Cordilleran metamorphic core complexes in Arizona: A contribution from geomorphology

C. F. Pain
School of Geography, University of New South Wales, P.O. Box 1, Kensington, New South Wales 2033, Australia

ABSTRACT

Cordilleran metamorphic core complexes consist of granitic cores surrounded by, in an outward direction, mylonite, chloritic breccia, and microbreccia. These rocks are separated by a low-angle detachment fault from typically unmetamorphosed but normally faulted rocks. Rocks above the detachment fault have been transported, relative to the core rocks, in one consistent direction, giving a distinct lineation to rocks below the detachment fault.

Dome-shaped metamorphic core-complex mountains show considerable structural control of landforms. Mylonitic rocks develop triangular dome facets around the margins and low relief areas in the central parts of the complexes. Chloritic breccia is much less resistant to erosion and has been almost completely removed from many complexes.

Drainage patterns in metamorphic core complexes are mainly radial, but an older set of drainage lines parallel to mylonitic lineation, especially channels that drain down the crests of antiformal ridges, suggests that drainage developed on a ramp on the detachment fault and the underlying breccia prior to lineation-parallel arching.

INTRODUCTION

Cordilleran metamorphic core complexes (Crittenden et al., 1980; Armstrong, 1982) have been a topic of considerable debate over the past decade. This debate has centered mainly around their age and tectonic significance, but other features, such as the nature of their doming, have also come under consideration. Geomorphology has much to offer the study of tectonics (Ollier, 1981), the landforms often constraining the timing and nature of tectonic movements.

Metamorphic core complexes are a group of domal or archlike uplifts forming a discontinuous belt within the North American Cordillera from Canada to Mexico (Coney, 1980). They are cored by metamorphic and granite rocks that are overprinted by a mylonitic fabric at higher structural levels. In some complexes the mylonitic foliation dips radially from the center, defining broad domelike structures; in others, it is simply homoclinal, or gently curved. The top of the mylonite is commonly altered to chloritic breccia, which in turn is capped by microbreccia. Together these rocks form the core, or lower-plate rocks.

The smooth upper surface of the microbreccia is the lower wall of a detachment fault on which upper-plate rocks moved as they were faulted against the core. The upper-plate rocks are broken by planar and listric normal faults and by some folds, but are otherwise undeformed. Tectonic denudation, which at least partially stripped the upper-plate rocks from the cores, took place in early to middle Tertiary time (55–15 Ma).

In contrast to variable foliation directions, mylonitic lineation is consistently oriented in the same direction regardless of position on the domed or arched core complex. This lineation is parallel to the fault-movement direction and was presumably produced by ductile shearing along the downdip projection of the fault.

Metamorphic core complexes are also landforms of some magnitude. Here I present evidence from these landforms that relates to questions about the temporal relationships between detachment faulting and doming. Information comes from topographic maps and aerial photographs and from field observations of the relationships between structure and landforms.

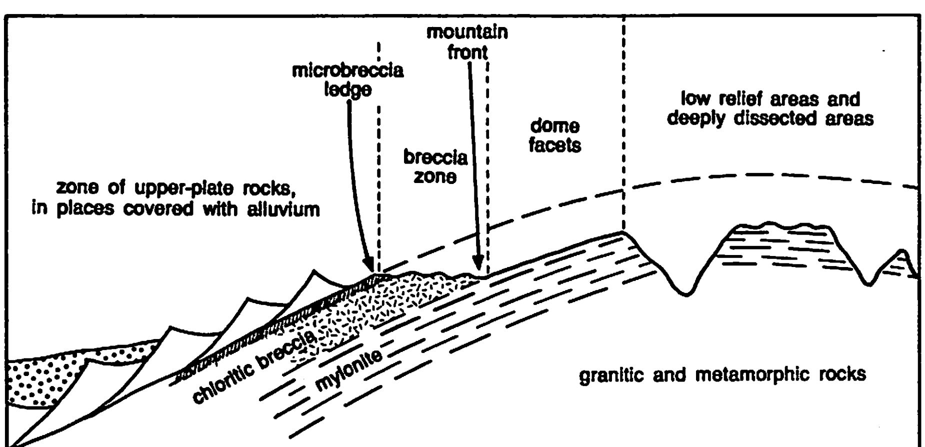

Figure 1. Diagrammatic cross section of landform zones on a metamorphic core complex.

