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EFFECTS OF DROUGHT ON RUNOFF IN THE SOUTHWEST

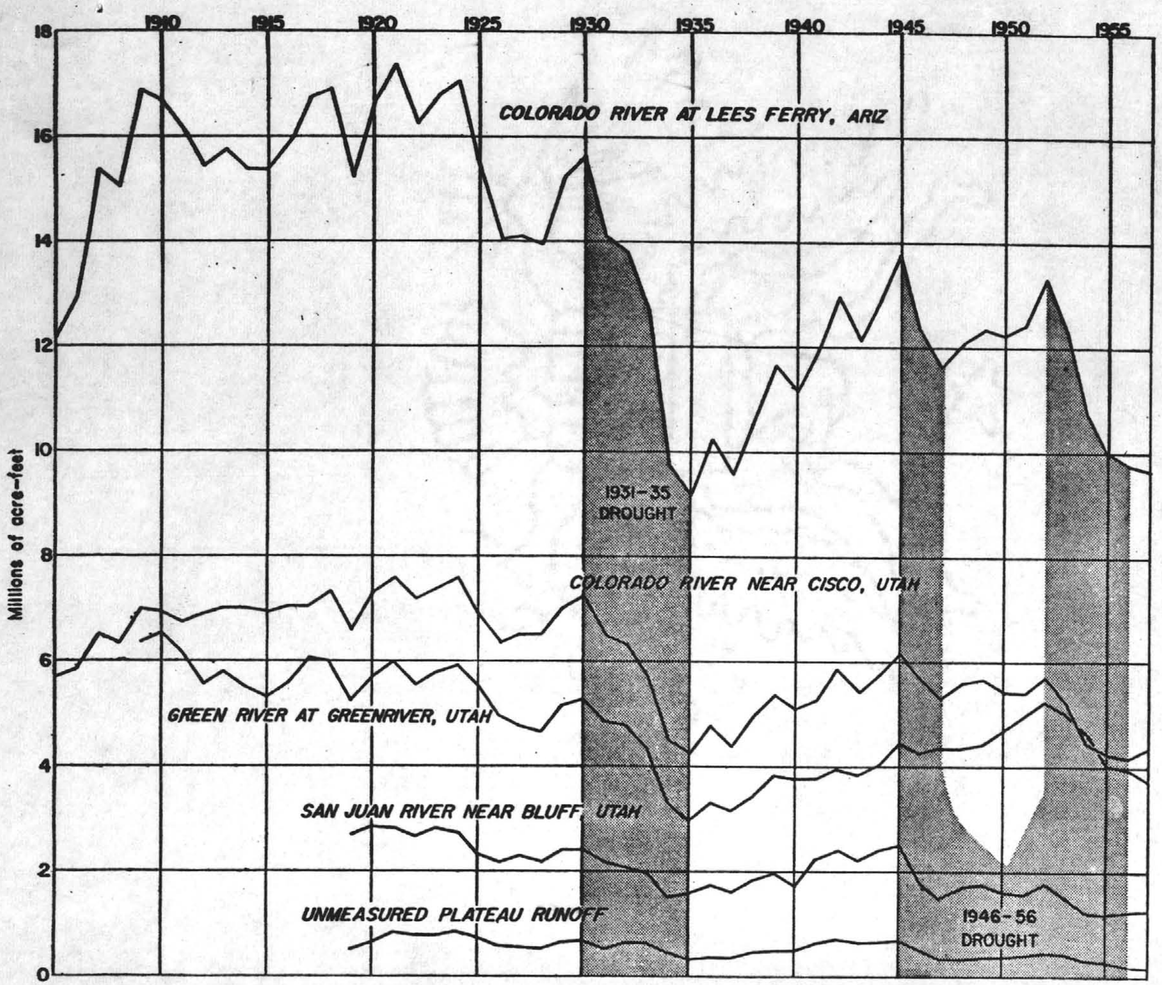

FIGURE 2.—Runoff from Upper Colorado River basin, in progressive 5-year averages, 1905–57.

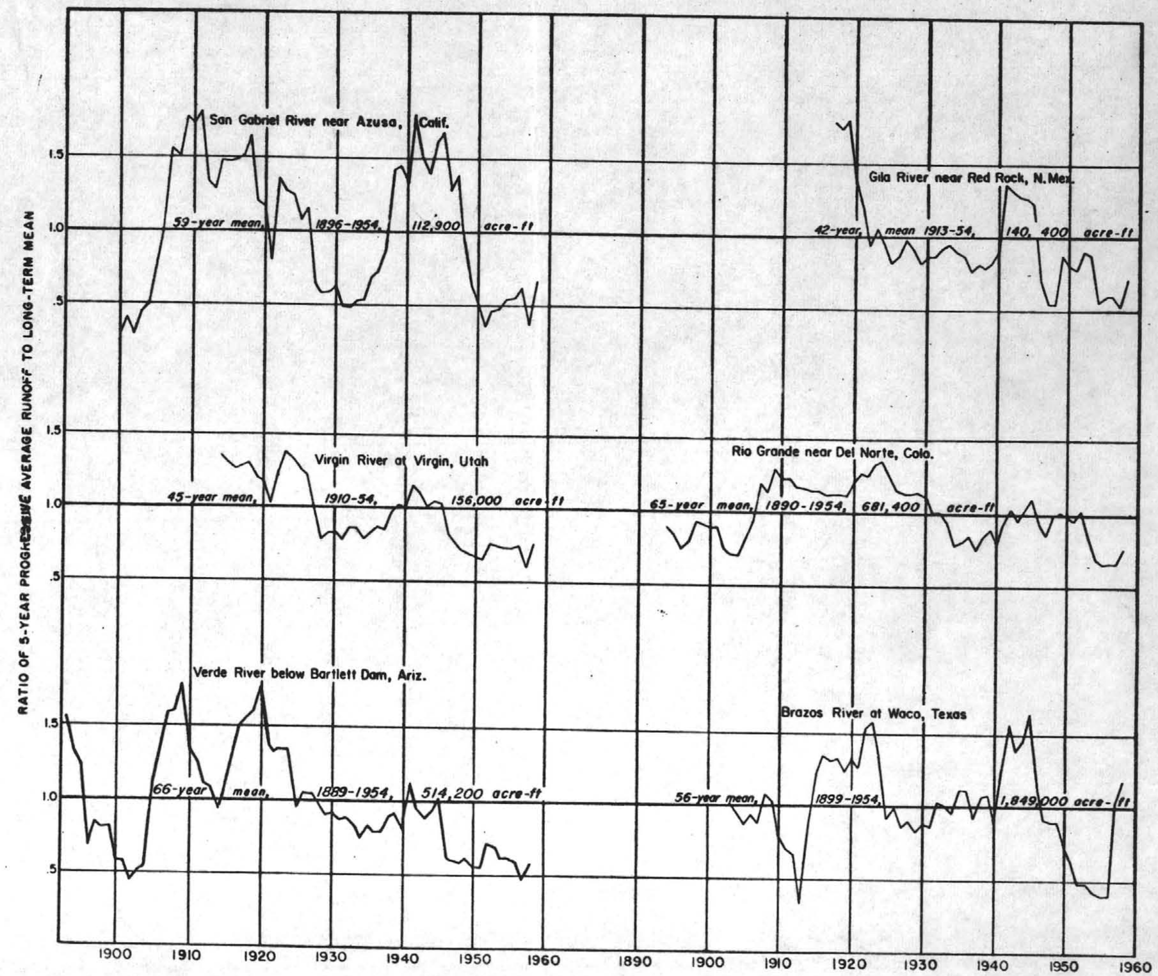

FIGURE 2.—Ratio of 5-year progressive average runoff to long-term mean runoff of six selected streams.

A fluctuating stream regimen during the 20th century is indicated by a continuous decline in streamflow, shown by the records at gaging stations in areas contiguous to the Navajo country. If the records of the Colorado River at Lees Ferry may be taken as representative of what may have occurred on the reservations, yearly runoff from 1930-55 was above the 1897-1955 median of the reconstructed virgin runoff only 3 years, whereas it was below the median 18 years (Alfonso Wilson, research engineer, U. S. Geological Survey, written communication, 1960).

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The prolonged drought of 1942–56 affected chiefly the lower part of the Colorado River basin and did not extend into the upper basin (the chief water-producing area) until 1953. Areas served by the Colorado River had adequate water supplies in spite of the local deficiency of precipitation. In the Gila River basin, there was a deficiency of streamflow during the drought years, and the water requirements of the present population exceed the yield of the basin even during years of average precipitation; the deficiency is overcome by mining of ground water.

:E ALLUVIAL-ARCHEOLOGICAL RELATIONS ALONG LAGUNA CREEK NEAR KAYENTA, ARIZONA

:eology and dendrochronology by Jeffrey S. Dean and :am J. Robinson, Laboratory of Tree-Ring Research, ersity of Arizona, Tucson, Arizona. Geology by M. E. Cooley, U. S. Geological Survey, Tucson, Arizona.)

Laguna Creek flows generally eastward from Laguna Canyon (Tsegi area), formed between Black and Skeleton Mesas in the area 20 miles west of Kayenta, Arizona, to its confluence with Chinle Wash 30 miles east of Kayenta. Its valley and channel are cut principally into the highly cross-bedded Navajo Sandstone of Jurassic and Triassic(?) age, which in this area is between 500 and 600 feet thick. The present arroyo, ranging in depth between 50 and 100 feet, was reported by Gregory (1917) to have begun cutting in 1884 as a result of severe runoff. Three alluvial units can be recognized at many exposures in the arroyo walls; two terraces are conspicuous in the upper reaches, but only one terrace is present in much of the lower reach of Laguna Creek and along Chinle Wash.

A good view of the alluvial units is from the bridge crossing Laguna Creek north of Kayenta. The oldest unit present may be of late Pleistocene age and may be correlated with the Jeddito(?) Formation of Hack (1942). The two younger units—correlated with the older Tsegi Formation and younger Naha Formation (Hack, 1942)—are of Recent age and are the fills of channels cut into the Jeddito(?) Formation and in places on the Navajo Sandstone. In general, the Jeddito(?) Formation is very thin to thin bedded, having individual layers that can be traced for long distances. It contains abundant plant material mixed in with sandy clay and silt to silty sand layers. Gravel, crossbedding, and channeling are rather uncommon. The overlying Tsegi Formation is a complex maze of lenticular layers of sand, silty sand, and silt that locally are interbedded with deposits of eolian origin. Channeling and some gravel are common. The Naha Formation is thinly bedded and in many respects is similar to the Jeddito(?) Formation, although in places the unit displays channels and lenticular beds. Upstream above the mouth of Laguna Canyon part of a lower jaw of a young horse (Equus), identified by George Lammers, University of Arizona, was found buried in the uppermost foot of the Naha Formation.

The upper part of the Tsegi Formation contains considerable remains of Basketmaker III and early Pueblo man. In the area four miles west of Kayenta these remains occur in the upper 25 to 30 feet of the formation, indicating that deposition was occurring during A. D. 750 to 1100. The terminal date of Tsegi deposition in this area is not known nor are the dates of the post-Tsegi–pre-Naha arroyo cutting, often referred to as occurring as a result of the "Great Drought" of the late A. D. 1200's, and of the beginning of Naha deposition, which must have continued until interrupted by the events associated with the present arroyo cutting.

The archeological site known as Three Mile Draw along Laguna Creek four miles west of Kayenta, Arizona, (NA 8300 in the Museum of Northern Arizona survey system) consists of a number of discrete dwelling units pertaining to periods of Southwestern prehistory called Basketmaker III and Pueblo I. These units are circular, subterranean pithouses lined with sandstone slabs. Interior features consist of central firepits with associated ashpits, storage cists, and floor ridges radiating from the firepit to a sidewall opening to the south or southeast serving as a ventilator. The superstructure was constructed of four main uprights set within the house and poles aroung the perimeter of the house which rested on the ground surface and on the uprights. The framework was then covered with juniper bark and clay. A hatchway roof entrance is inferred.

Surface indications of the site before excavation consisted of heavy concentrations of sherds and lithic material and the circular outlines of the upright slabs marking the dimensions of individual pithouses. Other roughly circular concentrations of burned material probably indicate other units whose slabs are still completely buried.

Excavations revealed three houses (Nos. 1, 2, and 4). House 1 was burned and a great deal of dendrochronological material was recovered. Species represented were Douglas-fir, pinyon, and juniper. A preliminary dating suggests placement of this house about A. D. 850. Houses 2 and 4 were in a stratigraphic relation to each other, as House 4 was excavated into and through the eastern section of House 2. Placement based on ceramic typology indicates that both House 2 and House 4 are older than House 1 (with tree-ring dates). The sequence of houses, therefore, from older to younger, would be House 2, House 4, and House 1. Since House 1 can be placed near A. D. 850 and since the architectural and ceramic continuity suggests a relatively short time span, the excavated portion of the site may be assigned generally to the time period A. D. 750-900. Surface material and one unexcavated structure lying at a slightly higher elevation relate to a later occupation of the site during the Pueblo II period, which by ceramic cross-dating should be placed perhaps as late as A. D. 1100.

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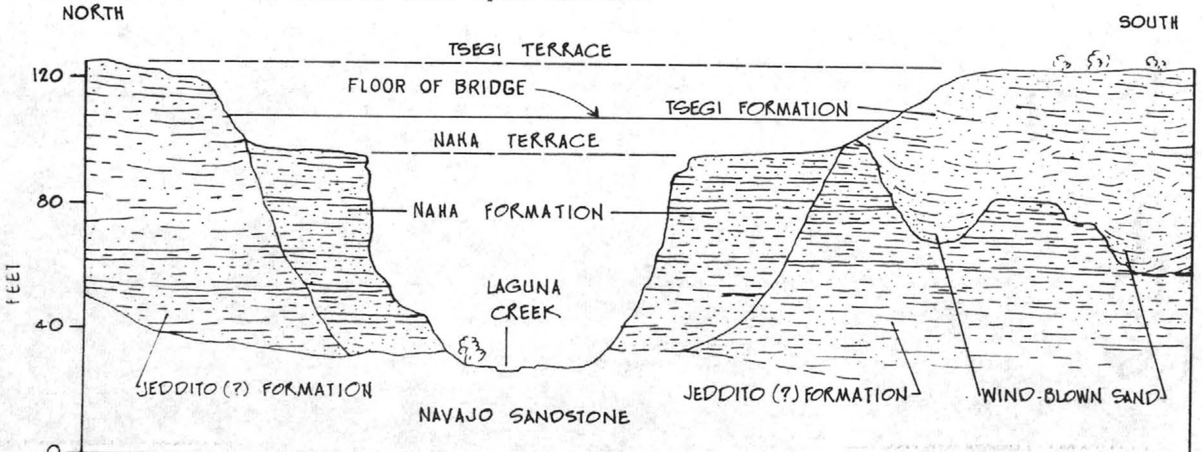

FIGURE -- SECTION SHOWING ALLUVIAL UNITS IN ARROYO OF LAGUNA CREEK, ALONG STATE HIGHWAY 464, 1 MILE NORTHEAST OF KAYENTA, ARIZ.

