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Constance Nuss Dodge

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PEBBLES FROM THE CHINLE AND MORRISON FORMATIONS

by

CONSTANCE NUSS DODGE
University of Arizona
Tucson, Arizona

INTRODUCTION

The Mogollon highland is an inferred positive area in central and southern Arizona and west-central New Mexico that existed during much of the Mesozoic Era (Stewart, Poole and Wilson, 1972; Repenning, Cooley and Akers, 1969; Cooley and Davidson, 1963; Harshbarger, Repenning and Irwin, 1957). The purpose of this study was: (1) to interpret the history of the Mogollon highland as revealed by pebble studies, and (2) to investigate the usefulness of relating sediments to their sources as a tool in the interpretation of major strike-slip movements. Several geologists, including William J. Purvis, a fellow graduate student at the University of Arizona, have hypothesized that a major strike-slip fault zone existed along the northern uplifted margin of the Mogollon highland during the Mesozoic. If such movement occurred between a source area and its depositional basin, this movement might be detected if the sediments of different ages in the basin can be related to their southern sources.

The pebbles from three widespread conglomeratic units on the southern portion of the Colorado Plateau were studied in order to test these ideas. The units are: the Shinarump Member of the Upper Triassic Chinle Formation, the Sonsela Sandstone Bed contained within the Petrified Forest Member of the Chinle Formation, and the Westwater Canyon Member of the Upper Jurassic Morrison Formation. The distributions of common pebble lithologies (quartz, quartzite and chert) and distinctive pebble types (fossiliferous, white chert and volcanic pebbles) were used to compare the Triassic Shinarump Member and Sonsela Sandstone Bed with the Jurassic Westwater Canyon Member for significant differences.

The location of the study area is shown in Figure 1; the locations of the sampling sites are shown in Figure 2. At each site, excluding Haystack Butte, a sample that accurately represents the relative abundances of the dominant pebble lithologies was collected from the face of the outcrop. At Haystack Butte, the pebbles are small and embedded in a well-cemented matrix, so the sample was collected from pebbles that had weathered from the outcrop.

All three conglomeratic units are believed to be alluvial plain deposits derived from the south. Grain-size and cross-stratification studies have revealed that the dominant transport directions of the southern Shinarump sediments were to the north, northwest and northeast (fig. 6), and that the major transport directions of the sediments of the Sonsela Bed were to the north and northeast (fig. 8; Stewart and others, 1972, pl. 4, fig. 20; Poole, 1961). Cross-stratification studies in the Westwater Canyon Member by George A. Williams (data furnished by L. C. Craig, written communication, 1973) indicate a dominate direction of sediment transport to the northeast, however facies distributions within the Westwater Canyon Member indicates that the major source area for the unit was south of Gallup, New Mexico (fig. 7; Craig and others, 1955, p. 156).

Previous studies of Triassic conglomerates on the Colorado Plateau include regional analyses of pebbles in most of the conglomeratic units of the Chinle Formation (Thordarson, Albee and Stewart, 1972) and a regional comparison of pebbles in the Shinarump and Moss Back members of the Chinle Formation (Albee, 1957). The methods of sampling, analyzing and comparing common pebble lithologies used in this study are similar to those used in the two studies listed above.

This paper is based on work which was completed for a M.S. thesis at the University of Arizona in May, 1973. Dr. Richard F. Wilson directed the study and made helpful suggestions. Thanks are due to the Museum of Northern Arizona and the Society of Sigma Xi, who granted financial assistance, and to Dr. Donald E. Livingston and the Geochronology staff of the University of Arizona, who dated two specimens. Correspondence with Larry C. Craig of the U.S. Geological Survey, which included cross-stratification studies by George A. Williams, was most helpful.

COMMON PEBBLE LITHOLOGIES

Many of the quartzite pebbles common to all three units are very similar to several Precambrian quartzite units that crop out in central and southern Arizona: the Alder Series (Wilson, 1939, p. 1121-1123) of older Precambrian age, the Mazatzal Quartzite (Wilson, 1939, p. 1124-1126) of older Precambrian age, and the Dripping Spring Quartzite (Shride, 1967, p. 17-19) of younger Precambrian age. The presence of older Precambrian pebbles in Triassic and Jurassic conglomerates suggests considerable uplift along the Mogollon highland during the Mesozoic.

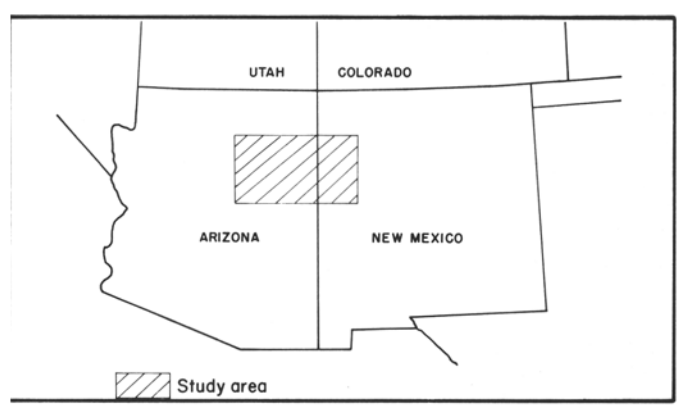

Figure 1.
Location of study area.

