Stacked Overthrusts of Precambrian Crystalline Basement and Inverted Paleozoic Sections Emplaced over Mesozoic Strata, West-Central Arizona

by

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Abstract

Geologic mapping in the western Harquahala Mountains and Little Harquahala Mountains of west-central Arizona has documented an extensive sequence of subhorizontal thrust sheets. The thrust sheets contain Precambrian crystalline basement and locally inverted Paleozoic strata and have been emplaced over Mesozoic rocks. Structural relationships suggest that large southeast-vergent folds in the Paleozoic rocks have been discordantly severed by a later episode of thrusting that is interpreted to have northerly or north-northeast transport. Preliminary geochronologic data indicate that the thrusts are Late Cretaceous or early Tertiary and represent a crucial link in a belt of crystalline (basement-involved) thrusts that extends from the Papago country of southern Arizona into southeastern California.

Introduction

Recent geological mapping in the western Harquahala Mountains of west-central Arizona (Fig. 1) has documented an extensive sequence of subhorizontal thrust sheets. The thrust sheets contain Precambrian crystalline basement and locally inverted strata and have been emplaced over Mesozoic sedimentary rocks. Reconnaissance suggests that the thrust-sheet stratigraphy in the western Harquahala Mountains extends into the eastern Harquahala and Little Harquahala Mountains. These detailed and reconnaissance observations, in conjunction with regional considerations, indicate that a major thrust-fault terrane is present in west-central Arizona, the extent of which has been previously unrecognized.

The existence of large-scale thrusts in the western Harquahala Mountains has not been adequately discussed because the area had been mapped only in reconnaissance fashion by earlier workers (Wilson, 1960; Rehrig and Reynolds, 1980). Wilson (1960) was the first to map (but did not describe) a thrust fault in the Harquahala Mountains that placed Precambrian schist on undifferentiated Paleozoic and

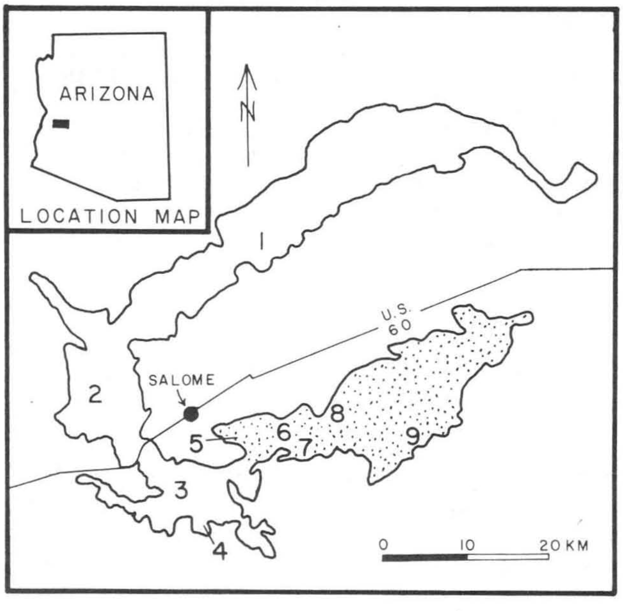

Fig. 1. Location of map for Harquahala Mountains (stippled) and vicinity. 1 - Harcuvar Mountains, 2 - Granite Wash Mountains, 3 - Little Harquahala Mountains, 4 - Martin Peak, 5 - S Mountain, 6 - Tenahatchapi Pass, 7 - Socorro Peak area mapped by Varga (1976, 1977), 8 - White Marble mine area, 9 - "Paleozoic window" mapped by Wilson (1960).

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Mesozoic rocks. He also mapped the lower contact between the Paleozoic-Mesozoic rocks and an underlying granite as a fault. Varga (1976, 1977) mapped and described folded Paleozoic rocks in the westernmost Harquahala Mountains. He inferred that the underlying granite was intrusive into the Paleozoic section and therefore post-Paleozoic. Rehrig and Reynolds (1977, 1980) examined the geology of parts of the Harquahala Mountains and surrounding ranges and recognized several Mesozoic-Tertiary events of metamorphism, plutonism, and deformation. They discussed the presence of low-angle faults in the Little Harquahala Mountains and described Tertiary mylonitization and dislocation phenomena in the eastern Harquahala Mountains that are, in part, considered characteristic of metamorphic core complexes (Coney, 1979; Davis and Coney, 1979). Rehrig and Reynolds (1977, 1980) did not discuss in detail the geology of the western Harquahala Mountains.