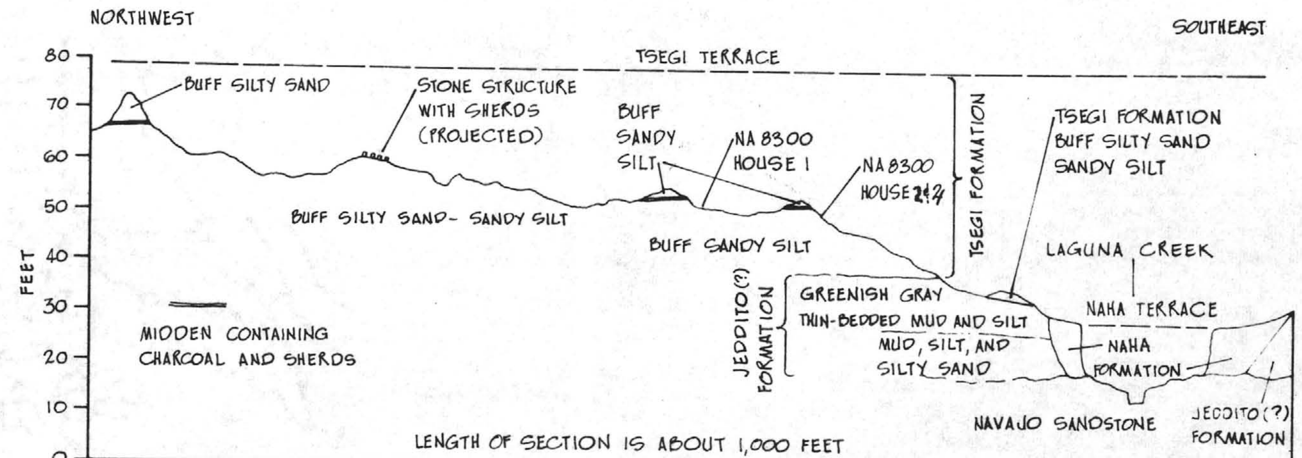

FIGURE 2.-- SECTION SHOWING ALLUVIAL UNITS AND ARCHEOLOGICAL SITES ALONG LAGUNA CREEK, 4 MILES WEST OF KAYENTA, ARIZ.

NOTES ON THE EROSIONAL STAGES OF THE SAN JUAN AND GLEN CANYONS

By

M. E. Cooley

(Investigation for the U.S. Geological Survey and Museum of Northern Arizona)

The several erosional stages along the San Juan and Colorado Rivers are recognized by different terrace levels that record the progressive cutting of San Juan and Glen Canyons during late Cenozoic time. Study of the terraces has given much insight into the developmental history of the Colorado River system in the central part of the Colorado Plateaus physiographic province. Unfortunately, there are few terraces in Marble and Grand Canyons, and the geomorphic history of these canyons is not as well known. The terraces are well exposed along the San Juan River in the reaches upstream and downstream from the "gooseneck" area of the Monument upwarp where only a few scattered remnants remain.

The oldest erosional surface or terrace that can be seen from the goosenecks is the surface that bevels the Cedar Mesa Sandstone Member of the Cutler Formation on the summit of Douglass Mesa at an altitude of about 6,000 feet. This surface—one of the Kaibito surfaces that occurs between 1,500 and 2,000 feet above the San Juan and Colorado Rivers—formed a broad valley that pre-dated the cutting of either San Juan or Glen Canyons. The drainage area on the Kaibito surfaces was nearly the same as the present drainage.

Accelerated downcutting continuing to the present must have terminated the planation of the Kaibito surfaces and initiated the excavation of Glen and San Juan Canyons. A period of intermittent stabilization took place when the rivers flowed at levels of 800 to 1,200 feet above their present stream beds. Several similarly formed terraces mark this interval, and they originally were traced by Baker (1936) from the Monument Valley area downstream to Navajo Mountain; Baker (1936) named these terraces the "Rainbow stage." Mapping during the 1950's has extended these terrace levels throughout the Glen Canyon area and upstream along the San Juan River in the Navajo Indian Reservation. During the Rainbow stage the San Juan River flowed in a shallow canyon between Douglass and Cedar Mesas and in the Piute Mesa area, and the Colorado River flowed in a canyon for a short distance downstream from Navajo Mountain. In the gooseneck area the San Juan River formed a wide valley cut on the weakly resistant Halgaito Tongue of the Cutler Formation. As the river gradually lowered its bed, it came into contact with the resistant Rico Formation, and it began to incise a canyon that developed into the highly sinuous meanders of the goosenecks.

Continued downcutting after the Rainbow stage deepened all the reaches of San Juan and Glen Canyons. Downcutting was interrupted at least five times when as much as 125 feet of gravelly sediments was deposited. The present bed of both rivers overlies bedrock for only short distances, and drilling records at the Glen Canyon Dam show that 117 feet of alluvium (oral communication, G. D. Lassen, 1959) underlies the bed of the Colorado River. Upstream from the gooseneck area the three lowest terraces—between 30 and 200 feet above the San Juan River—in the Shiprock-Farmington area in northwestern New Mexico are continuous upstream along the Animas River to Durango, Colorado. The highest of these deposits merges with the outwash sediments of the Durango glacial stage 10 miles south of Durango, which confirms a relation reported by Atwood and Mather (1932, p. 131). The deposits of the two remaining terraces are correlated with the younger outwash of the Wisconsin glacial stage (Atwood and Mather, 1932) in which Richmond (1954) has recognized two substages. The other terrace deposits may also be correlated with other outwash deposits, although additional investigation is needed to confirm this relation.

The composition of the material that forms the terrace deposits and the differences in the amount of caliche (calcium carbonate deposits) formed at the top of each deposit aid in the correlation and mapping of the terrace levels. Pebble analyses of about 8,000 pebbles indicate similar gravel for the terraces that are less than 1,200 feet above river level, the Rainbow and younger terraces, and the present channel gravel, but a difference is noted in the types of gravel present at more than 1,200 feet above river level in the Kaibito terraces. The major types of gravel below 1,200 feet above river level consist mainly (more than 60 percent) of granite, porphyry, quartzite, and chert—types derived from the Rocky Mountains, stock-laccolithic mountains, and other mountains bordering the Colorado Plateaus. Chert also is derived from canyons along the rivers where chert-bearing rocks are exposed. Gravel in the Kaibito terraces generally is locally derived sandstone and chert, and usually less than 5 percent is similar to that found in the Rainbow and lower terraces.

The large quantities of quartzite, porphyry, and granitic types and a decrease in the amount of chert on the Rainbow and younger terraces may be attributed to the overloading of the Colorado and San Juan Rivers in the higher mountainous source areas. Vigorous erosional processes, including strong freezing and thawing action and glacial scouring that attacked exposed sections of basement rocks, are indicated by the considerable amount of granitic gravel. If these are valid conclusions, then the beginning stage of glaciation in the Rocky Mountains is correlative with the Rainbow stage when the rivers were flowing about 1,000 feet above their present stream beds in San Juan and Glen Canyons.

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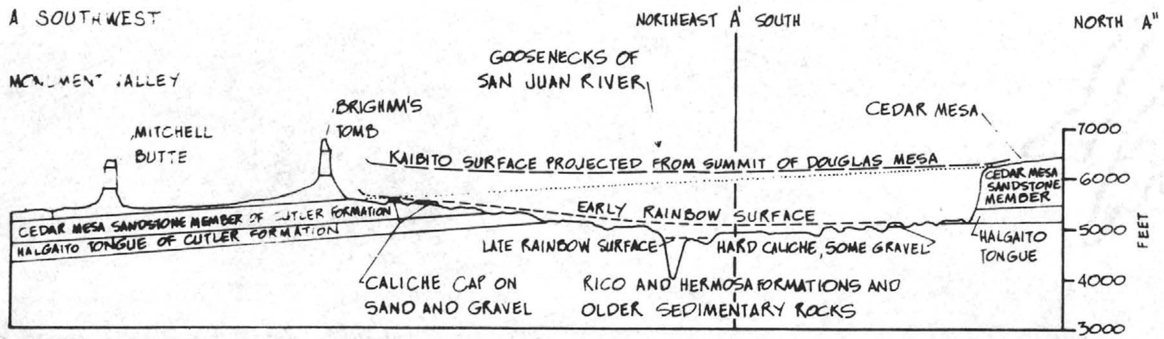
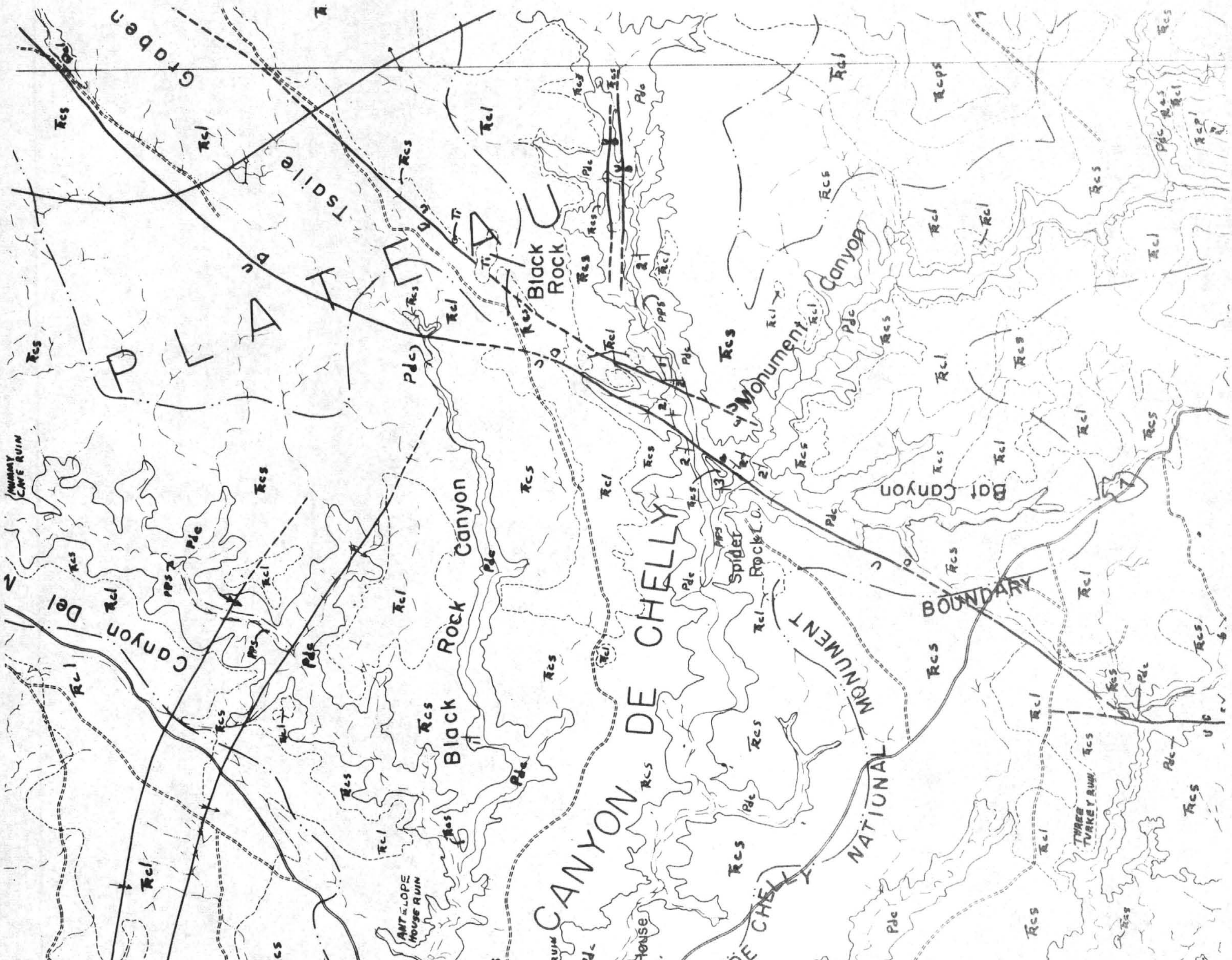


Location	Thickness	Type of deposit	Description of deposit	
Recent alluvium	-	-	Limy streaks in deposits: thin film on	grains and pebbles: few limy nodules.
PLEIST. TERRACES 30- 100 feet	-	Nodular	Calcareous deposit around pebbles	
100- 200 feet	2-3	Nodular	Calcareous and siliceous deposits around pebbles: some limy nodules in matrix and	in finer grained units: caliche is partly layer[illegible]d
200- 300 feet	2-5	Nodular and poorly formed layers	Calcareous and siliceous deposits around pebbles: massive caliche and layers formed in upper part of de-	posit: bedding of the gravel partly destroyed: some caliche layers.
400- 500 feet	2-10	Poorly to well-formed layer	Hard massive and irregular caliche layer capping terrace that grades downward into zone of weakly devel-	oped caliche [illegible] ir-regular siliceous [illegible]ering: bedding [illegible] gravel destroyed.
RAINBOW SURFACES 800-1,200 feet	3-20	Well-formed layer	Hard, firm, relatively pure, massive and layered caliche: some siliceous layering:	most of deposit shows some degree of calci[illegible]ation: bedding of the gravel destroyed.
KAIBITO SURFACES 1,500-2,000 feet	5-30	Well-formed layer	Thick, hard, pure to relatively pure massive and layered ca-	liche: considerable siliceous material