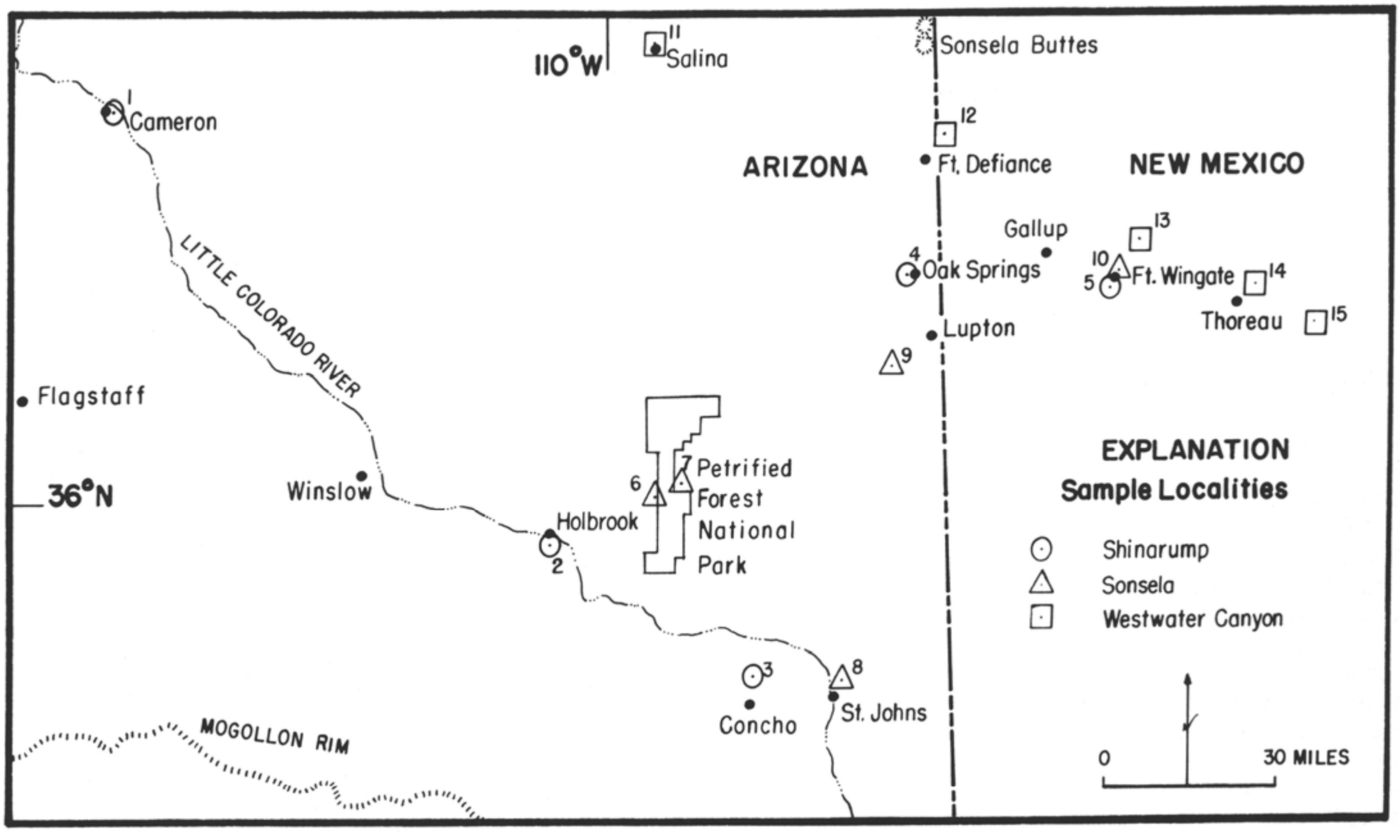

Figure 2.
Location of sample localities:

Shinarump Member
1. Cameron
2. Holbrook
3. Concho
4. Oak Springs
5. Fort Wingate

Sonsela Bed
6. Twin Buttes
7. Petrified Forest
8. St. Johns
9. Lupton
10. Fort Wingate

Westwater Canyon Member
11. Salina
12. Fort Defiance
13. Fort Wingate
14. Thoreau
15. Haystack Butte

In a simple model of an uplifted area contributing sediments to a depositional basin, one would expect that as denudation of the source area continues, stratigraphically younger deposits in the depositional basin will receive older source material. The lithologies of the Shinarump and Sonsela pebbles do not support such a simple model, as the older Shinarump Member contains abundant quartzite pebbles that are apparently Precambrian, whereas the younger Sonsela Sandstone Bed contains pebbles consisting dominantly of chert. Many of these pebbles are fossiliferous and obviously post-Precambrian. One might consider that either the drainage pattern shifted with time so that different units were contributing sediments during the deposition of each Chinle unit, or that renewed uplift occurred farther to the south or north in the Mogollon highland, exposing new sources of chert. The second hypothesis appears the more likely as dip directions of cross-strata indicate that the directions of sediment transport of the two units were very similar. Also, many of the quartzite pebbles present within the two units are very similar, so it is possible that the Shinarump Member and Sonsela Sandstone Bed had the same quartzite sources, although the relative abundance of quartzite within the Sonsela Sandstone Bed is low due to the influx of other material. Possibly renewed uplift occurred in the southern Mogollon highland during the Triassic, as Sonsela chert pebbles are generally smaller than the Shinarump pebbles.

Percentages of the dominant pebble lithologies are presented in Table 1. The percentages of pebbles under the heading "others" generally refer to weathered pebbles that could not be accurately identified. Many of these pebbles were probably originally chert or volcanic rocks.

