Description and Analysis of Mesozoic "Red Beds," Western Arizona and Southeastern California

by

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Abstract

Thick, Mesozoic clastic sequences crop out in western Arizona and southeastern California. The basal portions of a number of these sequences are lithologically similar and possibly correlative. Detailed study of this basal unit in the Plomosa Mountains, western Arizona, shows that it consists of a complex assemblage of coarse- to fine-grained, quartz-rich clastic rocks and very finely crystalline, gypsiferous carbonate rocks. Statistical analysis indicates that lithologic types are arranged stratigraphically as a succession of fining-upward cyclothems. These cyclothems probably represent channel, point-bar, and flood-basin accumulations of a meandering stream system. Orientation of cross-stratification and pebble imbrication indicate sediment transport from the north or northwest. Pebble composition and detrital mineralogy indicate that the source terrane primarily consisted of a Paleozoic cratonic sequence. Fossil angiosperm wood occurrences and intrusive and metamorphic relationships in possibly correlative strata combine to suggest an Early Cretaceous age for the fluvial cyclothems. The thick, Mesozoic clastic sequences may have been deposited in an east-west-trending, block-fault basin system. These thick sequences may be correlative with and genetically related to the Lower Cretaceous Bisbee Group of southeastern Arizona.

Introduction

The stratigraphic succession and relationships in western Arizona are poorly understood. As a result, the paleotectonic history of the region is largely speculative. Especially intriguing and problematical is the occurrence of extremely thick clastic sequences of probably Mesozoic and possibly Early Tertiary age (Harding, 1978; Miller, 1966, 1970; Pelka, 1973; Robison, 1979). These sequences crop out along a westerly trend in western Arizona and southeastern California (Fig. 1). This paper focuses on the basal portion of the sequence exposed in the Plomosa Mountains, western Arizona. Here, the basal portion, informally referred to as the red beds, is well exposed and mapped.

The Red Beds

The red beds in the Plomosa Mountains consist of a complex assemblage of coarse- to fine-grained clastic and very finely crystalline carbonate rock types. The various lithologic types are not separable into distinct members; rather they occur in an interbedded fashion. All rock types commonly occur within a very short stratigraphic interval.

In order to discuss the characteristics of these rocks in a coherent manner, rocks have been grouped into five major categories: conglomerate, sandstone, siltstone, mudstone, and carbonate rock. Division of the clastic rocks is somewhat artificial because clastic rocks within the red beds form a texturally continuous spectrum from conglomerate to mudstone (Robison, 1979).

Mudstone

Mudstone comprises approximately 40 percent of the red beds and is the most abundant lithologic type. Color varies from grayish red purple to grayish purple. Penetrative cleavage is well developed, and much mudstone has a slight phyllitic luster.

Mudstone units range from 0.2 to 9.5 m in thickness and have an average thickness of 2.3 m. Mudstone units generally are laterally continuous for more than 50 m. Generally, mudstone appears massive, but rarely, thin beds (terminology of McKee and Weir, 1953)

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are visible. Mud cracks (Miller, 1966), vertical burrows, bioturbated sediment, and root structures(?) occur, but other sedimentary structures that may exist are obscured by cleavage.

Mudstone primarily consists of hematitic and argillaceous material that has been partially recrystallized to microcrystalline quartz, chlorite, and sericite. Very finely crystalline calcite is also common, and much mudstone has been very slightly dolomitized. Isolated grains of sand- to silt-sized quartz are common, and chert, muscovite, magnetite, rutile, tourmaline, and zircon may be present in trace amounts. Rarely, intraclasts of siltstone or mudstone occur.

Sandstone

Sandstone comprises approximately one-fourth of the stratigraphic section and is the most prominent cliff- and ledge-forming lithology within the red beds. Color varies from light shades of red and pink to gray but is generally obscured by a black coating of desert varnish.

Sandstone units of uniform composition and texture range in thickness from 0.3 to 6.3 m. Average thickness is 1.6 m. Thickness is generally variable along strike, and sandstone units may be discontinuous. Most sandstone units occur in composite sets that overlie channel-form conglomerates and are gradational with them.

Individual sandstone units commonly consist of thin to thick beds of very thinly bedded to laminated strata. Bedding and grain size are directly related in that thinner beds tend to be finer grained than thicker beds. Within any given composite set, bedding thickness and grain size commonly decrease upward.