Within the past 6 years, we have mapped parts of the Little Harquahala and western Harquahala Mountains and have done much reconnaissance of the entire west-central Arizona region (see, for example, Reynolds, this volume; Rehrig and Reynolds, 1980; Coney, 1978). This mapping has been augmented by observations of Ed DeWitt, H. Wesley Peirce, William A. Rehrig, and Stephen M. Richard, Discussions with T. H. Anderson, G. H. Davis, W. R. Dickinson, L. E. Harding, G. Haxel, L. T. Silver, and R. Tosdal have provided additional perspective. Our studies of the area are continuing, but the relationships discussed below are so provocative and clearly expressed that they merit this preliminary research note. It is especially timely because of the current "great southwestern Arizona overthrust oil and gas play" (see Keith, 1979, 1980).

Geological Relationships

The geologic framework of the surrounding region has been summarized elsewhere in this and other volumes (Reynolds, this volume; Shafiqullah and others, this volume; Coney, 1978). Precambrian metamorphic and plutonic rocks are basement for a cratonic sequence of Paleozoic carbonate and clastic strata. Mesozoic rocks include volcanic and plutonic remnants of a magmatic arc that are overlain by thick sections of clastic rocks. Mesozoic to Tertiary plutonism, metamorphism, and deformation have been documented for large parts of the region (see summary and references cited in Reynolds, this volume). In addition, there is evidence for Tertiary mylonitization (with east-northeast-trending lineation) and listric normal faulting above low-angle dislocation surfaces in the eastern Harcuvar and Harquahala Mountains (Rehrig and Reynolds, 1980).

In the western Harquahala Mountains, structures are more complex than in many areas of the surrounding region (Fig. 2). The structural geology of the western Harquahala Mountains is dominated by a sequence of at least four thrust sheets and by extensive areas of steeply southeast-dipping to absolutely upside-down Paleozoic strata. In effect, the low-angle thrust sheets comprise a "thrust stratigraphy" that contains five distinctive terranes (Fig. 3), which are (from lowest to highest structural levels): (1) Mesozoic sedimentary rocks: (2) Precambrian metamorphic and granitic rocks; (3) Paleozoic carbonate and clastic rocks with local areas of attached Precambrian granite; (4) highly deformed, porphyritic Precambrian (?) granite; and (5) Precambrian crystalline rocks. We will outline the thrust stratigraphy beginning with the structurally low Mesozoic rocks.

Mesozoic Rocks

The structurally lowest rocks are a sequence of Mesozoic arkosic sandstones, calcareous clastics, quartzites, and quartz-pebble conglomerates exposed near S Mountain, south of Salome (Figs. 1 and 2). These rocks occupy a structural window beneath an overlying thrust sheet of Precambrian crystalline rocks. The Mesozoic rocks are metamorphosed to low grades but are correlative to Mesozoic rocks in adjacent areas (see references in Reynolds, this volume, and in Harding, this volume). Rocks similar to those at S Mountain are exposed in the central Little Harquahala Mountains where they are likewise overlain by a thrust sheet of Precambrian crystalline rocks (Rehrig and Reynolds, 1980).

Precambrian Crystalline Sheet

Mesozoic rocks in the window at S Mountain are overlain by a gently inclined thrust fault, above which lie foliated quartz diorite and mafic gneisses of probably Precambrian age. These rocks are evidently only the westernmost part of a large terrane of metamorphic rocks that crop out west of Tenahatchapi Pass (Varga, 1976, 1977). These metamorphic rocks are lithologically similar to known Precambrian rocks of the region and have been preliminarily dated by Rb-Sr whole-rock methods as Precambrian (Rehrig and Reynolds, unpublished data). Along Tenahatchapi Pass (Figs. 1 and 2), the high-grade metamorphic rocks are intruded on the east by a porphyritic granite (Varga, 1976, 1977). A Precambrian age is indicated for the granite by its lithology, by Rb-Sr analyses (Rehrig and Reynolds, unpublished data), and by our observation that locally the granite is unconformably overlain by Cambrian Bolsa Quartzite. The porphyritic granite strongly resembles the well-dated 1400- to 1450-m.y.-old granite suite described by Silver (1978). The porphyritic granite and the Precambrian gneiss that it intrudes constitute the upper plate of the lowest thrust we have mapped so far. A terrane of porphyritic granite and amphibolite gneisses similar to that in the Tenahatchapi Pass area is exposed in the Little Harquahala Mountains where it tectonically overlies Mesozoic clastic and volcanic rocks (Rehrig and Reynolds, 1980).

