ORIGIN OF THE DRAINAGE OF SOUTHEASTERN ARIZONA

By

Mark A. Melton

University of Arizona

INTRODUCTION AND ACKNOWLEDGEMENTS

As part of the utilization of Arid Lands Project of the University of Arizona, the general and historical geology of the Safford Valley, Graham County, is under intensive study by faculty and students of the Department of Geology. The writer's part in the project has been to investigate the geomorphic history of the area, particularly with the object of finding out details of the drainage development: changes of course and discharge of older rivers, source areas of river sediment, and causes of changes of river regimen.

The starting point of the work was to develop a history which would adequately explain the origin of the transverse segments of the Gila River across the Mescal and Dripping Springs mountain ranges, at the lower end of the Safford Valley, and between the south end of the Gila Mountains and the north end of the Peloncillo Mountains, at the upper end of the valley. The history must of course be consistent with the known and inferred regional geological and geomorphic history, and should help explain physiographic and sedimentary features within the Safford Valley.

Whatever merit the work presented below may contain is due very largely to the extensive knowledge and assistance of the writer's colleagues, Drs. J. W. Harshbarger and J. F. Lance, of the University of Arizona, and Dr. L. A. Heindl, Ground Water Branch, U. S. Geological Survey. Helpful information was also received from discussions with graduate students of the University who have worked in the area. Errors of fact and interpretation are of course the responsibility of the writer alone.

THE PROBLEM OF THE MODERN DRAINAGE

Characteristics of the Modern Drainage -- The modern, major drainage courses exhibit the following characteristics:

(1) The rivers alternately follow structural valleys and cross the intervening mountain ranges through erosional gorges. These gorges are almost invariably at right angles to the trend of the mountain ranges they cross, and show the results of two or three episodes of downcutting. The higher (older) part of the gorges evidently was of considerable antiquity before renewed downcutting produced the inner gorges.

(2) The transverse segments of the rivers show, in several cases, a remarkably nice alignment one with another or with major gaps through the mountain ranges that are not now occupied by rivers.

(3) Nowhere does a transverse river gorge pass through a major granitic or gneissic mountain block, such as the Santa Catalina, Pinaleno, or Chiricahua Mountain ranges. However, dry passes through the granite ranges exist, e.g., Redington Pass between the Santa Catalina and Rincon Mountains.

(4) Underlying Recent and Late Pleistocene river and alluvial fan sediments in the longitudinal valleys, fine-grained clastic sediments and limestones form a series that has been affected only slightly by diastrophic movements, although locally considerable

deformation has occurred. In many cases the deposits lie in depositional contact with the adjacent mountain fronts. In the Safford Valley, the base of the fine-grained sediments lies at a lower elevation than the present bedrock channel of the Gila River at the exit from the valley, at the Coolidge Dam.

(5) The general elevation of the Mescal Mountains near the Gila gorge is about 5, 000 feet above sea level; other low points on the perimeter of the Safford-San Simon Valley are found at elevations of 4730 feet, 4390 feet, 4200 feet, and about 3600 feet. The elevation of the Gila River at the Coolidge Dam is about 2286 feet.

Many more points could be listed but these are salient from a geomorphic point of view. The theory that will be presented was "made to order" to explain these particular points.

Earlier Theories -- Numerous attempts to explain the landform features of the region containing the Safford Valley can be found in the literature. These are mostly well known and need not be reviewed in detail here (Waibel, 1928; Sauer 1930; Davis, 1931; Howard, 1942; Gilluly, 1949; Tuan, 1959). As one example, Waibel believed that following a long period of structural stability and erosion, the present mountain ranges were uplifted in Pliocene time; faulting and vulcanism produced a large number of basins of interior drainage. Erosion of the mountain masses resulted in pediment development and partial filling of the basins with locally-derived, coarse, clastic debris. A change to a wetter climate allowed the accumulation of excess water in the form of lakes, and fine-grained, lacustrine deposits were laid down. The eventual overflow of some of these lakes at their lowest points produced a successively-integrated drainage system. Later, the lower basins "captured" the higher ones by headward erosion, somewhat as in the standard or "textbook" description of the arid cycle of erosion. We may call this the "integration by lake overflow" theory. A number of difficulties make any simple lake-overflow theory unacceptable:

(1) Most transverse gorges cut through parts of the mountain ranges where the general elevation of the summits is not the lowest point of the basin rim -- the Gila gorge through the Mescal and Dripping Springs mountains, for example. Similarly, the Gila River enters the Safford Valley by a gap through mountains whose general elevation is considerably greater than the elevation of the same range, the Peloncillos, farther to the south. The deposition of the "lake" sediments was not contemporaneous with the uplifting of the mountains, and probably began long after diastrophism had ceased. Therefore, it seems most unlikely that post "lake" uplift could have raised the regions near the hypothetical point of overflow.

(2) The lake-overflow theory cannot explain the alignment of the transverse river segments.

(3) The lake-overflow theory does not explain why the fine-grained "lake" deposits in many cases lie directly against the mountain front without intervening coarse facies. Hypothetically the lake stage would preceed an intergrated-river stage that would allow importing of fine material, without the necessity of deriving it locally from the bordering mountain masses. If the lakes were formed in closed basins, there should be in every case a marginal coarse facies.

A more fruitful hypothesis was anticipated by Sauer (1930, p. 375), in his conjecture that the sequence of broad mountain passes followed by the main line of the Southern Pacific Railroad could have been formed by a major river whose course was almost entirely transverse. Sauer, however, despaired of ever finding supportive evidence.

Possible modes of origin of a transverse drainage system -- There are four plausible ways in which the transverse drainage present today could have originated:

(1) Lake overflow; this theory has already been discussed and rejected.

(2) Headward erosion and capture by tributaries to an original, entirely longitudinal system of lakes or rivers. This requires that the transverse river segments lie along cross faults or zones of weakness which would have favored a headward-eroding tributary. Evidence for such zones cannot be found. This theory does not explain the alignment of transverse segments, and so is rejected.

(3) Regional superposition of a southwest-flowing drainage system, followed by capture by tributaries eroding headward along major structural troughs. This theory requires a post-orogenic, more-or-less planar cover whose surface sloped to the southwest from about 9000 feet above sea level near Alpine to about 4000 feet near Tucson. The hypothetical cover might have been either a sheet of lava, tuff, or alluvial sediment. Consequent streams this surface, upon eroding downward, would be positioned across the axes of the northwest-trending mountains. After further down-cutting and a series of captures, most of the southwest-flowing drainage would be diverted to courses along the structural valleys. Although this would explain the alignment spoken of, there is no evidence that the required cover ever existed. In fact, postulating a vast cover would raise more problems than it solves.

Regional superposition of a number of southwesterly-flowing rivers across the mountain ranges seems very unlikely, although locally, superposition from a lava or sedimentary cover may have occurred.

(4) Antecedence of pre-orogenic, southwesterly-flowing rivers. According to this theory at least four rivers flowed from north-east to southwest across southeastern Arizona prior to the major uplift of the present mountain ranges. These rivers maintained their courses throughout the orogeny, but following downcutting, perhaps induced by regional tilting, northwesterly-flowing tributaries following the structural troughs successively captured the transverse rivers. This is the theory favored by the writer, and is explained in detail in the following section.

THEORY OF ANTECEDENT DRAINAGE

Pre-orogenic Rivers -- If we assume that the straight, aligned, transverse segments of modern rivers are remnants of pre-orogenic rivers, and are therefore older than the longitudinal river segments as well as at least most of the mountain-building activity, then it is necessary to postulate that at least four major rivers flowed across southeastern Arizona before the present topography came into existence. The earliest direction of flow is not definitely known; the writer favors a southwesterly flow because that is the direction of the modern drainage and also because the San Juan Mountains could have been a source of water, although it is not definitely established that a remote source of water is a necessary condition. Others favor a northeasterly direction of flow (S. C. Creasey, U.S.G.S., personal communication). The direction of flow is somewhat less important than that channels existed at the right places. The courses and proposed names of the four hypothetical rivers are shown in Figure 1.