Cross-stratification is locally well developed. Medium- to small-scale, medium- to low-angle, trough and tabular planar sets are most common. Other sedimentary structures include heavy mineral concentrations along bedding planes, cuspate and parallel ripples, and parting lineation.

Sandstone generally consists of medium to very fine, well-rounded to subrounded grains that are moderately sorted. Detrital monocrystalline quartz is the primary component of all of the sandstone. Lithic grains of chert also are common but very rarely make up more than 15 percent of the detrital constituents. Muscovite, tourmaline, rutile, and zircon are commonly present in trace amounts, but detrital feldspar is almost nonexistent. Very fine grained sandstone contains abundant matrix and is gradational with siltstone.

Siltstone

Approximately 15 percent of the red beds are siltstone. The color of most siltstone is grayish red purple or a shade of red. Penetrative cleavage is common.

Siltstone units range in thickness from 0.1 to 2.9 m and have an average thickness of 1.2 m. Siltstone is generally thin to thick bedded. Beds commonly appear internally structureless, but ripple laminations and vertical burrows are rarely present.

Coarse quartz silt and very fine quartz sand are the major components of siltstone. Lithic grains of chert also are present but not abundant. Rarely, intraclasts of mudstone or siltstone and detrital grains of muscovite, tourmaline, zircon, magnetite, and rutile may be present. The matrix in siltstone is very hematitic and argillaceous and resembles mudstone in both composition and fabric. Siltstone commonly grades upward into mudstone.

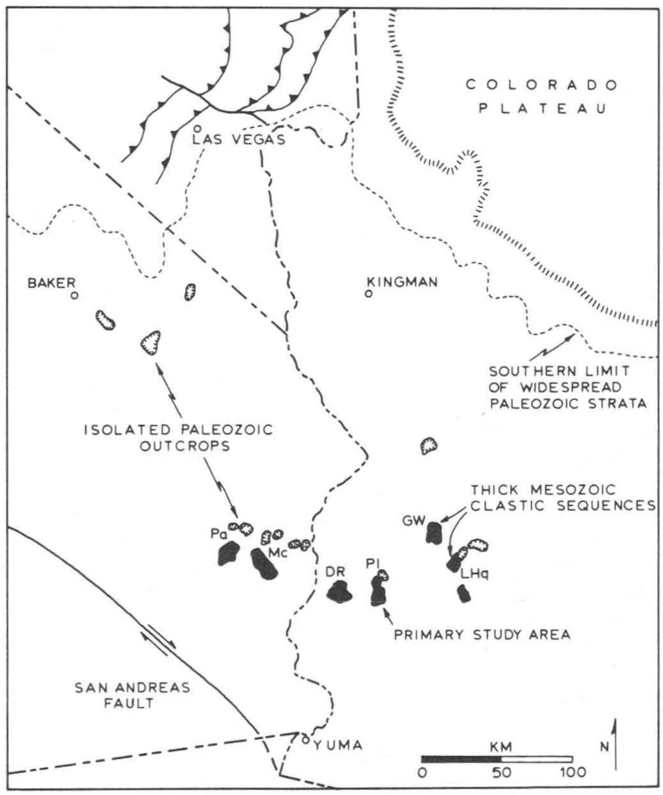

Fig. 1. Geologic setting of thick, Mesozoic clastic sequences (black) in western Arizona and southeastern California: DR - Dome Rock Mountains; GW - Granite Wash Mountains; LHq - Little Harquahala Mountains; Mc - McCoy Mountains; Pa - Palen Mountains; Pl - Plomosa Mountains. (Modified from Robison, 1979.)

Carbonate Rock

Very finely crystalline carbonate rock comprises approximately 15 percent of the red beds. However, in terms of number of distinct units within the section it is the most abundant lithologic type. Color is commonly a shade of brown, red, or purple.

Calcareous units range in thickness from 0.1 to 4.4 m. Average thickness is only 0.2 m. Calcareous strata are generally thinly bedded. Some individual strata appear to consist of coalesced nodules, and many strata are laterally discontinuous.

Calcareous strata are commonly bioturbated and appear mottled. Small (0.5 mm) calcite-lined tubules of unknown origin are abundant in some strata. Desiccation cracks are common in calcareous strata containing gypsum.