Paleozoic Sheet

In numerous exposures in both ranges, the porphyritic granite is in low-angle fault contact with an overlying sequence of Paleozoic rocks. In some exposures, the fault abruptly truncates the stratigraphic section in the Paleozoic strata and rocks as young as Pennsylvanian-Permian are faulted against the underlying brecciated granite. In other localities such as north of the White Marble mine and west of Martin Peak (Figs. 1 and 2), the porphyritic granite is depositionally overlain by Cambrian Bolsa Quartzite. In these areas, we infer that the fault exists below the depositional contact and juxtaposes granite on granite. Therefore, the Paleozoic section and minor amounts of attached Precambrian granite and Mesozoic rocks constitue the second sheet of rocks underlain by low-angle faults.

In the Little Harquahala and westernmost Harquahala Mountains, the Paleozoic section is only slightly metamorphosed but is folded on a large scale, with much of the strata overturned to varying degrees to the southeast (Wilson, 1960; Varga, 1976, 1977; Rehrig and Reynolds, 1980). In the area of the White Marble mine and farther to the southwest, the Paleozoic section can be demonstrated to be upside-down, although gently dipping. All stratigraphic units from Cambrian Bolsa Quartzite through Permian Coconino quartzite can be observed in correct order but are inverted. There are many incompletely resolved complications in the Paleozoic sheet, including granite fault slices, numerous low-angle fault imbrications, and abrupt juxtaposition of upside-down and right-side-up sections. Nevertheless, overturning is apparently related to large-scale, southeast-vergent folding such as described by Varga (1976, 1977).

Fifteen kilometers east-southeast of the White Marble mine (Fig. 1), an extensive area of metamorphosed Paleozoic rocks is exposed in the southeastern Harquahala Mountains (Wilson, Moore, and Cooper, 1969; Rehrig and Reynolds, 1980). Reconnaissance mapping by Wilson (Wilson and others, 1969) indicates that the Paleozoic section is in low-angle tectonic contact with overlying and underlying Precambrian crystalline rocks. Limited reconnaissance in the area by S. Reynolds and E. DeWitt affirms these relationships in a general way. It is our present view that the Paleozoic rocks of this area represent a continuation of the Paleozoic sheet we have mapped in the western Harquahala Mountains.

Porphyritic Granite Sheet

In the White Marble mine and extending farther to the south, the inverted Paleozoic rocks are overlain by a thin thrust sheet of mylonitically deformed, porphyritic Precambrian(?) granite. The contact between the Paleozoic rocks and the overlying granite is a sharp fault, which commonly contains southerly trending slickensides. Mylonitic foliation in the granite is subparallel to the underlying thrust fault, and lineation in the mylonitic granite is subparallel to slickensides on the fault surface. The granite comprises the third and thinnest of the four major thrust sheets. This sheet is of remarkably uniform thickness (30 to 150 m) throughout much of the map area.

Precambrian Crystalline Sheet

Above the thrust sheet of granite is a thicker (locally at least 1,500 m) sheet consisting of probably Precambrian quartzo-feldspathic gneiss, amphibolite, and granitic rocks. The contact between the metamorphic rocks and the underlying granite is a well-defined mylonitic zone. This profound structural discontinuity has been mapped by us for over 10 km to the northeast into the central Harquahala Mountains and extends well beyond the present limits of our mapping. Foliation and lineation in the mylonitic zone parallel those of the underlying granite. Folds exposed in the mylonitic zone have a predominant north to north-northeast vergence. Above the mylonitic zone, the metamorphic rocks exhibit their original steep Precambrian foliation.

Kinematics and Timing of Deformation

There is clear evidence for two major episodes of deformation in the western Harquahala and Little Harquahala Mountains: an early period of folding with southeast vergence and a later period of north or north-northeast thrusting. The main evidence for the temporal priority of the southeast-vergent, recumbent folding is provided by field relationships at the White Marble mine. Here, *both* limbs of a large, southeast-overturned fold in the Paleozoic plate are *discordantly* truncated by low-angle thrusts, indicating that folding predated thrusting. A somewhat similar relationship exists in the Little Harquahala Mountains (Reynolds, this volume).