Evidence of three smaller, tributary rivers positioned between the major rivers has been found:

a. A small river probably flowed from the Pinal Mountains area across the Mescal Mountains and across what is now Troy Gap in the Dripping Springs Mountains.

b. A small river probably flowed across the Galiuro Mountains where the Aravaipa Creek now crosses (L. A. Heindl, personal communication).

c. A river probably flowed north of the present Winchester Mountains and through the Redington Pass area, between the Rincon and Santa Catalina Mountains.

No names are proposed for these rivers.

The northeastward extent of these rivers is not known, but it is reasonable to suppose that the Clifton River (Figure 1) may have extended up via the plains of San Augustin to the vicinity of Alburquerque and perhaps drained the upper Rio Grande watershed. The others may have originated on the present Colorado Plateau area. Neither is the southwestward extent of the rivers known, and evidence on this is lacking.

Independent evidence -- Evidence for the existence of a preorogenic, southwest-northeast-oriented drainage system, that is independent of the listed features which we are trying to explain, falls into two categories:

A. Evidence that a transverse drainage system was formerly more extensive than now is found in a relatively high-level surface that appears to extend from the New Mexico-Arizona line near San Simon westward at least as far as Gila Bend. Existing remnants of this surface are various accordant (i.e. approximately of equal elevation) summit levels of many of the smaller mountain ranges, and shoulders or spurs on the sides of the larger ranges. The surface itself must have been a compound erosional and constructional surface, perhaps consisting of a large number of coalescing pediments and bajadas, whose general level was controlled by (probably) southwestward flowing rivers. This surface is named the Tortolita Surface, as the Tortolita Mountains north of Tucson are about in the center of the known extent of the surface, and because the accordant summits of the Tortolita Mountains provide perhaps the best evidence for its existence. The elevation of the surface declines slowly from about 4950 feet above sealevel near the Peloncillo Mountains in southeastern Arizona, to about 4200 in the Tucson area, to 3950 feet near Phoenix, to perhaps 3000 feet near Ajo. "Form lines" on the surface have roughly a NNW-SSE trend. Besides the Tortolita Mountains (4300 feet), other remnants of the Tortolita Surface possibly are part of the summit of the Tucson Mountains (4200 feet), Redington Pass (ca. 4350 feet), accordant summits of the Dripping Springs Mountains (4400 feet), the sub-volcanic granite surface north of the Pinal Ranch, Pinal Ranch, Quad., Arizona (4400 to 4500 feet), the saddle of the pass through the Peloncillo Mountains southeast of the Whitlock Mountains (4950), accordant summits of many hills north and northeast of Willcox (4800 to 4900 feet); west of the Tucson area, there is a suggestion of summit accordances near Arivaca (4100 feet), the Sierra Estrella southwest of Phoenix (3950 feet), and possibly near Ajo (3000 feet). Much more field work will be required before existence of the Tortolita Surface in the western and west-central parts of southern Arizona can be satisfactorily demonstrated.

It is particularly interesting that the Tortolita Surface appears to be restricted to the area traversed by the hypothetical rivers referred to above. That is, it appears to be limited to the north by plateau structure, and traces of it have not been found in the higher mountains to the south. The mean gradient of the surface from the Peloncillo Mountains to Ajo is 9 feet per mile, which compares well with the gradient of the Gila River from Safford to Gila Bend, about 10 feet per mile. There is reason for believing that the Tortolita Surface represents a compound surface controlled by a number of major rivers flowing southward across southern Arizona during a fairly long period of relative stability following uplift of the mountains. This river system must have contained many more transverse segments than now exist. Therefore, there is independent geomorphic evidence against the theory of integration by lake overflow and the theory of capture of an original, entirely longitudinal system of rivers and lakes by headward erosion of favored tributaries, and evidence favorable to the theory of antecedency.

An older, higher surface may have existed also. Possible remnants can be found at about 6100 feet in the Huachuca Mountains-Canelo Hills area, the north end of the Santa Rita Mountains, the Sierrita Mountains, the Mazatzal Mountains north of Four Peaks, and elsewhere. Correlation on the basis of elevation alone is hazardous, and as the localities mentioned are widely spread other explanations are possible for the observed summit accordances.