All calcareous rock in the red beds consists of slightly recrystallized calcareous mud. Hematite is commonly disseminated throughout the rock. Approximately half of the calcareous units contains gypsum, which may account for up to 30 percent of the carbonate rock. Dolomite does not occur in calcareous strata.

Conglomerate

Pebble-supported conglomerate comprises approximately 5 percent of the stratigraphic section. Color is generally obscured by desert varnish, but where visible it varies from light gray and orange to variegated.

Thickness of conglomerate ranges from 0.2 to 3.0 m and is highly variable along strike. Conglomerate is generally discontinuous laterally, and it may change stratigraphic position. Except for the occurrence of imbricate pebbles, most conglomerate is internally structureless. The basal contact of conglomerate is an irregular surface of erosion with relief of as much as 2.0 m locally developed on underlying strata. Pebbles commonly show a crude fining-upward trend, and conglomerate grades upward to sandstone, which is gritty or pebbly.

Most pebbles are well rounded. The means of the average pebble diameters from specific conglomerate beds range from 2.3 to 3.3 cm. Pebble compositions include quartzarenite, chert, quartzite, limestone, and dolomite. Quartzarenite is the most abundant pebble type. Rarely, chert pebbles contain molds of brachiopods and crinoid columnals. Neither conglomerate abundance, pebble size, nor pebble composition shows any recognizable trend within the area of outcrop.

The matrix of pebble-supported conglomerate is compositionally similar to sandstone within the red beds and is commonly very hematitic and argillaceous.

Stratigraphic Trends

Markov chain analysis is a statistical technique for the detection of repetitive events in space or time. The technique can be used to determine both the random and actual probabilities of lithologic types occurring in a specific sequence within any given succession (Miall, 1973).

Data from the most continuous succession of the red beds have been subjected to Markov analysis using five different lithologic divisions (Robison, 1979). Figure 2 illustrates the expected (random) and actual probabilities of particular events or transitions occurring within the succession. These are the only transitions that occur with frequencies greater than those due to random chance alone. Together these transitions define a fining-upward sequence that occurs repetitively within the stratigraphic succession.

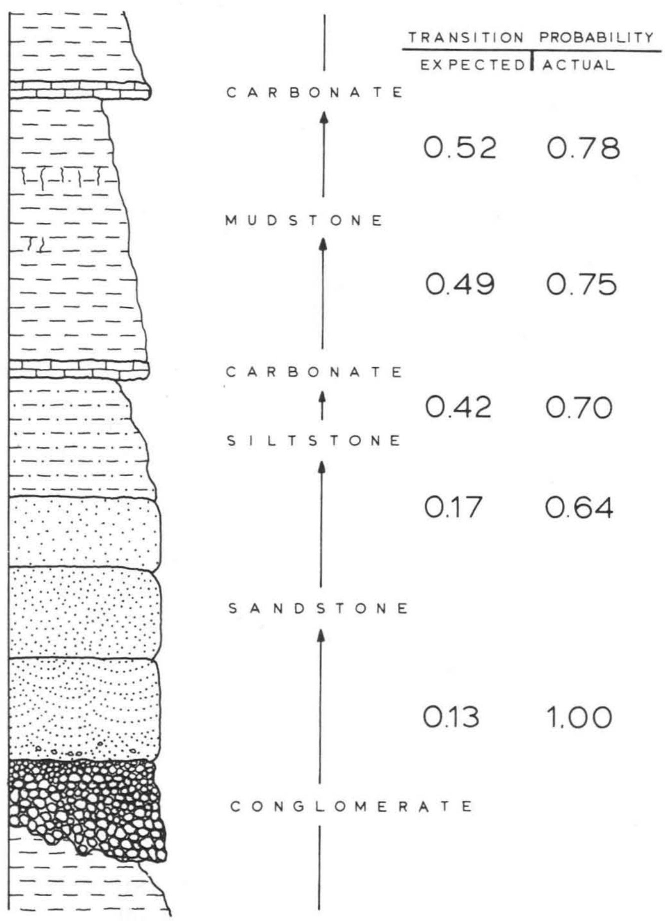

Fig. 2. Expected (random) and actual transition probabilities associated with the vertical sequence of one cycle within the red beds.