Transport direction for the thrusting is indicated by abundant slickensides, lineations, and folds associated with the thrusts. Hundreds of southerly trending (south ± 30°) slickensides have been observed on Bolsa Quartzite immediately beneath the porphyritic granite thrust

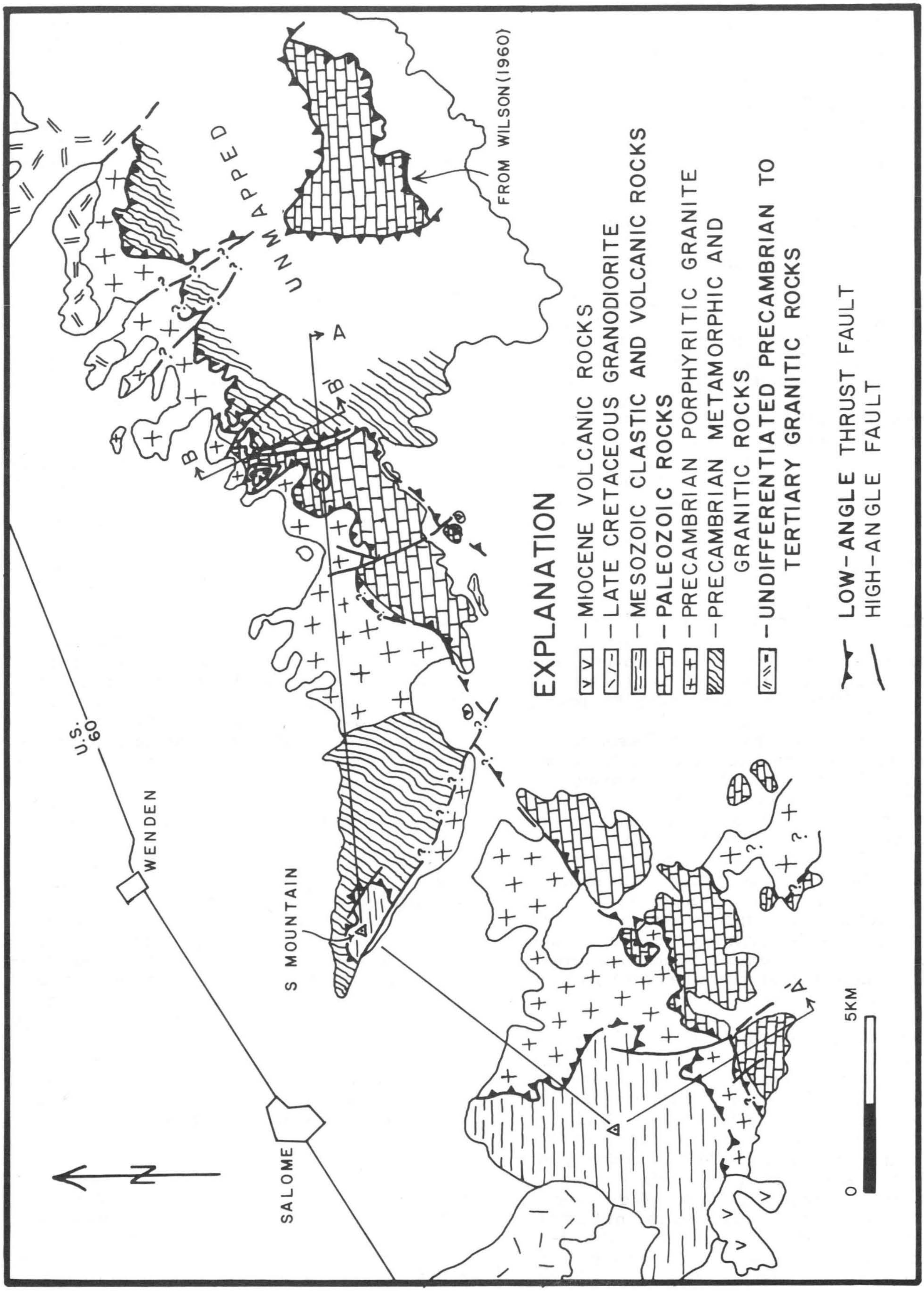

Fig. 2. Generalized geologic map of the western Harquahala Mountains and Little Harquahala Mountains. Includes data from Wilson (1960), Varga (1976, 1977), Rehrig and Reynolds (1980), and new geologic mapping by S. B. Keith and S. J. Reynolds.

