DAVID BLOOM

Late Cretaceous to early Tertiary ductile deformation: Catalina-Rincon metamorphic core complex, southeastern Arizona

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ABSTRACT

Detailed mapping and kinematic analysis have revealed east-vergent Late Cretaceous to early Tertiary ductile deformation in the eastern Santa Catalina Mountains within the Catalina-Rincon metamorphic core complex. A gently dipping tectonite fabric formed concurrently with greenschist to amphibolite facies metamorphism in Precambrian through Upper Cretaceous sedimentary and plutonic rocks. The tectonites contrast in age, lineation orientation, shear sense, and deformational style with younger mid-Tertiary mylonites that are kinematically coordinated with the detachment fault. The Late Cretaceous to early Tertiary deformation may reflect crustal thickening prior to mid-Tertiary extension of the complex.

INTRODUCTION

Cordilleran metamorphic core complexes are characterized by major low-angle normal (detachment) faults that separate a brittlely distended hanging-wall block from a footwall block of ductilely deformed metamorphic tectonites and their protoliths (Coney, 1980). Many workers (Crittenden et al., 1980, among others) have recognized that detachment faulting and hanging-wall brittle deformation represent profound Tertiary crustal extension. However, the relation between detachment faulting and lower-plate ductile deformation has been the subject of intensive study and debate. In some complexes the ductile deformation is kinematically, spatially, and temporally related to detachment faulting (e.g., Davis, 1980; Davis et al., 1986; Reynolds et al., 1986a; Tempelman-Kluit and Parkinson, 1986). In a second group of complexes, however, some of the ductile deformation is related to Mesozoic and early Tertiary compression (e.g., Haxel et al., 1984; John, 1986; Reynolds et al., 1986b). In this paper we present evidence that at least two distinct episodes of ductile deformation affected the Catalina-Rincon metamorphic core complex in southeastern Arizona, Late Cretaceous to early Tertiary ductile deformation (Keith et al., 1980; Drewes, 1981; Bykerk-Kauffman and Janecke, 1986) preceding mid-Tertiary extension (Davis, 1980, 1983; Dickinson, 1983; Naruk, 1986).

PREVIOUS INTERPRETATIONS OF THE CATALINA-RINCON CORE COMPLEX

The Santa Catalina Mountains form the northern half of the Catalina-Rincon metamorphic core complex in southeastern Arizona (Fig. 1). The timing and kinematic significance of ductile deformation and metamorphism in this range have been hotly disputed. Creasey et al. (1977) postulated that emplacement of a mid-Tertiary batholith caused the deformation. Keith et al. (1980) proposed three episodes of ductile deformation between the Late Cretaceous and the middle Tertiary. Keith (1983) and Keith and Wilt (1985) further suggested that most of the tectonites formed during Laramide southwest-directed overthrusting.

Similar interpretations have arisen from work in the Rincon Mountains in the southern part of the Catalina-Rincon complex. Drewes (1974, 1977, 1981) and Thorman and Drewes (1981) related the bulk of the ductile deformation to northeast-vergent Laramide thrust faulting, and Davis (1980), Lingrey (1982), and Lingrey and Davis (1982) attributed the ductile deformation to Tertiary extension.

Although there is no consensus on the tectonic significance of the ductile deformation in the complex, it is clear that detachment faulting and brittle distension of the hanging-wall block represent mid-Tertiary extension (Dickinson, 1983, 1984; Spencer and Reynolds, 1984). S-C mylonites (Berthe et al., 1979) on the southwest flank of the complex were derived, in part, from the 50–44 Ma Wilderness granite (Keith et al., 1980). In the nearby Tortolita Mountains, the mid-Tertiary Tortolita quartz monzonite displays a similar mylonitic fabric (Keith et al., 1980), indicating a mid-Tertiary age of the mylonites. Most of the mylonites on the southwest flank of the complex record southwest-directed shear, concordant with the sense of displacement on the detachment fault. This