EXPLANATION

Qal	Alluvium
Ti	Basalt
Pdc	De Chelly Sandstone
Ps	Supai Formation

Rcps, Rcpl, Rcl, Rcs — Chinle Formation: Shinarump Member Rcs; Lower Red Member Rcl; Lower Part, Rcpl, and Sonsela Sandstone bed, Rcps, of Petrified Forest Member (Rcp)

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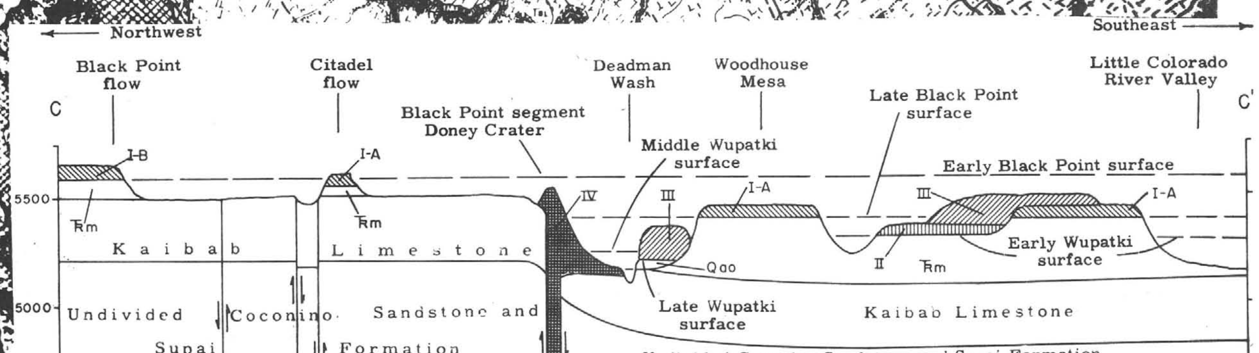
SAN FRANCISCO VOLCANIC FIELD

Colton (1950) (Basaltic stages only)	Cooley (This paper) Basaltic stage and typical flow	Flows of intermediate types	Viscosity of basalt and physiographic location	Erosion cycle	Relationship with depositional unit	Age
Stage V	V. Sunset Crater	None	Fairly fluid; in broad canyon.	Post Late Wupatki	CINDERS INTERBEDDED WITH LATE RECENT ALLUVIUM, A.	Recent
Stage IV	IV. Black-Grand Falls flow; Doney Crater	NONE	Chiefly highly fluid, some viscous; in narrow canyons.		Underlies alluvial Tsegi formation; overlies intermediate alluvium, B.	Late Pleistocene(?) to early Recent
Stage III (III a, b, c)	III. Flow along Deadman Wash west side of Woodhouse Mesa; flows in Doney Park area	3 Flows flanking O'Leary Peak	Viscous, formed broad lobes; did not flow down narrow canyons.	Late Wupatki, 2A, 2B.	Deposited contemporaneously with intermediate alluvium; overlies older alluvium.	Late Pleistocene
Stage II	II. Tappen Spring	Robinson's fourth and fifth eruptive stages of San Francisco Mountain	Highly fluid; in narrow canyons and broad valleys.	Middle and Early Wupatki, 2C, 2D, 2E.	Contemporaneously with and underlies older alluvium, C.	Middle to Late Pleistocene
	II. Flows east of Wupatki pueblo	2A, 2B			Underlies older alluvium	
	IA or II. Flows of upper Tappen Wash	Robinson's second and third eruptive stages of San Francisco Mountain; Elden Mountain.		Period of chiefly downcutting	Underlies and was source for older alluvium.	Early to Middle Pleistocene
Stage I	Stage I IA. Woodhouse Mesa; Citadel flow	1 Robinson's first eruptive stage of San Francisco Mountain; Observatory Mesa.	Fluid; broad and narrow valleys.	Late Black Point	Thin gravelly deposits	Early(?) Pleistocene (Blancan(?))
	Stage I IB. Black Point	TRANSITIONAL BASALTS TBy	Fluid; broad valleys.	Early Black Point		Late(?) Pliocene (Blancan(?))
	Older basalts TB Anderson Mesa; Oak Creek Canyon area; Red Butte; flow south of Cedar Ranch.	None	Fluid; gently sloping plains.	Zuni-HOPI BUTTES	Interbedded with silty sand, overlies gravel and sand.	Pliocene



A.--Section C-C', Wupatki Pueblo area, showing relationships of the basaltic stages to the Black Point and Wupatki surfaces.

G1, G2 - GLACIAL AND GLACIAL FLUVIAL DEPOSITS ON SAN FRANCISCO MTN.

Ћm - MOENKOPI FORMATION

Pk - KAIBAB LIMESTONE

Pc - COCONINO SANDSTONE

FAULT SHOWING DOWN-THROWN SIDE

CINDER DUNE

TERRACE AND ALLUVIAL DEPOSITS

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LOWER BOUNDARIES OF QUATERNARY PERIOD AND RECENT EPOCH

(**Summarized** from "Hydrogeology of the Surficial Deposits of **the Navajo** and Hopi Indian Reservations, Arizona, New **Mexico,** and Utah," by M. E. Cooley, J. T. Callahan, and **William** Kam: U. S. Geol. Survey Prof. Paper 521-___, in **preparation.**)

The lower boundary of the Quaternary period in the **Navajo** country is placed at some point between the end of **deposition** of the Bidahochi Formation of roughly early and **middle** Pliocene age and deposition of the Jeddito Formation **of middle(?)** and late Pleistocene age and equivalent de**posits**—such as the Gamerco Formation (Leopold and Snyder, **1951**) and terrace deposits. Although erosion dominated **deposition** in late Pliocene and early Pleistocene time, sedi**ments** referred to as terrace deposits were laid down in many **parts** of the Navajo country. These deposits overlie the Black **Point** surfaces formed by the Little Colorado River and the **Kaibito** and Rainbow surfaces formed by the Colorado and San **Juan** Rivers. Erosion represented by the Black Point sur**faces** terminated the **deposition** of the Bidahochi Formation. **The** only fossils in the **Navajo** country, which occur near the **lower** boundary of the Quaternary, are vertebrates found in **the deposits** of Charley Day Spring near Tuba City. The fos**sils include** camel, elephant, and other mammal bones **(Colton, 1931)**, some of which may be as old as early Pleis**tocene** (Lance, 1960). The terrace deposits that overlie the **late Black** Point surfaces near Tuba City are about 100 feet **higher** than those of Charley Day Spring and, therefore, are **older** than or at least as old as the Charley Day Spring de**posits.** The Jeddito Formation (Hack, 1942) and the de**posits** on the Wupatki surfaces were laid down contempora**neously** (Cooley, 1958), and they contain fossil elephants and **horse** teeth of middle to late Pleistocene age (Reiche, 1937; **Hack, 1942;** Lance, 1960). All these deposits are in valleys **excavated** below the level of the late Black Point surfaces. **The** fossil evidence indicates that the Black Point surfaces **were** formed during late Pliocene and early Pleistocene time, **and** in the Little Colorado River area the lower boundary of **the** Quaternary should be placed during the planation of the **Black** Point surfaces.

In the area drained by the Colorado and San Juan **Rivers**, Quaternary time may have begun during the ero**sional** period that occurred between the planation of the **Kaibito** and Rainbow surfaces or more probably during the **formation** of the Rainbow surfaces. Mapping of the surfaces **and** terrace deposits in the Navajo country has revealed that **the** Kaibito and Rainbow surfaces are mainly equivalent to the **Black** Point surfaces. If this correlation is accurate, then **the** lower boundary of the Quaternary occupies similar phys**iographic** positions in both the Little Colorado and the Colo**rado-San** Juan River drainages. Support for placement of **the** lower boundary is indicated by the differences in com**position** of the gravel deposited on the Kaibito and Rainbow **surfaces** (see " Notes on the Erosion Stages of Glen and **San** Juan Canyons" in this handout).

The approximate position of the lower boundary of the **Quaternary** at the confluence of the Colorado and San Juan **Rivers** is between 1,000 feet—the uppermost limit of the **Rainbow** surfaces at that point—and 1,500 feet—the lower**most** limit of the Kaibito surfaces—above river level. In **the** southwestern part of the reservations near Wupatki Ruin, **the** lower boundary is about 600 feet above the Little Colorado **River**. Generally, the height of the boundary above the pres**ent** river levels decreases slightly upstream and increases **downstream** because the gradients of the older surfaces are **less** than the present gradients of the rivers.

The Pleistocene-Recent boundary is placed some**where** in the erosional interval that occurred between the deposition of the youngest Pleistocene terrace deposit or alluvium and the late Recent alluvium. Along the Little Colorado River the deposit on the youngest Wupatki terrace probably is correlative with the youngest outwash deposit (Wisconsin stage of Sharp, 1942) on San Francisco Mountain near Flagstaff (Cooley, 1962). Along the San Juan and Colorado Rivers the youngest gravelly terrace deposit may be equivalent to part of the Wisconsin outwash of Atwood and Mather (1932). Along all three rivers late Recent deposits overlie unconformably the youngest Pleistocene deposits.

Upstream from Wupatki Ruin along the Little Colorado River and parts of tributary drainages, the Pleistocene-Recent boundary is obscure because the younger Wupatki terraces were buried by alluvium that accumulated behind lava dams in the Black Falls-Grand Falls area (near Wupatki Ruin) of the Little Colorado River and because of differences in alluviation and erosion throughout the drainage system. Upstream from Grand Falls the deposits behind the lava dam may have been laid down locally during latest Pleistocene and early Recent time. In Jeddito Valley and other tributary valleys the Jeddito Formation is overlain unconformably by the Tsegi Formation of late Recent age, and, locally, more than 50 feet of the Jeddito was removed before the deposition of the Tsegi. In comparison, along reaches of Laguna Creek and other drainages in the northern part of the reservations, latest Pleistocene-early Recent erosion removed as much as about 100 feet of the late Pleistocene deposits, and in some canyons all the late Pleistocene deposits may have been removed. The lower boundary of the Recent deposits, therefore, is placed somewhere during this erosional period. Similarly, in the Gallup, N. Mex., area the Pleistocene-Recent boundary is placed in the erosional period that formed a channeled surface that separated the late Pleistocene Gamerco Formation and late Recent Nakaibito Formation (Leopold and Snyder, 1951).

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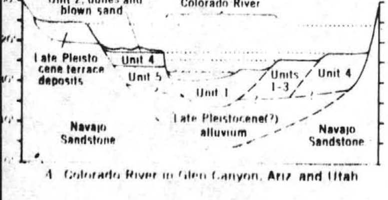
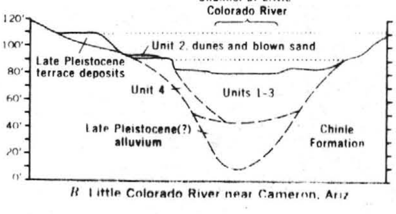
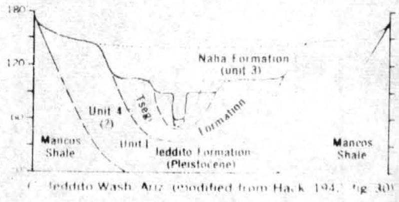


A. Colorado River in Glen Canyon, Ariz. and Utah



B. Little Colorado River near Cameron, Ariz.



C. Jeddito Wash, Ariz. (modified from Hack, 1942, fig. 30)

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THE MOGOLLON HIGHLANDS—THEIR INFLUENCE ON MESOZOIC AND CENOZOIC EROSION AND SEDIMENTATION[1/]

By

M. E. Cooley and E. S. Davidson

U.S. Geological Survey, Tucson, Arizona
Prepared in cooperation with the Arizona State Land Department and the Navajo Tribe

The effects of regional upwarping became increasingly prominent during the Late Cretaceous Period and resulted in a complete withdrawal of the seas by the end of the period. The seas in the Rocky Mountain geosyncline withdrew northward into Utah and eastward and southeastward through northern Mexico. Differential uplift and subsidence divided the region into local highs and basinlike structures or troughs in which coarse detrital material accumulated (fig. 8). Basinlike structures may have been present as early as Early Cretaceous time in southern Arizona, but folding that produced basins and uplifts on the Colorado Plateau did not begin until late in the Cretaceous Period and was not completed until about the end of Eocene time.

Colorado River System

Major changes occurred during the late part of mid-Tertiary (Miocene) time, and accelerated regional upwarping resulted in the development of the ancestral stages of the Colorado River system and in the outlining of the physiographic provinces of the Southwest. The renewed rising of the Mogollon Highlands and the formation of some of the basin-and-range features accompanied the upwarping, but there is no evidence of strong differential structural movement in the Colorado Plateau during this time. Mid-Tertiary thrust faulting has been noted in southeastern Arizona and in west-central Arizona near the Colorado River (Wilson and Moore, 1959, fig. 12). No notable thrusting took place within the Mogollon Highlands, but early movement along some of the large normal faults and some folding along the western edge of the Colorado Plateau may date from this period. In the nearby part of southern California, deformation and volcanism during the late part of Miocene and during Pliocene time caused the formation of local, interior-drained basins in the Mohavia Highlands (Reed, 1933). Thus, there was general widespread upwarping within the Mogollon Highlands and Colorado Plateau regions of Arizona and New Mexico, and intense deformation in many parts of the Basin and Range province.

The initial stage of the Colorado River system is represented by the Valencia surface, whose remnants are present in the southern part of the Colorado Plateau (Cooley and Akers, 1961, p. 244-245). Differential uplift of the Mogollon Highlands and of the Zuni-Defiance-Monument uplift area, accompanied by early basaltic eruptions in some of the volcanic fields, restricted the ancestral systems of the Colorado and Little Colorado Rivers approximately to their present positions. The Valencia surface is present at altitudes of more than 7,500 feet beneath basalt flows capping Red Butte near the Grand Canyon and on other buttes and small mesas in the White Mountains volcanic field. The general trend of the drainage on the Valencia surface was west-northwest in the Little Colorado River area and southwestward in the Colorado River area, as reconstructed from the remnants of the surface and from the stream patterns on the following Hopi Buttes and Zuni surfaces (fig. 10). The eastern and northern parts of the Mogollon Highlands were then drained to the Colorado, and a volcanic pile formed by the Datil Formation maintained a drainage divide near the Arizona-New Mexico State line.