B. Channels of former rivers that flowed across certain mountain ranges before at least the later stages of vulcanism and tectonic activity. Former river channels, transverse to the ranges and buried by Tertiary volcanic material, have been found by Heindl near the confluence of Aravaipa Creek with the San Pedro River, by Harshman (1939) in Queen Creek Canyon above Superior, and by Melton in the Haunted Canyon Quadrangle, 0.7 miles south of J K Mountain. The channels found by Harshman and Melton have been affected by post-volcanic tilting, and both line up well with the trend of the Rockinstraw River (Figure 1).

Post-orogenic events -- The sequence of events necessary and inferred, if one accepts the theory of antecedency, cannot be stated in great detail and confirmed on the basis of present knowledge. However, a skeleton history is as follows:

1. Establishment of dominant southwesterly-trending drainage, probably influenced by the northeast trend of lineation in the Precambrian rocks of the area, and locally by other structures.

2. Uplift of the present mountain ranges across the courses of the rivers; downcutting of the rivers. The river courses were probably changed somewhat as uplift progressed.

3. Development of the Tortolita Surface by both erosion of the mountain masses and deposition between the mountains. Possibly an older surface was developed, also.

4. Further downcutting by the rivers of 800 to 1200 feet, which may have been induced by regional tilting down to the northwest.

5. Headward growth of northwest-flowing tributaries and capture of the Winkelman, Clifton, ancestral Aravaipa, and other rivers. The Winkelman river was probably diverted into a nothwesterly course earlier than rivers to the southeast because of the time required for headward erosion (Figure 2). At about this time the Rockinstraw River was probably diverted from its course near Superior by the accumulation of the Apache Leap-Pickert Post Mountain volcanic pile, and assumed a course nearer the present Salt River.

6. Completion of the capture of the southwest-trending drainage; establishment of longitudinal drainage from Mexico in the San Simon and Aravaipa valleys (Figure 3).

7. Gradual damming of the ancestral Salt River by the accumulation of the volcanic pile south of the Mazatzal Mountains. By this action the base level of the entire drainage area was raised which caused deposition of predominantly fine-grained sediments -- the so-called lake beds. Locally, basalt flows and intrusions and alluvial fans or deltas probably formed small lakes, such as near Mt. Triplet in the Safford Valley, in which lime and gypsum acculumated. The Upper Verde Valley was dammed independently by volcamism and uplift south of Camp Verde (Jenkins, 1923, p. 76-78; confirmed by recent work of the U.S.G.S., Ground Water Branch). The San Pedro River was dammed independently by uplift and/or vulcanism at a lower elevation. The Gila River was probably also partially dammed by diastrophism in the Globe area.

8. When the level of the river in the Safford Valley reached an altitude of 3600 to 3800 feet, the Gila reoccupied its old course through the Mescal Mountains and began rapid downcutting that was the result of about 1000 feet difference in elevation between the Safford and San Pedro valley levels. The shift in the course of the Gila River may have been related also to the vast sheet of basalt north of San Carlos which probably extended farther to the southwest at the time it was extruded.

Perhaps at about this time the rivers that supplied water to the San Simon and Sulphur Springs valleys from Sonora were captured and diverted to the south by the Rio de Bavispe.

9. The erosional history of the Safford Valley is complicated by six or more stages of lessened rates of downcutting, recorded as terraces and pediment levels.