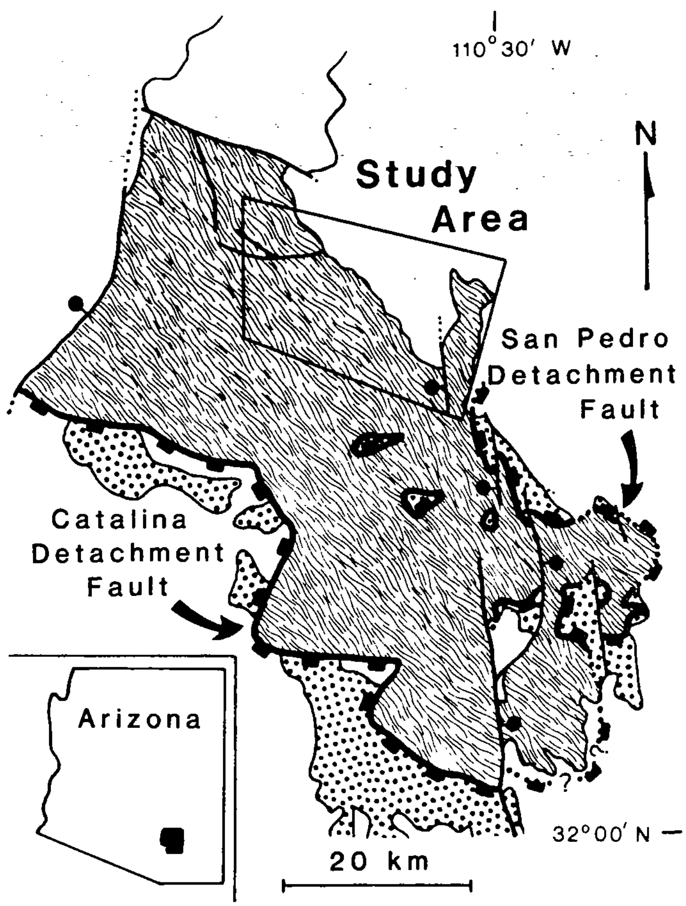

Figure 1. Tectonic map of Catalina-Rincon metamorphic core complex. Wavy-line pattern = footwall block; dot pattern = hanging-wall block. Locations of detachment faults compiled from Pashley (1966), Drewes (1974, 1977), Lingrey (1982), Dickinson (1983), and Bykerk-Kauffman (unpub. data).

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movement picture is complicated by a northeast-directed shear zone that offsets the zone of southwest-directed shear (S. Naruk, in prep.). However, like the southwest-directed zone, the northeast-directed zone is normal slip and therefore accommodated extension. Thus, both the age and kinematics of the mylonites strongly suggest that they represent ductile shear associated with mid-Tertiary extension and detachment faulting (Davis, 1983). It is not clear, however, whether all of the ductile deformation throughout the complex is related to mid-Tertiary extension or whether some of it is inherited from previous episodes of deformation.

Detailed mapping and kinematic analysis of deformational fabrics, structures, and crosscutting relations in the eastern Santa Catalina Mountains reveal an Upper Cretaceous to lower Tertiary tectonite fabric that records east-directed shear (Bykerk-Kauffman, 1986b; Janecke, 1986). Thus, the tectonites in this area are not related to mid-Tertiary southwest-directed detachment faulting. In this paper we describe the spatial distribution, geometry, physical expression, kinematics, and age of the Upper Cretaceous to lower Tertiary tectonites, contrast them with the detachment-related mylonites, and suggest that the Upper Cretaceous to lower Tertiary tectonites may record crustal thickening prior to mid-Tertiary extension.

GEOLOGIC SETTING OF THE LATE CRETACEOUS TO EARLY TERTIARY DEFORMATION

The study area is in the eastern Santa Catalina Mountains, structurally below the projection of the Catalina–San Pedro detachment fault system (Dickinson, 1984; Spencer and Reynolds, 1984) and northeast of the associated mylonite zone (Fig. 2). In this area, Proterozoic crystalline rocks and Proterozoic through Lower Cretaceous metasedimentary rocks generally dip homoclinally to the northeast. The strata have been metamorphosed under greenschist and lower amphibolite facies conditions, locally warped by northwest-trending folds, disrupted by several generations of faults, and intruded by three suites of plutons: the 74–64 Ma Leatherwood quartz diorite suite (including the Rice Peak granodiorite porphyry), the 50–44 Ma Wilderness granite suite, and the 29–27 Ma Catalina Granite suite (geochronology of Keith et al., 1980) (Fig. 2).

DESCRIPTION OF FABRIC

The metamorphic fabric in the northeastern part of the range has a subhorizontal foliation and an east-trending lineation (Fig. 2). The fabric elements are very consistent in orientation, even though foliation and lineation are expressed by a wide variety of features. Aligned and segregated phyllosilicates, pressure shadows, flattened mineral grains, new mineral growth, pressure solution seams, and deformed pebbles mark the foliation. Foliation generally parallels the λ_1-λ_2 plane of the strain ellipsoid, as evidenced by the shapes of deformed pebbles and mineral grains. Mineral growths, elongate and aligned phenocrysts, bedding-foliation intersections, deformed pebbles, and fold axes define the lineation. Granitic rocks locally display a mylonitic fabric.