Accelerated downcutting formed the Hopi Buttes (Gregory, 1917, p. 121-122) and Zuni (McCann, 1938, p. 260-279) surfaces in late Miocene and Pliocene time and entrenched the ancestral Colorado system to an average depth of about 1,200 feet below the level of the Valencia surface. However, cutting was interrupted temporarily in the ancestral valley of the Little Colorado River by the deposition of the Bidahochi Formation (fig. 10). The Bidahochi Formation was divided into a lacustrine and fluvial lower member, a volcanic middle member, and a fluvial upper member (Repenning and Irwin, 1954, p. 1821-1826). Fine-grained sediments which are lithologically similar to the lower member of the Bidahochi in the Hopi Buttes area crop out beneath basalt flows near Flagstaff in the structural saddle between the Kaibab uplift and the Mogollon Highlands.

Contours drawn on the base of the Bidahochi Formation and lateral equivalents indicate that the Defiance uplift-Chuska Mountains-Zuni Mountains area formed a divide between the ancestral Little Colorado system and the drainage in the San Juan Mountains area (Cooley and Akers, 1961, fig. 237.3). The Little Colorado may not have been connected with the Colorado River in the area upstream from the Grand Canyon until about late Pliocene time, during the formation of the Zuni erosion surface. The contours indicate also that part of the "rim gravel" near the Mogollon Rim and some of the volcanic rocks and clastic sediments in the San Francisco volcanic field are a lateral equivalent of the Bidahochi Formation. The rim gravel was derived from the south (McKee, 1951, p. 498) and is composed of coarse debris eroded from the Precambrian and Paleozoic rocks in the central part of the Mogollon Highlands.

Along the southern border of the Mogollon Highlands and in southern Arizona, generally coarse-grained gravel, tilted and moderately deformed by normal faulting, is exposed along the flanks of the various mountain ranges. This gravel, informally termed "deformed conglomerate or gravel" by Davidson (1961, p. 151) for exposures in the Safford basin, was deposited during the general time represented by the Valencia, Hopi Buttes, and Zuni surfaces on the Colorado Plateau and indicates a major stage in Cenozoic deposition in Arizona. The deformed gravel occurs at the top of a thick section of basalt flows of mid-Tertiary age, and in the Safford area and elsewhere the flows and gravel are interbedded. This gravel overlies the early and mid-Tertiary andesitic flows, tuffs, and correlative deformed deposits similar to the Helmet Fanglomerate and underlies the relatively undeformed basin-fill sediments. The gravel is part of the type section of the Gila Conglomerate of Gilbert (1875); it is generally equivalent to the Mimbres Conglomerate of Hernon, Jones, and Moore (1953) and to part of the Santa Fe Formation in New Mexico. Thick sections of the deformed gravel are exposed in the Safford basin, in the Aravaipa, San Pedro, and upper Santa Cruz Valleys, in the Big Sandy Valley, and near Wickenburg between the Gila River and the Mogollon Highlands. In southwestern Arizona, where dissection has not been so severe, the gravel is covered generally by younger-fill materials. In the Mogollon Highlands gravel similarly deformed as that in the Basin and Range province is exposed near Silver City, Globe, and south of Bagdad. Dips in the gravel beds are usually away from the larger mountain masses, and in most exposures their composition is reflective of the rocks of the nearby highlands.

Sediments correlative with the deformed gravel and the Bidahochi Formation were deposited in valleys throughout the Mogollon Highlands. These deposits and associated basalt flows crop out in about one-fourth of the highland area, and, judging from their association with widely scattered fossil localities, are of Pliocene age. The oldest dated deposit is near Walnut Grove and "***contains diagnostic fossils of lower Pliocene age" (Lance, 1960, p. 156). Other deposits containing fossils of Pliocene age are in the Tonto basin, Big Sandy Valley, and near Anderson mine (Lance, 1960, p. 156).

By the beginning of Quaternary time, all drainages of the Colorado Plateau and Mogollon Highlands were established in their present courses. Headward-cutting tributaries from the south had completely isolated the Colorado Plateau drainage from the central part of the Mogollon Highlands, and the Mogollon Rim extended uninterrupted from the White Mountains to beyond the Verde Valley (fig. 11). From this time on, structural movements in the Mogollon Highlands had little effect on erosion and sedimentation in the Little Colorado River area.

Quaternary time on the Colorado Plateau is represented by as many as seven terraces along the Colorado River and in the lower reaches of the Little Colorado River. Terrace deposits overlie the Black Point surfaces (Gregory, 1917, p. 120) of early Pleistocene age and the Wupatki surfaces (Childs, 1948, p. 379-381) of middle and late Pleistocene age. Mapping of the terraces over an area of about 35,000 square miles has shown that their formation was controlled by regional events. The terrace deposits are as much as 200 feet thick and are composed of gravelly sediments derived from the sedimentary bedrock, volcanic rocks, and the reworking of older gravel. Near Holbrook the present valley of the Little Colorado River was excavated about 800 feet below the base of the Bidahochi Formation (Hopi Buttes surface). Downstream the cutting was more severe, but upstream from St. Johns it was less than 200 feet.

Table 1. --Summary of geological events in the Mogollon Highlands and nearby regions during Cenozoic time.

Age				Erosional and depositional events			Volcanism	Structure
				Colorado Plateau	Mogollon Highlands	Basin and Range province		
QUATERNARY	PLEISTOCENE	MIDDLE AND LATE	Events related to Colorado River	Downcutting and terracing	Downcutting and terracing	Downcutting, terracing, or alluvial deposition	Chiefly basalt	Warping and some movement along normal faults
		EARLY (BLANCAN)		Downcutting and terracing	Downcutting, terracing, and deposition of basin-fill sediments	Deposition of the basin-fill sediments and formation of pediments		
TERTIARY — LATE	PLIOCENE	LATE		Formation of Zuni surface and deposition of the upper member of the Bidahochi Formation	Canyon cutting and deposition of sediments containing Pliocene fossils and the deformed gravel	Channel erosion, formation of pediments, and deposition of the deformed gravel, locally may be gradational with sediments above and below		Accelerated upwarping and large-scale normal faulting, formation of many basin and range structures
		EARLY		Formation of Hopi Buttes surface and deposition of the lower member of the Bidahochi Formation				Regional and local uplift; some normal faulting
	MIOCENE			Formation of the Valencia surface	Formation of Valencia surface, valley erosion, and deposition of the deformed gravel			
TERTIARY — MIDDLE	MIOCENE, OLIGOCENE		Events not related to Colorado River	Deposition of upper sedimentary unit of Wrucke (1961)	Erosion, deposition of Datil Formation, upper sedimentary unit of Wrucke (1961), and sediments similar to the Helmet Fanglomerate	Erosion, deposition of Helmet Fanglomerate and similar (Pantano Formation of Brennan 1957 sedimentary rocks	Chiefly rhyolite, dacite, and andesite	Thrust faulting and local folding
LATE CRETACEOUS AND EARLY TERTIARY (PALEOCENE AND EOCENE)				Deposition in structural basins, including the nonvolcanic sediments of Willard (1959)		Erosion and deposition of Silver Bell and Claflin Ranch Formations of Richard and Courtright (1960) Hidalgo Volcanics and equivalents, formation of Tucson surface	Chiefly andesite some silicic pyroclastic rocks	Formation of uplifts and basins on Colorado Plateau, uplift with thrust faulting in Basin and Range province. Rocks mildly metamorphosed (chlorite, epidote)

Large-scale and local structural movements of the Mogollon Highlands and surrounding regions during Quaternary time also controlled sedimentation and erosion in the Salt-Gila River system, and in general, uplift in southern Arizona and New Mexico did not keep pace with uplift of the Mogollon Highlands. Differential movement is indicated by a general depression of the area centering in Phoenix, which is structurally lower than the surrounding regions. Much of the structural movements in southwestern Arizona in Quaternary time may be associated with downfaulting in the Gulf of California area (Eardley, 1951, p. 460-473) and with the formation of the San Andres rift.

In early Quaternary time, thick accumulations of generally fine-grained alluvium were laid down in most of the valleys of the Basin and Range province and along the southwestern flank of the Mogollon Highlands. This alluvium, often called erroneously "lake-bed" deposits, is referred to informally as basin fill. The basin-fill sediments are more than 1,500 feet thick and constitute the bulk of the valley fill exposed in the Basin and Range province. Most of the sediments are derived locally and consist of stream-deposited gravel, sand, and clay interbedded with lesser amounts of lacustrine clay and limestone.

Reconstruction of drainage patterns from the terrace levels, the types of deposition, and the association with basaltic volcanism suggest that in the reaches upstream from Phoenix, the ancestral drainage of the Salt River predates that of the Gila River. By late Pliocene time the Verde River seems to have been a south-flowing tributary to the Salt River in the Verde Valley area. The headward extension of the Salt River east of Tonto basin essentially was completed by Quaternary time. The upper part of the Gila River system, however, seems to have developed later, and, based on the variation in the erosion and alluviation within the several valleys, its development was by headward capture and diversion of drainages that previously flowed southward and southeastward from the Mogollon Highlands. The amount of erosion along the Gila River and lower reaches of tributary valleys is greater in the area between the Tortilla and Peloncillo Mountains, where downcutting has been more than 1,000 feet. It seems likely that the Santa Cruz and San Pedro Rivers were integrated as part of the Gila system during early Pleistocene time or before, but the Safford basin and upstream areas were not connected with the Gila until the early part of middle Pleistocene time. This diversion of the drainage in the Safford basin terminated the deposition of the basin-fill sediments, which contain vertebrate fossils of early and early-middle Pleistocene age (Wood, 1960, p. 141-143). At the present time, north-flowing tributary streams of the Gila River are eroding headward and dissecting the northern part of the broad alluvial valleys east of the San Pedro River in Arizona and New Mexico.

Erosional-depositional conditions of early Quaternary time, owing to faulting and to volcanic damming of drainage courses, were extremely variable within the Mogollon Highlands. As a result, fine sediments (Verde Formation) were laid down in the Verde Valley, and gravelly sediments were deposited in the Tonto basin and in places in the Chino Valley area. Erosion was predominant in the area above Salt River Canyon and in most of the headwater reaches of streams elsewhere. However, terrace deposits in these reaches are more than 100 feet thick.

In the Basin and Range province, alluvial deposition during middle and late Quaternary time was concentrated chiefly in the troughlike depression in the Phoenix basin, in a considerable part of southwestern New Mexico, and in isolated basins elsewhere in Arizona (fig. 11). In the Mogollon Highlands and in the more rugged parts of the Basin and Range province, prominent terraces were formed along the Santa Cruz, San Pedro, Verde, Salt, and Gila Rivers and other streams. The episode of terracing exhumed many large pediments overlain by the basin-fill sediments and the deformed gravel. In southeastern Arizona and southwestern New Mexico, cutting and the formation of terraces have not been extended far upstream from the main stem of the Gila River, except along the San Pedro and Santa Cruz Rivers. Alluviation and only slight terracing occurred in the valleys of southwestern Arizona.

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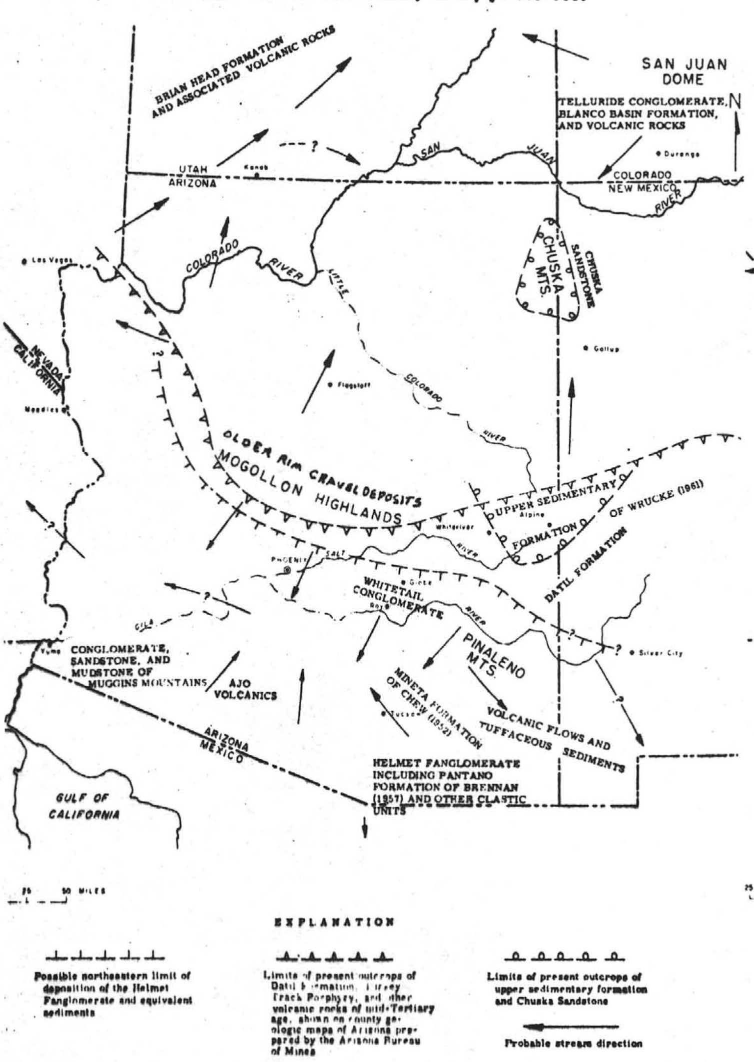
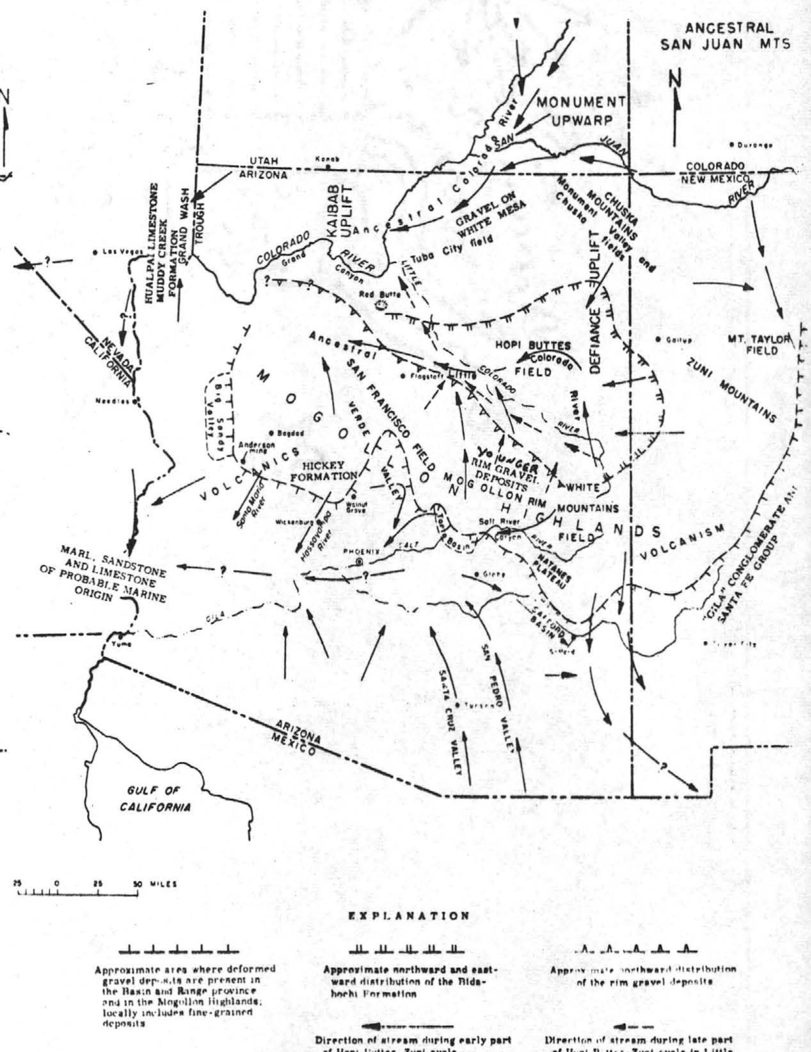