The distribution of the common lithologies (quartz, quartzite and chert) of pebbles in the Shinarump and Westwater Canyon members were compared because these two units represent an age difference in terms of millions of years. The distributions of quartz, chert and quartzite pebbles within the two units are shown in Figures 3, 4 and 5, respectively. Generally, the distributions of Triassic quartz and chert pebbles in northeastern Arizona are similar to the distributions of Jurassic quartz and chert pebbles found farther to the east in northwestern New Mexico. In the Triassic Shinarump Member, the percentages of quartz pebbles drop to low values at Holbrook, Concho and Oak Springs in Arizona, whereas in the Westwater Canyon Member, the drop in percentage of quartz pebbles occurs farther to the east at Fort Wingate, New Mexico. In the Shinarump Member the percentage of chert pebbles is high at Holbrook, Arizona, whereas in the Westwater Canyon Member, the percentage of chert pebbles increases to the east at Fort Wingate and Haystack Butte. The values of percentages of quartzite pebbles are more constant than the quartz and chert pebble percentages.

Table 1.
Percentages of the dominant pebble lithologies.

Sample Site	Quartz	Quartzite	Chert	Volcanic Rocks	Feldspar	Granitic Rocks	Other
Shinarump Member							
Cameron	42	46	10				2
Holbrook	6	40	42				12
Concho	8	53	19				20
Oak Springs	5	67	15	1			12
Fort Wingate	70	21	8				1
Sonsela Sandstone Bed							
Twin Buttes		15	64	20			1
Petrified Forest		11	77	12			
St. Johns		29	65	1			5
Lupton	1	19	79				1
Fort Wingate	1	12	83				4
Westward Canyon Member							
Salina	5	34	19	12	10	3	17
Fort Defiance	5	43	15	6	12	3	16
Fort Wingate	1	39	29	15	7	6	3
Thoreau	9	25	22		25	5	14
Haystack Butte	4	29	34	2	10	3	18

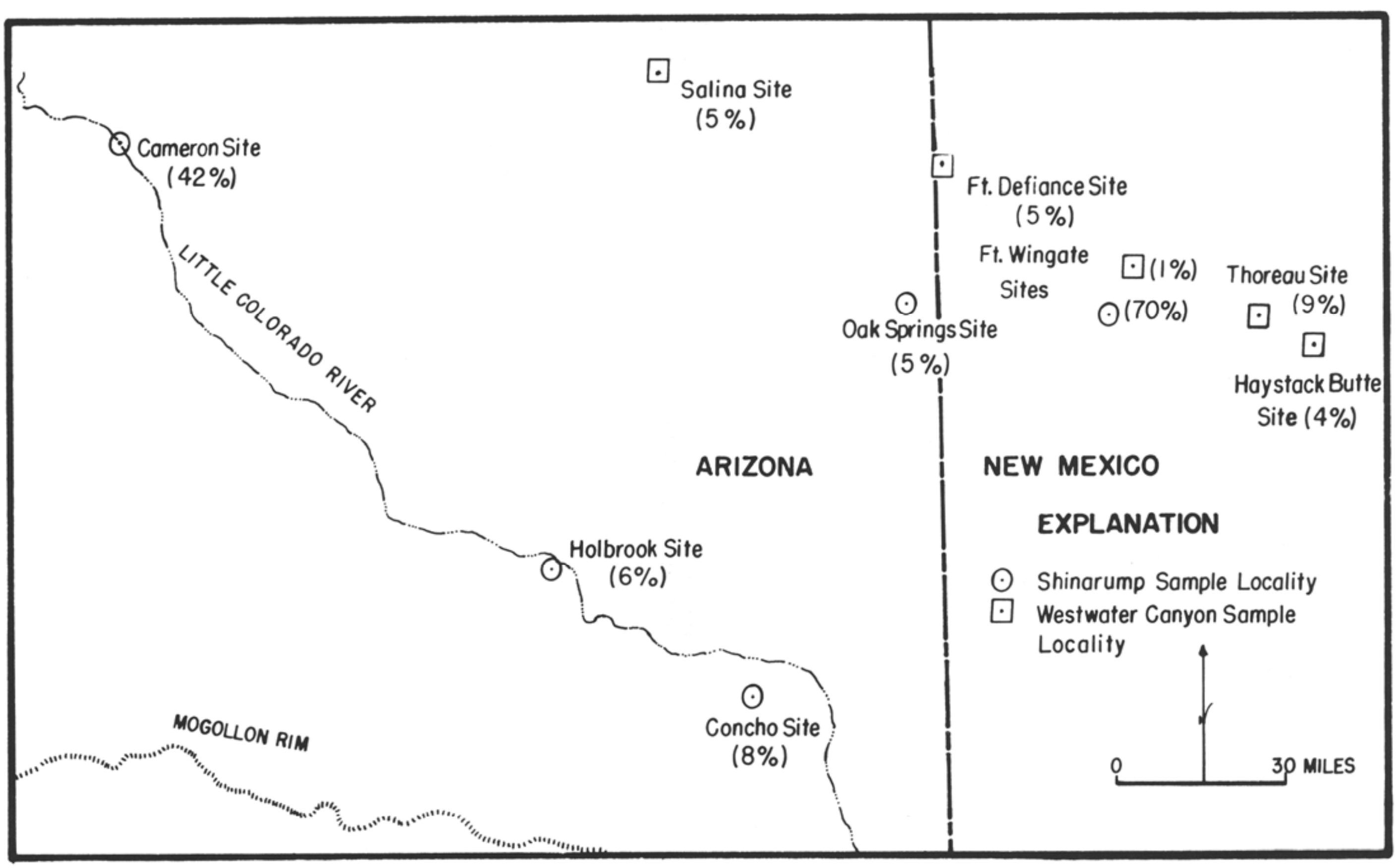

Figure 3.
Distribution of percentages of quartz pebbles within the Shinarump and Westwater Canyon members.