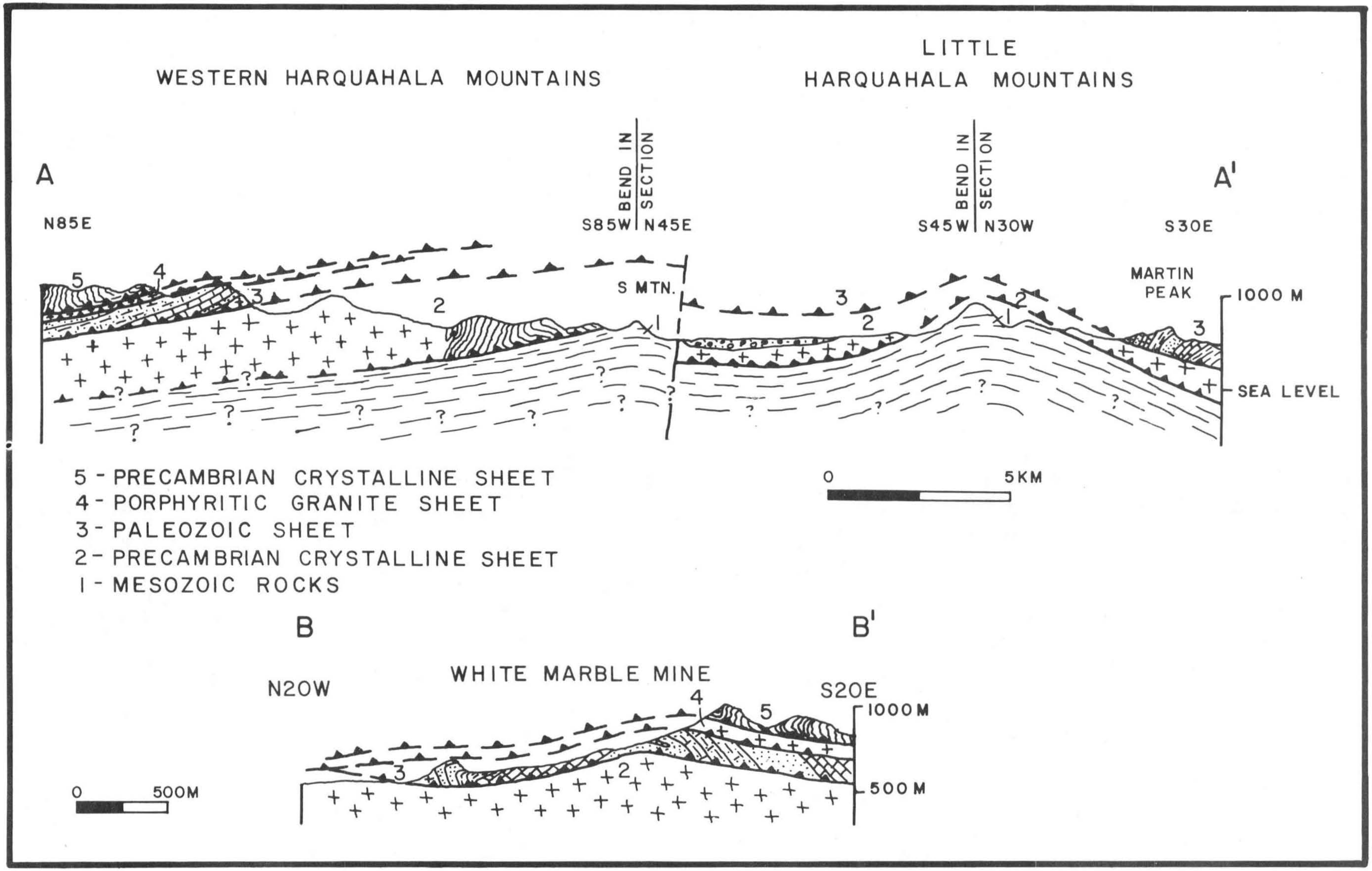

Fig. 3. Schematic cross sections A-A' and B-B'. See Figure 2 for location of cross sections. Note that A-A' is viewed to the south and east.

sheet near the White Marble mine. Lineation in the overlying granite and Precambrian crystalline sheets is parallel to slickensides in the quartzite. The sense of tectonic transport is provided by the north or north-northeast vergence of numerous kink-style folds in mylonitic rocks above the quartzite. The distance of transport is unknown, but movements over distances of tens of kilometers would have been required to produce the overlaps observed in the four thrust sheets. The total distance of transport was possibly *much* greater.

