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DEVONIAN AND MISSISSIPPIAN GEOLOGY OF ARIZONA

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ABSTRACT

Sedimentary rocks of Devonian and Mississippian age once covered all of Arizona except the Defiance-Zuni positive area in the east-central part of the state. Outcrops are extensive in all but the southwestern part of Arizona where most mid-Paleozoic strata were metamorphosed or eroded after the Paleozoic Era.

Devonian and Mississippian strata are predominantly marine carbonates but include subordinate clastic sediments, particularly in the Devonian System. Sedimentary material was deposited in varying marine environments during periodic marine transgressions across a broad and relatively stable continental shelf adjacent to and east of the Cordilleran miogeocline. The thickest sections of Devonian-Mississippian rocks are in the northwest and southeast corners of the state and reach a maximum of 500 m (1,600 ft).

Strata of the Devonian System form two depositional complexes and record deposition during two major transgressive-regressive episodes of the sea across Arizona in Late Devonian time. The lower complex is mainly early Late Devonian (Frasnian) age and includes the Temple Butte, Elbert, and Aneth formations in the north, and all of the Martin Formation and the lower parts of the Morenci, Portal, and Swisshelm formations in central and southern Arizona. The upper complex is of latest Devonian (late Famennian) age and includes the Pinyon Peak Limestone and Ouray Formation in the extreme northwest and northeast corners of the state and all of the Percha and upper Morenci, Portal, and Swisshelm formations in the southeast. A major unconformity lasting for about half of Famennian time separates rocks of these two complexes.

Mississippian strata rest unconformably on Devonian or older rocks across Arizona and are almost entirely limestone and dolomite except for minor terrigenous silicoclastic rocks in the northwest and southeast corners of the state. Most Mississippian strata are included in a major and extensive lower depositional complex formed during two transgressive-regressive episodes in Early to early Late Mississippian time. This complex includes the Redwall Limestone in the northern two-thirds of the state and the Escabrosa Limestone in the southeast. A third, less extensive marine transgression produced an upper depositional complex in latest Mississippian (Chesterian) time as recorded by the Paradise Formation in the southeast and the Surprise Canyon Formation in the northwest.

INTRODUCTION

Devonian and Mississippian rocks in Arizona are entirely of sedimentary origin and are widely distributed in all but the southwestern part of the state. The occurrence of both systems is coincidental throughout the state with minor exceptions in La Paz County, in parts of eastern Grand Canyon, and along the margin of the Defiance-Zuni positive area in Apache and Navajo Counties where Mississippian rocks locally rest on Cambrian or Precambrian rocks.

In the Colorado Plateau of northern Arizona most mid-Paleozoic strata are buried beneath late Paleozoic and Mesozoic rocks. Exposures within the plateau are in a narrow strip along the walls of Marble Canyon and Grand Canyon and in a broader belt along the southern and western plateau margins. In southern and extreme northwestern Arizona, within the Basin and Range Province, major outcrops are limited to numerous narrow elongate strips along isolated mountain blocks. Outcrops are common in the southeastern part of the state but rare in the southwest (figs. 1 and 2).

Combined thickness of Devonian-Mississippian strata ranges from 0 to 500 m (1,600 ft). Thickest sections are in the southeast and northwest corners of the state. Mississippian rocks make up approximately two-thirds of the total thickness and are almost entirely carbonates. Devonian rocks are predominantly limestone or dolomite but include subordinant amounts of various clastic lithologies.

Previous Work

The first recorded scientific observations of Paleozoic strata in Arizona were by Marcou (1856), who recognized lower Carboniferous limestone in northern Arizona. Newberry (1861) recorded lower Carboniferous strata in the Grand Canyon region, and Gilbert (1875, p. 178) applied the formal name Red Wall Limestone to these strata. Devonian rocks in the Grand Canyon were first reported by Walcott (1880, 1883) and were formally named the Temple Butte Limestone in eastern Grand Canyon (Walcott, 1889).

In southern Arizona, Devonian and Mississippian rocks were first described by Ransome (1904) who named them, respectively, the Martin Limestone and Escabrosa

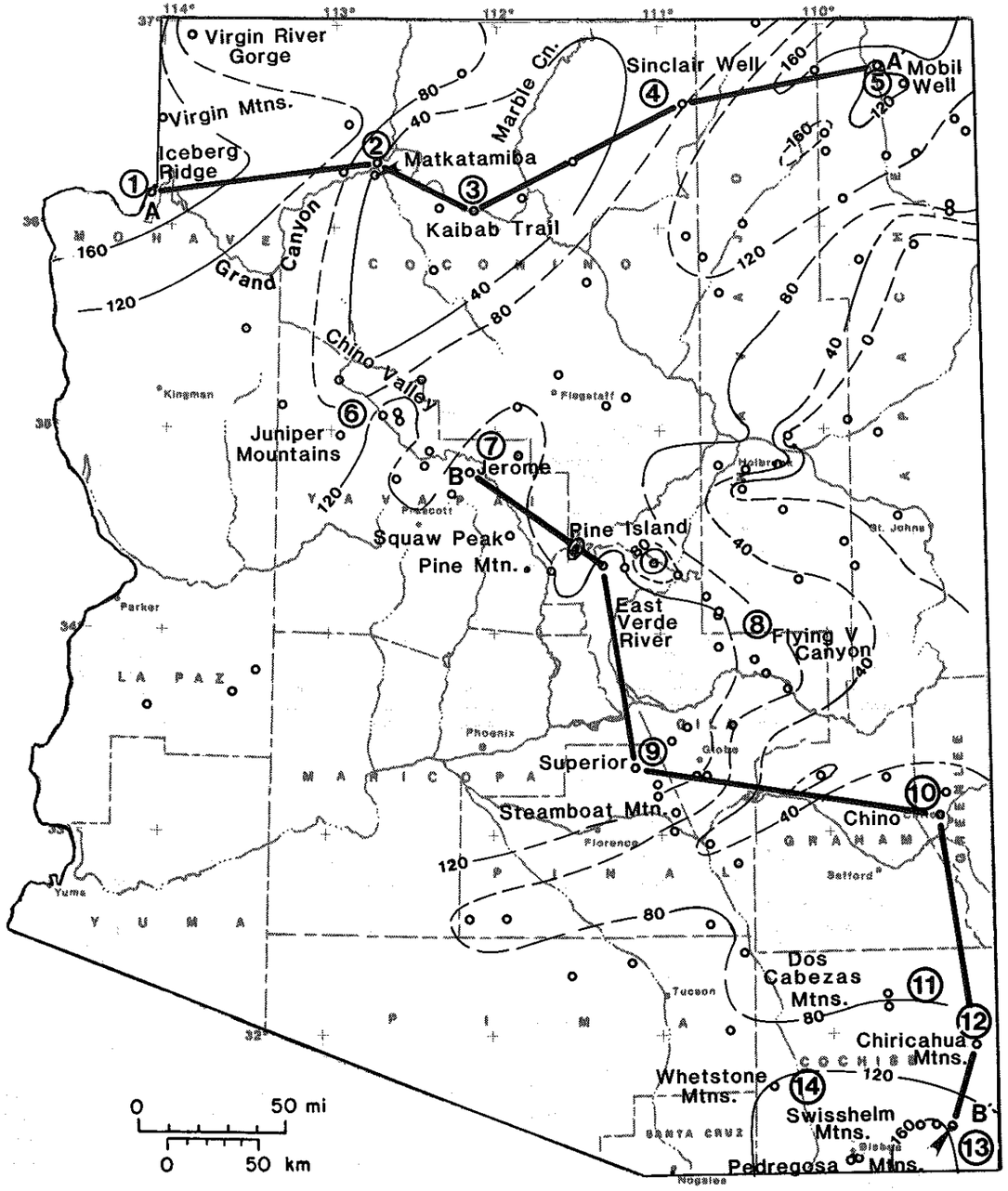

Figure 1. Isopach map of Devonian rocks in Arizona. Contour interval is 40 m. Small circles are thickness data points.

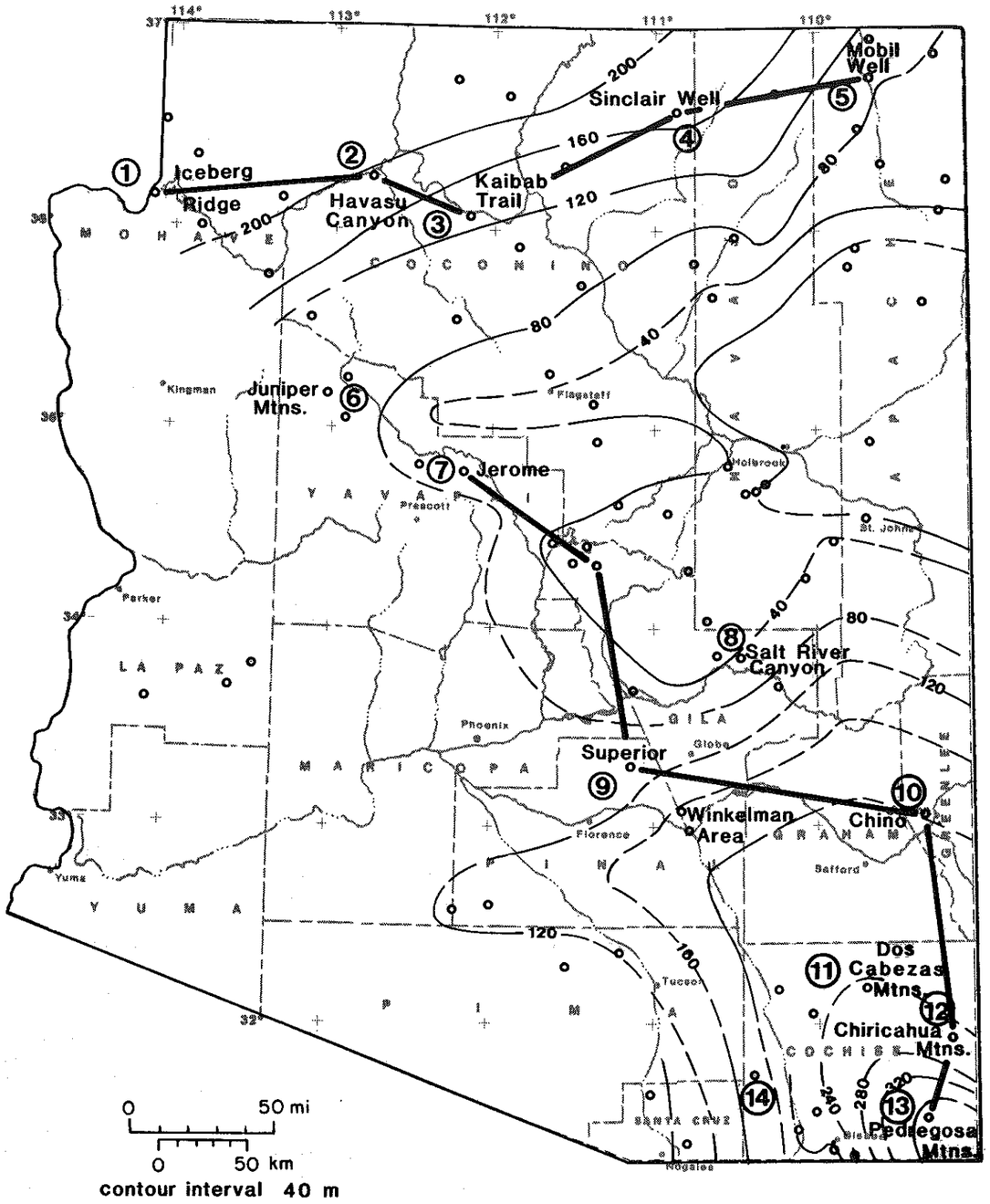

Figure 2. Isopach map of Mississippian rocks in Arizona. Contour interval is 40 m. Small circles are thickness data points.