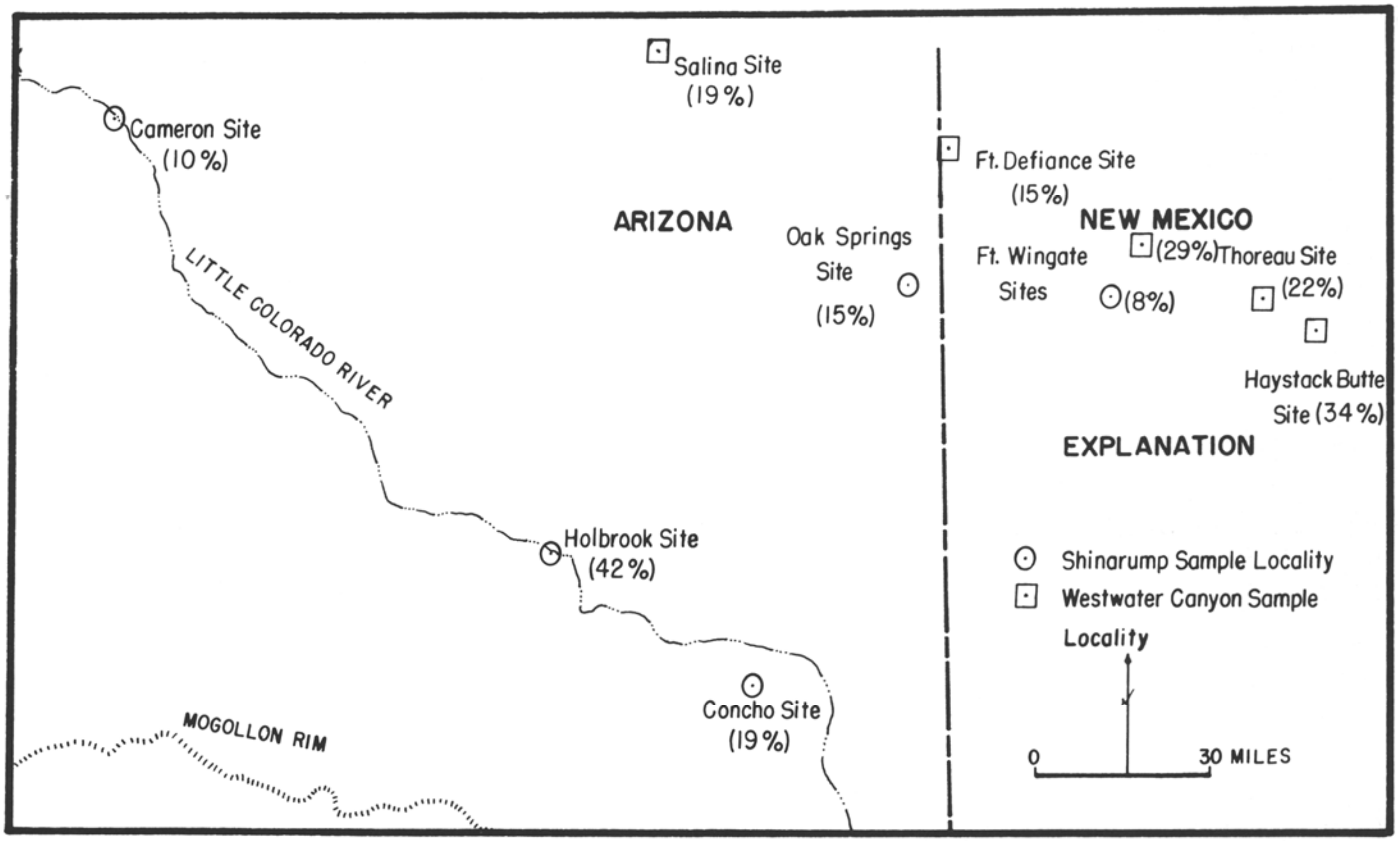

Figure 4.
Distribution of percentages of chert pebbles within the Shinarump and Westwater Canyon members.