GEOLOGY AND GROUND WATER IN VERDE VALLEY - THE MOGOLLON RIM REGION ARIZONA: F.R.TWENTER AND D.G.METZGER, 1963, U.S.GEOLOGICAL SURVEY BULL.1177.

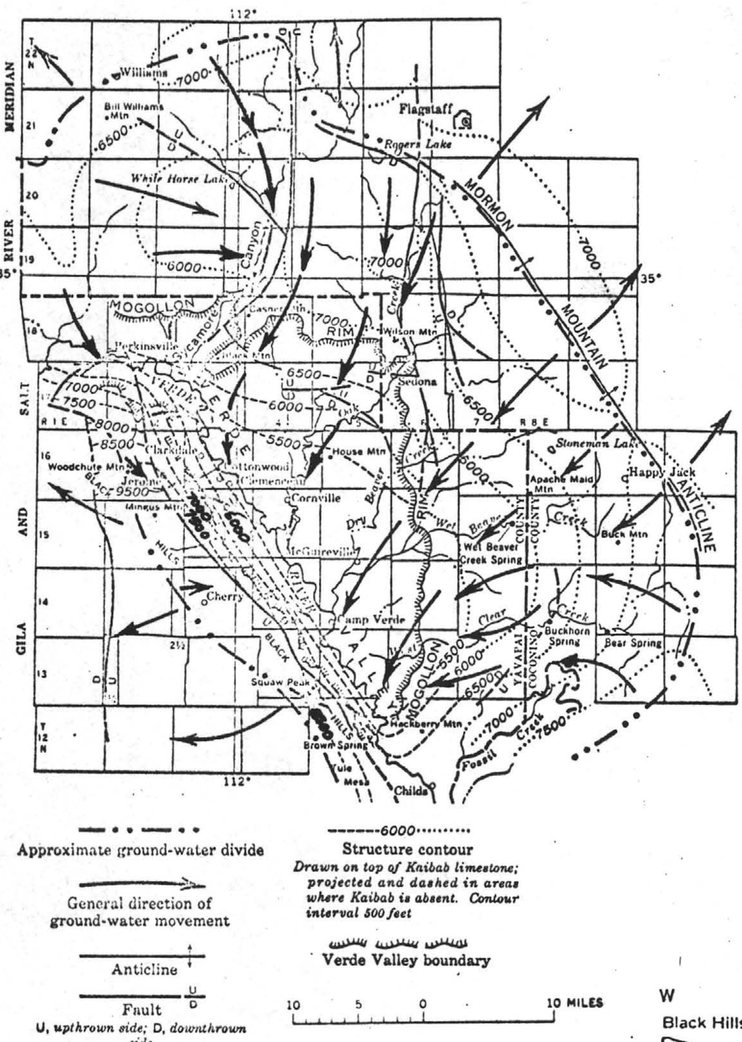


FIGURE 37.—Map showing relation of ground-water movement to structure in the Verde Valley area.

The paths—through fractures, solution channels, bedding planes, and permeable beds—by which the ground water finds its way from the recharge area of high precipitation (fig. 36) to its temporary base level, the Verde River, are many and are complexly interrelated, but the general pattern can be presented simply. Some of the water precipitated as rain or snow on the Colorado Plateaus enters the surface rock—in most areas, Kaibab Limestone or Tertiary volcanic rocks—and becomes ground water. It percolates downward through the underlying Toroweap Formation and into the Coconino Sandstone. In parts of the Colorado Plateaus where the Coconino is saturated, the water moves laterally, Where deep canyons intersect the water table, the water will issue as springs or seeps. In parts of the Colorado Plateaus where the Coconino Sandstone is not saturated, the water percolates downward into the underlying Supai Formation. In the Sedona area, part of the lower member of the Supai Formation is saturated, and the water moves laterally to the southwest. If, as in the Sycamore Creek area, the Supai Formation is not saturated, the water percolates into the underlying Redwall Limestone.

Ground water probably moves from the Supai Formation and the Redwall Limestone directly into the Verde Formation. In the Verde Formation, ground water moves generally southwestward toward the Verde River. The bending of the contours upstream shows that the Verde River and its principal tributaries are effluent and receive ground-water discharge in parts of their courses.

All ground water discharged in the Verde Valley ground-water basin, except that lost through evapotranspiration, flows out of the basin at the Chasm gaging station as surface water in the Verde River. The base flow of the river, where it exits from the valley, is 225 cfs. This flow represents the minimum quantity of ground water discharged from rocks in Verde Valley.

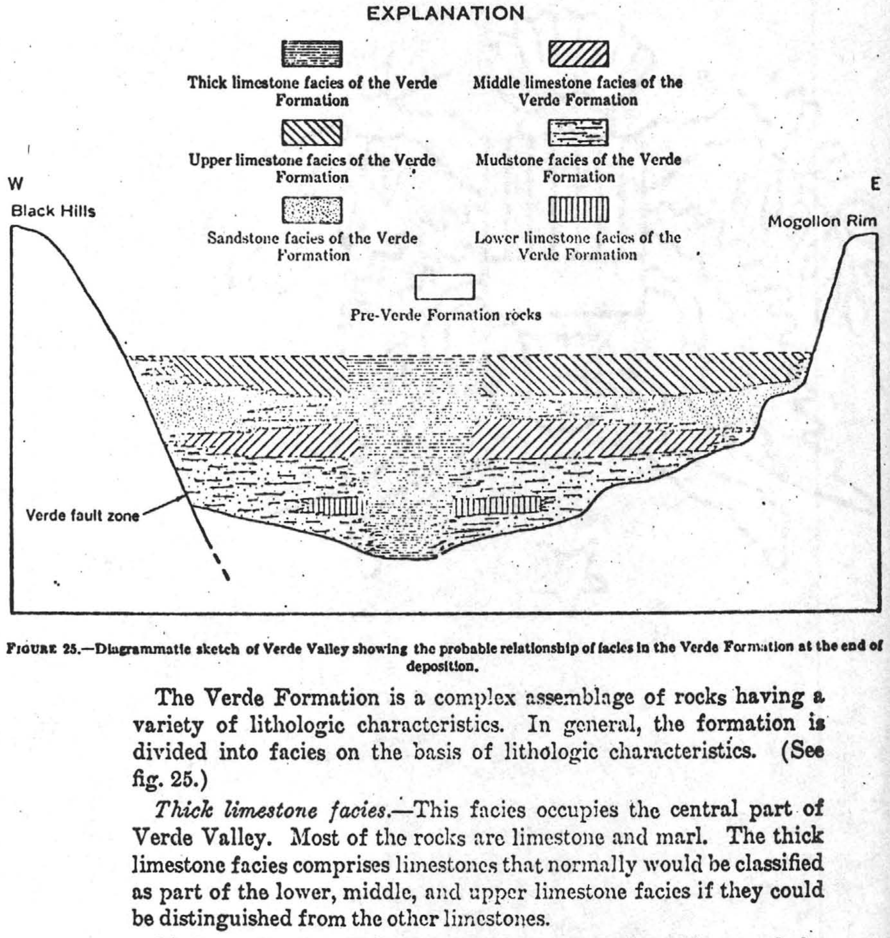


FIGURE 25.—Diagrammatic sketch of Verde Valley showing the probable relationship of facies in the Verde Formation at the end of deposition.

The chief means of recharge to the Verde Valley ground-water reservoir is by direct penetration of water from precipitation on the Colorado Plateaus (fig. 36). Some recharge to the Verde Formation is from pre-Verde rocks such as the Supai Formation and Redwall Limestone.

Ground-water reservoirs that have not been materially affected by development are in hydrologic balance—that is, the amount of recharge is about equal to the amount of discharge. The Verde Valley ground-water basin is in hydrologic balance; the amount of water recharged to rocks in the basin is about equal to the amount of water discharged as base flow at the Chasm gaging station (fig. 36). The average base flow at the gaging station during the winter—225 cfs or 150,000 acre-feet per year—is an approximation of the minimum quantity of water recharged to all rocks in the ground-water basin. The area of rock yielding ground water to surface flow is about 1,400,000 acres; therefore, each acre yields ground water at the rate of 37,000 gallons per year.

The recharge area, about 900,000 acres, receives 20 inches of precipitation per year, and the rest of the ground-water basin receives 12 inches per year; thus, the average annual precipitation in the Verde Valley ground-water basin is 17 inches. Each acre of land receives water from precipitation at the rate of 460,000 gallons per year. On this basis and on the basis that the rocks in the basin yield 37,000 gallons per acre per year, the recharge is 8 percent.

Most ground water in the Verde Formation is in limestone, although sandstone, conglomerate, and siltstone yield some water. The water is discharged by springs, artesian wells, and flowing wells.

The regional movement of ground water in the Verde Valley ground-water basin is basinward from the Mormon Mountain anticline and the crest of the Black Hills (fig. 37). Thus, all ground water flows to the Verde River and its tributary streams. Then, as surface water in the Verde River, it leaves the valley.

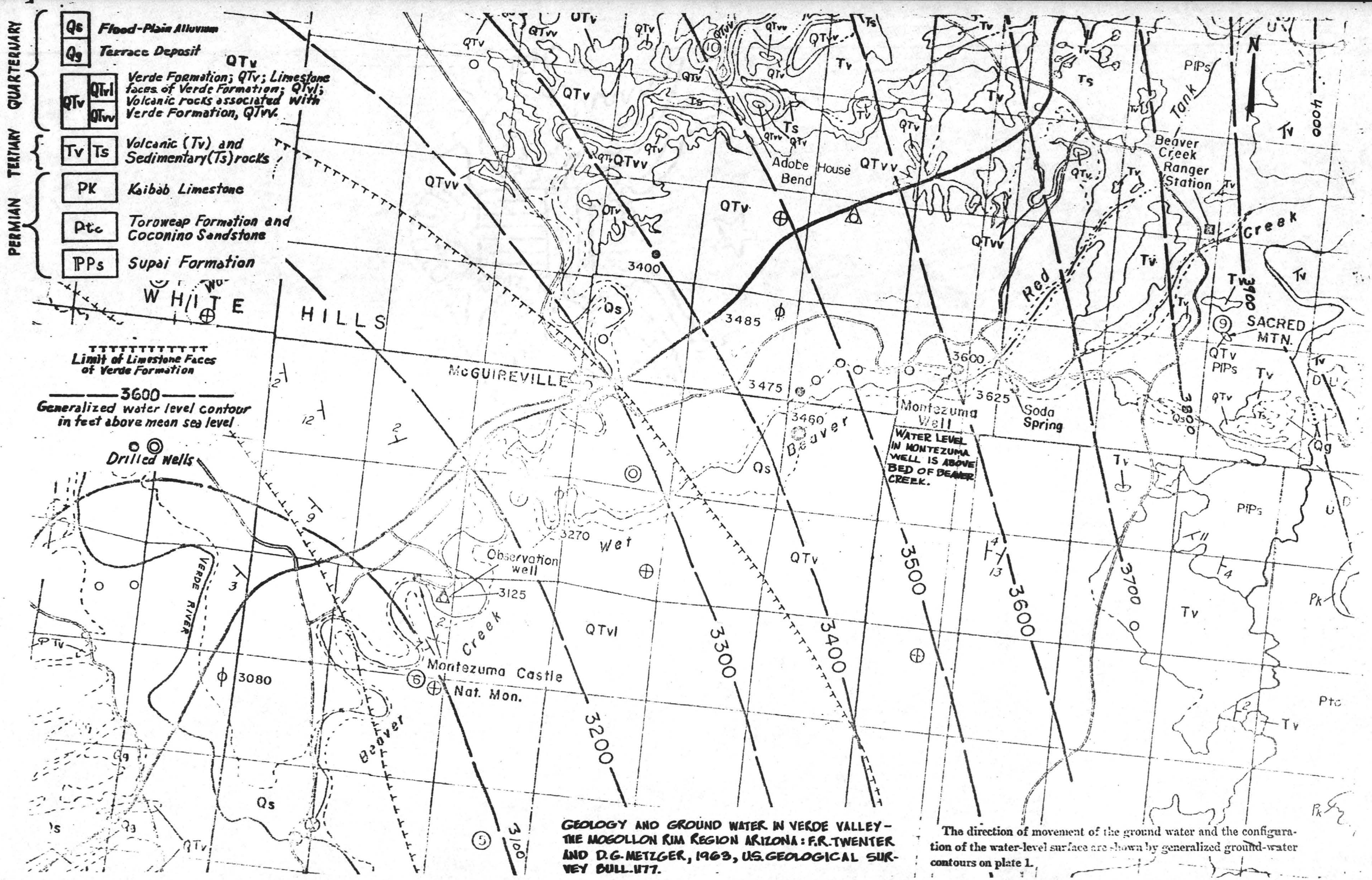
The Verde Formation is a complex assemblage of rocks having a variety of lithologic characteristics. In general, the formation is divided into facies on the basis of lithologic characteristics. (See fig. 25.)