LANDFORM ZONES

Landforms in metamorphic core complexes reflect several structural zones (Fig. 1).

Zone of Upper-Plate Rocks

Upper-plate rocks, having undergone normal faulting above gently to moderately dipping detachment faults, give a blocky landscape with a rectangular drainage pattern (e.g., eastern Whipple Mountains, southeastern California, Fig. 2).

Breccia Zone

Where it crops out, the resistant microbreccia commonly forms a small ledge in the landscape (see, e.g., Fig. 13 in G. H. Davis, 1980). The detachment fault, as well as the microbreccia ledge if present, is commonly separated from the mountain front by the breccia zone, an area of gently rounded hills (Fig. 1). This zone is transitional from highly resistant mylonitic rocks at the mountain front through less resistant chloritic breccia to the microbreccia ledge. The chloritic breccia weathers to form blocky fragments usually less than 20 cm across. The mylonitic rocks, on the other hand, break into tabular blocks up to 1 m across. The chloritic breccia is thus much less resistant to erosion than the mylonitic rocks.

Dome Facets

Dome facets are formed where the crests of valley walls intersect as they leave the mountain front. They are thus triangular-shaped remnants of an original dome-shaped surface. They have gently convex slope forms, ranging from 15° to 30° and are almost always parallel to the mylonitic foliation. Dome facets are only slightly dissected compared with much of the mountain range. They are particularly well developed along the southern front of the Santa Catalina Mountains and the west side of the Rincon Mountains near Tucson, Arizona, where they rise to 850 m above the adjacent pediment surfaces (Figs. 3, 4).