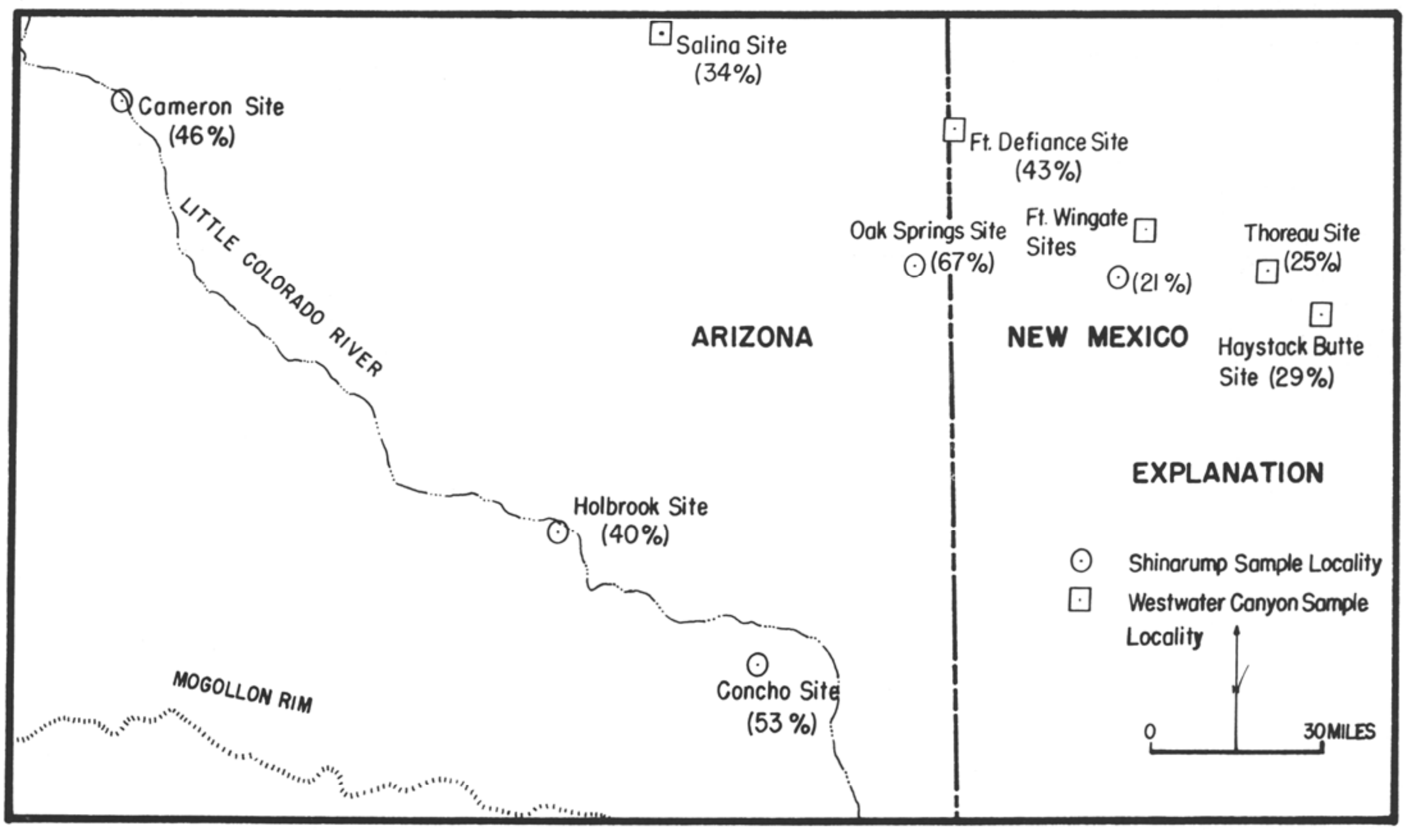

Figure 5.
Distribution of percentages of quartzite pebbles within the Shinarump and Westwater Canyon members.

DISTINCTIVE PEBBLE TYPES

Several distinctive pebble types were studied petrographically for the purpose of comparing the pebbles that were deposited during different periods of time more precisely and relating them to their southern sources.

One pebble type, fossiliferous, white chert, is present locally within the Shinarump and Westwater Canyon members. It constitutes 10 percent of the Shinarump sample at Holbrook, Arizona, and 9 percent of the Westwater Canyon sample at Thoreau, New Mexico. It is also present in smaller amounts in the Westwater Canyon Member at Haystack Butte. Identification of the chert in a hand specimen was based upon the following characteristics: white color; mottled appearance; and fossil material consisting of crinoid stems, echinoid spines and bivalve hash. Specimens from both the Shinarump and Westwater Canyon members were examined petrographically with the aid of acetate peels and were found to have the same textural characteristics (Dodge, 1973, p. 38).

Other distinctive pebbles, fresh and slightly altered volcanic rock, are localized in the Sonsela Sandstone Bed at Twin Buttes and the Petrified Forest, Arizona, and in the Westwater Canyon Member at Fort Wingate, New Mexico. These pebbles, which have been studied in thin section (Dodge, 1973, p. 39-46), are very silica rich and range in composition from rhyolite to dacite, using the classification scheme of Williams, Turner and Gilbert (1953, p.121). They dominantly consist of microlitic groundmasses composed of quartz and feldspar that surround phenocrysts of quartz (usually embayed), feldspar, minor biotite, hornblende and opaque minerals. Common textural features include spherulites, elongated blebs of recystallized quartz and possible flow banding. These pebbles probably represent source rocks that were at one time glassy, silicic lava flows, which later devitrified and possibly recrystallized to form the microlitic groundmasses.

The textures and mineralogy of the pebbles described above are strikingly similar to those of the Precambrian Red Rock Rhyolite, which crops out in the Mazatzal Mountains of central Arizona. Therefore it was suggested that these pebbles had a Precambrian source. However, two rhyolitic pebbles, one from the Sonsela Twin Buttes locality and one from the West-water Canyon (Fort Wingate locality), were dated by rubidium-strontium method in the Isotope Geochemistry Laboratory of the University of Arizona. Both pebbles were found to be 241 million years old ± to 31 million years. Therefore the sources for these pebbles were either of Late Permian or Triassic age instead of Precambrian.

INTERPRETATION OF PEBBLE DISTRIBUTIONS

Fossiliferous, white chert pebbles and rhyolitic pebbles in the Shinarump Member, Sonsela Sandstone Bed and Westwater Canyon Member are identifiably the same. However, such pebbles in the Triassic strata are localized in northeastern Arizona, whereas in the Jurassic strata they are localized in northwestern New Mexico. To interpret this distribution, inferred sources of these pebbles were located.

The orientations of resultant dip directions of cross-strata and generalized directions of stream flow in the Shinarump Member are shown in Figure 6. Superimposed on this map is an isopleth map of the maximum size of quartz, quartzite and chert gravel. To the east of Holbrook, the locality where fossiliferous, white chert pebbles were abundant, the directions of sediment transport were predominantly east and north, whereas to the west of Holbrook the direction of sediment transport was predominantly northwest. The pebbles in the Shinarump Member at Holbrook possibly had a source directly south of Holbrook.