Limestone. Additional general studies of the distribution and correlation of mid-Paleozoic strata in Arizona were by Ransome (1916), Darton (1925), Stoyanow (1926, 1936, 1942), McKee (1951), McNair (1951), and Huddle and Dobrovolny (1952).

A comprehensive treatment of Devonian rocks in central Arizona was done by Teichert (1965). A report of similar scope was done for the Mississippian rocks of northern and central Arizona by McKee and Gutschick (1969). More recent studies of selected areas or selected rock units of middle Paleozoic age were completed for the Devonian System of southern Arizona by Schumacher (1978), the Mississippian System of southern Arizona by Armstrong and others (1980), the Devonian of northern Arizona by Beus (1973, 1980) and the Mississippian of northern Arizona by Kent and Rawson (1980). A review of the Mississippian System in Arizona was presented by Peirce (1979) and a review of Mississippian paleotectonics by McKee (1979). Numerous graduate student theses reports provide local details of the mid-Paleozoic strata of Arizona and are referenced in subsequent sections of this report.

Paleotectonic Setting

In middle Paleozoic time Arizona occupied a tectonic position along the southwest flank of a craton and adjacent to the Cordilleran miogeocline to the west (Drewes, 1981, p. 89). Nearly all the deposits formed during this time were carbonate or clastic sediments that record deposition under tectonically quiet conditions on a gently submerged continental shelf. The minor tectonic activity recognized was epeirogenic and involved only mild tilting, arching, or sagging (Peirce, 1976). Major positive tectonic elements in Arizona were the emergent Defiance-Zuni positive area in the east-central part of the state and the Ensenada positive area at the Mexican border to the southwest. Negative tectonic elements were the Arizona-New Mexico trough (McKee, 1979) or Pedregosa basin of Kottlowski (1962) portion of the Sonoran geosyncline to the southeast and the Oraibi trough in the northeast (fig. 3). Major tectonic events of the Antler orogeny occurred in the Cordilleran mobile belt to the northwest of Arizona during the Late Devonian and Mississippian and in the Uncompahgre uplift belt to the north-northeast during the Carboniferous. These events had little effect on deposition in Arizona except as they contributed to changes in sea level and consequent marine transgressions or regressions across the state.

DEVONIAN STRATA

Distribution and Character

Devonian sedimentary rocks of mainly marine origin once covered most of Arizona except in the east-central part where they pinch out against the Defiance-Zuni positive area. Devonian strata are still extensively present except in the southwest where they have been mostly removed or altered after Mississippian time.

The total thickness patterns of the Devonian rocks are shown in figure 1. Maximum thickness occurs in the northwest, northeast, and southeast corners of the state. Pronounced thinning occurring over the Marble Canyon—eastern Grand Canyon area—the Grand Canyon shelf of Beus (1980)—indicates shallowing and local emergence of the continental shelf in Late Devonian and Early Mississippian time (fig. 4). Devonian strata thicken southeastward into the Arizona-New Mexico trough and also northeastward into the Oraibi trough (fig. 5). Abrupt local thickness variations in the subsurface rocks of the Oraibi trough may reflect the influence of mid-Paleozoic block faulting in the basement rocks of the Four Corners area (Beus, 1980, p. 55; Stevenson and Baars, 1977). Increasing thickness in the northwest marks an approach to the shelf edge at the eastern margin of the Cordilleran miogeocline.

Devonian lithology is predominantly limestone or dolomite but locally exhibits as much variety as any system in the Paleozoic. The multiplicity of names applied, especially in southeastern Arizona, reflects this variation (fig. 6).

No rocks of Silurian or Early Devonian age are known in Arizona. Thus the base of the Devonian System marks a major unconformity that truncates rocks of Precambrian, Cambrian, and Ordovician age (fig. 7). The pre-Devonian surface was one of generally low relief. However, locally small knobs of Precambrian basement rock projected above Devonian sea level and remain today as inliers surrounded by Devonian rocks (fig. 5). In general the Devonian rocks truncate successively older rocks and wedge out toward the Defiance-Zuni positive area from the north, west, and south.

Rocks of the Devonian System were deposited in two major episodes during the Late Devonian. The lower, Frasnian, depositional complex was the most widespread and produced mainly carbonate deposits with minor terrigenous clastics occurring locally. This complex is represented by the Temple Butte Formation in the northwest, the Elbert and Aneth formations in the northeast, and the Martin Formation plus the lower Morenci, Portal, and Swisshelm formations in the southeast (fig. 8). No Silurian rocks are recognized in Arizona, and the Early and Middle Devonian Epochs are likewise unrepresented except for latest Middle Devonian strata of the Martin Formation (particularly the Beckers Butte Member) and possibly the lowermost Temple Butte and Aneth formations). The Chino Valley Formation shown in the Jerome section (fig. 8) is not accurately dated but is considered of probably Middle Devonian in age.

The upper depositional complex is of middle to late Famennian age. The two complexes are separated by a major disconformity representing about half of Late Devonian time (fig. 8). Included in the upper complex are the Pinyon Peak Limestone in the northwest, the Ouray Formation in the northeast, and the Percha, upper Morenci, Portal, and Swisshelm formations in the

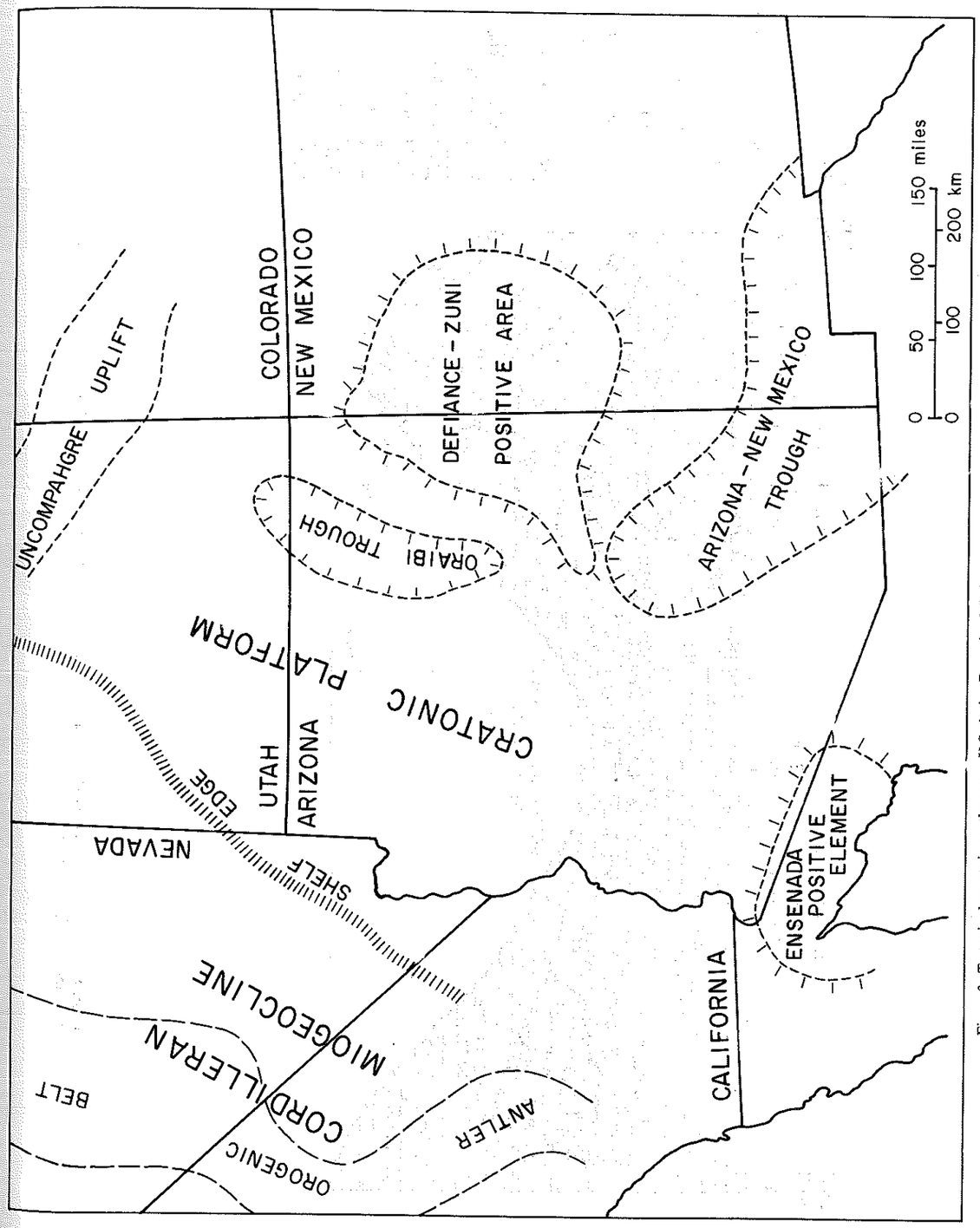

Figure 3. Tectonic elements in southwestern U.S. during Devonian Mississippian Time.

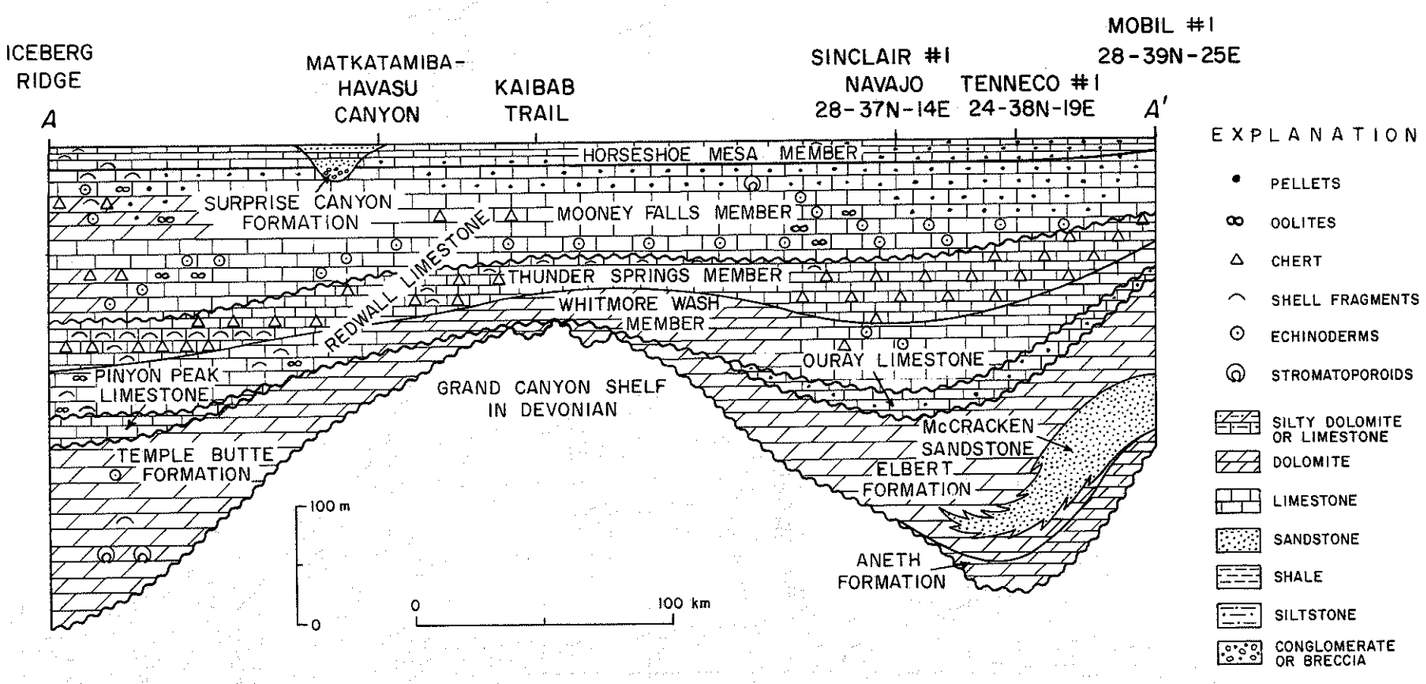

Figure 4. Cross section of Devonian-Mississippian strata across northern Arizona. Position located on figures 1 and 2. Datum is the top of the Mississippian System.

