"GEFÜGERELIEF" ILLUSTRATED BY "SCHIST TOR" TOPOGRAPHY IN CENTRAL OTAGO, NEW ZEALAND

FRANCIS J. TURNER

ABSTRACT. Throughout much of central Otago, blocky outcrops of schist ("schist tors") are elongated and aligned in a NW to NNW direction. This is parallel to the \( b(B) \) axis of the schist fabric. The tor topography reflects the control of differential weathering by rock fabric and so provides an illustration of what Sander has termed Gefügerelief.

The concept of Gefügerelief, developed in Professor Sander's latest work on structural petrology (Sander, 1948, pp. 206-208), concerns the topographic expression of rock fabrics. In regions underlain by metamorphic rocks, some elements of the rock fabric—\( s \)-surfaces (schistosity), lineations (especially \( b \)-lineations in B-tectonites) and joints—may maintain regular orientation over large areas. Moreover, they may so influence the processes of differential weathering and erosion as to become clearly expressed in the topographic detail of the land surface, especially as revealed in air photographs. Sander has applied the term Gefügerelief to those elements of topographic relief that can be correlated with rock fabric.

A fine illustration of this phenomenon is afforded by the minor details of the land surface in the central portion of the Province of Otago, southern New Zealand (approximately long. 170°E., lat. 45°S.). The region in question is a basin-and-range province about 3,000 square miles in extent, with topographic relief of about 4,000 feet, and having a varied climate which in the lower levels inclines to aridity. The landscape is treeless; and though the upper slopes of the ranges support a cover of "tussock" grass, vegetation is sparse in the more arid parts of the province.

The oldest rocks are schists which outcrop extensively over the upland surfaces which, over large areas, comprise remnants of stripped plains of erosion cut in early Cretaceous times. Upper Cretaceous and Tertiary sediments still fill the intervening basins. These rocks, too, especially in the vicinity of the east coast have been uplifted and partially truncated by a mid-Tertiary erosion surface which locally overlaps onto the schist terrane and so intersects the early Cretaceous peneplane.

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(Benson, 1941, p. 209). Present relief is largely the result of Pliocene block faulting. Although climatic conditions must have varied considerably during late Pliocene and Pleistocene times, it should be noted that at no stage within these periods was the central Otago region subject to glaciation.

One of the most characteristic features of the central Otago landscape is the ubiquitous occurrence of “schist tors” over the length and breadth of the stripped erosion surfaces. These tors are isolated blocky outcrops which, over considerable areas, tend to exhibit some regularity of form. They have been described in detail by a number of writers (Finlayson, 1907; Park, 1908, p. 12; Cotton, 1917, pp. 287-289), and their mode of origin has recently been discussed by Raeside (1949) and by Ward (1951). Clearly the tors are products of differential weathering; and Raeside and Ward both emphasize the importance of pre-Miocene weathering of the Cretaceous erosion surface in this connection.

Several generalizations pertinent to the present discussion have been noted by previous writers:

1. Tor topography is confined to areas of strongly foliated schist and does not develop on adjacent surfaces eroded in greywacke or imperfectly foliated semischists (cf. Cotton, 1917, p. 288; Ward, 1951, p. 195).

2. Individual tors mostly range from a few feet to thirty feet in height (cf. Cotton, 1917, p. 288, figs. 24, 25), but some are much larger than this.

3. A rudely rectangular form due to development of boundary surfaces defined by two sets of steep joints is prevalent: and flat-topped tors tend persistently to develop in areas where one of the more pronounced surfaces of schistosity is approximately horizontal (cf. Finlayson, 1907; Park, 1908, p. 12).

4. Over areas of many square miles tors are elongated and aligned in parallel rows which maintain an astonishingly regular NW to NNW trend, imparting a conspicuous “grain” to the land surface as it appears in an air photograph (Raeside, 1949, fig. 3; Ward, 1951, pp. 193-194, fig. 5). Ward attributes this linear pattern to the presence of parallel belts (perhaps originally strata) of schist differing mutually in their weathering behavior. However, the possibility that original sedimentary
strata persist and maintain such a regular trend in this intensely deformed region cannot seriously be entertained. The parent rocks were massive greywackes in which absence of recognizable bedding is a characteristic feature. Moreover, no geologist has yet succeeded in recognizing within the schist terrane of eastern and central Otago either stratification or formational boundaries distinct enough to allow elucidation of even local structures.