A facies map based upon textural differences in the Westwater Canyon Member and resultant dip directions of cross-strata are shown in Figure 7. The conglomeratic sandstone facies can be divided into two regions: (1) a central region in which pebbles are commonly as large as 4 inches in diameter, and (2) a peripheral region in which pebbles are generally less than 1 inch in diameter. A sandstone facies, characterized by the absence of pebbles surrounds the conglomeratic sandstone facies on the west, north and east. This facies distribution indicates that a major sediment source for the Westwater Canyon Member existed south of Gallup, New Mexico (Craig and others, 1955, p. 156), even though resultant dip directions indicate transport directions to the northeast. Therefore, the Jurassic source for fossiliferous, white chert pebbles at Thoreau and Haystack Butte, New Mexico, was probably south of Gallup, New Mexico, whereas the Triassic source for the fossiliferous, white chert at Holbrook, Arizona, was probably south of Holbrook.

The orientation of resultant cross-strata dip directions and generalized directions of stream flow for the Sonsela Sandstone Bed are shown in Figure 8. An isopleth map of the maximum sizes of quartz, quartzite and chert particles is superimposed on this data. The directions of sediment transport at Twin Buttes and the Petrified Forest, where rhyolitic pebbles make up 20 percent, 12 percent of the sample were north, northeast, and northwest (fig. 8). Farther east at St. Johns, where only a few such pebbles were collected, the transport direction was practically due east. It is reasonable to place the inferred Triassic source of the rhyolitic pebbles in an area located chiefly south of Twin Buttes and the Petrified Forest. The inferred Jurassic source for the Westwater Canyon pebbles collected at Fort Wingate, New Mexico, is south of Gallup, New Mexico.

Assuming that the chert and volcanic pebbles contained within the Shinarump, Sonsela and Westwater Canyon units each came from one stratigraphic unit, three explanations for the distributions of these pebbles can be examined:

1. The volcanic unit and the sedimentary unit containing the chert in the Mogollon highland were quite widespread, and there western extents were exposed to erosion during the Triassic while their eastern extents were exposed to erosion later during the Jurassic.
2. The units in the source area contributing the distinctive pebbles were not widespread but were restricted to an area south and southeast of the Petrified Forest. The drainage system which deposited the pebbles in Arizona during the Triassic shifted and deposited the chert and volcanic pebbles in New Mexico during the Jurassic.
3. Left-lateral, strike-slip movement occurred between Upper Triassic and Upper Jurassic time along a west-trending zone north of the Mogollon highland, causing movement of the source area relative to the sedimentary basin.

In the middle three Shinarump samples (Holbrook, Concho and Oak Springs) fossiliferous chert pebbles are common. This suggests that Paleozoic rocks were exposed in the Mogollon island and were eroded and redeposited in the Late Triassic. If