The tectonite fabric is strongly influenced by lithology and by a north to south gradient of increasing metamorphic grade and strain intensity. Changes in the dominant deformation mechanisms coincide with this gradient. The rocks in the northern part of the study area are lowermost greenschist facies and show little evidence of penetrative deformation. The deformation that has occurred was accommodated by dissolution and brittle deformation mechanisms. In the central part of the area, where metamorphism reached middle greenschist facies, the competent quartzite and dolomite units are typically little affected by the deformation, whereas weaker calcite-rich beds and phyllites exhibit strong foliation and linea-

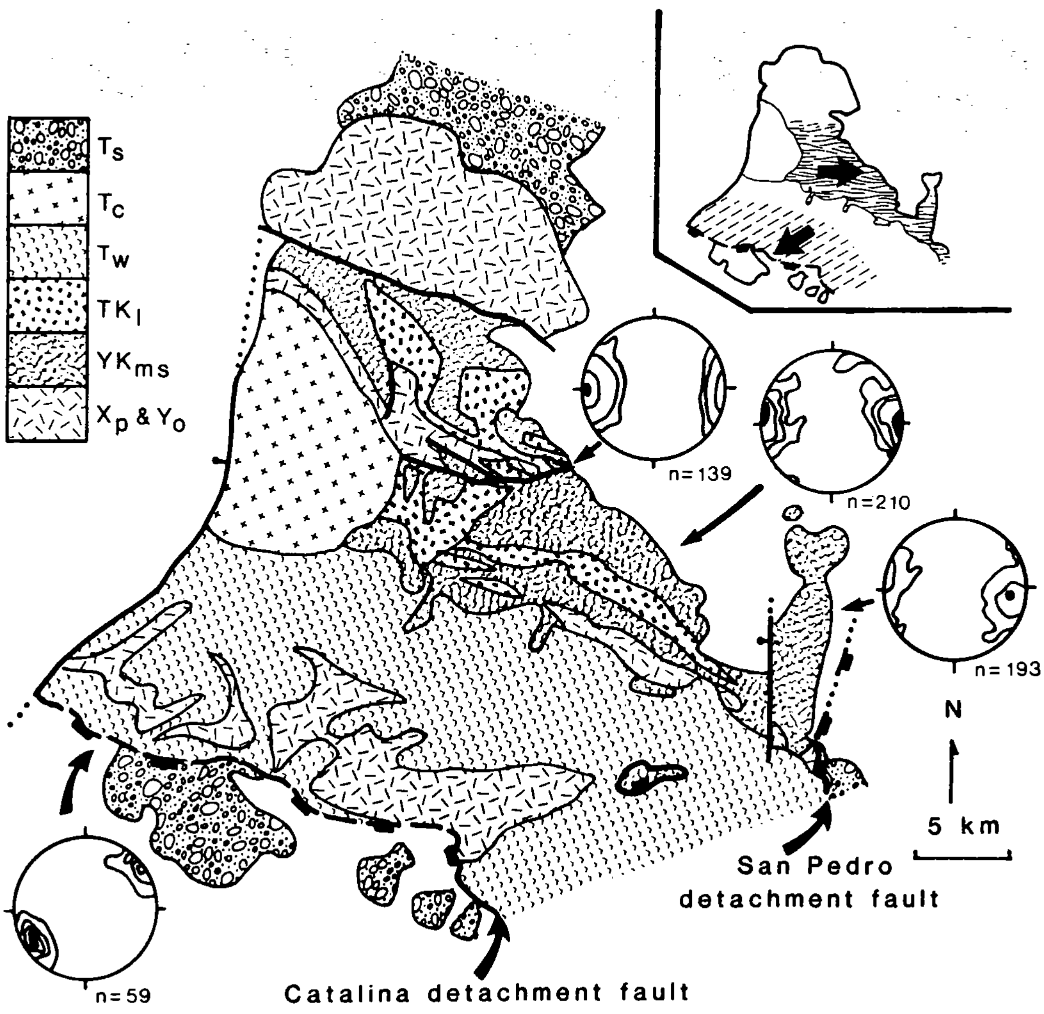

Figure 2. Generalized geologic and tectonic map of Santa Catalina Mountains showing distribution of Proterozoic Pinal Schist and 1400 Ma Oracle Granite (X_p & Y_o), Proterozoic through Cretaceous sedimentary and metasedimentary rocks (YK_{ms}), 74–64 Ma Leatherwood suite plutons (TK_l), 50–44 Ma Wilderness suite granites (T_w), 29–27 Ma Catalina suite granite (T_c), and Oligocene-Miocene sedimentary rocks (T_s). Contoured equal-area, lower-hemisphere projections of lineation orientations are shown for selected areas. Inset shows areas affected by mid-Tertiary mylonitization (dashed lines) and Early Cretaceous to early Tertiary regional metamorphism (wavy lines). Lines approximately parallel lineation. Arrows show predominant sense of shear. Compiled from Creasey (1967), Creasey and Theodore (1975), Banks (1976, 1980), Dickinson (1983), Bykerk-Kauffman (1983, 1986a, and unpub. data), and Janecke (1986).

tion, and bedding is locally transposed by the fabric. Calcite is deformed by dislocation creep, and quartz is deformed by brittle fracture and dissolution. Feldspar is fractured and altered to phyllosilicates. Pressure shadows are common around competent grains, and new phyllosilicate and calc-silicate grains parallel foliation surfaces. In the southern part of the area, near the contact with the Wilderness pluton, metamorphism reaches amphibolite facies, and dislocation creep was the dominant deformation mechanism; it was locally operative even in feldspar grains.

As the magnitude of strain increases toward the south, the type of strain changes from pure flattening to flattening with a component of elongation. Deformed limestone cobbles in the central part of the area record these changes; aspect ratios range from 6:6:1 through 13:13:1 to 60:16:1 from north to south (Bykerk-Kauffman, 1983). Farther south, strain increases to the point where individual limestone cobbles are no longer recognizable.

AGE OF FABRIC

The age of the tectonite fabric is well constrained by crosscutting relations with the detachment fault and various plutonic rocks. Deformation must postdate 74 Ma because the 74–64 Ma Leatherwood suite plutons display the tectonite fabric (Keith et al., 1980; Bykerk-Kauffman, 1983, 1986a, 1986b; Janecke, 1986). The tectonites are truncated by the mid-Tertiary San Pedro detachment fault (Bykerk-Kauffman, unpub. data); thus, deformation predates detachment faulting.