Thick limestone facies.—This facies occupies the central part of Verde Valley. Most of the rocks are limestone and marl. The thick limestone facies comprises limestones that normally would be classified as part of the lower, middle, and upper limestone facies if they could be distinguished from the other limestones.

Mudstone facies.—This facies lies on either side and around the southern edge of the thick limestone facies. It may underlie, be stratigraphically equivalent to, or overlie the lower limestone facies. The rocks in the mudstone facies are predominantly mudstone and claystone, some of which contain evaporite minerals. In some places along the margin of the basin, conglomerate and tuffaceous rock form a major part of the mudstone facies.

Lower limestone facies.—This facies extends laterally from the thick limestone facies until it interfingers with the mudstone facies. The rocks in this facies are principally limestone and marl.

Middle limestone facies.—This facies extends laterally from the thick limestone facies until it overlaps pre-Verde Formation rocks or until it interfingers with clastic rocks of the Verde Formation along the margin of the valley. The middle limestone facies is separated from the lower limestone facies by rocks of the mudstone facies. Most rocks in the middle limestone facies are limestone and marl.



GEOLOGY AND GROUND WATER IN VERDE VALLEY–THE MOGOLLON RIM REGION ARIZONA: F.R. TWENTER AND D.G. METZGER, 1963, U.S. GEOLOGICAL SURVEY BULL. 1177.

The direction of movement of the ground water and the configuration of the water-level surface are shown by generalized ground-water contours on plate 1.

CONTACTS MODIFIED FROM ARIZONA BUREAU OF MINES COUNTY GEOLOGIC MAPS.

RECONNAISSANCE GEOLOGIC MAP OF THE BLACK CANYON HIGHWAY AREA (FLAGSTAFF TO PHOENIX), ARIZONA.

BY M.E. COOLEY, U.S. GEOLOGY SURVEY, TUCSON, ARIZ.

Qs - DEPOSITS OF MIDDLE AND LATE QUATERNARY AGE.

QTs - DEPOSITS OF LATE PLIOCENE AND EARLY QUATERNARY AGE, INCLUDING VERDE FORMATION IN VERDE VALLEY.

Ts - DEPOSITS OF MIOCENE (?), MIOCENE AND LOWER TO MIDDLE PLIOCENE AGE.

(Tv) - VOLCANIC ROCKS OF MIOCENE (?), MIOCENE, AND PLIOCENE AGE, INCLUDES FEW DEPOSITS OF CONGLOMERATE.

VOLCANIC ROCKS OF QUATERNARY (?) AND QUATERNARY AGE.

D - DOWNTHROWN SIDE
U - UPTHROWN SIDE
FAULT
DOTTED WHERE CONCEALED

D - DOWNTHROWN SIDE
U - UPTHROWN SIDE
POSSIBLE FAULT OR FAULT ZONE

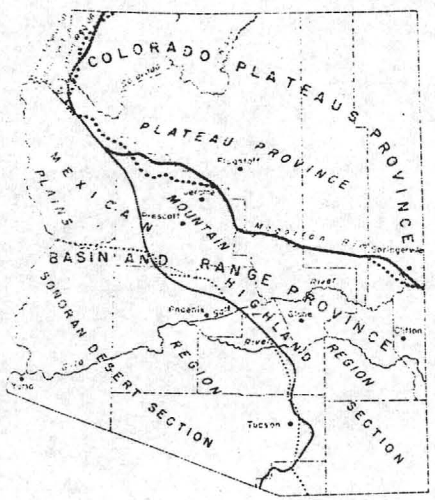
B - LATE PLIOCENE - EARLY PLEISTOCENE
H - MIDDLE PLIOCENE
C - EARLY PLIOCENE
● - FOSSIL LOCALITY

ANTICLINE
SYNCLINE
MONOCLINE
DOTTED WHERE CONCEALED

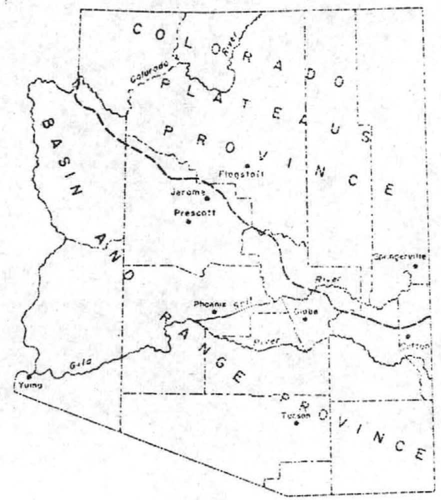
DEPOSITS CONSISTING MOSTLY OF SILTY SAND, SILT, CLAY, AND SOME LIMESTONE, GYPSUM AND GRAVEL.

DEPOSITS CONSISTING MOSTLY OF SAND TO GRAVEL CONTAINING SOME SILT AND CLAY.

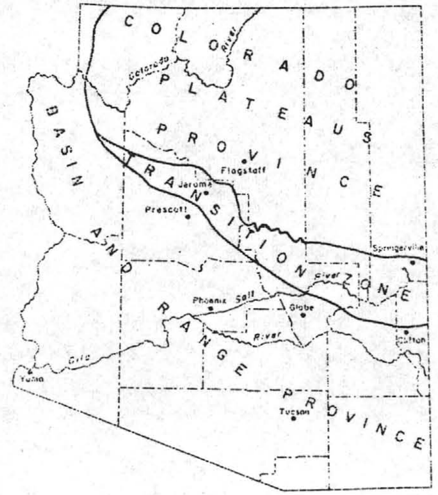
GENERALIZED FACIES DISTRIBUTION OF DEPOSITS OF MIOCENE TO EARLY QUATERNARY AGE.



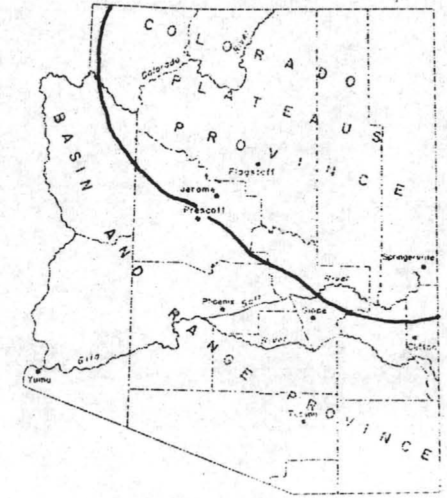
B. Comparison of the physiographic provinces of Ransome (1923) and Fenneman (1931). Boundaries and names after Ransome (1923) shown by solid lines and slanted lettering; boundaries and names after Fenneman (1931) shown by dots and vertical lettering.

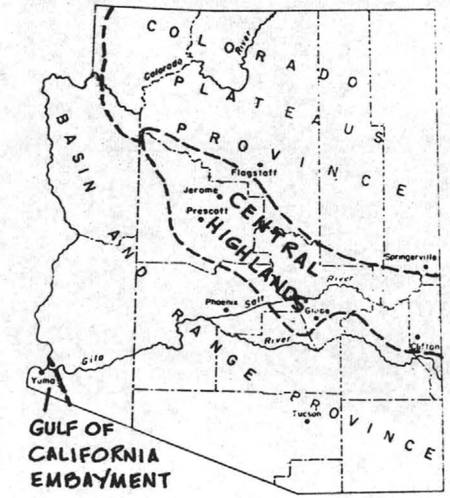


C. Structural boundary of physiographic provinces by Bromfield and Shride (1956)



D. Structural provinces by Wilson and Moore (1959).





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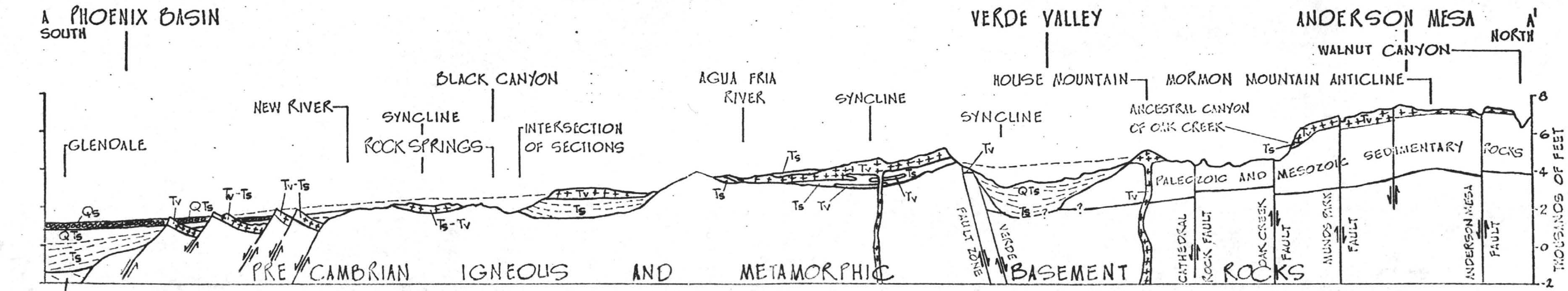
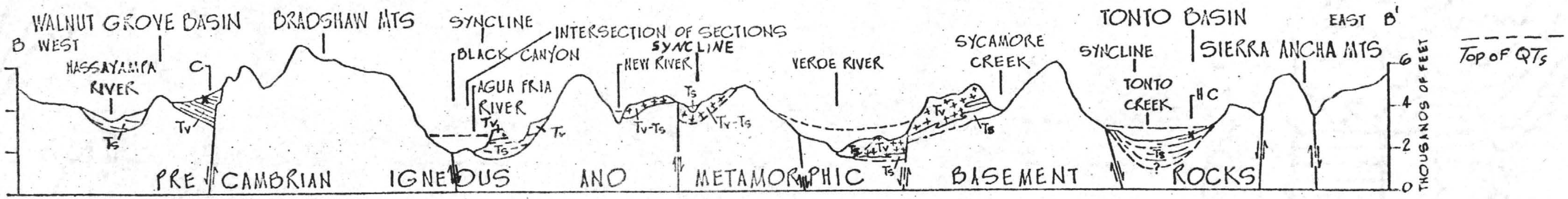
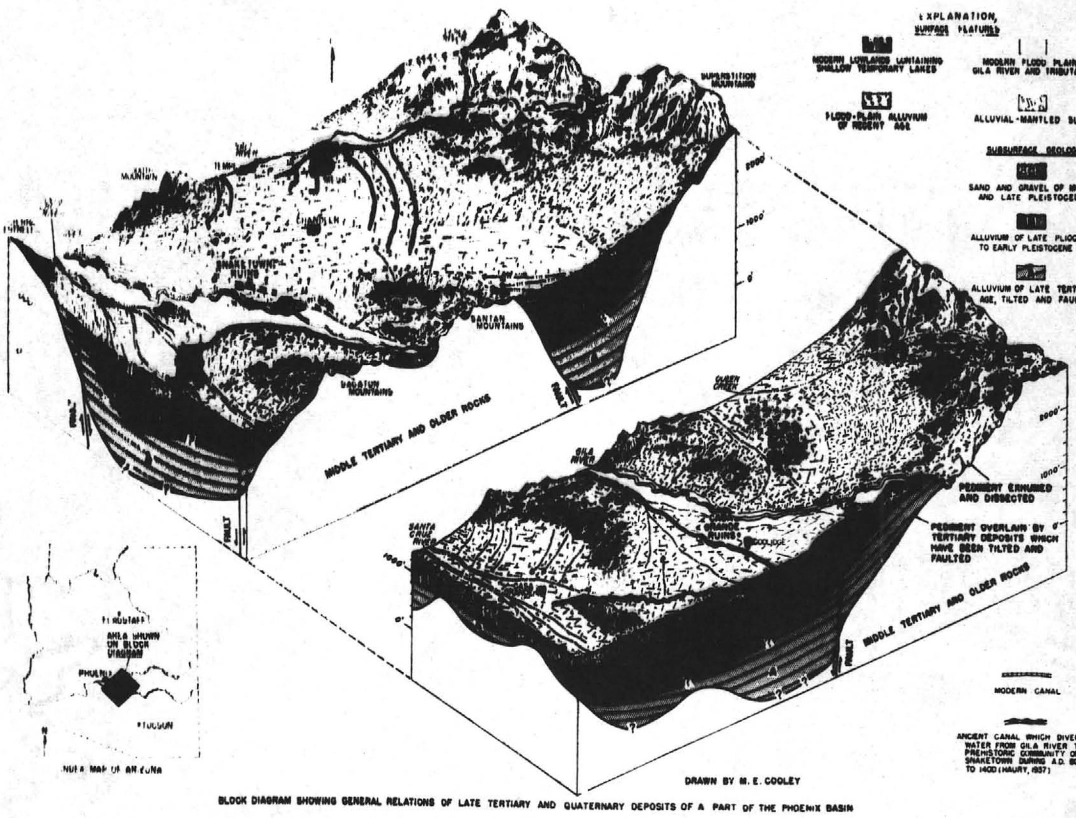
HYDROGEOLOGIC SUBDIVISIONS OF ARIZONA USED BY ARIZONA DISTRICT, U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION.