CONCLUSIONS

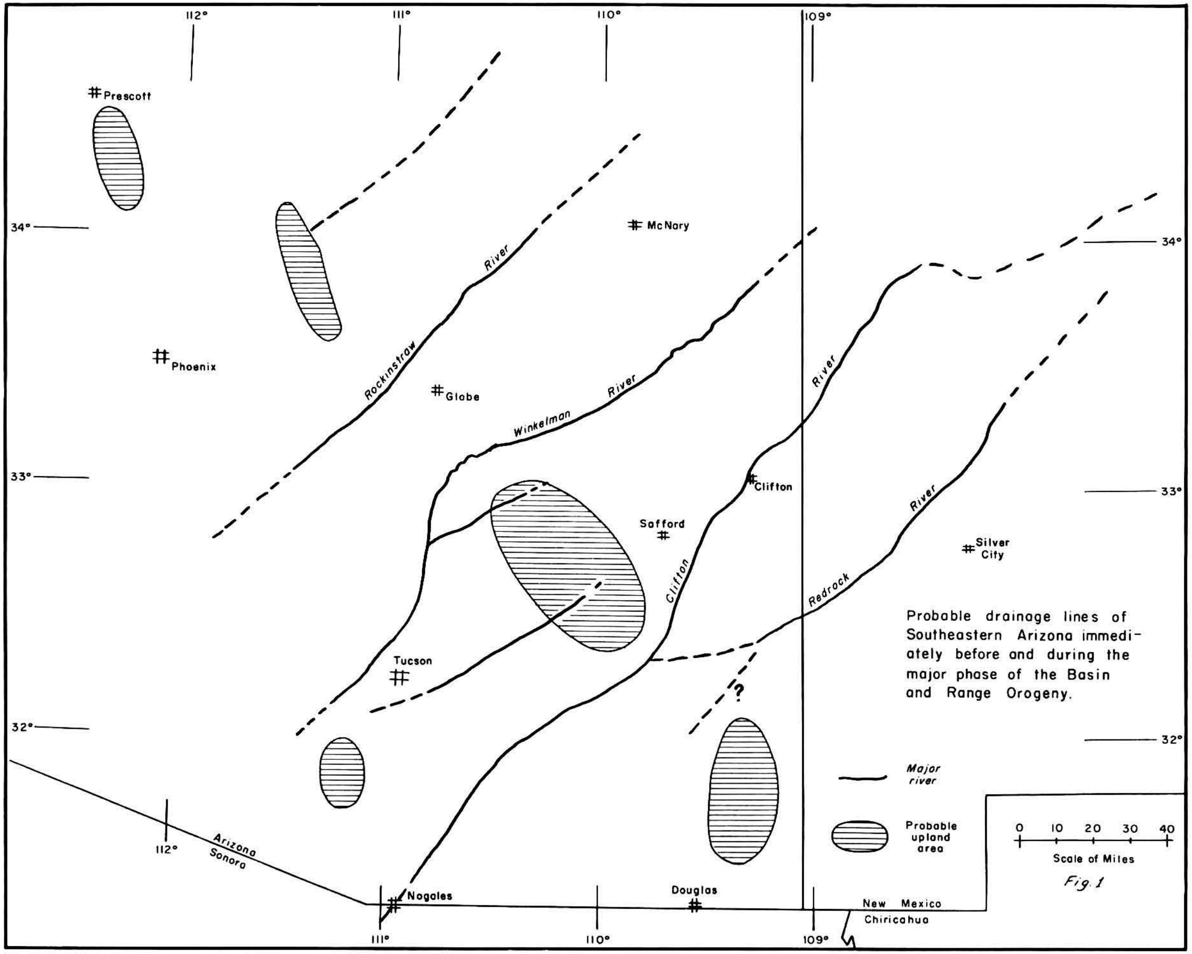
A number of generalizations can be emphasized here without repeating material already presented. Of primary significance, contrary to the "textbook" concept of the arid cycle of erosion, drainage history of desert basins does not necessarily begin with uplift of mountains and formation of undrained basins. In the region studied a pre-existing drainage system was able to maintain itself throughout the mountain-building epoch, probably with only minor changes of course influenced by local structures, and was disrupted not by diastrophism but much later by capture by structurally favored tributaries. Secondly, desert basin fills are not necessarily entirely the product of erosion of the bounding mountain ranges. At times, erosion in the mountains is sufficiently slow to allow rivers to import fine-grained material and to deposit it next to the mountain front. The cause of deposition of the "lake sediments" in the region studied apparently was not related to mountain uplift but to the accidental coincidence of the mouth of the major drainage with a center of vulcanism that raised the base level of the entire system.

The theory and history presented explain the features posed at the beginning of the paper. However, many features remain that cannot be explained.

(1) What is the relation between the large basins of internal drainage in northern Chihuahua and valleys in eastern Arizona and western New Mexico.