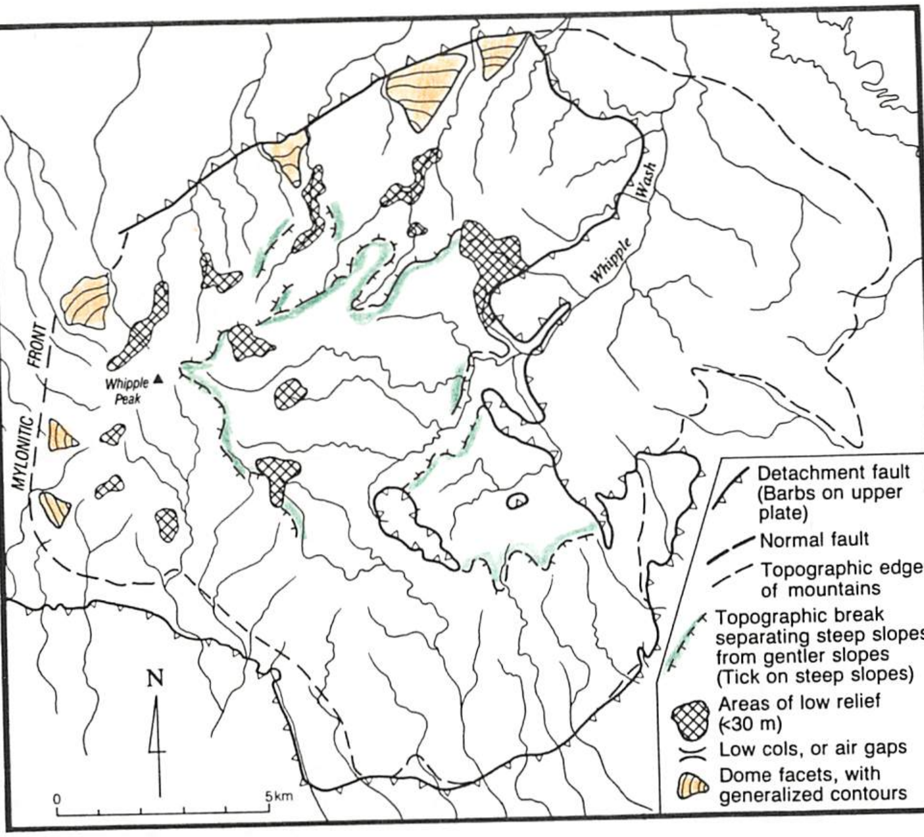

Figure 2. Landform features of Whipple Mountains, southeastern California. Detachment fault location from G. A. Davis et al. (1980) and Dickey et al. (1980). On western margin, topographic edge of mountain coincides with mylonitic front.

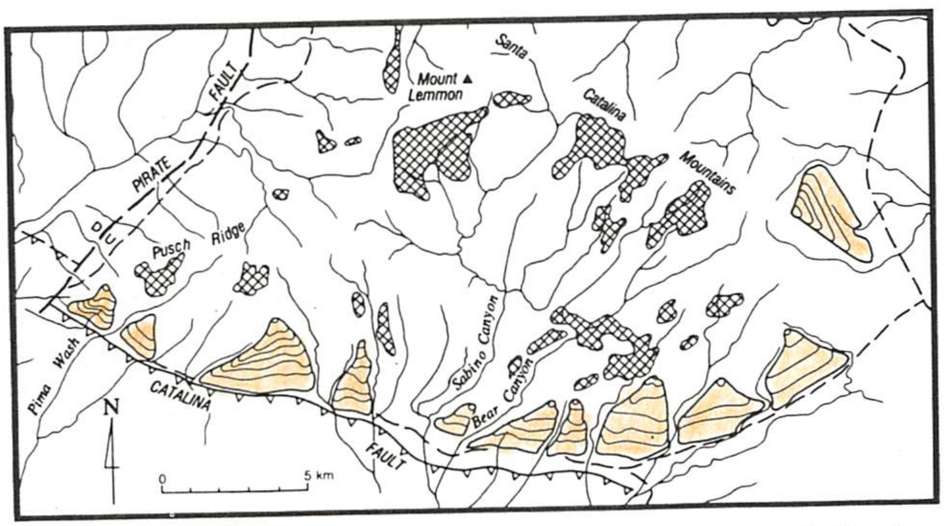

Figure 3. Landform features of Santa Catalina Mountains, southeastern Arizona. Fault locations from Banks (1976) and Keith et al. (1980). Symbols as in Figure 2.

Low-Relief Areas and Deeply Dissected Areas

Many metamorphic core complex mountains have gently sloping areas with a relative relief generally less than 30 m. Many of these low-relief areas lie near the mountain crests (Figs. 2, 3, 4, 5). As with dome facets, low-relief areas are most strongly developed on rocks with strong mylonitic fabrics, and in some cases are a low-angle continuation of nearby dome facets.

High-relief areas have developed in the central parts of most core complexes where streams have incised through the mylonitic rocks into the less resistant granitic and metamorphic rocks below. In many places slopes of 30°–35° on these core rocks rise to vertical cliffs on the caprock of mylonite.

DRAINAGE PATTERNS AND DISSECTION

Overall drainage patterns are radial, with three major exceptions. (1) In several cases one drainage basin in a complex has been enlarged at the expense of others. Whipple Wash (Fig. 2) and Sabino Canyon (Fig. 3) are examples of this. (2) The stream pattern on upper-plate rocks tends to be rectangular rather than radial (e.g., Whipple Mountains, Fig. 2). (3) Many streams draining metamorphic core complexes flow parallel to the lineation direction. The most remarkable examples are found in the South Mountains near Phoenix (Fig. 5) and in the Rincon Mountains (Figs. 4, 6). In these mountains, streams flow down the axes of major antiformal ridges. The most notable examples are the streams flowing down Tanque Verde Ridge and Posta Quemada Canyon, both in the Rincon metamorphic core complex (Fig. 6).