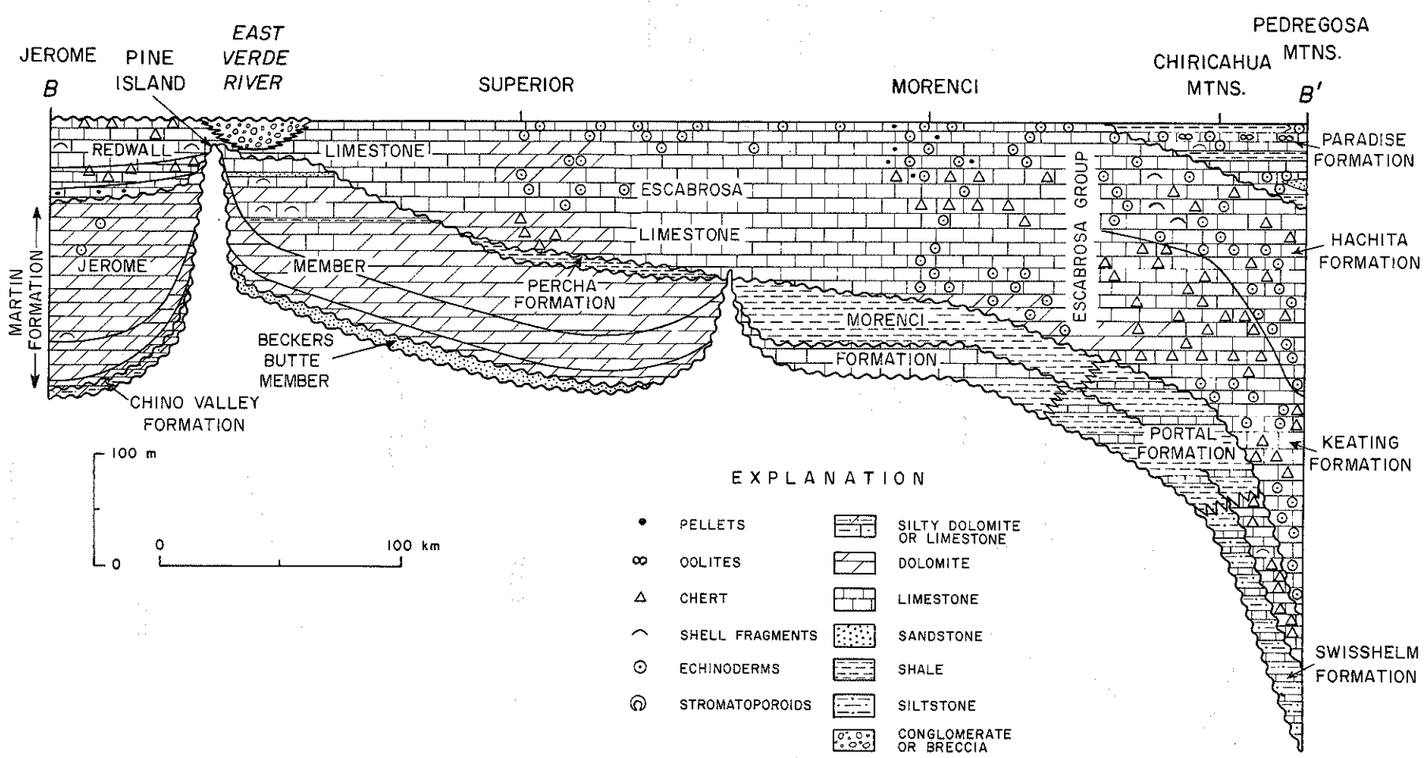

Figure 5. Cross section of Devonian-Mississippian strata in central and southeastern Arizona. Position located on figures 1 and 2. Datum is the top of the Mississippian System.

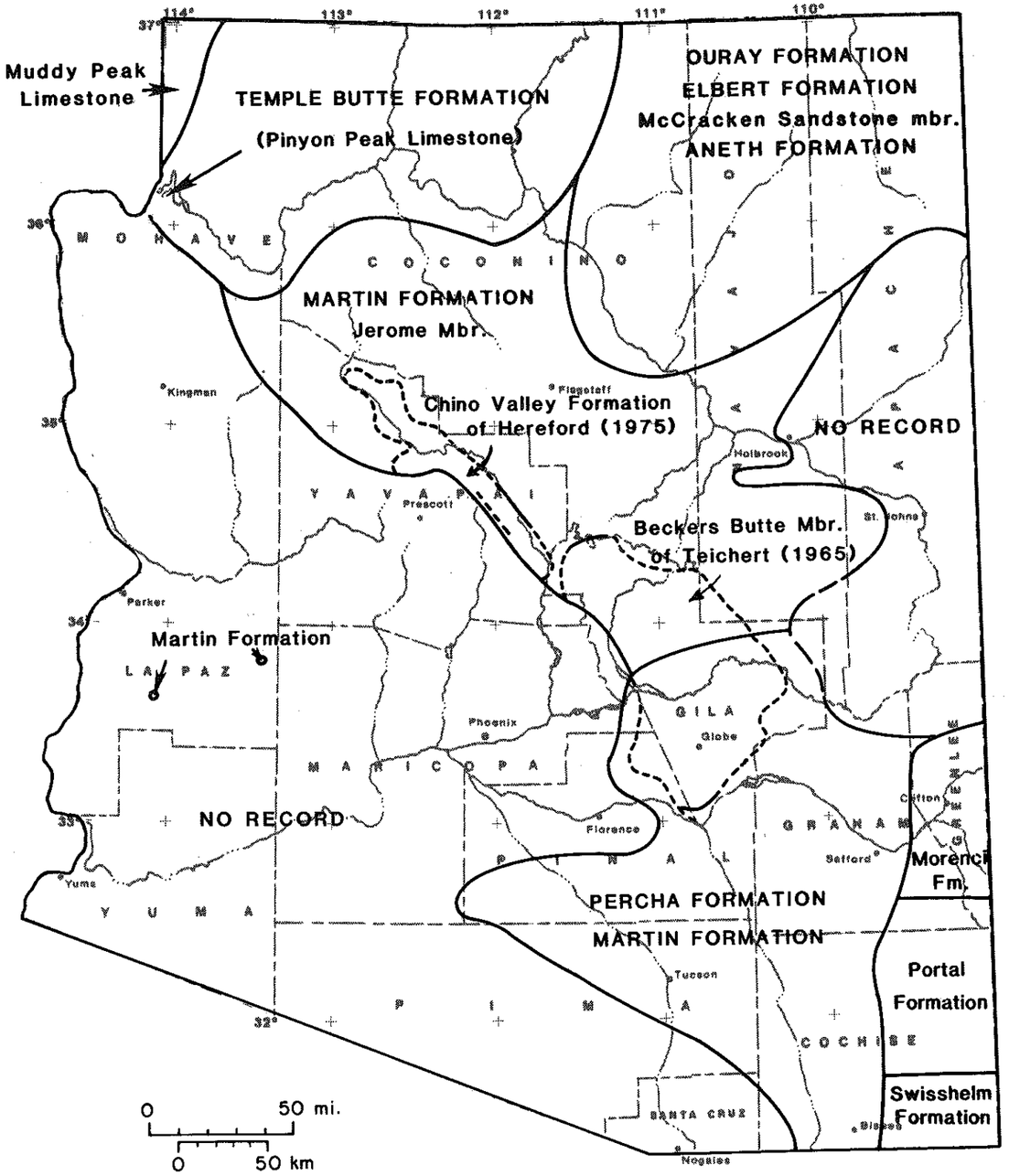

Figure 6. Nomenclature for Devonian rocks in Arizona.

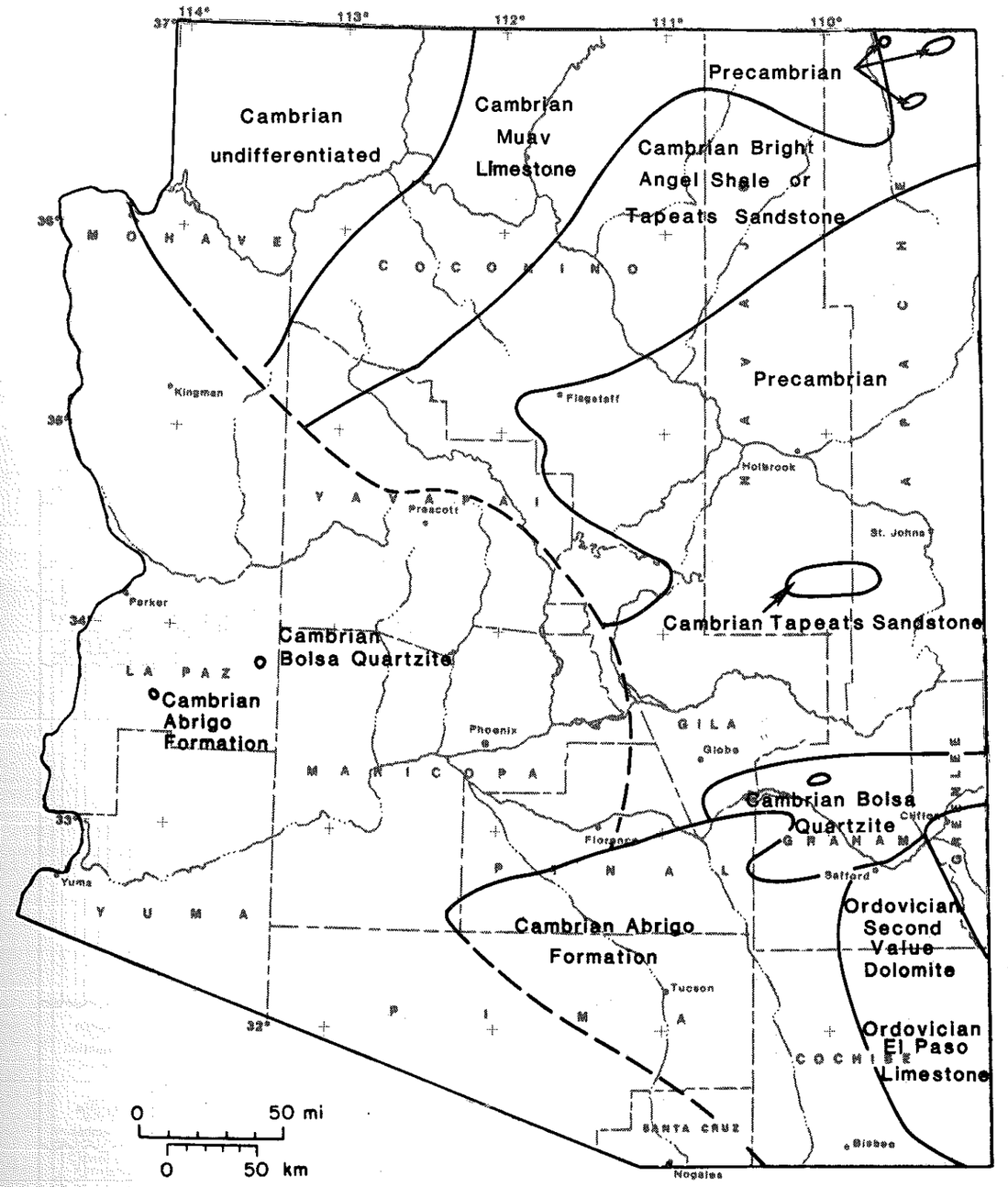

Figure 7. Paleogeologic map of Arizona at the beginning of Devonian deposition.

