformation the orientation of small folds, fracture cleavage, etc., may be controlled by inhomogeneities caused by sedimentary structures.

(3) Movement along a cleavage tends to rotate bedding (and consequently bedding-plane structures) toward parallelism with the cleavage.

**FABRIC STUDIES**

The fabric of a number of specimens of regionally metamorphosed quartzite from Tasmania showing ripple-like structures were studied to determine the relationship between the internal fabric and the "ripples" and to see whether petrofabric analysis is useful in distinguishing deformed ripples from pseudo-ripples.

The rocks differed in their degree of deformation as follows:

(1) Undeformed quartzite with undistorted ripples (Fisher A quartzite).

(2) Slightly deformed quartzite with a lineation oblique to the distorted ripples (Fisher B quartzite).

(3) Moderately to strongly deformed quartzites with a tectonic lineation parallel to distorted, ripple-like structures (Mount Mullens quartzite, Franklin River quartzite, Mount Mary quartzite).

1. **Fabric of undeformed quartzite containing ripple marks.**—One might expect quartz-fabric diagrams from sandstones to show an almost random orientation with some slight concentration of axes near the bedding and perhaps parallel to ripples, because quartz grains tend to weather into ellipsoids with the longest ellipsoid axis close to the crystallographic c axis (Ingerson, 1940).

The specimen (Fisher A) is from the Precambrian Fisher Group on the Mersey River, Tasmania (Spry, 1958). The quartzite is granular and contains no mica, cleavage, or lineation. The ripples (pl. 1-A, fig. 2a) are symmetrical with a wave length of 1.8 cm, amplitude of 4 mm, ripple index of 4, and side slopes (angle of slope of the sides of the ripples) of 25°. In plan the axes are irregular with departures of 20° from the general direction for short distances. Planar bedding passes through the specimen 5 mm from the troughs of the rippled surface. Ripples on adjacent surfaces differ in direction, wave length, and amplitude. The evidence is conclusive that this is ripple mark, probably undistorted.

There is no obvious indication of a preferred orientation of quartz optic axes in figure 3a.

2. **Fabric of slightly deformed quartzite with distorted ripple marks.**—A quartzite from the Fisher Group (Fisher B quartzite) on the Forth River, Tasmania (Spry, 1958), crops out about 3 miles from the Fisher quartzite described earlier. The identity of the ripples (fig. 2b; pl. 1-B) is established on criteria discussed earlier, i.e., discordance of ripple directions on adjacent beds, lack of disturbance of bedding close to the ripples, and the presence of secondary small ripples on the back slope of the crests. This evidence is considered to be conclusive. The ripples are asymmetrical with the steeper parts sloping at 80° and the back slopes at 30°; the wave length is 13 mm, the amplitude 5 mm, and the ripple index 2 1/2. The high slopes and low index indicate that the ripples have been distorted and the nature and intensity of this
Fig. 2. Cross sections of ripple marks in slightly or strongly deformed quartzites from Tasmania.


deformation will be discussed later. A weak tectonic lineation is visible on the bedding at 30° to the ripples; it is not folded by the ripples but was formed later as the intersection of bedding and cleavage.

The mica diagram (fig. 3d) in a section normal to the lineation, shows a girdle with a long maximum denoting an S-plane at about 60° to the bedding. Coincidence occurs between the macroscopic lineation, the pole to the mica girdle, and the intersection of the foliation and the bedding. The ripple mark lies 30° away and is not related to any tectonic feature.

The significance of the quartz diagram (fig. 3c) is not clear. The fabric is monoclinic to triclinic and is not related to any known tectonic direction.

This study confirms Ingerson’s (1940) findings that ripple marks may be preserved in metaquartzites which have been sufficiently deformed to have a preferred orientation of quartz and mica and that discordance between the ripple and all tectonic directions supports the validity of a sedimentary origin for the structure.