Ideally, from bottom to top each complete cycle consists of conglomerate, sandstone, siltstone, very finely crystalline carbonate rock, and mudstone. An alternating sequence of carbonate rock and mudstone continues until a new cycle begins. Overall, the probability is 0.84 that any given lithologic unit is of equivalent or finer grain size than the directly underlying unit.

Characteristically, conglomerate initiating a new cycle has an erosional base. Conglomerate grades upward into horizontally and cross-stratified sandstone. Sandstone grades upward into siltstone. The upper, alternating carbonate-mudstone sequence consists of distinct, nongradational units.

Complex structural relationships within the study area (Miller, 1966, 1970; Robison, 1979) and the cyclic nature of the stratigraphic succession make it impossible to demonstrate any large-scale stratigraphic trends. Furthermore, it is difficult to assign an accurate thickness to the red beds. Based on outcrop distribution and comparison with possibly correlative strata the thickness is estimated to be a thousand meters.

Interpretation of the Red Beds

Environment of Deposition

Environmental reconstruction is based primarily on the vertical sequence of lithologic units and the characteristic textures and structures exhibited. This is especially true of fluvial deposits (Allen, 1965; Bernard and Major, 1963; Visher, 1965, 1972).

Deposits of meandering streams are cyclic. A specific sequence, one cycle, is repeated vertically through a succession of progressively younger strata. The lowermost lithologic unit of each cycle consists of a poorly sorted, very coarse grained sandstone or conglomerate with an irregular, erosional base (Pettijohn, 1975; Visher, 1965). The basal unit grades upward into light-colored sandstone. This sandstone may be horizontally bedded or contain medium-size sets of trough and (or) tabular planar cross-stratification. Sandstone becomes finer grained upward and grades into siltstone and mudstone (Bernard and Major, 1963; Blatt, Middleton, and Murray, 1972; Pettijohn, 1975; Visher, 1965). The upper portion of each cycle consists of reddish siltstone and (or) mudstone. Siltstone may be massive or ripple laminated, while mudstone is generally massive (Allen, 1965; Pettijohn, 1975). Both commonly exhibit desiccation features and burrow or root structures (Allen, 1965; Visher, 1965).

Small calcareous masses may become so abundant in the upper portion of each cycle that they coalesce to form limestone beds (Pettijohn, 1975). These limestones are generally very finely crystalline, discontinuous laterally, and unfossiliferous and may contain evaporite minerals, especially gypsum. Dolomite is rare (Picard, 1957; Picard and High, 1972).

Fining-upward cyclothems that comprise the red beds share many characteristics with the typical fluvial succession and have been interpreted as resulting from deposition of a meandering stream system (Robison, 1979). The conglomeratic lowermost unit of each cycle represents a channel-lag deposit (Blatt and others, 1972; Pettijohn, 1975). Sandstone represents point-bar deposits, sedimentary accumulations on the inside of meander loops. Cross-stratification results from the migration of giant ripples on the lower part of the point bar. Siltstone and mudstone primarily represent upper point-bar and flood-basin accumulations (Blatt and others, 1972).

Where limestone is interbedded in a dominantly fluvial succession, lacustrine deposition is commonly suggested (Picard, 1957). Within the red beds, calcareous strata are commonly gypsiferous and may have desiccation cracks. This suggests formation during evaporation of water on a playalike or sabkhalike flood plain (Reineck and Singh, 1973). Thus, the alternating carbonate-mudstone sequence may represent periods of flooding and desiccation on a meandering stream's flood plain.

Provenance

The question of provenance concerns characterization of the source area (Pettijohn, 1975). In fluvial systems the direction of the source can be derived from paleocurrent data, and source area lithology is reflected by pebble composition and detrital mineralogy.

Orientations of the downdip trends of cross-stratification and of the updip trends of imbricate pebbles are plotted in Figure 3. Both indicators yield downstream direction. Radius vector summation (Krumbein, 1939) gives a mean value of S. 26° E. A north to northwesterly source area is indicated.