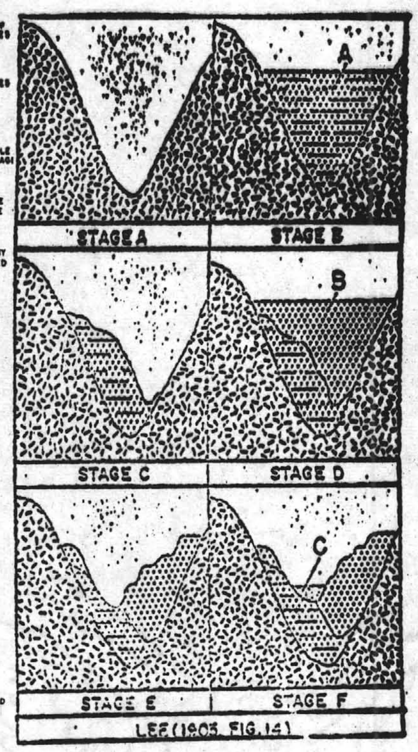


NORTH-SOUTH SECTION, NEAR BLACK CANYON HIGHWAY. SYMBOLS AND LOCATIONS OF SECTIONS ARE IN EXPLANATION OF GEOLOGIC MAP OF BLACK CANYON HIGHWAY AREA.



EAST-WEST SECTION





BLOCK DIAGRAM SHOWING GENERAL RELATIONS OF LATE TERTIARY AND QUATERNARY DEPOSITS OF A PART OF THE PHOENIX BASIN

"There have been, then, since the original formation of Tonto Basin at least 5 separate stages: (1) the period of erosion, which, in part at least, formed the basin, corresponding with stage A of fig. 14; (2) a period of accumulation, during which the breccia just described was deposited, this period corresponding to stage B; (3) a period of erosion, probably inaugurated by uplift and tilting, in which the breccia was dissected, this period corresponding to stage C; (4) a period of accumulation, in which the younger sediments of the basin were deposited on or against the dissected breccia—stage D; (5) a period of erosion, the present stage of the river, during which the present valley has been excavated—stage E" (Lee, 1905, p. 112-113). The depositional, erosional, and structural stages indicated on the block diagram are similar to those reported by Lee (1905) for much of Arizona. Three periods of deposition, deposits A, B, and C, are separated by periods of erosion; each younger deposit overlies unconformably the older deposits. Deposit C on the block diagram is contemporaneous with the terraces and deposit C of stages E and F of figure 14 of Lee (1905).

Lee, W. T., 1905, Underground waters of Salt River valley, Arizona: U.S. Geol. Survey Water-Supply Paper 136, 196 p.

MAP SHOWING SOME ANCIENT CANYONS, VALLEYS, AND ESCARPMENTS THAT INFLUENCED THE DEVELOPMENT OF MANY PRESENT PHYSIOGRAPHIC FEATURES, MOGOLLON RIM AREA, ARIZONA. COMPILED BY M.E. COOLEY, U.S. GEOLOGICAL SURVEY, TUCSON, ARIZONA.

ESCARPMENT, LARGELY OF THE ANCESTRAL MOGOLLON RIM.

OUTLINE OF ALLUVIAL DEPOSITS IN THE PRESENT VALLEYS AND BASINS.

CANYON OR VALLEY FEATURES THAT PRE-DATE OR WERE FORMED DURING TIME OF LARGE-SCALE NORMAL FAULTING AND ACCOMPANYING UPLIFT OR SUBSIDENCE.

DIRECTION OF SEDIMENT TRANSPORT OF OLDEST KNOWN DEPOSIT IN CANYON OR VALLEY, OLIGIOCENE (?) TO PLIOCENE (?) IN AGE. THE EARLY MIDDLE TERTIARY DRAINAGE WAS FLOWING GENERALLY TO THE NORTHEAST AND EAST.

FIGURE 205.2.—Diagrammatic section of typical basin or valley, in central mountains of Arizona. Black line in volcanic rocks and dotted lines in lacustrine and fluviatile rocks are hypothetical marker beds.

TWENTER, F.R., 1960, MIOCENE AND PLIOCENE HISTORY OF CENTRAL ARIZONA: U.S. GEOL. SURVEY RESEARCH 1961, SHORT PAPERS IN THE GEOLOGIC AND HYDROLOGIC SCIENCES, PROFESSIONAL PAPER 424-C, P. 153-156.

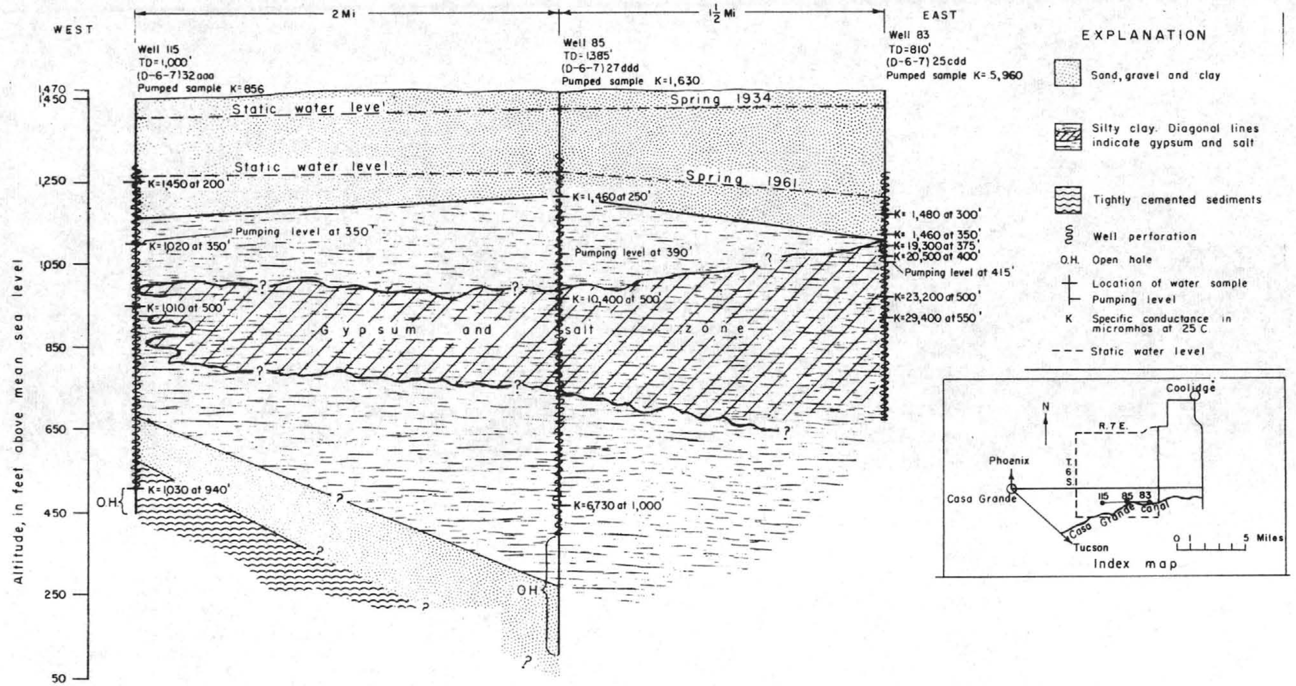


Figure 2.—Geologic section across T. 6 S., R. 7 E., lower Santa Cruz basin, Ariz., showing changes in conductance of water with depth.

Arizona Geological Society Digest, Volume IV, November 1961

CORRELATION OF GROUND-WATER QUALITY WITH DIFFERENT SEDIMENT TYPES, LOWER SANTA CRUZ BASIN, ARIZONA

By

L. R. Kister and W. F. Hardt

U.S. Geological Survey, Tucson, Arizona

To correlate water quality with sediment types, a geologic section (Fig. 2) was prepared from drillers' logs and examination of drill cuttings. The section is in T. 6 S., R. 7 E., and extends 3-1/2 miles eastward from well 115 to well 83. The section (Fig. 2) shows a permeable zone of sand and gravel and some clay at the land surface to a depth of 260 to 375 feet below the land surface. This shallow zone yields moderate to large amounts of water to wells. In the spring of 1934, the static water level along the profile was about 35 to 50 feet below the land surface. With little recharge of water to the aquifer and continued pumping for irrigation, the water level declined markedly. In the spring of 1961, the static water level along the profile was about 185 to 260 feet below the land surface. Wells were deepened because of the declining water table, and a thick layer of silty clay was found below the permeable sediments. This silty clay is less permeable and finer grained than the overlying sediments, and water yield per foot of drawdown is small. The silty clay probably was deposited in a body of standing water—where a body of water lacks an outlet, evaporation causes the formation of gypsum and other salts as indicated in the geologic section. If the lake is ephemeral there may be different horizons of gypsum and salt deposition. Thus, other gypsum and salt zones may be found elsewhere in the basin.

Explanation of the apparent water-quality anomalies at wells 83, 85, and 115 was greatly simplified when the values for specific conductance were added to the section illustrated in Figure 2 at appropriate depths. The specific conductance of the water in well 83 ranged from 1,480 micromhos at 300 feet to 29,400 micromhos at 550 feet below the land surface. The well was reported to be 810 feet deep, but owing to caving it was not possible to collect samples below 550 feet. The conductivity changed markedly between 350 and 375 feet, near the contact of the upper sandy horizon with the gypsum and salt zone in the silty clay layer. A conductivity traverse made at a later date showed that the conductivity changed at 360 feet below the land surface.

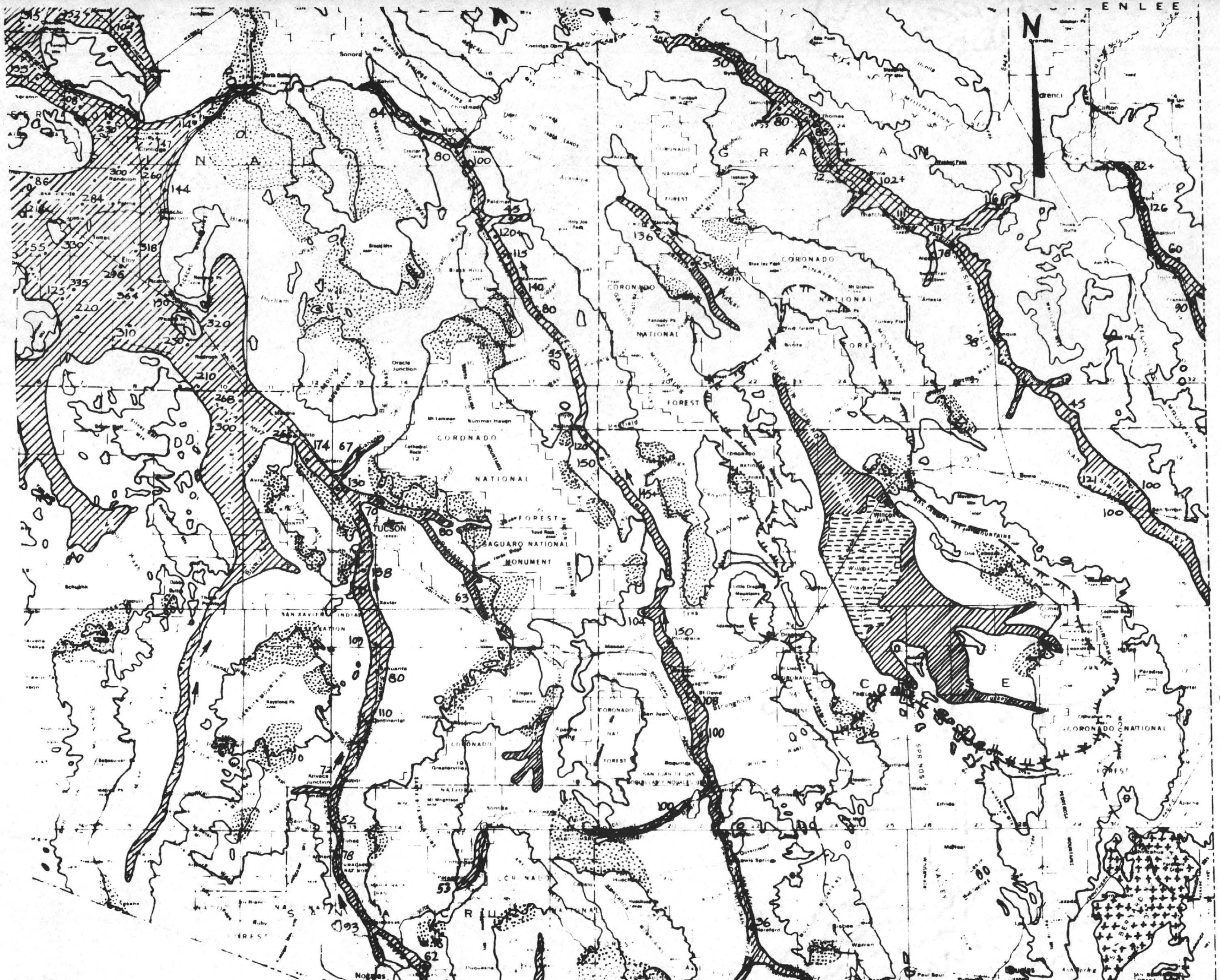
When well 83 was pumped, the specific conductance of the composite sample collected at the discharge pipe was 5,960 micromhos. The pump setting was at 440 feet. In 1960 the well yielded 675 gpm (gallons per minute) with 214 feet of drawdown for a specific capacity of 3.2 gpm per foot of drawdown. The pumping level in May 1961 was at 415 feet, which is in the gypsum and salt zone in the silty clay bed. Most of the water pumped from the well probably came from the more permeable zone above 360 feet, because the conductivity of the pumped sample was only about one-fourth as great as the conductivity of the water in the gypsum and salt zone of the less permeable silty clay beds.

Simple laboratory tests were made to determine what proportion of mixing of the waters of different conductivities would be required to produce a composite sample with a conductivity of 5,960. It was assumed that the water from the gypsum and salt zone in the lower silty clay bed had an average conductivity of 24,000 micromhos. When 186 parts of water with a conductivity of 24,000 was combined with 1,000 parts of water with a conductivity of 1,480, the resultant conductivity of the water mixture was 5,960 micromhos. This is a ratio of about 1 to 5.