3. Fabric of deformed quartzite with “ripples” of questionable origin.—A quartzite from the Mary Group (Spry, 1957; Spry and Zimmerman, 1958) at Mount Mullens is shown in plate 1D and in figure 2d. “Ripples” occur on the bedding (?) surfaces of laminated quartzite and are generally straight, although some are curved and bifurcated. The wave length is very regular at 1.7 cm, the amplitude is 0.3 cm, the ripple-index about 6; the ripples are asymmetrical with slopes of 11° and 24° relative to the bedding. These data are all compatible with undeformed ripples. Figure 2d shows that many of the ripples are crudely compound. A weak, streaky lineation of tectonic origin
Fig. 3. Petrofabric diagrams.

a. Fisher A quartzite.  b. Grand Canyon (Ingerson, 1940, fig. 11) quartz axes.

A, D, E, F, H, and J are Fisher B quartzite.  G, I, and J are Mount Mullens quartzite.  N, H, and I are strongly deformed, non-ripped quartzite 2 miles from Mount Mullens.  I, Mount Mary quartzite, possible ripples, 8 miles from Mount Mullens.
Ripple Marks and Pseudo-Ripple Marks in Deformed Quartzite

is approximately parallel to the ripples. Ripple marks satisfying many of the
criteria defined earlier occur in adjacent quartzites, and it is thought probable
that the structure is ripple mark and not pseudo-ripple mark.

The mica diagram (fig. 3f) of the Mount Mullens quartzite has a double
maximum defining a foliation at about 50° to the bedding in a girdle whose
pole is about 8° from the ripple axis. The quartz diagram (fig. 3e) does not
have a simple pattern and is somewhat similar to that of the Fisher quartzite
in figure 3c. An irregular girdle is recognizable with an axis somewhere in the
region of the ripple axis (fig. 3f). The symmetry is monoclinic to triclinic.

The fabric evidence is not conclusive in determining whether this is a
ripple mark or not. It may be interpreted as a tectonic feature or as ripple
mark that happens to be parallel to the tectonic "grain". Ingerson (1940, p.
565) recognized that, if this kind of structure was originally ripple mark, it
must have been deformed about an axis that coincided almost exactly with the
ripple mark direction.

Quartzites from the Mary Group (Spry, 1957) at the Franklin River
(6251)¹ and at Mount Mary (6225) have ripples similar to those from the
Mount Mullens specimen except that they are less perfectly formed and do not
retain any morphological features truly diagnostic of ripple marks. Tiny, ir-
regular ribs give the rock a tectonic lineation parallel to the possible ripples.
The quartz fabric of both rocks is orthorhombic with girdle normal to the
lineation (fig. 3i,j). It is not possible to decide whether the structure is dis-
torted ripple or is purely tectonic, but, as indubitable ripples occur within a
few yards of the Mount Mary specimen of the same general size and shape as
those on the Mount Mullens specimen, it appears likely that they are ripples,
even though the tectonic axis is close to the ripple axis.

Maxson and Campbell (1934) described what they first considered to be
ripple marks in quartzite from the Grand Canyon, and the structure in their
photograph has many of the properties of deformed ripple mark, e.g.: (1) The
structure lies on a bedding surface: (2) the crests and troughs are not straight
but irregularly curved and anastomosing; (3) the crests are sharp and the
troughs rounded; (4) the schists in contact are not crenulated, and there is no
cleavage oblique to the bedding; (5) other sedimentary structures such as
cross-bedding, scour, concretions, etc., are preserved in associated rocks; (6)
the fabric axis may not be coincident with the ripple direction.

Maxson and Campbell (1939) revised their opinion (apparently largely
on the basis of a fabric investigation by Ingerson, (1940)) and concluded that
the structures were pseudo-ripples.

Ingerson’s quartz diagrams are not easy to interpret; he (1940, p. 565)
stated with respect to his diagrams 11 and 12 that (1) there are well developed
girdles normal to the lineation in each. (2) the fabric is practically identical
in each.

Ingerson’s figure 11 (reproduced here as fig. 3b) shows that the girde is
incomplete and poorly developed; the best choice of a girdle in figure 3b is
nearer 45° to the ripple axis than normal to it.