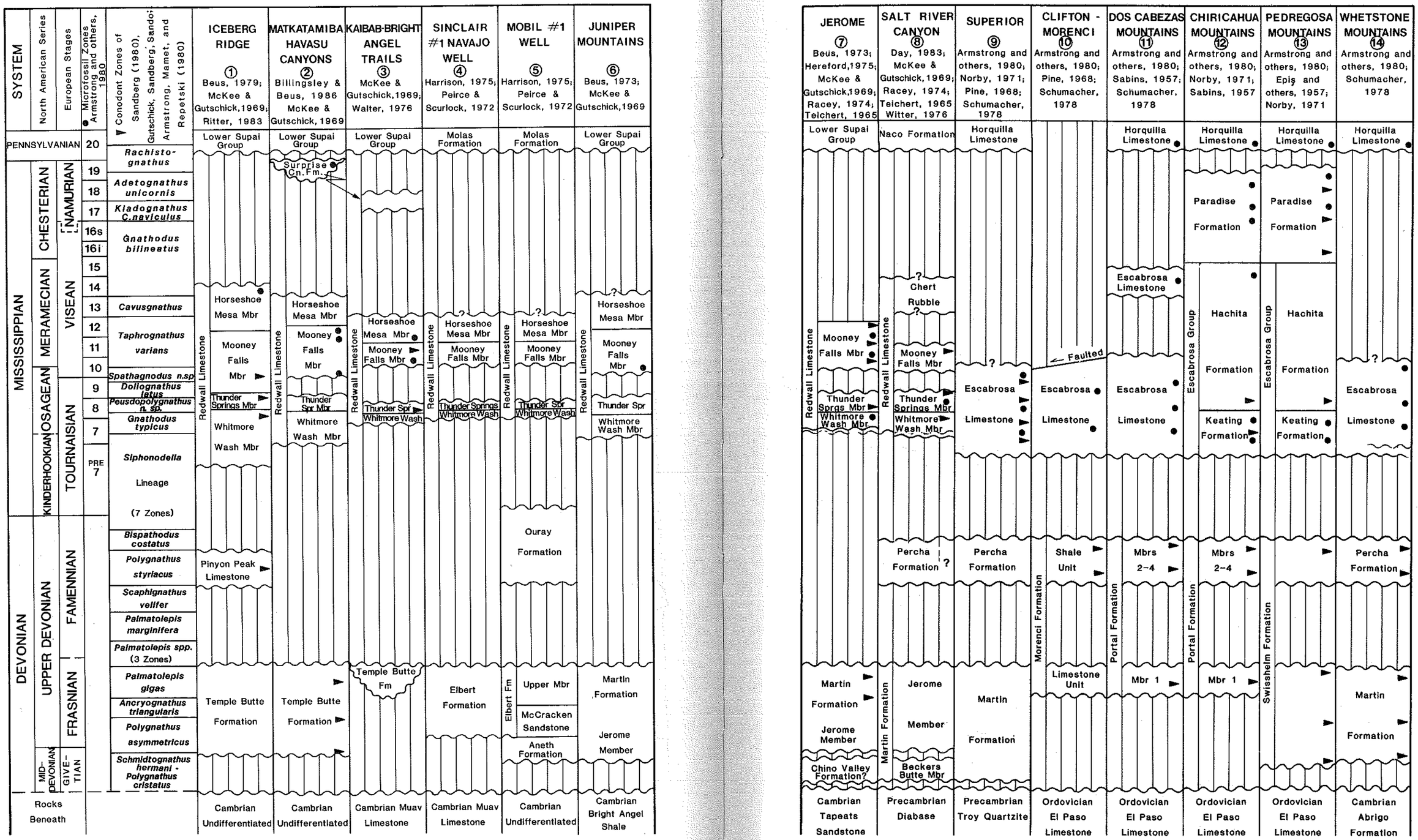

Figure 8. Correlation chart of Devonian-Mississippian strata in Arizona. Position of named localities shown on figures 1 and 2.

southeast. In northern Arizona the upper complex is limestone or dolomite and is recognized only in the extreme northeast and northwest corners of the state. In the southeast, the complex has a more varied lithology. It consists mainly of green to gray or black shales with overlying carbonates but includes some sandstones to the west (Schumacher, 1978, p. 179). The unconformity at the top of the upper complex represents latest Famennian time and much of earliest Mississippian (Kinderhookian) time except in the subsurface of the northeast corner where the Ouray Formation may include earliest Mississippian rocks (Baars, 1972, p. 91).

Temple Butte Formation

Walcott (1889, p. 50) proposed the name Temple Butte Limestone for a thin and locally discontinuous section of Devonian dolomite and minor sandstone exposed in eastern Grand Canyon. The Temple Butte Formation has been extended by McKee (1939) and others to include the much thicker and more continuous Devonian strata throughout the Grand Canyon and extending nearly to the northwest corner of the state.

In the eastern Grand Canyon the Temple Butte is a fine-grained purplish-gray silty to sandy dolomite that fills channels up to 21 m (70 ft) deep cut into the top of the Muav Limestone. In central and western Grand Canyon, beginning at the Hermit Basin area, the Temple Butte is a continuous sequence of light- to dark-gray, finely to coarsely crystalline dolomite that thickens to 176 m (577 ft) at Iceberg Ridge.

Fossils are scarce in the Temple Butte. Walcott (1883, p. 438) reported rare corals, brachiopods, gastropods, and placoganoid fish at Kanab Canyon. Noble (1922, p. 51, 52) collected plates of *Bothreolepis*, a freshwater fish (Denison, 1951) from Sapphire Canyon. Diagnostic conodonts of probable latest Givetian (late Middle Devonian) through late Frasnian (early Late Devonian) were obtained from the Temple Butte at Matkatamiba Canyon by D. Schumacher (Elston and Bressler, 1977, p. 423).

Muddy Peak Limestone

The name Muddy Peak Limestone (Longwell, 1921) is used for Devonian rocks in the Muddy Mountains of southern Nevada and the adjacent Virgin Mountains of Arizona. Steed (1980) measured 109 m (358 ft) of this unit in the Virgin River Gorge in the northwest corner of Arizona. In the Virgin Mountains the Muddy Peak consists mainly of medium crystalline dolomite but includes some limestone beds in the upper part and a few thin chert and quartzite beds. The presence of rare conodonts and corals from the Muddy Peak outcrops in northwestern Arizona indicates a Late Devonian age (Steed, 1980). The Muddy Peak is considered correlative with the Temple Butte Formation of the Grand Canyon.

Pinyon Peak Limestone

The Pinyon Peak Limestone was named in the East Tintic Mountains of central Utah. The name has been extended by Sandberg and Poole (1977, fig. 12, p. 167) to include upper Famennian rocks assigned to the *Polygnathus styriacus* conodont Zone in southern Nevada and northwestern Arizona. Thus the upper 26 m (85 ft) of the Devonian carbonate section at Iceberg Ridge, containing diagnostic late Famennian conodonts, are designated the Pinyon Peak Limestone (Ritter, 1983, p. 6). At Iceberg Ridge the Pinyon Peak is a light-gray mudstone to oolitic wackestone. It apparently pinches out eastward and has not been recognized in the Grand Canyon.

Ouray Formation

The Ouray Formation, named from Ouray, Colorado, is present only in the subsurface of northeastern Arizona. It is up to 33 m (119 ft) thick as recognized in well cores from the Four Corners area. The Ouray is a dark-brown dense limestone composed mainly of pelleted and locally oolitic skeletal wackestone. The presence of fossil brachiopods in outcrops of the Ouray in southwestern Colorado indicate a Late Devonian (Famennian) age (Baars, 1966). However, Mississippian endothyrids at or near the top of the Ouray from wells in southwestern Colorado and southeastern Utah indicate that the Ouray transgresses the Devonian-Mississippian boundary and that the upper "few feet" are of earliest Mississippian age (Baars, 1966, p. 2089, 2093). The regional stratigraphic picture indicates that the upper and lower boundaries of the Ouray are unconformities (fig. 8), although the unit appears locally to be gradational with the Elbert Formation below and Mississippian rocks above.

Aneth Formation

The Aneth Formation is entirely a subsurface unit defined from well cores in the Four Corners region. It is a dark-gray fetid dolomite mudstone with minor dark-gray shale and is up to 61 m (200 ft) thick in the type well (Shell Oil Company No. 1 Bluff) 55 km (35 mi) northwest of the Four Corners in San Juan County, Utah. In Arizona the Aneth is recognized from the Four Corners 235 km (146 mi) to the southwest beneath Black Mesa (Harrison, 1976).

No fossils are known from the Aneth in Arizona, but fish plates of *Bothreolepis coloradoenis* Eastman, indicating a Late Devonian age, occur in the type area (Baars, 1972, p. 91). Stromatolitic structures are common in the Aneth of northeastern Arizona (Harrison, 1976). Johnson and Sandberg (1977, fig. 8) considered the Aneth to be Givetian (latest Middle Devonian) in age and correlative with the Beckers Butte Member of the Martin Formation in central Arizona. I prefer the interpretation shown here (fig. 8) because the Aneth is nearly lithologically identical with the fetid dolomite unit of the Jerome Member, Martin Formation, which overlies the Beckers Butte in central Arizona.

Elbert Formation

In Arizona, the Elbert Formation is known only in the subsurface. It is penetrated by wells throughout the northeastern part of the state north of the Defiance-Zuni positive area and east of the Grand Canyon. The Elbert ranges in thickness from a few meters at the depositional, or erosional, edge along the Defiance area to 160 m (525 ft) in the center of Black Mesa. The Elbert Formation comprises the lower dolomite, McCracken Sandstone, and upper members.

Lower Dolomite Member: A light-gray dolomite unit of the lower Elbert Formation in part underlies and in part grades laterally into the McCracken Sandstone (fig. 4). It is here referred to informally as the lower dolomite member of the Elbert Formation and consists of fine-grained to aphanitic dolomite and commonly yields some gypsum after acid etching. Thickness is 10-100 m (33-330 ft) where it has been recognized in the subsurface. No skeletal fossils have been found in the lower dolomite, but stromatolites were recognized in one well section by Harrison (1976, p. 55). In the subsurface of northeastern Arizona the lower dolomite overlies the Aneth Formation or Precambrian or Cambrian rocks. Harrison (1976) recognized it as far west as the eastern part of Coconino County and the northern half of Navajo County.

McCracken Sandstone Member: In the Four Corners area a lower sandstone unit of the Elbert is designated the McCracken Sandstone Member. In northern Arizona it is white to pink, medium- to coarse-grained, medium- to well sorted quartz sandstone (Harrison, 1976 p. 20). The quartz grains are commonly bimodal in size and cemented with dolomite. In the subsurface of northeastern Arizona the McCracken overlies the Aneth Formation or, in its absence, a quartzite of Cambrian age. Westward from the Four Corners area the McCracken appears to rise in stratigraphic position and is separated from the Aneth by the lower dolomite member of the Elbert Formation (Parker and Roberts, 1966, p. 2415; Harrison, 1976, pl. 1). It ranges in thickness from a thin edge at the Defiance-Zuni positive area to a maximum of 45 m (150 ft).

Upper Member: The upper member of the Elbert Formation was originally described by Knight and Cooper (1955, p. 56) from Shell Oil Company No. 1 Bluff Well, in southeastern Utah, where it consists of 92 m (302 ft) of thin-bedded dolomite interbedded with green and red shale. In northeastern Arizona, the upper member is a fine- to coarse-grained pelleted dolomite containing minor interbedded shale (Harrison, 1976, p. 20). The upper member averages 91 m (300 ft) in thickness in the Black Mesa area, pinches out against the Defiance-Zuni positive area to the east, and grades into the upper Jerome Member of the Martin Formation and the Temple Butte Formation to the southwest and west. The top of this unit, and of the Elbert Formation, is marked in the subsurface by a widespread and distinct waxy shale (Harrison, 1976, p. 15). It is overlain by the Famennian Ouray Formation.