Clasts in conglomerate within the red beds are all of sedimentary origin. The mature nature of the pebble lithologies suggests erosion of a cratonic sedimentary sequence. Light-colored, fossiliferous chert pebbles strongly resemble chert that occurs in the Kaibab Limestone on the Colorado Plateau. This indicates a Paleozoic age for at least part of the source terrane. The occurrence of quartzite suggests that Precambrian metasediments were also exposed in the source terrane because the Precambrian stratigraphy of Arizona and adjacent

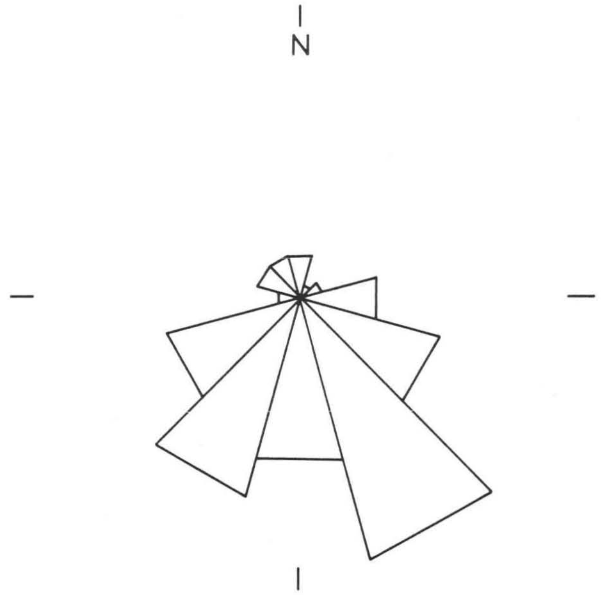

Fig. 3. Orientation of current indicators within the red beds - 167 measurements (from Robison, 1979).

areas to the west is dominated by thick sequences of quartzite (Shride, 1967; Stewart, 1970). The occurrence of limestone and dolomite pebbles suggests that part of the source terrane had considerable relief and (or) was located close to the site of deposition.

Graham, Ingersoll, and Dickinson (1976) have suggested that a ternary plot of monocrystalline quartz (Qm), feldspar (F), and total lithic fragments (Lt) emphasizes provenance. Figure 4 is a Qm-F-Lt plot of relatively matrix-free, medium- to fine-grained sandstones from the red beds. Points lie along the Qm-Lt axis and cluster near the QM pole. Feldspar is almost nonexistent. All identifiable rock fragments are of sedimentary origin, chert being most common. These data also suggest erosion of a sedimentary sequence.

The overall abundance of silt- and clay-size detrital material within the red beds plus the persistent occurrence of muscovite and magnetite suggest that an igneous or metamorphic terrane of low relief may have been exposed. However, pebble lithology and detrital mineralogy virtually preclude the possibility of any major volcanic, plutonic, or metamorphic exposures of moderate relief in the source area. This conclusion is supported by the relatively high percentage of the ultrastable minerals zircon, tourmaline, and rutile in the heavy mineral fraction of clastic rock within the red beds.

Age

The red beds explosed in the Plomosa Mountains are lithologically similar to and possibly correlative with basal portions of thick clastic sequences in the Little Harquahala and Granite Wash Mountains, western Arizona, and the basal portion of the McCoy Mountains Formation exposed in the McCoy and Palen Mountains, southeastern California (Fig. 1). In the Plomosa Mountains the red beds are interbedded with and conformably overlain by the basal member of the Livingston Hills Formation (Robison, 1979). Possible equivalence of the basal portions of these thick clastic sequences coupled with the lack of recognized unconformities within the sequences (Harding, 1978; Pelka, 1973; Robison, 1979) suggests that all are potentially time equivalent.

The age of these sequences is poorly documented. In the McCoy Mountains, southeastern California, the McCoy Mountains Formation nonconformably overlies a hypabyssal rhyodacite porphyry dated by D. Krummenacher as 175.8 ± 2.7 m.y. (K-Ar, plagioclase) (Pelka, 1973). The red beds nonconformably overlie a similar but undated porphyry (Robison, 1979). This suggests a post-Early Jurassic age for the red beds and equivalent strata.

Well-preserved fossil wood has been collected from several horizons within the McCoy Mountains Formation. Independent identifications verify that the wood belongs to the angiosperm class (Hayes, 1970; Pelka, 1973). The oldest known angiosperms are generally believed to be no older than Early Cretaceous (V.