In the South Mountains (see Fig. 3 of Reynolds and Rehrig, 1980), part of the lineation-parallel drainage has been captured by streams in the radial drainage pattern (Fig. 5). This has also occurred in the Rincon Mountains (e.g., the headwaters of Rincon Creek). These captures show that the lineation-parallel drainage pattern is older than the radial drainage pattern.

GEOMORPHIC EVOLUTION

Cameron and Frost (1981) and Spencer (1984) noted that metamorphic core complexes are associated with antiformal uplifts with axes either parallel or perpendicular to the direction of upper-plate transport. Domal uplift resulted where an antiform with its axis parallel to the transport direction formed at the same place as one with its axis perpendicular to the transport direction. Spencer (1984) presented models of tectonic denudation which predict the final form of a low-angle normal fault such as that represented by the detachment fault of metamorphic core complexes. All the models he considered produced an antiformal warp of the fault surface perpendicular to the transport direction (Fig. 7, A and B). Antiformal warps with their axes parallel to the transport direction and spaced along the perpendicular axis lead to the formation of a number of discrete domal uplifts which give the metamorphic core complexes their relief (Fig. 7C).

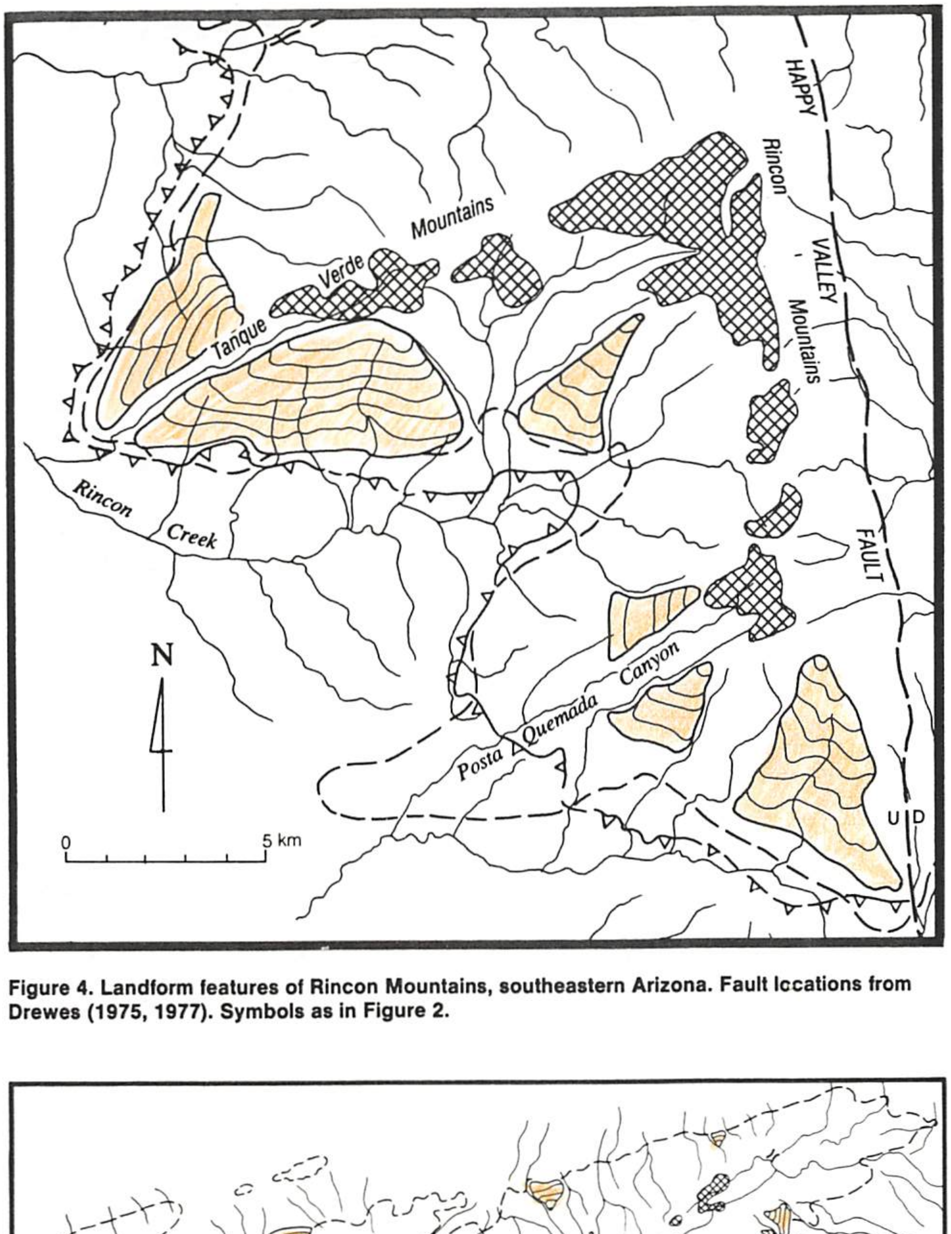

Figure 4. Landform features of Rincon Mountains, southeastern Arizona. Fault locations from Drewes (1975, 1977). Symbols as in Figure 2.

Figure 5. Landform features of South Mountain, central Arizona. Symbols as in Figure 2.

Most landforms in metamorphic core complexes resulted from exhumation of structures previously buried at depth. In areas structurally below the detachment fault, erosion may have been temporarily slowed by the microbreccia, but it would then have proceeded rapidly through the breccia zone. On reaching the mylonite, erosion rates would have slowed considerably, preserving this structural zone as dome facets and areas of low relief. In some areas, erosion has breached the mylonitic rocks and attacked the more erodible rocks below, producing much greater relief and degree of dissection.