Martin Formation

The Martin Formation is the most widely recognized Devonian unit in Arizona. It was originally named the Martin Limestone from a predominantly limestone and dolomite sequence in the Bisbee area of southeastern Arizona by Ransome (1904). Subsequently the name Martin Limestone or Formation has been applied to equivalent strata from central Arizona by Ransome (1916), Stoyanow (1936), Huddle and Dobrovolny (1952), and Teichert (1965) all the way to the southern Grand Wash Cliffs in the northwest (McNair, 1951, p. 551). Isolated Devonian outcrops in southwestern Arizona are also referred to the Martin Formation (fig. 6).

In central Arizona Teichert (1965) defined two members of the Martin: a thin basal Beckers Butte Member and the overlying Jerome Member, which constitutes most of the formation.

Beckers Butte Member: The Beckers Butte Member is a thin sequence of light-gray quartz sandstone to granule conglomerate with minor dolomite and shale at the base of the Martin Formation. It is up to 40 m (130 ft) thick and rests on an irregular surface developed on Precambrian or Cambrian rocks in central Arizona. At the type section in the Salt River Canyon (Flying V Canyon) the upper shale unit yields a rich psilophyte flora of latest Givetian or earliest Frasnian age (Canwright, 1970). Teichert (1965) extended the name from the Salt River Canyon area northwest 147 km (82 mi) to Squaw Peak in the Verde Valley. Elston and Bressler (1977) extended the name Beckers Butte Member to include all strata below the fetid dolomite unit of the Jerome Member, Martin Formation, that yield a Devonian paleomagnetic pole position and thus considered that the Beckers Butte Member extends to Jerome, 186 km (116 mi) northwest of the type area.

Pine (1968) has recognized Beckers Butte strata as far south of the type section (90 km, 55 mi) as Steamboat Mountain. Hereford (1978, pers. comm.) has demonstrated that the Beckers Butte Member together with the entire Martin Formation wedges out against the Pine Island topographic high (Teichert, 1965) northwest of Payson. West of this ancient highland, strata in the Beckers Butte position, immediately beneath the fetid dolomite unit of the lower Jerome Member, are orange-red shale-like dolomite that is lithologically very distinct from the Beckers Butte and is better assigned to the Chino Valley Formation. The extent of clearly recognized Beckers Butte is shown in figure 6.

Jerome Member: The major part of the Martin Formation in northern and central Arizona is the Jerome Member of Teichert (1965, p. 29). It is recognized from Jerome, the type section, to the southern Grand Wash Cliffs in the northwest and as far south as the Steamboat Mountain locality in eastern Pinal County (Pine, 1968) (fig. 6). The Jerome Member is generally between 75 and 140 m (245-460 ft) thick except where it wedges out against the Defiance-Zuni positive area and around local knobs of

Precambrian rocks near the Mogollon Rim. At the base, the Jerome rests unconformably on Precambrian or Cambrian rocks or locally on the Beckers Butte Member or Chino Valley Formation. Three units, essentially informal members, are recognized in the Jerome Member from the Chino Valley area southward to Steamboat Mountain. The lower unit is a uniformly fine-grained, dark-gray fetid dolomite mudstone up to 12 m (37 ft) thick. The middle unit is a distinctive light-gray aphanitic dolomite mudstone up to 55 m (180 ft) thick. A marker bed of reddish-brown sandstone or sandy dolomite up to 2 m (7 ft) thick occurs locally near the top. The upper unit of the Jerome Member is the thickest (up to 96 m, 316 ft) and most fossiliferous part of the member. This unit is typically medium-gray to brownish-gray dolomite or limestone having a skeletal wackestone or packstone texture. Fossils include abundant corals, brachiopods, mollusks, and less common trilobites, bryozoans, crinoids, and fish plates. Conodonts are locally present and together with the brachiopods indicate a late Frasnian age for this upper unit (Teichert, 1965; Beus, 1978).

In parts of southeastern Arizona, strata originally included in the upper part of the Jerome Member were demonstrated by Schumacher and others (1976) to be of Famennian age and disconformably separated from the rest of the Martin. These strata are now assigned to the Percha Formation.

Percha Formation

The name Percha Formation was proposed by Schumacher and others (1976) to accommodate a sequence of slope-forming shale, siltstone, or sandstone with overlying ledgy carbonate beds that disconformably overlies the Martin Formation in most of southeastern and south-central Arizona. The Percha Formation is up to 21 m (65 ft) thick and is lithologically similar to the Percha Shale of New Mexico with which it is considered a correlative. The occurrence of rhynchonellid brachiopods and conodonts of the *Polygnathus styriacus* Zone indicates a late Famennian age for the Percha Formation of Arizona (Schumacher, 1978).

Swisshelm Formation

Devonian rocks in the Swisshelm and Pedregosa Mountains of southeastern Arizona were referred to the Swisshelm Formation by Epis and others (1957). The Swisshelm is similar to the Martin Formation of southern Arizona except for the dominance of sandstone and siltstone over carbonate rocks in the former. The presence of conodonts and macrofossils indicates a late Givetian to Frasnian age for the lower two-thirds of the formation. The upper third of the unit is of late Famennian age (Boyd, 1978; Schumacher, 1978).

Morenci Formation

The Morenci Shale is a local name used by Lindgren (1905) for the Devonian limestone and shale (now more properly Morenci Formation) in the Clifton-Morenci area of southeastern Arizona. The lower limestone has yielded a conodont fauna of Frasnian age, but no diagnostic fossils are known from the upper shale beds. Schumacher (1978, p. 178) considered the upper shale unit of the Morenci to correlate with the Famennian shale of the Percha Formation to the west.

Portal Formation

The Devonian sequence of calcareous and siliceous shale and limestone in the Chiricahua and Dos Cabezas Mountains of southeastern Arizona was named the Portal Formation by Sabins (1957). Four informal members of the Portal in ascending order are: 1) calcereous gray shale and nodular lime mudstone, 2) black siliceous shale, 3) alternating calcareous gray shale and lime mudstone, 4) thick-bedded skeletal lime grainstone with thin shale beds. Conodonts from the Portal Formation reported by Schumacher (1978) indicate that member 1 is of Frasnian age. Members 2-4 are of Famennian age and are disconformable above member 1.

Chino Valley Formation

The Chino Valley Formation was named by Hereford (1975) to accommodate a rock unit of unknown age between the Cambrian Tapeats Sandstone and the Late Devonian Martin Formation in northwestern Arizona south of the Grand Canyon. Three facies are recognized in the Chino Valley: a lithic sandstone, a pebble to boulder conglomerate, and a red shale-like dolomite. The Chino Valley is recognized by Hereford (1976, 1982, pers. comm.) from northwestern Chino Valley southeastward to Jerome (the type section), Squaw Peak, and as far south as the Pine Mountain-Verde River area where it laps out against a topographic high of Precambrian quartzite (fig. 5). Elston and Bressler (1977) have shown that the Chino Valley Formation at Jerome, which they consider to be the Beckers Butte Member of the Martin, and the Beckers Butte Member in the East Verde River area both have a Devonian paleomagnetic pole position. The Chino Valley Formation and Beckers Butte Member are thus equivalent magnetostratigraphic units and are considered here to be probable correlatives of late Givetian or early Frasnian age. To date, no diagnostic fossils have been found in the Chino Valley Formation.

MISSISSIPPIAN STRATA

Mississippian strata of marine origin probably once covered all of Arizona except the Defiance-Zuni positive area. Present outcrops are mainly in the canyons and plateau-edge escarpments of the Colorado Plateau region and in elongate isolated mountain ranges in the Basin and Range part of Arizona. Flat-lying Mississippian strata are present in the subsurface throughout most of the plateau region.

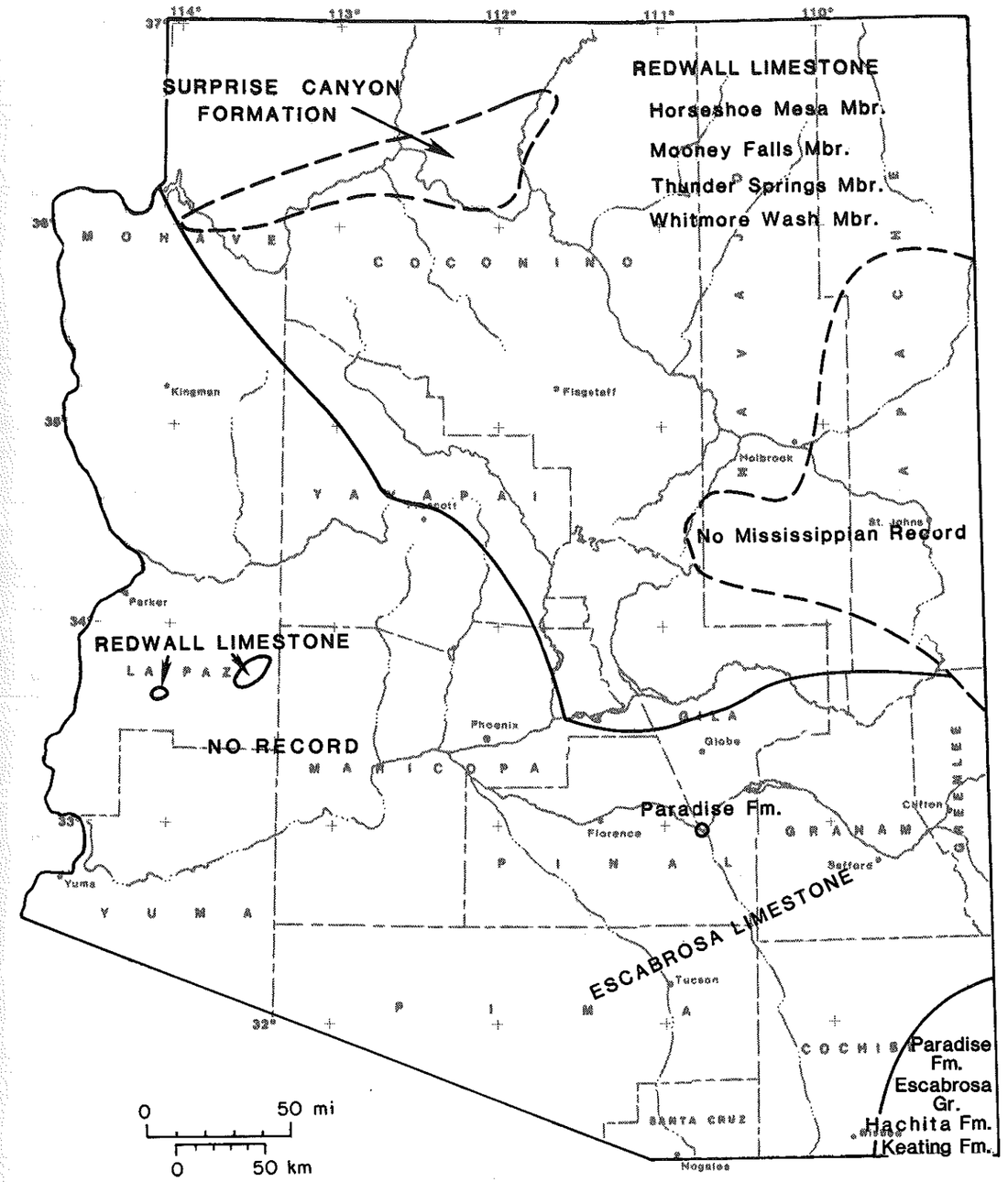

Figure 9. Nomenclature for Mississippian rocks in Arizona.

Thickness patterns are shown in figure 2. Variations in thickness are gradual and reflect a thinning to 0 against the Defiance-Zuni positive area in east central Arizona, a gradual thickening northwest toward the Cordilleran miogeocline and a more rapid thickening southeast toward the Arizona-New Mexico trough or Pedregosa Basin to a maximum of 380 m (1,245 ft). Mississippian lithology is predominantly limestone or dolomite with locally abundant chert. Throughout the northern two-thirds of the state Mississippian strata are assigned to the Redwall Limestone of Kinderhookian to Meramecian age (fig. 9). Isolated outcrops of valley-fill strata atop the Redwall in the Grand Canyon area are in the Surprise Canyon Formation of Chesterian age.