¹ Numbers refer to the rock catalogue, Geology Department, University of Tasmania.
Shrock (1948, p. 125) considered that the ripple structure shown by a specimen of Ocoee quartzite was "unquestionably of tectonic origin", but the evidence is inconclusive, and they may well be sedimentary ripples along which a later, minor fracture cleavage has developed.

Petrofabric analysis provides useful information as to the origin of structures with the appearance of ripple marks in deformed quartzite but is not conclusive in distinguishing true ripples from pseudo-ripples. In many cases the macroscopic evidence is conclusive that the structure is either ripple mark or is tectonic. In other examples the fabric evidence merely indicates a tectonic direction nearly coincident with the "ripples", and the macroscopic evidence favors a sedimentary origin.

DEGREE OF DEFORMATION OF RIPPLE MARKS

Distorted sedimentary structures such as ooliths, concretions, fossils, and pebbles have been used to estimate the amount of deformation of the enclosing rocks. Ripple marks are not particularly useful in this respect (for reasons given below), but if sufficient can be deduced about the original shape of the ripples, the type, and direction of movement, then some estimate may be made of the amount of strain.

The effect of various kinds and degrees of strain on ripples can be determined graphically or on packs of cards. Deformation results in changes of amplitude, wave length, ripple index, and symmetry. In figure 4, simple asymmetrical ripples with slopes of 25° and 30° and a ripple index of 5 are changed by varying amounts of simple shear along a cleavage at 60° to the bedding. Ripples with side slopes of 75° and 20° and a ripple index of 2½ (similar to the Fisher B quartzite) can be produced by an angle of shear of 45°. Thus the Fisher quartzite ripple marks in figure 2b and plate 1-B, could have been produced from either symmetrical or asymmetrical ripples by simple shear along the cleavage with an angle of shear of 45°. The deformation is assumed to be simple shear acting along the cleavage because the mica diagram has a monoclinic symmetry with a girdle normal to the foliation. The ripples were probably asymmetrical because similar ripples a few inches away have the secondary ripple on the back slope typical of current ripples (fig. 1), but it makes little difference whether the ripples were originally symmetrical or asymmetrical.

Ripple marks are not reliable indicators of the amount of deformation of the rocks in a region because they are essentially two-dimensional structures, they differ widely in initial shape, particularly in symmetry and ripple index, and they may be obliterated by small strains, particularly bedding plane slip.

Ripple mark has yet to be recognized with certainty in strongly deformed rocks; the debatable examples such as those from the Grand Canyon and Mount Mullens do not have a strong fabric. The Mount Mary and Franklin River specimens have a pronounced fabric and thus presumably have been at least moderately deformed, but the possible ripples are parallel to the lineation and of irregular shape.

Ripple marks, like other sedimentary structures, may only be preserved in less deformed parts of an inhomogeneously strained region and thus reflect the
Fig. 4. Different degrees of deformation of asymmetrical ripples by simple shear parallel to a foliation at 60° to the bedding.
minimum amount of deformation. Studies of the Mount Mullens (Spry, 1957; Spry and Zimmerman, 1959) and the Mersey-Forth (Spry, 1958) areas indicate that deformation has not been homogeneous. Some quartzites are tightly folded and recrystallized and have a strong lineation and a preferred orientation of quartz, but others are broadly folded with little or no preferred orientation. The most micaceous sediments have been most strongly deformed, and macroscopic evidence suggests that movement was concentrated along the more pelitic horizons and that the thick massive quartzites moved as comparatively competent units.

The study of ripple marked specimens supports this. The quartz fabric diagrams in figure 3 lettered a, c, e, g, i, and j are arranged in order of increasing deformation as determined macroscopically. Ripple mark is undistorted in diagram (a), is moderately deformed in (c), is of debatable validity in (e), (i), and (j), and is not present in (g). The quartz fabrics range from an almost random distribution in (a), to a preferred orientation with an irregular symmetry in (c), to the increasingly perfect girdles of the more deformed (e), (g), (i), and (j).

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REFERENCES