Timing for the southeast-vergent folding event is only loosely constrained to post-Paleozoic in the Harquahala Mountains, but regional relationships discussed by Reynolds (this volume) and newly obtained paleomagnetic data of Harding and others (1980) appear to bracket the deformation between mid-Jurassic and mid-Cretaceous. In the Harquahala Mountains, the thrusting postdates the southeast-vergent folding and predates muscovite pegmatites of probably early Tertiary age. Preliminary correlation of metamorphic fabrics in the Harquahala Mountains with dated fabrics in the Harcuvar Mountains (Rehrig and Reynolds, 1980) indicates a Late Cretaceous to early Tertiary age for thrusting.

Summary

In summary, a sequence of four thrust sheets is exposed in the western Harquahala Mountains, and correlatives of the two lowest sheets are exposed in the Little Harquahala Mountains (Fig. 3). Mesozoic strata are the structurally lowest rocks observed (so far) and are successively overlain by thrust-bounded sheets of: (1) Precambrian metamorphic and granitic rocks; (2) locally inverted Paleozoic and clastic strata with minor attached Precambrian granite; (3) mylonitically deformed, porphyritic Precambrian (?) granite; and (4) Precambrian crystalline rock. Local field relationships and regional considerations suggest that southeastward-vergent folding of the Paleozoic rocks predates and is discordantly cut by later thrusting that had tens of kilometers of north or north-northeast transport. Geochronologic study of the area is incomplete but preliminary data indicate a Late Cretaceous or early Tertiary age for the thrusting.

Regional Implications

Low-angle faults that involve Precambrian crystalline basement and possess clear older-on-younger juxtaposition have not been previously described for this area. Also, the presence of crystalline thrusts in west-central Arizona has not been discussed in the various regional tectonic syntheses of western North America. It is, however, becoming increasingly apparent to us that thrusts constitute a major tectonic element of the area. Our mapping raises the possibility or probability that large terranes of "normal Precambrian basement" in western Arizona are allochthonous, perhaps to startling degrees.

We are currently attempting to correlate the thrusts described herein with those we have mapped or observed in adjacent ranges. Much of the thrust geology mapped by Miller (1970) in the southern Plomosa Mountains 50 km to the west is similar in style to thrusts of the Little Harquahala Mountains. Miller described a stack of basement-involved thrust sheets emplaced over Mesozoic clastic strata. Thrusts involving crystalline basement and Mesozoic rocks may be very widespread in the Mohave Desert of southeastern California (Hamilton, 1971; Pelka, 1973; Howard, Miller, and Stone, 1980). In addition, Haxel and others (this volume) have reported thrust-fault relationships in the Papago Indian Reservation of southern Arizona that are extremely similar to those observed by us in west-central Arizona. The west-central Arizona thrust-fault terrane is a crucial connecting segment of a major belt of crystalline (basement-involved) thrusts that extends from the Papago country through western Arizona and into the Mohave Desert of southeastern California. Throughout much of the thrust belt, Mesozoic rocks are lower plates to thrust sheets that, from place to place, contain Precambrian crystalline basement, Paleozoic strata, and Mesozoic igneous and sedimentary rocks. Along its extent, thrusting is evidently Late Cretaceous or early Tertiary (Haxel and others, this volume; Miller and McKee, 1971; Pelka, 1973; Howard and others, 1980).

Our understanding of this thrust belt will surely increase as we continue mapping and studying its tectonic elements. The results of these studies may drastically alter our perception of the tectonics of the region. In addition, they may have profound implications for the current "great southwestern Arizona overthrust oil and gas play" in which companies are beginning to explore for oil beneath hypothesized overthrust sheets of Precambrian crystalline rocks (Keith, 1979, 1980).

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