In southeastern Arizona, Mississippian strata of Kinderhookian through Meramecian age are in the Escabrosa Formation or Group. Late Meramecian- and Chesterian-age rocks in extreme southeastern Arizona are assigned to the Paradise Formation (figs. 8,9).

Most Mississippian strata were deposited in a single major episode of deposition to form a lower depositional complex of late Kinderhookian through middle Meramecian age. The Redwall Limestone and Escabrosa Limestone make up this complex. An upper depositional complex, much less extensive than the lower and mainly of Chesterian age, is represented locally by the Paradise Formation in southeastern Arizona and by isolated patches of the Surprise Canyon Formation rocks in the northwest.

Throughout the state, Mississippian strata rest disconformably on Devonian rocks. Where exposed the lower contact is commonly marked by a recess forming oxidized zone at the base of resistant limestone cliffs overlying less-resistant Devonian carbonate or shale beds. In a few isolated spots along the Defiance-Zuni positive area, in eastern Grand Canyon and elsewhere Mississippian strata rest on Cambrian or Precambrian rocks. The top of the Mississippian System in Arizona is disconformable with the overlying Pennsylvanian strata. The unconformity represents part of Meramecian, all of Chesterian, and part of earliest Pennsylvanian time over most of the state. In the northwest and southeast corners of the state, where Chesterian-age strata occur, the unconformity spans only very latest Mississippian and earliest Pennsylvanian time (fig. 8).

Redwall Limestone

The Redwall Limestone is recognized in outcrop and in the subsurface throughout most of northern Arizona. It was named by Gilbert (1875, p. 177) for exposures of red-stained cliff-forming limestone in Grand Canyon. The Redwall typically forms sheer cliffs 150-240 m (500-800 ft) high through the Grand Canyon. Four members of the Redwall were defined by McKee and Gutschick (1969). They are, in ascending order, the Whitmore Wash, Thunder Springs, Mooney Falls and Horseshoe Mesa Members.

Whitmore Wash Member: The Whitmore Wash Member of the Redwall is a fine-grained, generally thin-bedded dolomite or limestone. Common textural rock types are pelleted and skeletal or oolitic wackestones and packstones (Kent and Rawson, 1980). Exposed thickness is from 0 m in the east to 40 m (130 ft) at Iceberg Ridge in the northwest. It is up to 60 m (200 ft) thick in the subsurface of northeastern Arizona.

The Whitmore Wash Member is of late Kinderhookian age in the western Grand Canyon and early and middle Osagian to the east, as interpreted from brachiopod and foraminiferid fossils (McKee and Gutschick, 1969, p. 30). Late Kinderhookian conodonts were reported from the lower part of the member at Salt River Canyon and at Gold Gulch near Globe in east-central Arizona by Racey (1974). Ritter (1983, p. 17) obtained Osagian conodonts from the upper part at Iceberg Ridge.

Thunder Springs Member: The Thunder Springs Member is typically thin-bedded limestone or dolomite interbedded with thin beds or lenses of chert. In outcrop it is the most distinct member of the Redwall Limestone owing to the dark color and banded appearance imparted by the chert beds (fig. 10). Carbonate rock in the Thunder Springs is mostly coarse-grained dolomite in the subsurface of northeastern Arizona but is more commonly limestone to the west. The member is thickest in the northeast and under the Kaibab Plateau in north-central Arizona where it is up to 71 m (235 ft) thick (Kent and Rawson, 1980, p. 103).

Invertebrate marine fossils are commonly preserved in the chert of the Thunder Springs and include diagnostic conodonts of Osagian age (Racey, 1974; Ritter, 1983). The Thunder Springs is conformable with the underlying Whitmore Wash Member. In most areas it is disconformable with the overlying Mooney Falls Member except in the northwest corner of the state (fig. 8).

Mooney Falls Member: The Mooney Falls is the thickest member of the Redwall. It is up to 125 m (410 ft) at Iceberg Ridge and 137 m (450 ft) in the subsurface of eastern Mojave County (Kent and Rawson, 1980, p. 103). It generally thickens from southeast to northwest. The Mooney Falls is predominantly pure limestone except locally where dolomitized. Carbonate grains include oolites, pelloids, and a variety of skeletal fragments dominated by crinoid plates. Invertebrate fossils are abundant in the member and include diagnostic foraminifera (Skipp, 1969; Mamet and Skipp, 1970, p. 338) and conodonts (Racey, 1974; Ritter, 1983) of late Osagian and Meramecian age.

Horseshoe Mesa Member: The Horseshoe Mesa Member is the thinnest and least extensive member of the Redwall Limestone. This member is up to 45 m (150 ft) thick in northwestern Arizona but wedges out due to erosion about 48-58 km (30-40 miles) south of the Grand Canyon (McKee and Gutshick, 1969, p. 64). It is possibly present in northeastern Arizona but difficult to recognize

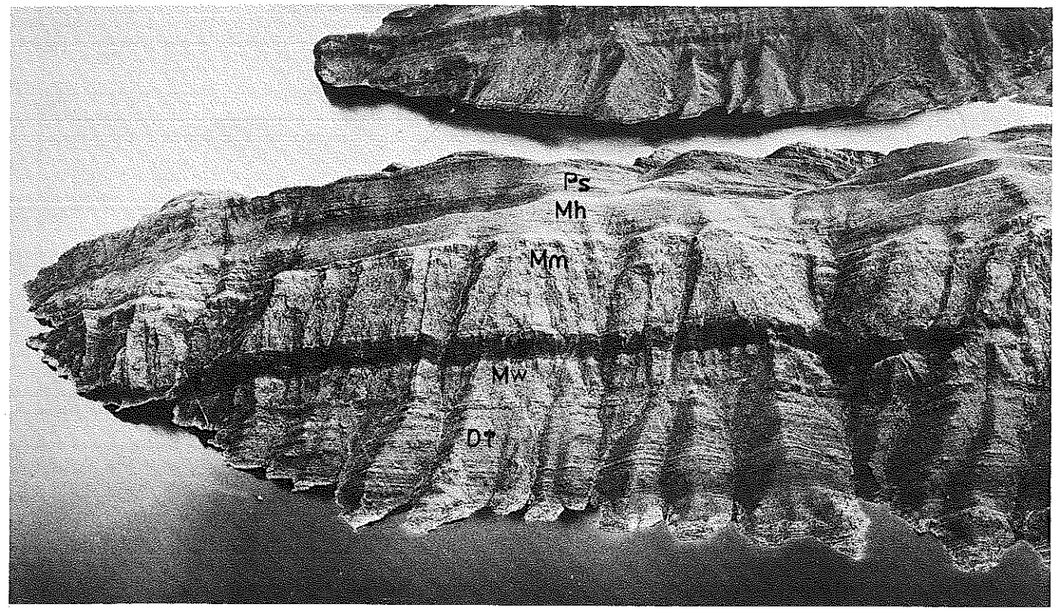

Figure 10. Air view of Iceberg Ridge in northwestern Arizona. Dt, Temple Butte Formation; Mw, Whitmore Wash Member; Mt, Thunder Springs Member (dark band); Mm, Mooney Falls Member; Mh, Horseshoe Mesa Member of the Redwall Limestone; Ps, Basal Supai Group.

from well cuttings because of post-Redwall—pre-Supai erosion and weathering (Kent and Rawson, 1980, p. 103). The Horseshoe Mesa is typically thin-bedded lime mudstone to wackestone. Some chert lenses occur in the upper part. The presence of diagnostic foraminifera in Grand Canyon sections of the lower Horseshoe Mesa and upper Mooney Falls Member indicates a Meramecian age.

Surprise Canyon Formation

McKee and Gutshick (1969, p. 190) reported a single outcrop of limestone containing Chesterian-age brachiopods on top of the Horseshoe Mesa Member of the Redwall Limestone along the Bright Angel trail in eastern Grand Canyon. More recently Billingsley and McKee (1982) reported channel-fill strata of latest Chesterian age filling valleys cut into the top of the Redwall Limestone in western Grand Canyon. Isolated lens-shaped outcrops of this unit (fig. 11), containing both marine invertebrate and terrestrial plant fossils, are now known through most of the Grand Canyon and as far east as Marble Canyon. These outcrops are now recognized as the Surprise Canyon Formation (Billingsley and Beus, 1986) of late Chesterian and possibly earliest Pennsylvanian age. This unit is up to 120 m (400 ft) thick in western Grand Canyon but much thinner to the east. The Surprise Canyon is exposed only as discontinuous lenses representing the sediment filling of valleys cut into the top of the Redwall Limestone. In western Grand Canyon the lower part of the section is typically fluvial conglomerate and sandstone locally containing *Lepidodendron* logs. The upper part of the section is yellowish-gray marine limestone rich in invertebrate fossils. Key index fossils include the brachiopod *Rhipidomella nevadensis*, the foraminiferid *Eosigmoilina explicata*, and the conodont *Adetognathus unicornis* (Webster, 1985, pers. comm.) all of which indicate a late Chesterian age. Deposition of the Surprise Canyon appears to have occurred in a marine to nonmarine estuarine system that was tidally dominated in the west and mainly fluvial in the east.

Escabrosa Limestone

The Escabrosa Limestone was named by Ransome (1904) for Mississippian strata in the Mule Mountains near Bisbee in southeastern Arizona. All but Chesterian-age Mississippian strata in southern Arizona are included in this unit. The Escabrosa was raised to group status and divided into a lower Keating Formation and an upper Hachita Formation by Armstrong (1962, p. 5). The latter nomenclature is restricted to the Chiricahua and Pedregosa Mountains in extreme southeastern Arizona (fig. 9). The Escabrosa is thickest in the Pedregosa Mountains (306 m, 999 ft) and thins northwestward to 113 m (370 ft) near Superior (Norby, 1971, p. 14).

The Escabrosa is mainly a light-gray crinoidal limestone in the type section at the Mule Mountains. In the Chiricahua Mountains the lower two-thirds of the Escabrosa, the Keating Formation of Armstrong (1962), is

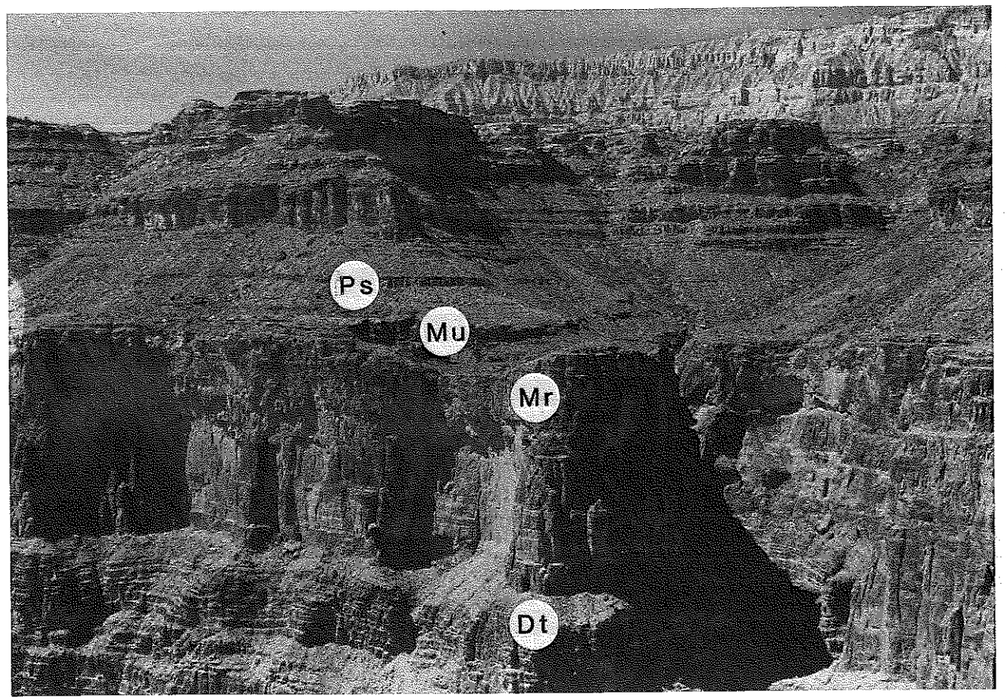

Figure 11. View of north wall of central Grand Canyon near Fern Glen Canyon. Dt, Temple Butte Formation; Mr, Redwall Limestone; Mu, Chesterian age Surprise Canyon Formation strata filling valley cut into the top of the Redwall Limestone; Ps, basal Supai Group.

a dark-gray lime mudstone having a crinoidal grainstone at the base. It is massive in the lower part and thin bedded and cherty in the upper part (Norby, 1971). The upper third of the Escabrosa, the Hachita Formation of Armstrong (1962), is almost all a light-gray, thick-bedded to massive crinoidal grainstone.