Drainage lines that parallel the lineation direction, particularly those on the crests of antiformal ridges, are harder to explain. Two possibilities are suggested.

1. Drainage in the lineation direction could have been superimposed on the mylonites from above after arching took place. In this case, drainage developed in upper-plate rocks as they were being stripped from the mylonites. However, there is no evidence that the upper-plate ground surface ever sloped continuously away from the domed high of mylonite in the lineation direction. Instead, normal faults and elongate tilted fault blocks are perpendicular to the lineation direction, and topographic lows would run parallel to faults and fault blocks (Fig. 1) (e.g., south and east of Whipple Wash, Fig. 2). The chances of persistent drainage parallel to lineation being developed in upper-plate rocks therefore seems small.

2. Drainage parallel to the lineation direction may well have developed on a gentle sloping ramp of chloritic breccia exposed by tectonic denudation during warping and uplift perpendicular to the transport direction (Fig. 7, A and B). Initial incision through the chloritic breccia would develop valleys tens to hundreds of metres deep before streams encountered the much more resistant mylonites. Subsequent arching of the ramp, with arch axes parallel to lineation, would divert most drainage into a radial pattern. However, some lineation-parallel channels were left on the crests of anticlines and were able to maintain their former direction. Headward extension of radial streams would lead to the drainage captures best illustrated in the South Mountains (Fig. 7C).