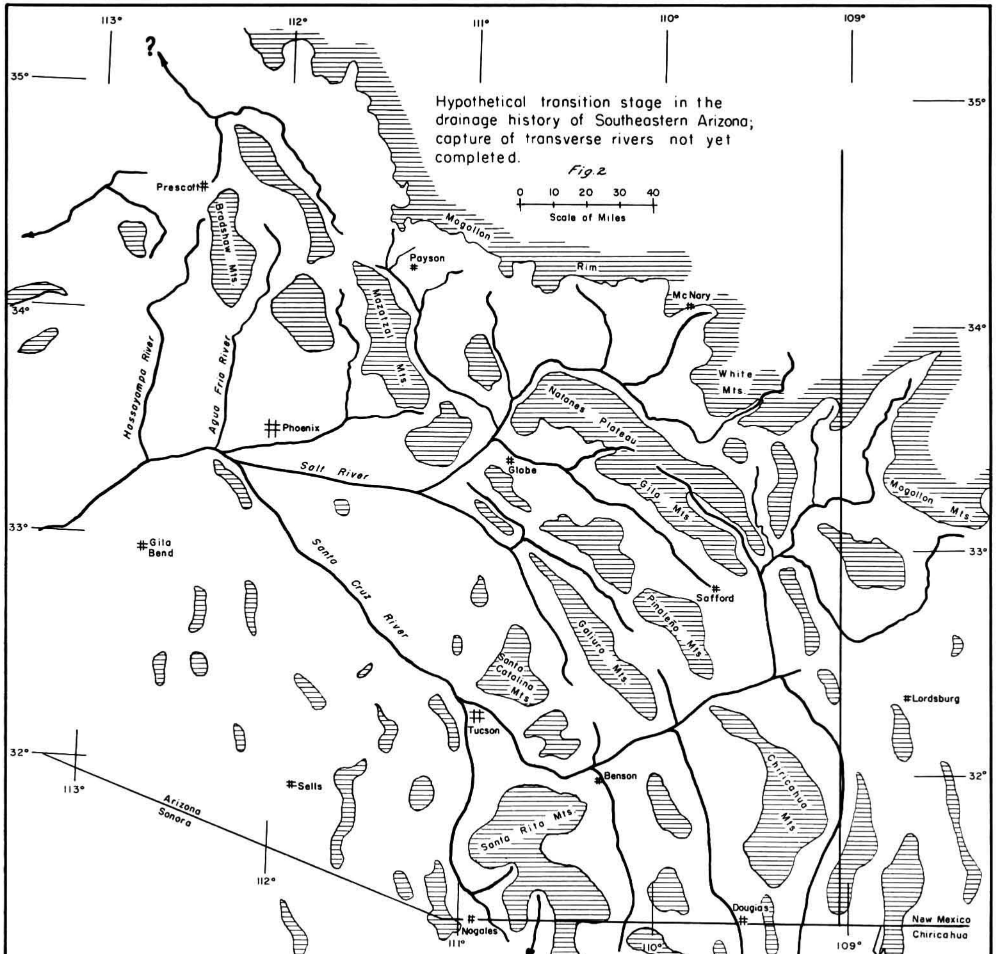
(2) Why are certain valleys filled to their margins with fine-grained sediments, while in others there is a coarse facies between the mountains and the fine sediments? What conditions could have prevented erosion in the rugged mountains from contributing quantities of coarse material, even if the finer material was being brought in by larger rivers?

(3) What was the mode of origin of the hypothetical transverse drainage system; what direction did it flow and where did it go?



Probable drainage lines of Southeastern Arizona immediately before and during the major phase of the Basin and Range Orogeny.

Fig. 1



Hypothetical transition stage in the drainage history of Southeastern Arizona; capture of transverse rivers not yet completed.

Fig. 2

Probable drainage of Southeastern Arizona at time of deposition of fine-grained, "Lake," beds.