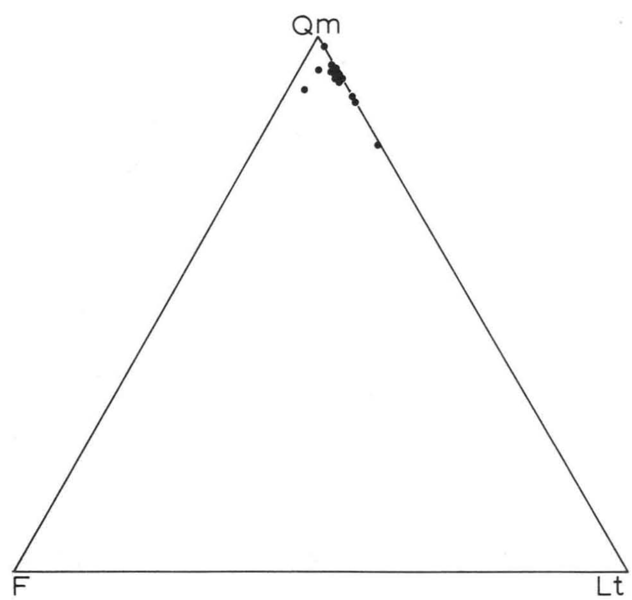

Fig. 4. Qm-F-Lt ternary plot of 15 sandstones within the red beds (from Robison, 1979).

Markgraf, pers. comm., 1979). These plant fossils indicate that at least a portion of the sequence is Early Cretaceous or younger.

The assignment of an upper age limit is based on exposures in the Granite Wash Mountains, western Arizona. A thick Mesozoic(?) clastic sequence is intruded by Late Cretaceous plutons (70 to 85 m.y.) (Reynolds, this volume). Late Cretaceous or earlier metamorphism of the clastic sequence is suggested by K-Ar data and by the cross-cutting relationship of an undeformed Late Cretaceous pluton (Reynolds, this volume). If the thick clastic sequence in the Granite Wash Mountains correlates with similar sequences in this region, then these data suggest that all of these strata may be approximately Early Cretaceous.

The nearest sedimentary rock of established Early Cretaceous age crops out in southeastern Arizona. Lower Cretaceous conglomerate, sandstone, and limestone constituting the Bisbee Group are exposed south and east of Tucson, Arizona (Hayes, 1970; Rangin, 1978). Correlation between the Bisbee Group and the thick clastic sequences in western Arizona and southeastern California is a definite possibility (Robison, 1979).

Tectonic Setting

Krynine (cited in Folk, 1974) originally pointed out that tectonic setting determines preferred orientations of source-area lithology, relief, geomorphic processes, and rates of basin subsidence. The composition and rate of sediment influx into a basin, combined with the rate of subsidence of that basin, influence overall composition and textural maturity of the sediment deposited and quantitatively determine environmental distribution. Therefore, composition and textural maturity may reflect tectonic framework, while volumetric importance of specific environments determines tectonic setting.

Sandstone from the red beds contains a significant proportion of sedimentary rock fragments, especially chert (Robison, 1979). Time-equivalent sandstone from the basal portion of the Livingston Hills Formation is both arkosic and lithic (Harding, 1978). Other possibly correlative strata in southeastern California show similar compositional variability (Pelka, 1973), suggesting a complex tectonic framework.

Sandstone containing greater than 5 percent matrix is classified as texturally immature (Folk, 1974). Over 85 percent of the sandstone from the red beds is texturally immature (Robison, 1979). Most of the sandstone from possibly correlative strata is also immature (Harding, 1978; Pelka, 1973). This suggests rapid deposition in a tectonically unstable environment.

The red beds and time-equivalent strata within the Livingston Hills Formation primarily represent point-bar, flood-basin or playa, sheetflood, and debris flow (alluvial fan) deposits (Harding, 1978; Robison, 1979). The association of fluvial and alluvial fan deposits is highly characteristic of deposition in rapidly subsiding, scarp-bounded basins. Intense normal faulting and internal drainage are often indicated (Folk, 1974; Reineck and Singh, 1973).