To me the linear "grain" of the schist landscape appears to be a clear example of Gefügrelief. The schists of Otago are quartz-rich rocks composed principally of quartz, albite, epidote, muscovite and chlorite. Where a single set of $s$-surfaces (schistosity) predominates it is subhorizontal over large areas. More commonly several sets of $s$-surfaces intersecting in a $b(B)$ lineation may be recognized. Banding due to metamorphic differentiation of an initially homogeneous rock into bands alternately rich in quartz-albite and in muscovite-chlorite-epidote is ubiquitous. The most striking and consistent element in the rock fabric is the $b(B)$ lineation marked by microfolding of $s$-surfaces and bands, intersection of $s$-surfaces, and girdle orientation of mica, chlorite and quartz (Turner, 1940). It trends NW to NNW with remarkable persistence (fig. 1; see also Turner, 1938, 1940) and is either horizontal or gently plunging. A second lineation with a more northerly trend in some localities intersects the principal $b$ lineation. Vertically or steeply dipping joints approximately normal ($ac$ joints) and parallel ($\{k0l\}$ joints) to the principal lineation are common and conspicuous.

The following generalizations apply to schist outcrops which I have examined throughout the eastern portion of central Otago:

1. Individual tors tend to be elongated parallel to the trend of the $b(B)$ lineation. In many instances they are terminated abruptly by steep $ac$ joints. The rectangular flat-topped form of tor develops in areas where there are steep $\{k0l\}$ joints as well as $ac$ joints and where one set of $s$-surfaces is horizontal.

2. Regional alignment of tors, as illustrated in plate 1, is typically parallel to the trend of the $b(B)$ axis of lineation in the schists. There are some areas, however, in which two or more linear elements are blended in the topographic detail of the schist surface. Figure 1 of plate 2 represents such a case. In this particular area, some eight miles east of the town of
Plate 1. Air photograph showing alignment of schist tors about six and a half miles south of Middlemarch, Sutton Survey District, Otago. [Trend of lineation observed in this vicinity is N25°W to N30°W.]
Fig. 1. Air photograph showing distribution of schist tors approximately 8 miles east of Middlemarch, SE corner of Strath Taieri Survey District, Otago. [Trend of main b lineation, N30°W; minor lineation N10°W; main ac joints strike between N70°E and N80°E.]

Fig. 2. Air photograph of schist terrane with tors poorly developed or absent, SE corner of Hyde Survey District, Otago. [Observed trend of b lineation, N35°W to N45°W.]
Middlemarch, the main elements in the megascopic fabric of the schist are as follows (Turner, 1940, p. 180): main lineation b trends N30°W; minor lineation trends N10°W; vertical ac joints strike N70°E to N80°E. In the left-hand portion of the

Fig. 1. Map of part of eastern and central Otago, New Zealand. Bars show observed trends of b(B) lineations in schists (Turner, 1940, p. 74). Points marked 1, 2, and 3 show respective locations of plate 1 and figures 1 and 2 of plate 2.
photograph a transverse alignment of tors reflects the dominating influence of ac jointing. Elsewhere, e.g., near the top right corner, alignment is parallel to one or other of the observed lineations.

(3) In schist country devoid of fully developed tors, a NW to NNW “grain,” parallel to the trend of the $b(B)$ axis of underlying schists, can still be discerned in some air photographs. This condition is determined by vaguely defined minor features of relief, and is illustrated by the area north of Lee Stream on the Middlemarch road (plate 2, fig. 2).

(4) In some areas the smaller streams consistently conform to trends approximating NW or SW (plate 1 and plate 2, fig. 1), which may reflect the respective influence of $b(B)$ lination and ac jointing in the underlying schists.

The topographic details summarized above are here interpreted as constituting a pattern of Gefügerelief resulting from differential weathering controlled by the megascopic and microscopic fabric of the schist affected. This pattern, integrated over the schist province of Otago, should give a comprehensive picture of the movements involved in deformational metamorphism of the schist terrane. Data gleaned from rapid scrutiny of air photographs covering an area extending 100 miles inland from Dunedin in a northwest direction, emphasize regional persistence of a $b(B)$ axis trending between NW and NNW.

I wish to record my thanks to Professor B. Sander who first demonstrated to me the concept of Gefügerelief; and to the John Simon Guggenheim Memorial Foundation for a fellowship which made possible not only consultation with Professor Sander but subsequent re-examination of the schist terrane of Otago. Air photographs were supplied by the Director-general of the Department of Lands and Survey, New Zealand, to whom I am indebted for permission to publish them as well as for facilities for examining many other photographs covering central Otago.

References


Department of Geological Sciences
University of California
Berkeley, California