The Escabrosa contains a variable invertebrate fauna including abundant brachiopods and corals and less common mollusks and trilobites. Conodonts and foraminifera indicate an age of late Kinderhookian through late Meramecian (Mamet foraminiferid zones, pre-7, 7-14) for this unit (Armstrong and others, 1980, p. 84).

The base of the Escabrosa is everywhere a disconformity above Late Devonian strata. However, it is not easily recognized in some parts of southeastern Arizona (Whetstone Mountains) where Escabrosa-like dolomites yield Famennian conodonts. The Escabrosa is overlain unconformably by Pennsylvanian strata in most sections except in extreme southeastern Arizona where the Chesterian-age Paradise Formation conformably overlies it.

Paradise Formation

The Paradise Formation was named by Stoyanow (1926) from the abandoned mining camp of Paradise in the Chiricahua Mountains. It is known only in extreme southeastern Arizona and southwestern New Mexico. An isolated outcrop of probably Chesterian age overlying the Escabrosa Limestone near Winkelman, in central Arizona, may be an erosional remnant of the Paradise (Ross, 1973, fig. 4), although Purves (1978, p. 41) considered it to be a new rock unit distinct from the Paradise.

The Paradise is 44 m (144 ft) thick at Blue Mountain in the Chiricahua Mountains (fig. 12) and 76 m (251 ft) in the Pedregosa Mountains. Lithology is gray shaly limestone in the lower part with alternating dark-gray lime-stone, shale, and sandstone in the upper half. It typically forms a slope or saddle between the more resistant Escabrosa Limestone below and the Horquilla Formation above. It appears conformable with the Escabrosa below. The contact with the Horquilla Formation above is a disconformity representing a part of late Chesterian time and earliest Pennsylvanian time (fig. 8).

Hernon (1935) described a marine invertebrate fauna from the Paradise including abundant brachiopods, bryozoans, and mollusks plus less common crinoids blastoids and trilobites. Norby (1971, fig. 2) reported middle Chesterian conodonts from the Paradise. Armstrong and others (1980, figs. 2, 5) considered it to be late Meramecian through middle Chesterian age (foraminiferid zones 16-18).

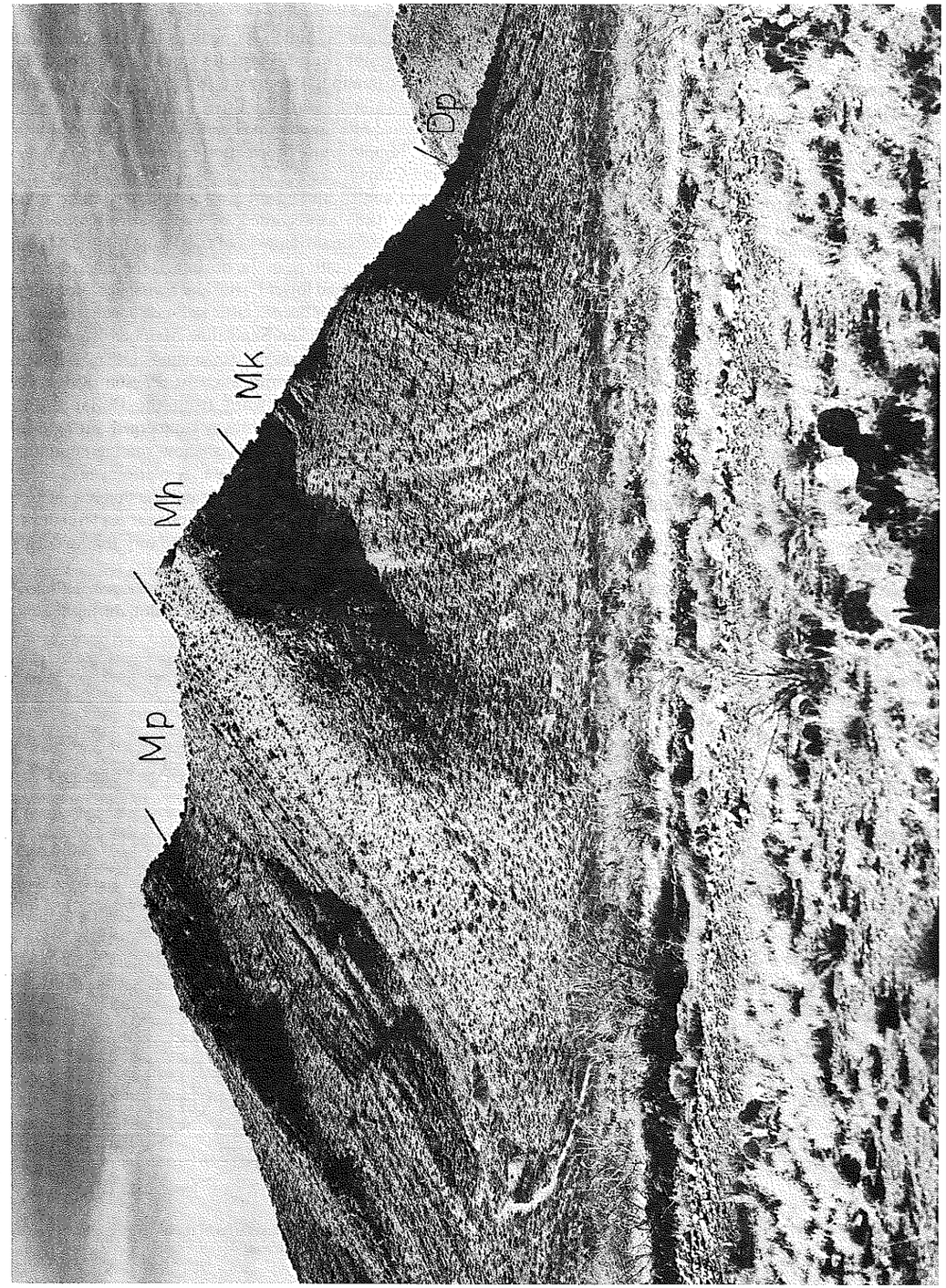

Figure 12. Mid-Paleozoic strata at Blue Mountain in the Chiricahua Mountains, southeastern Arizona. Dp, Portal Formation; Mk, Keating Formation; Mh, Hachita Formation of Escabrosa Group; Mp, Paradise Formation.

SUMMARY OF PALEOGEOGRAPHY AND GEOLOGIC HISTORY

The Devonian-Mississippian depositional history of Arizona is represented by a series of paleogeographic maps (figs. 13-20) that illustrate general facies distribution. The rock record of depositional events can be conveniently divided into a series of depositional complexes each of which involves a major transgression and regression of the sea across the broad cratonic platform of which Arizona was a part. Strata in each complex are separated from the next by a regional unconformity. Complexes recognized in Arizona are:

Devonian (defined by Schumacher, 1978)

1. A lower complex which began in the late Givetian and ended near the Frasnian-Famennian time boundary.
2. An upper complex which formed principally during Polygnathus styriacus conodont Zone time (late Famennian).

Mississippian (defined by Rose, 1976)

1. A lower complex including strata of late Kinderhookian through middle Meramecian age.
2. An upper complex containing strata of late Meramecian through late Chesterian age.

Devonian Period

Lower Depositional Complex (Frasnian): The onset of deposition of this complex as presently known was in the northwest and central part of the state in latest Givetian or earliest Frasnian time. It includes the Beckers Butte Member of the Martin Formation and possibly the Chino Valley Formation. These were formed of siliciclastic and carbonate sediments in fluvial to marginal marine conditions. Shallow marine conditions are marked by the lower Temple Butte Formation in central and western Grand Canyon (fig. 3). Transgression of the sea was from the west and south and progressed to a maximum in late Frasnian time as recorded by the marine faunas and extensive carbonate deposits of the Temple Butte, Martin, and Elbert formations in the north and the limestone unit of the Morenci and lower Portal and Swisshelm formations in the south. An influx of clastic sediments from the east is seen in the McCracken Sandstone Member of the Elbert Formation and siliciclastic sediments of the Swisshelm Formation. Promontories such as Payson Ridge and islands extending westward from the Defiance-Zuni positive area were finally mostly submerged during latest Frasnian time (figs. 4, 5) as shallow marine conditions prevailed over most of the state. A platform area in the vicinity of present-day eastern Grand Canyon and Marble Canyon seems to have remained at or near sea level during this time as Devonian strata there are very thin or locally missing (fig. 4).

Upper Depositional Complex (late Famennian): Following a period of nondeposition and erosion during the first

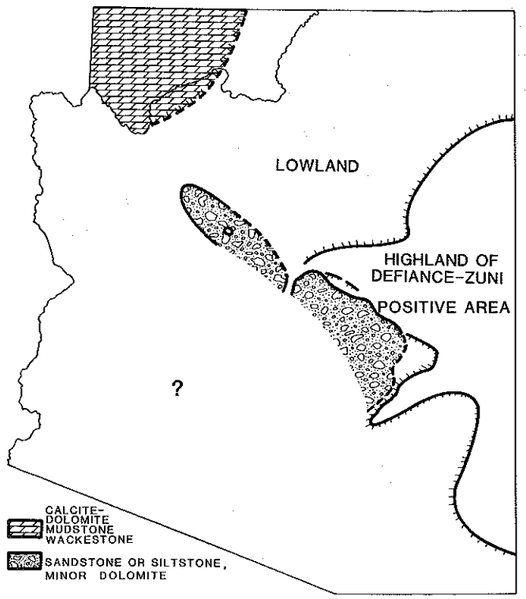

Figure 13. Paleogeography and facies of the latest Givetian-early Frasnian in Arizona.

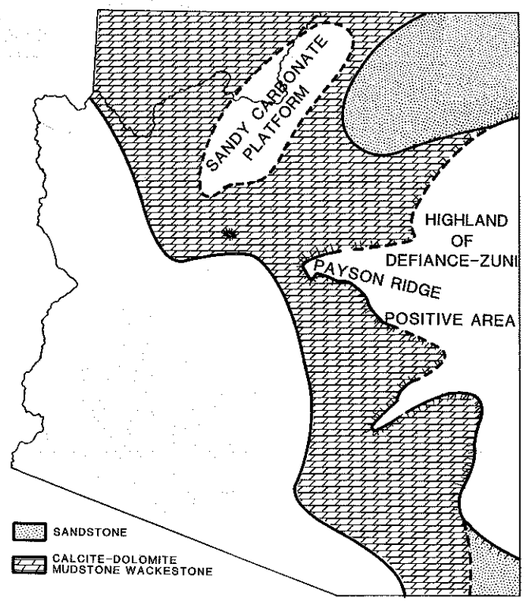

Figure 14. Paleogeography and facies of the lower part of the Frasnian depositional complex in Arizona.