The relation between the tectonite fabric and the 50–44 Ma Wilderness granite further brackets the age of the ductile deformation. Metamorphic grade increases toward the Wilderness granite, suggesting that the pluton acted as a heat source for the metamorphism. In general, metamorphic minerals are aligned with the foliation. However, metamorphic minerals have grown across the foliation in the high-grade rocks immediately adjacent to the Wilderness pluton. The main body of the Wilderness granite is undeformed, and in most places the pluton intrudes across the tectonites. Small dikes of the granite are locally deformed, however (Bykerk-Kauffman, 1986b). The dikes are offset along C(slip)-surfaces in surrounding S-C mylonites, and they display an incipient mylonitic foliation parallel to the foliation in the deformed country rock. Thus, the granite appears to have intruded late during deformation. These lines of evidence indicate that deformation occurred in Late Cretaceous to early Tertiary time, beginning after 74 Ma and continuing until 50–44 Ma.

KINEMATICS

A wide variety of asymmetric kinematic indicators show that the deformation involved shear strain. Indicators include S-C foliations in granitic rocks, offset markers, outcrop-scale shear zones in quartzites and diabase intrusions, sheath folds in carbonates and phyllites, and elongate, dynamically recrystallized calcite grains oriented oblique to the macroscopic foliation in calc-mylonites. More than 100 examples of these indicators observed throughout the area consistently indicate a component of east-directed shear, parallel to the east-trending lineation.

Four major ductile faults parallel the metamorphic fabric and probably result from the same episode of east-directed shear that formed the fabric (Janecke, 1986; Bykerk-Kauffman, 1986b). Three of these faults place rocks in younger-on-older juxtaposition, implying extension. However, there is evidence for previous episodes of deformation that could have tilted the section. In addition, the structurally highest fault, which has the greatest stratigraphic throw, puts older rocks on younger rocks. Thus, the ductile faults and the metamorphic fabric are probably in essence compressional features.

CONTRAST BETWEEN LATE CRETACEOUS TO EARLY TERTIARY AND MID-TERTIARY DUCTILE DEFORMATION

The Upper Cretaceous to lower Tertiary metamorphic fabric in the eastern Santa Catalina Mountains records east-directed ductile shear. By contrast, the mid-Tertiary extensional fabric on the southwestern side of the range records predominant southwest-directed ductile shear (Fig. 2). In addition to the differences in age, spatial distribution, and sense of shear between the two fabrics, there are differences in strain, association with a major structure, and fabric characteristics.