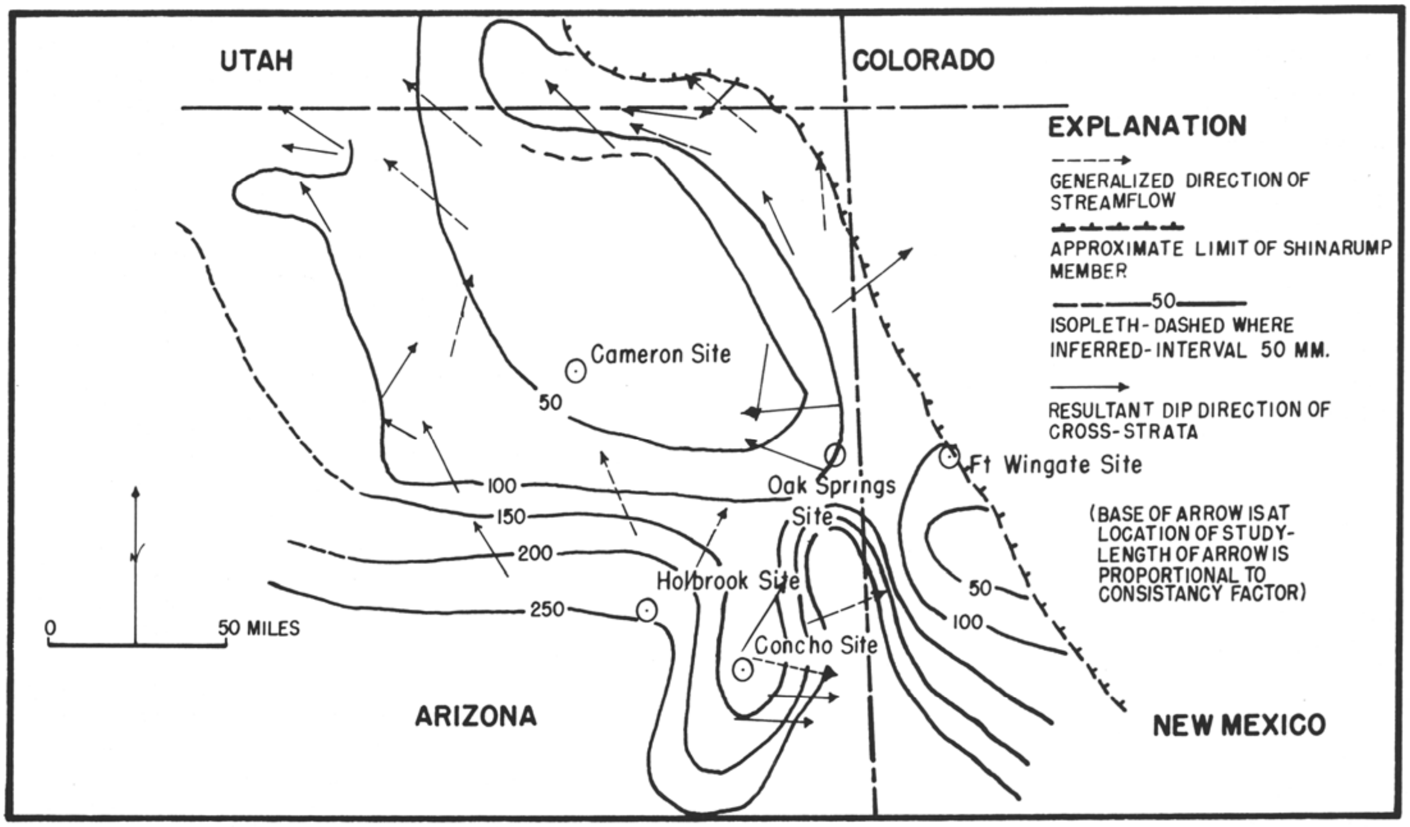

Figure 6.

Change in maximum size of gravel (quartz, quartzite and chert) and flow directions in the Shinarump Member. Isopleth map and resultant dip directions of cross-strata are after Stewart and others (1972). Generalized directions of stream flow are after Poole (1961).

the unit containing the white chert was widespread, it is reasonable to expect it to be represented at other Shinarump localities—but it is not. The second hypothesis appears reasonable if one considers only the Triassic and Jurassic cross-stratification data. A shift from north, northeast and northwest directions of sediment transport in the Upper Triassic to a dominantly northeast direction in the Upper Jurassic could account for the locations of specific pebble types. The facies distribution within the Westwater Canyon Member, however, indicates that the source of the Jurassic pebbles present in New Mexico was not in Arizona but in west-central New Mexico. Therefore, the second hypothesis does not constitute a model which is in agreement with all the available data.

The third hypothesis of strike-slip movement occurring between the source area and the depositional basin accounts for the distributions of pebble types and is in agreement with the inferred locations of Triassic and Jurassic pebble sources; this appears to be a more valid explanation. However, the first two explanations should not be completely eliminated until more data are obtained.

CONCLUSIONS

It appears that throughout much of the Mesozoic Era, Precambrian units were exposed to erosion in the Mogollon highland. This is evidenced by quartzite pebbles which have been incorporated within the Shinarump, Sonsela Sandstone Bed and Westwater Canyon units of Triassic and Jurassic ages. Renewed uplift in the Mogollon highland region during Triassic time is evidenced by a large quantity of post-Precambrian chert pebbles present within the Sonsela Sandstone Bed but not present within the older Shinarump Member. Late Permian or Triassic volcanism is evidenced by volcanic pebbles in the Sonsela Sandstone Bed and the Westwater Canyon Member.

Assuming that the source areas existed to the south and southeast of their present outcrops of conglomerate, three models are given to explain the pebble distributions:

1. Portions of distinctive rock units were exposed in the Mogollon highlands at different periods of time.
2. Shifting drainage patterns deposited material from the same local source units during different periods of time.
3. Left-lateral, strike-slip movement occurred along the uplifted region of the Mogollon highland during Triassic and Jurassic time.

Lithologies of the common pebbles show a Triassic distribution in northeastern Arizona that is similar to the Jurassic distribution in northwestern New Mexico. Fossiliferous, white chert and volcanic pebbles are localized in Triassic strata of northeastern Arizona and in Jurassic strata of northwestern New Mexico. Inferred locations of southern sources for both the Upper Triassic and Upper Jurassic strata support the third model. However, without more data the other two models cannot be completely eliminated.

An analysis of the pebbles within the Cretaceous Dakota Sandstone in northeastern Arizona and northwestern New Mexico, and a comparison of them with those studied in this project might be a valuable follow-up study.