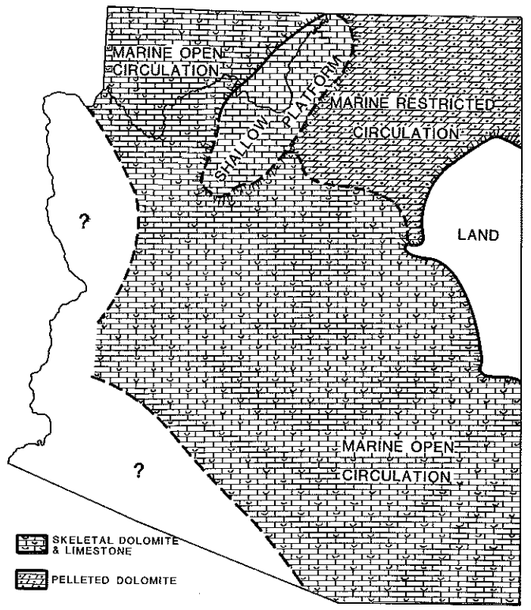

Figure 15. Paleogeography and facies of the upper part of the Frasnian depositional complex in Arizona.

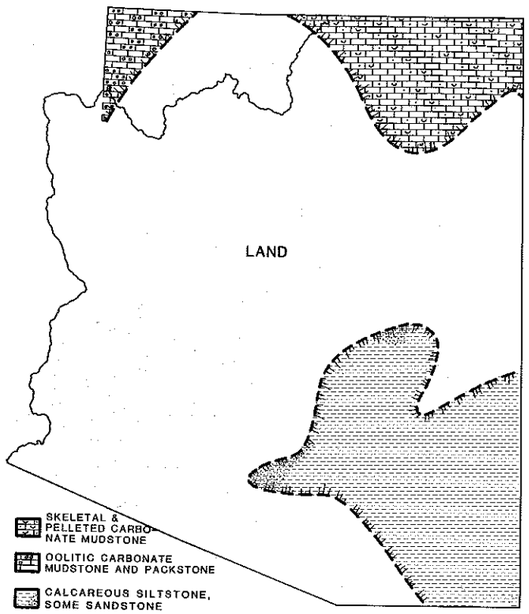

Figure 16. Paleogeography and facies of the late Famennian in Arizona.

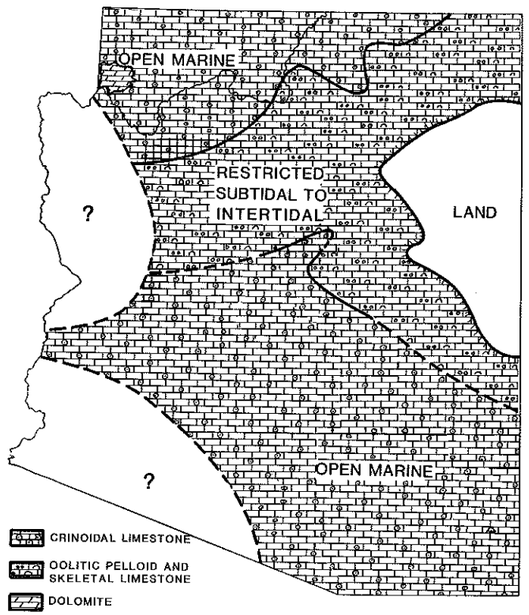

Figure 17. Paleogeology and facies of the late Kinderhookian-early Osagian during the first marine transgression and formation of the lower depositional complex in Arizona.

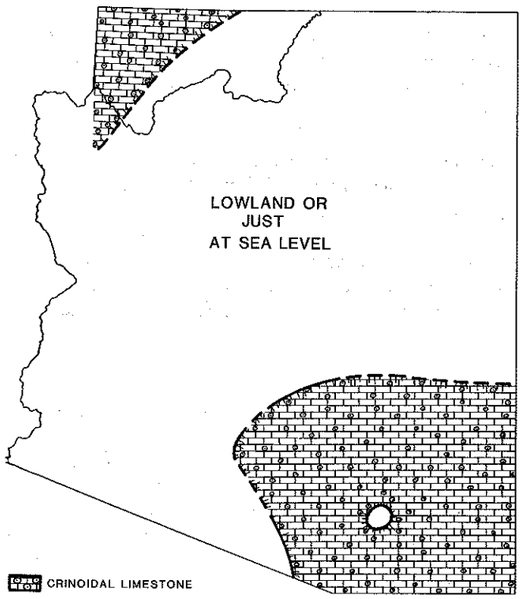

Figure 18. Paleogeography and facies at approximately latest Osagian time during the maximum regression and formation of the lower depositional complex of the Mississippian in Arizona. Modified from Armstrong and others (1980) and McKee (1979).

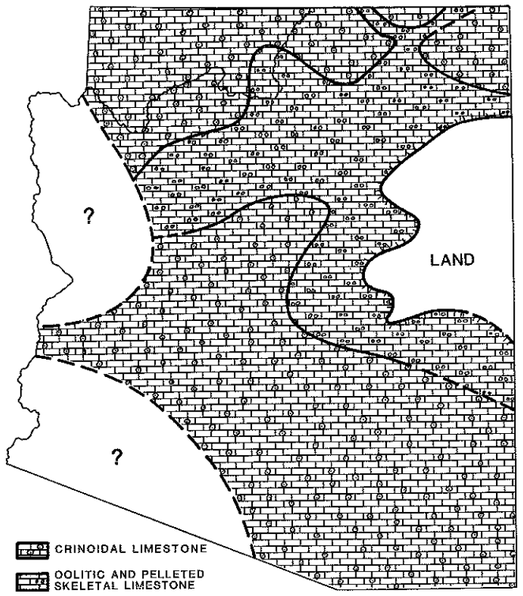

Figure 19. Paleogeography and facies at approximately early Meramecian time in Arizona during the second marine transgression and formation of the lower depositional complex. Modified from Armstrong and others (1980), Kent and Rawson (1980) and Rose (1976).

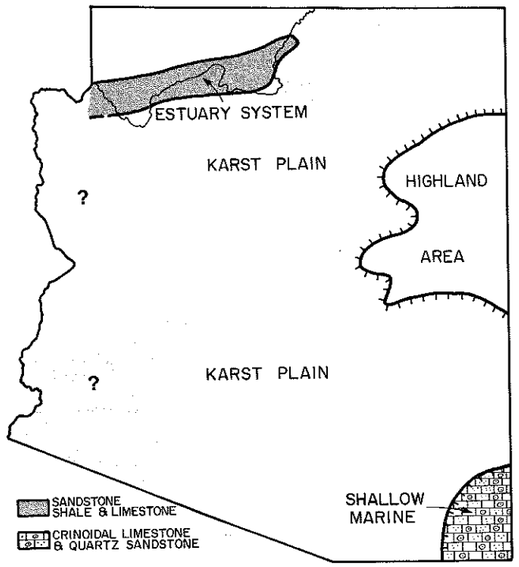

Figure 20. Paleogeography and facies during approximately late Chesterian time in Arizona.

half of Famennian time, a second transgression of the sea again brought shallow marine conditions to Arizona. Strata of this upper complex in southeastern Arizona are shale and overlying carbonate of the Percha, upper Portal and upper Swisshelm formations. Locally these strata contain reworked Frasnian fossils from the Martin Formation and, in the Galiuro Mountains, rest on Cambrian rocks where the Martin is missing (Schumacher, 1985, pers. comm.). Late Famennian strata in northern Arizona are the Pinyon Peak Limestone in the northwest corner, and the Ouray Formation in the northeast corner, where deposition may have continued into earliest Mississippian time.

Mississippian Period

Lower Depositional Complex (late Kinderhookian to early Meramecian): This complex includes the major part of the Mississippian strata in Arizona—essentially the Redwall Limestone in the north and the Escabrosa Limestone in the south. In northern Arizona two depositional cycles, each involving a transgression and regression across the state, are defined in the lower complex (McKee and Gutschick, 1969; Kent and Rawson, 1980). The first cycle was the more extensive, according to Kent and Rawson (1980), and involved the deposition of the Whitmore Wash and Thunder Springs Members of the Redwall. Initial supertidal or nearshore subtidal deposits of dolomite in the lower Whitmore Wash Member were gradually supplanted by pelloidal and oolitic lime sand and finally by crinoidal lime sediments. These record a shift toward more offshore open marine conditions through time (fig. 17). Transgression probably progressed slowly from northwest to southeast. The Thunder Springs Member of the Redwall records a regression of the sea (McKee and Gutschick, 1969, p. 73). A widespread unconformity at the top of the Thunder Springs marks an episode of nondeposition and some erosion during the regression in approximately middle Osagian time (fig. 17) (Skipp, 1979, fig. 76).

A second transgression in northern Arizona during Osagian time is recorded by the Mooney Falls Member of the Redwall (fig. 19). This second transgression was more rapid and, according to McKee and Gutschick (1969, p. 62), slightly more extensive than the first. Crinoidal grainstone and packstone facies developed widely across northern Arizona and reached a climax in the deposition of the upper Mooney Falls Member (Kent and Rawson, 1980, p. 73). This second cycle was ended by a slow regression as the Horseshoe Mesa Member was deposited and then in part eroded during early or middle Meramecian time (fig. 18).

In southern Arizona crinoidal packstone and grainstone facies of the Escabrosa Limestone similar to those in the Redwall record a major transgression from the southeast beginning in the late Kinderhookian (pre-foramaniferid Zone 7) time and reaching a maximum in the late Osagian

(Armstrong and Mamet, 1978, p. 185). This was followed by a regression in the Meramecian involving the upper Escabrosa. The Escabrosa has other minor hiatuses within it, one of which may correlate with the major break to the north in the middle of the Redwall Limestone. However, present data do not indicate a major regression in the middle of Escabrosa deposition time (fig. 8).

Upper Depositional Complex (Chesterian). Deposits of a more localized marine transgression during Chesterian time are represented by the carbonate and terrigenous clastic rocks of the Paradise Formation in southeastern Arizona (fig. 20). Isolated remnants of Chesterian age limestone—the "Paradise Formation" outcrop south of Winkelman (Ross, 1973)—indicate that rocks of this upper complex may have once covered much of Arizona but were eroded. Moreover, the Chesterian-age Surprise Canyon Formation valley-fill strata in the Grand Canyon record local deposition of marine and nonmarine sediments in a belt across northwestern Arizona (Billingsley and McKee, 1982; Billingsley and Beus, 1986).

Armstrong and others (1980, p. 87) would extend the lower boundary of this upper complex to include the uppermost Escabrosa Limestone (and Hachita Formation of the Escabrosa Group) plus the Horseshoe Mesa Member of the Redwall Limestone. However, these strata appear conformable with the underlying beds and seem better assigned to the top of the lower complex rather than the base of the upper.

The presence of both marine and nonmarine deposits in the upper depositional complex indicates significant changes in depositional environment during the latest Mississippian as compared with the exclusively marine conditions recorded by the lower complex. McKee (1979, p. 205) has pointed out the similarity of the Mississippian upper complex strata to the overlying Pennsylvanian rocks that record dramatic changes toward more continental conditions in northern Arizona.

UNSOLVED PROBLEMS

Microfossil and macrofossil data, where present, permit reasonably accurate correlations of Devonian and Mississippian rocks throughout most of Arizona. Problems in paleogeographic reconstruction and geologic history interpretations are mainly related to the lack of fossils in some units and the scarcity of outcrops in some areas.

An unresolved problem in central Arizona is the age of the Chino Valley Formation and its relationship, if any, to the Beckers Butte Member of the Martin Formation. It occupies the same stratigraphic position as the Beckers Butte but has yielded no diagnostic fossils and may not even be of Devonian age.

The mid-Paleozoic history in southwestern Arizona is not well understood because much of the record is gone and the few known outcrops contain metamorphosed and attenuated relics of the original strata. Current mapping will shed some additional light on this area but we will probably never fully document this time span.

Isolated outcrops of Chesterian-age rocks in central and northern Arizona appear to be remnants of a once much more extensive rock record for the latest Mississippian. Additional studies of these rocks in northern Arizona may reveal a more complete record and enhance our understanding of Late Mississippian history there.

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