Within granitic mid-Tertiary mylonites, strain is fairly uniformly distributed, at least on the scale of tens of metres within the same lithology. By contrast, strain distribution is quite heterogeneous in granites affected by the Late Cretaceous to early Tertiary deformation; most of the strain is confined to widely scattered discrete zones that are a few metres thick.

Many of the mylonites on the southwest flank of the Santa Catalina Mountains are spatially, geometrically, and kinematically associated with one major structure, the Catalina detachment fault (Davis, 1983; Naruk, 1986). On the eastern flank of the range the metamorphic fabric is also geometrically and kinematically associated with several low-angle faults (Bykerk-Kauffman, 1983, 1986b; Janecke, 1986). However, much of the variation in intensity of the regional metamorhic fabric is related to increasing metamorphic grade toward the 50–44 Ma Wilderness pluton. Thus, variations in the magnitude of strain in the Late Cretaceous to early Tertiary domain are associated with variations in temperature conditions during deformation, as well as proximity to faults.

In a regional study of metamorphism in Arizona, Reynolds et al. (1987) recognized differences in the character of fabrics formed during middle Tertiary mylonitization and those formed during Mesozoic and early Tertiary metamorphism and thrusting. These differences are also evident in the two ages of fabrics in the Santa Catalina Mountains. For the same degree of foliation development, the Late Cretaceous to early Tertiary tectonites are less lineated than the mid-Tertiary tectonites. The mid-Tertiary tectonites are all mylonites, whereas the Upper Cretaceous to lower Tertiary tectonites are generally schists, phyllites, marbles, and quartzites; only the marbles and granites are locally mylonitic. Late Cretaceous to early Tertiary deformation was contemporaneous with prograde metamorphism in the metasedimentary rocks, and new mineral grains commonly define foliation and lineation. Mid-Tertiary mineral assemblages remained unchanged or regressed during mylonitization, and the fabric is defined by deformed preexisting grains. These characteristics may be useful elsewhere for the differentiation of compression- and extension-related metamorphic tectonites.

SUMMARY AND DISCUSSION

East-vergent Late Cretaceous to early Tertiary ductile deformation has affected much of the eastern Santa Catalina Mountains. A metamorphic fabric formed between 74 and 44 Ma in sedimentary and plutonic rocks. The fabric intensity, strain magnitude, and metamorphic grade generally increase toward the 50–44 Ma Wilderness granite, which intruded late during deformation.

Our work supports, in general, the interpretations of Keith et al. (1980), Drewes (1981), Thorman and Drewes (1981), Keith (1983), and Keith and Wilt (1985) that predetachment ductile deformation is indeed widespread in the Santa Catalina Mountains. These authors, however, did not recognize the east-trending lineation nor the east-directed shear that pervades the eastern flank of the range. We also differ with Drewes (1981), Thorman and Drewes (1981), Keith (1983), and Keith and Wilt (1985) on the interpretation of the mylonites on the southwest flank of the range: we relate them to mid-Tertiary extension and detachment faulting, whereas they related these mylonites to Laramide compression.

The timing and character of deformation in the eastern Santa Catalina Mountains are similar to Late Cretaceous to early Tertiary ductile deformation described by Haxel et al. (1984) in south-central Arizona. Haxel et al. (1984) related greenschist to lower amphibolite facies metamorphism to major thrust faulting and intrusion of syntectonic early Tertiary peraluminous granites; they interpreted this deformation as a crustal thickening event. Although lineation orientations in south-central Arizona differ considerably from those in the Santa Catalina Mountains, the similarities in age, metamorphic grade, fabric, and association with peraluminous granites suggest that deformation in these two areas may be broadly correlative.

The timing of deformation, the possible correlation with the crustal thickening event in south-central Arizona, and the association with a peraluminous pluton all suggest that the ductile deformation in the eastern Santa Catalina Mountains records a compressional event. Thus, our work may support the models of Armstrong (1982), Coney and Harms (1984), and England et al. (1985) that relate extension in metamorphic core complexes to an overthickened crust that had been created by previous episodes of compression. These models predict a spatial association of Tertiary extensional fabrics and Mesozoic–lower Tertiary structures and metamorphic fabrics, as in the Catalina-Rincon core complex.

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