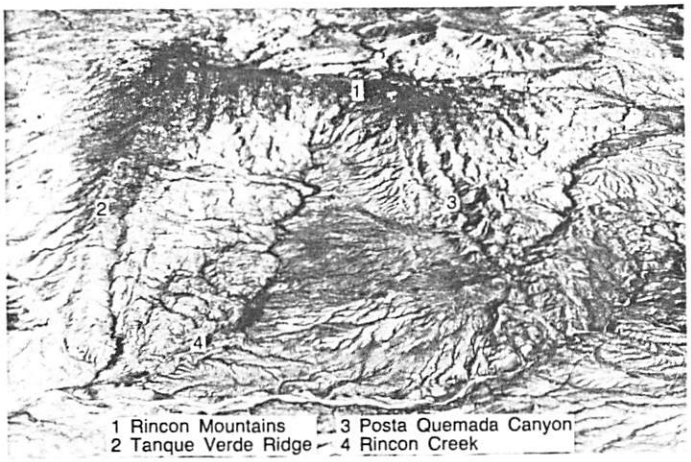

Figure 6. U2 oblique aerial photograph of Rincon Mountains metamorphic core complex, looking northeast. Drainage parallel to lineation is well developed around Posta Quemada Canyon. (Photograph supplied by G. H. Davis.)

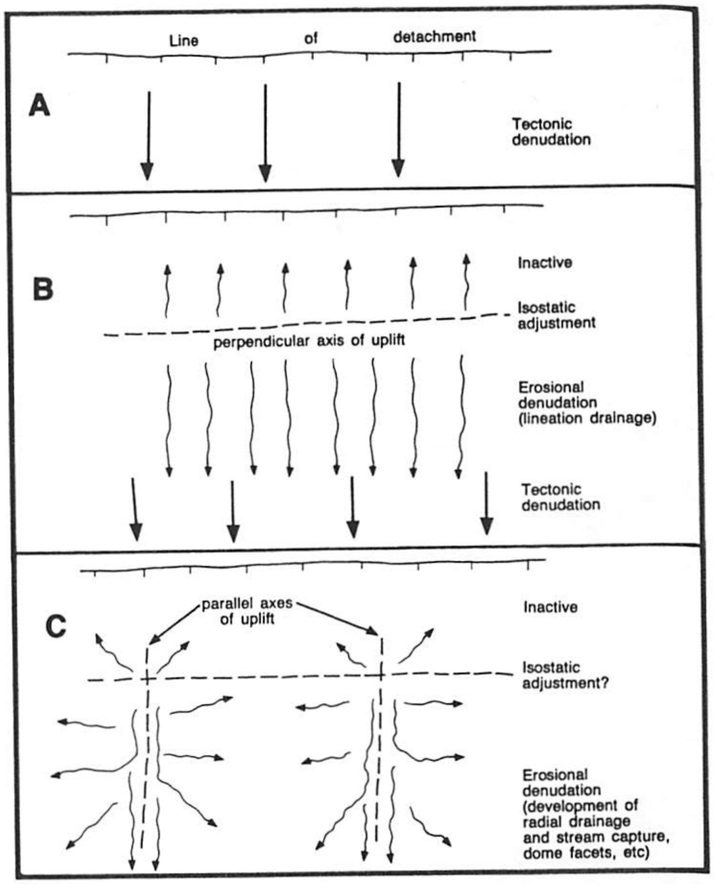

Figure 7. Postulated sequence leading to drainage patterns observed on some metamorphic core complex mountains. A: Tectonic denudation on low-angle normal faults. B: Isostatic adjustment leads to uplift along axis perpendicular to transport direction of upper-plate rocks. Drainage parallel to tectonic transport direction develops on exposed ramp. C: Arching and uplift occurs along axes parallel to transport direction, leading to domal forms. Radial drainage develops, and stream capture diverts most of lineation-parallel drainage. Continued erosional denudation leads to development of dome facets, low-relief areas, and deep incision of central part of uplifted antiforms. Incised, lineation-parallel channels are preserved on crests of lineation-parallel arches. (Tectonic sequence in part after Spencer, 1984.)

Landforms of metamorphic core complexes thus support the idea that there were two periods of antiformal arching in their development. The first occurred perpendicular to the tectonic transport direction of upper-plate rocks and led to the formation of a ramp down which streams flowed parallel to the lineation in the mylonites. The second period of antiformal arching occurred with arch axes parallel to the tectonic-transport direction, and it took place in part after the lower plate had been subareally exposed and incised by streams.

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