The red beds and possibly correlative strata crop out along a linear trend in western Arizona and southeastern California (Fig. 1). Paleocurrent data for these strata are oriented at a high angle to this trend (Harding, 1978; Pelka, 1973; Robison, 1979). This suggests that the trend may approximate depositional strike of a major block-fault basin system. Prevenance data suggest that the basin system was bounded on the north by a continental terrane (Harding, 1978; Pelka, 1973; Robison, 1979) and on the south by a volcanic terrane (Pelka, 1973).

Because the red beds and lithologically similar strata reflect erosion of a cratonic sedimentary sequence, the source area must have existed south of presently widespread, preserved Paleozoic strata (Fig. 1). Mesozoic strata preserved on the Colorado Plateau indicate that a source area, the Mogollon highland, existed through most of Mesozoic time south and southwest of the plateau (Dodge, 1973; Harshbarger, Repenning, and Irwin, 1957; Stewart, Poole, and Wilson, 1972). Because the red beds and lithologically similar strata were derived from the north, they must have been derived from this same source area. Furthermore, during red bed time the Mogollon highland must have consisted of a fairly narrow belt lying southwest of the Colorado Plateau and north of present exposures of the red beds. Figure 5 is a hypothetical cross section extending from western to northern Arizona portraying these relationships.

Isopach patterns of possibly correlative Lower Cretaceous strata in southeastern Arizona and adjacent areas show a pronounced, linear, west to west-northwest trend (McKee, 1951). Bilodeau (1978) recognized that deposition of the basal formation of the Bisbee Group was controlled by west- to west-northwest-trending, down-to-the-south normal faults. These data suggest a possible genetic relationship between the Bisbee Group and the thick clastic sequences exposed in western Arizona and southeastern California. The red beds and possibly equivalent strata could have accumulated in a western extension of the Bis-

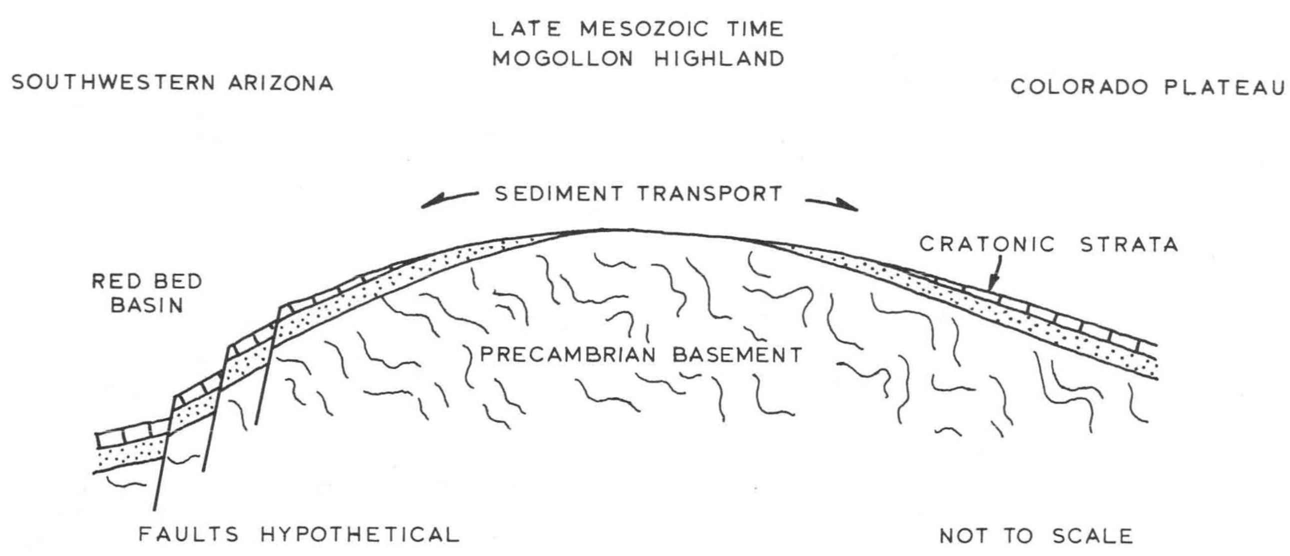

Figure 5. Hypothetical cross-section depicting tectonic setting of the red beds and possibly equivalent strata (modified from Robison, 1979).

bee basin (Robison, 1979). However, the continuity of the basin has not been established, and much work remains to document the possible connection.

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