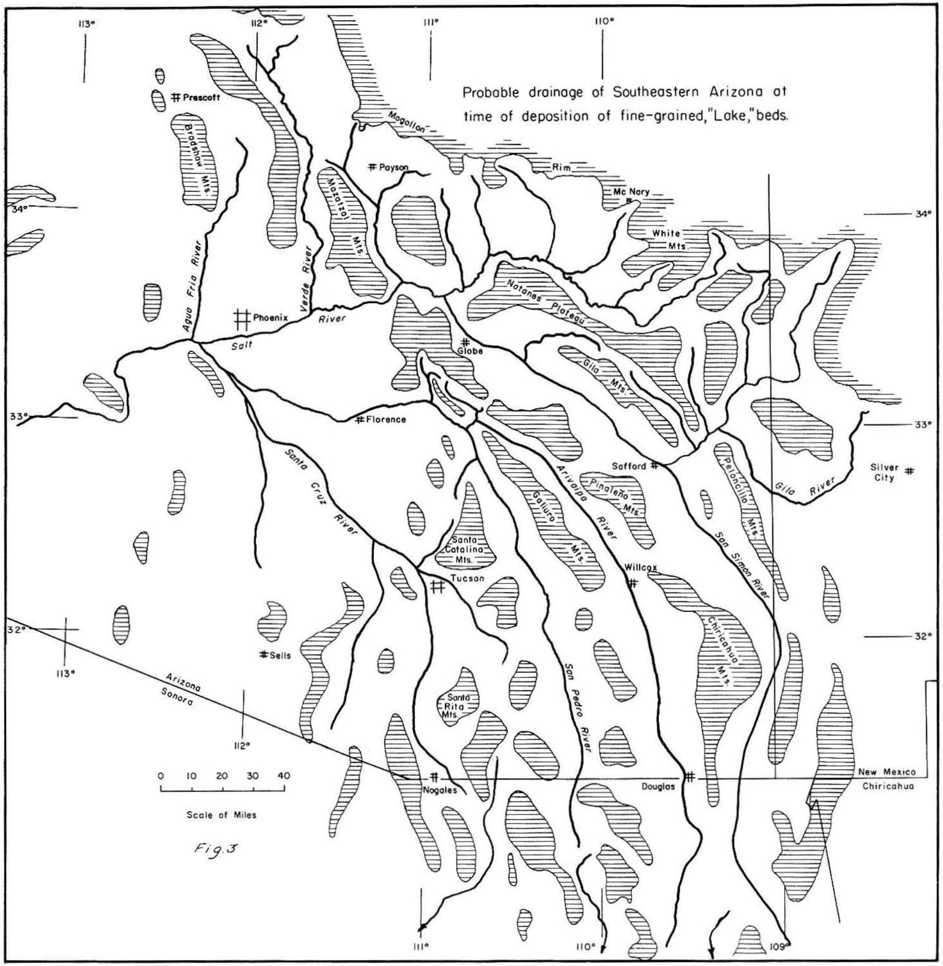


Fig. 3

The writer believes that answers to the above and similar questions must come through topical studies as well as detailed field mapping and stratigraphic correlation. Of particular interest would be (1) studies of the distribution of heavy minerals in the fine sediments and their possible source areas, (2) detailed mapping of characteristic rock types found in the sediments for provenance studies, (3) geochemical dating and correlation of volcanic rocks throughout the area, (4) geophysical studies of the configuration of the basement complex in the alluvial basins, (5) studies of the clay-mineral components of the fine sediments for information on the nature of weathering of their source, and (6) morphological studies of the mountain fronts themselves for possible differences in erosion rates.

REFERENCES

Davis, W. M., 1931, The Santa Catalina Mountains, Arizona: American Jour. Sci., v. 22, p. 289-317.

Gilluly, J., 1956, General geology of central Cochise County, Arizona: U.S.G.S. Prof. Paper 281, 169 p.

Harshman, E. N., 1939, Geology of the Belmont-Queen Creek area, Superior, Arizona: Unpubl. Ph.D. thesis, Dept. of Geology, Univ. of Arizona.

Howard, A. D., 1942, Pediments and the pediment pass problem: Jour. Geomorphology, v. 5, p. 3-31, 95-136.

Jenkins, O. P., 1923, Verde River lake beds near Clarkdale, Arizona: Amer. Jour. Sci., 5th series, v. 5, p. 65-81.

Sauer, C. O., 1930, Basin and range forms in the Chiricahua area: Univ. Calif. Publ. Geogr., v. 3, p. 339-414.

Tuan, Yi-Fu, 1959, Pediments in southeastern Arizona: Univ. of Calif. Publ. Geogr., v. 13, p. 1-163.

Waibel, L., 1928, Die Inselberglandschaft von Arizona und Sonora: Gesell. Erdkunde Berlin, Zeitschr., Sonderband zur Hundertjahrferer, p. 68-91.