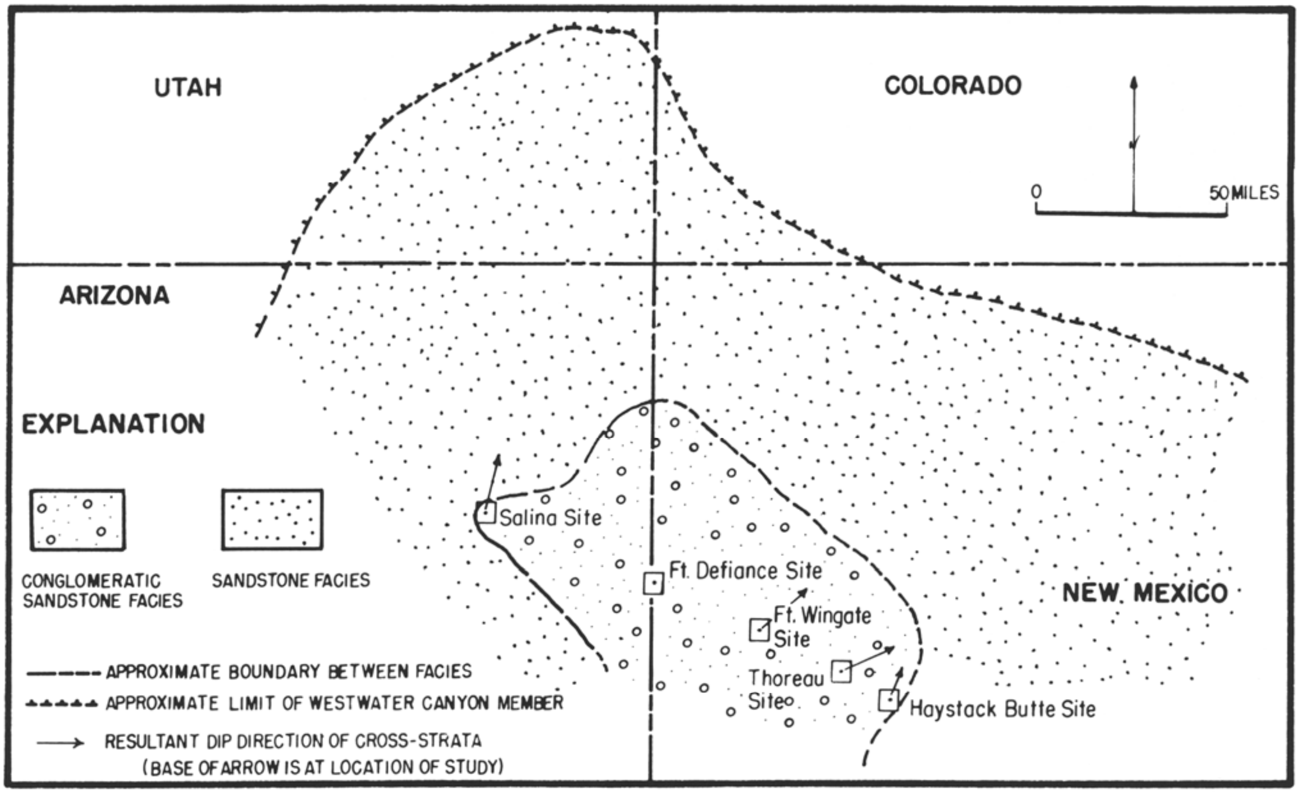

Figure 7.

Generalized facies map and resultant dip directions of cross-strata of the Westwater Canyon Member. The facies map is after Craig and others (1955). Resultant dip directions are from data of G. A. Williams (Craig, written communication, 1973).

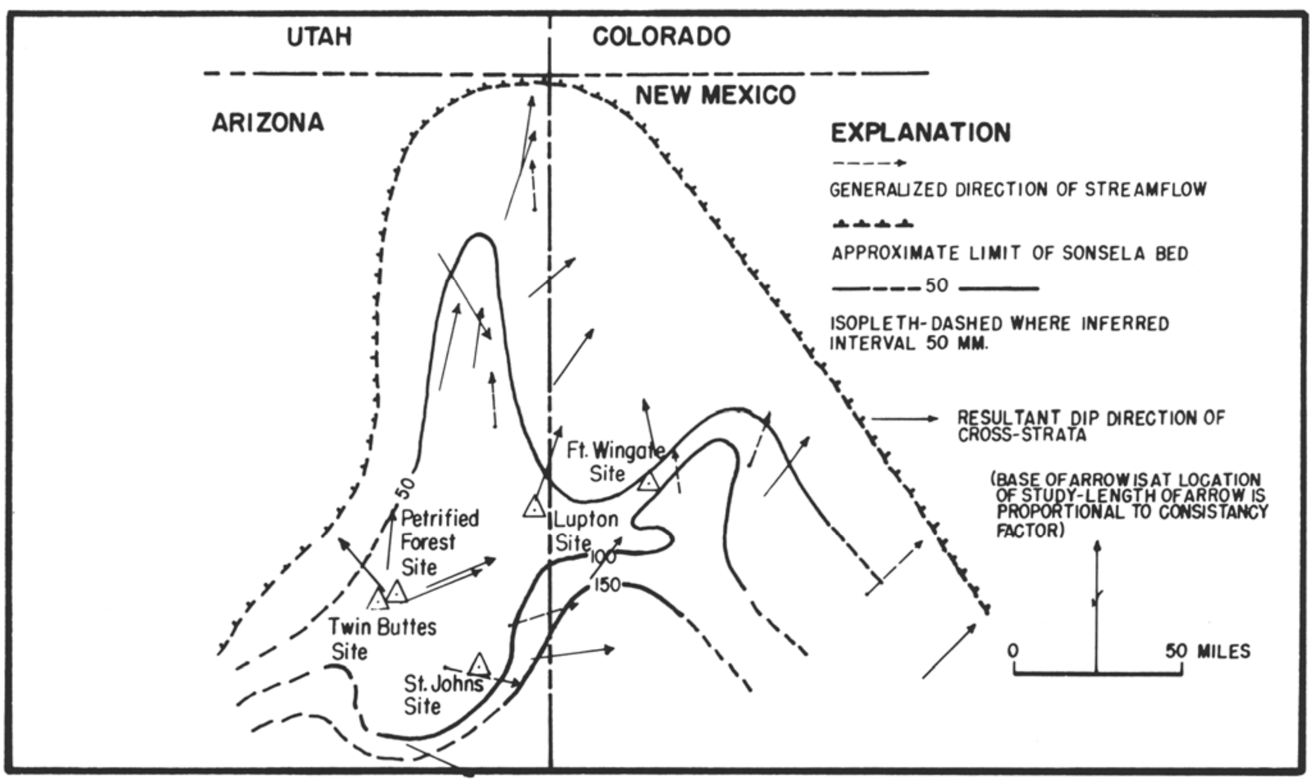

Figure 8.

Change in maximum size of gravel (quartz, quartzite and chert) and flow directions in the Sonsela Sandstone Bed. Isopleth map and resultant dip directions of cross-strata are after Stewart and others (1972). Generalized directions of stream flow are after Poole (1961).

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