Assuming that the average conductivity of the water from the gypsum and salt zone in the silty clay layer at well 85 is 8,500 micromhos—the average specific conductance of samples collected at 500 and 1,000 feet—only about 2 percent of the water pumped came from the gypsum and salt zone. The remaining 98 percent came from the more permeable sandy zone above 260 feet and (or) from the more permeable zone below 1,200 feet.

The specific conductance of the sample at the discharge pipe of well 115 was 856 micromhos, and the specific conductance of the point samples ranged from 1,010 to 1,030 in the silty clay and tightly cemented sediments. The tightly cemented sediments probably yield little or no water, so water of excellent quality under artesian pressure must be coming from the permeable sand, gravel, and clay zone at 770 to 870 feet below the land surface. Unfortunately no water sample was collected from this zone. Undoubtedly water of high conductivity is in the silty clay layer penetrated by the well, but it is masked in the well bore by the upward flow of good water. Analyses of drill cuttings indicate that silty clay contains gypsum at about 450 feet below the land surface.

The pumping levels of wells 83, 85, and 115 are in different lithologic horizons, and the hydrologic conditions at each well are different. This explains the difference in the quality of the water at the discharge pipes. As the water levels continue to decline because of extensive pumping for irrigation, less water of good quality will be available from the shallow sand, gravel, and clay zone. The gypsum and salt zone in the silty clay may cause deterioration of water quality in the future at wells 83 and 85. If a pump is set near the gypsum and salt zone in well 115, the conductivity of the water at the discharge pipe probably will increase. However, if the lower sand, gravel, and clay zone contributes moderate amounts of water of good quality, the change in the quality of the water yielded by the well probably will not be great.



EXPLANATION

Flood plain Alluvium

Playa deposits

Volcanic rocks of late Pliocene to late Pliestocene age

Pediment, defined as a gently tilted surface of low relief truncating middle Tertiary and older rocks. The pediments are over lain by early Quaternary and (or) Pliocene deposits and locally older rocks; They were exhumed principally during middle and late Quaternary time

Area of interior drainage, draining to Willcox Playa

Area of interior drainage

Direction of sediment transport

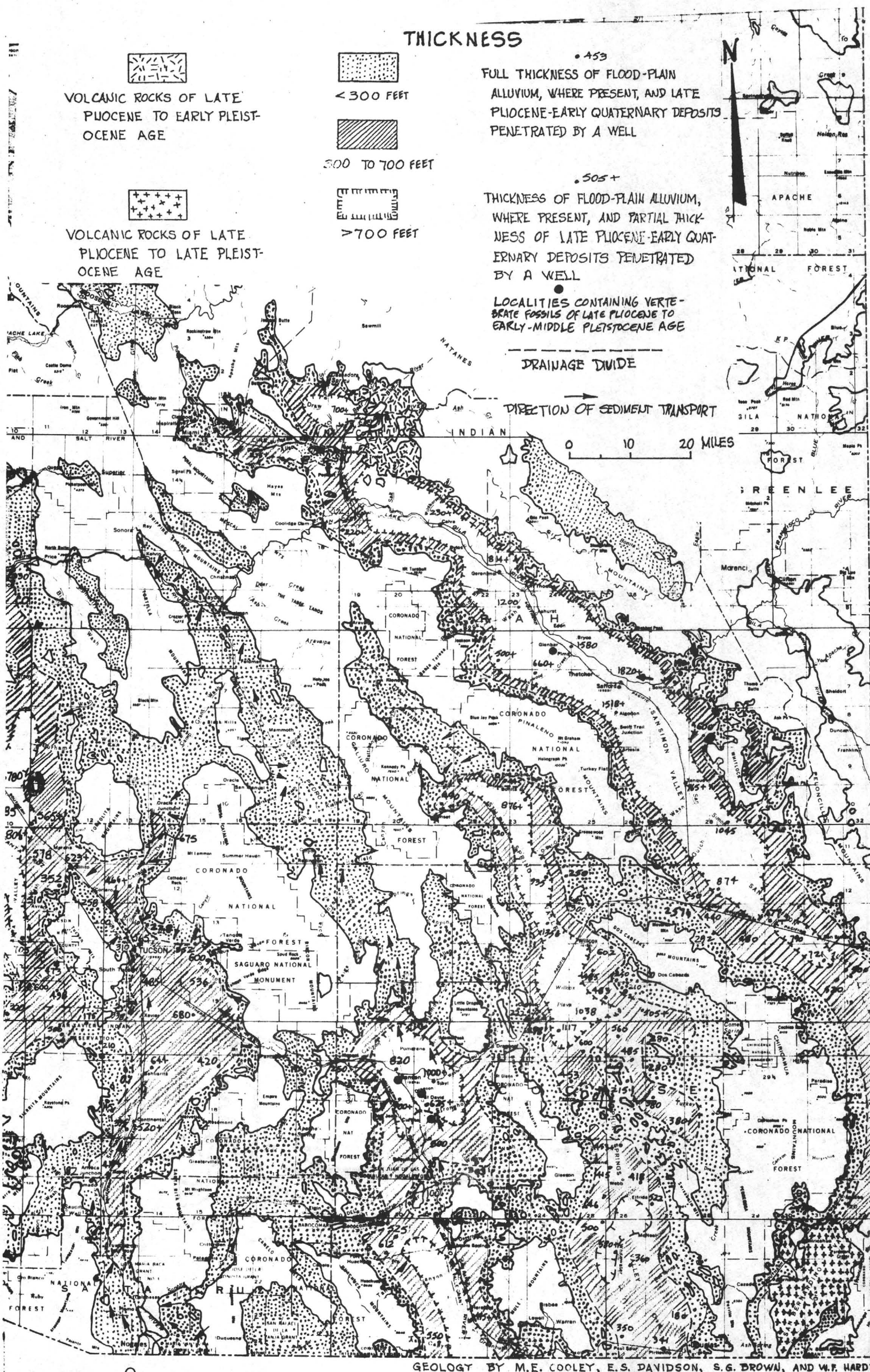
• 300
Full thickness of flood-plain Alluvium penetrated by a well

• 102+
Partial thickness of flood-plain Alluvium penetrated by a well

0 10 20 MILES

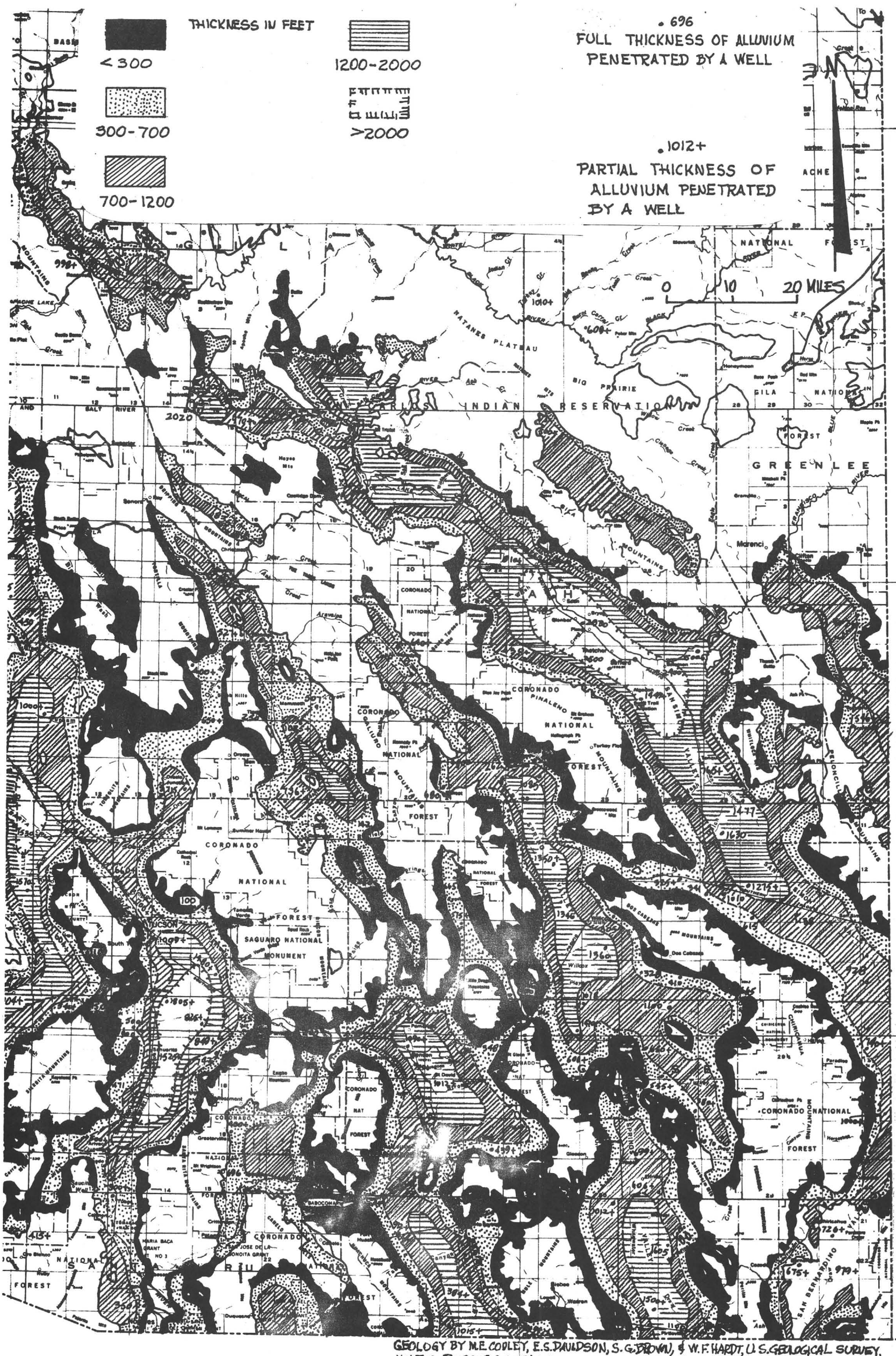
GEOLOGY BY M.E. COOLEY, E.S. DAVIDSON, S.G. BROWN & J. EHARDT, U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION, TUCSON, ARIZONA

MAP SHOWING THICKNESS OF FLOOD-PLAIN ALLUVIUM, DISTRIBUTION OF VOLCANIC ROCKS, AND OTHER FEATURES OF MIDDLE AND LATE PLEISTOCENE TIME



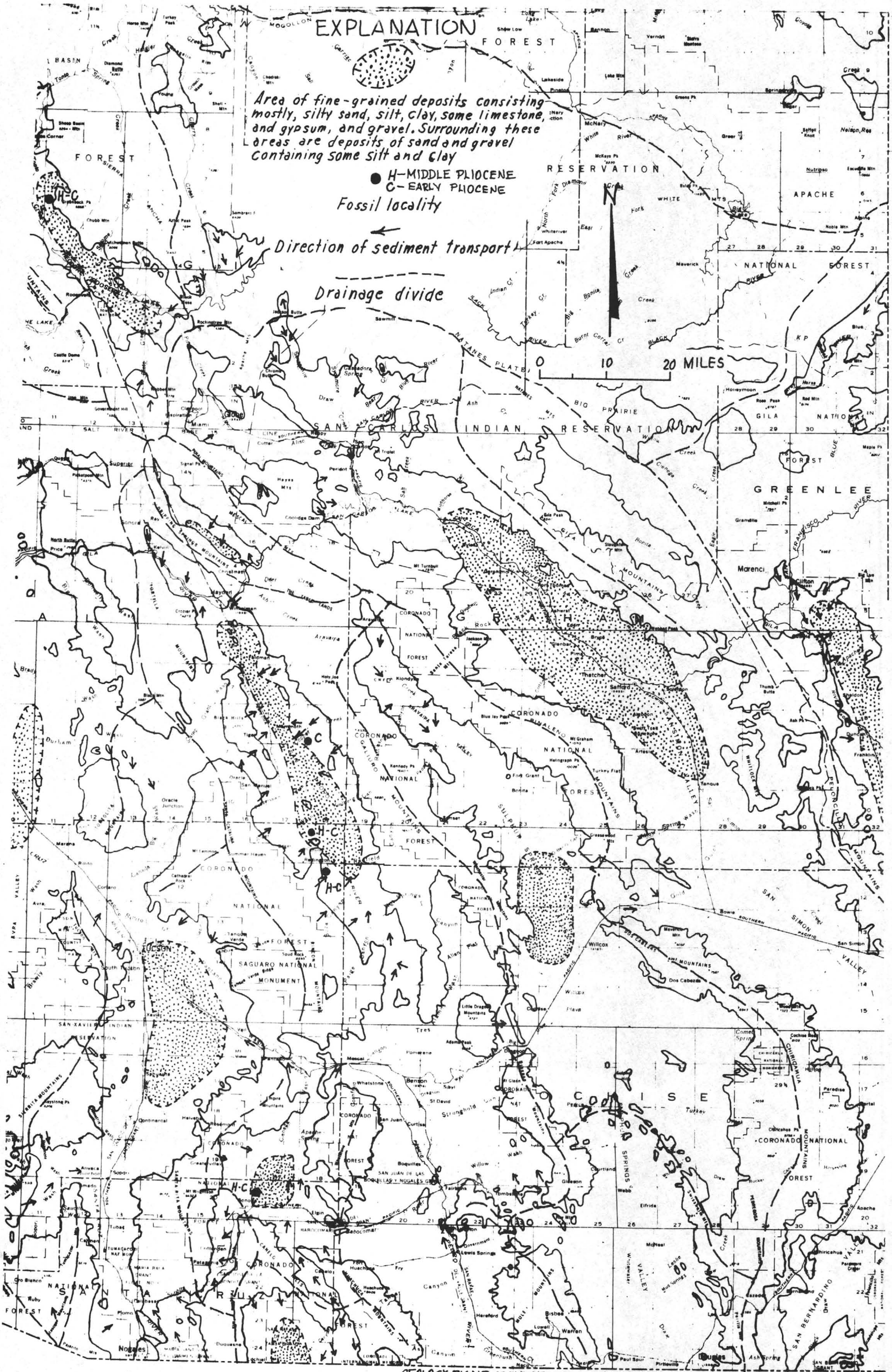
GEOLOGY BY M.E. COOLEY, E.S. DAVIDSON, S.G. BROWN, AND W.F. HARDT, U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION, TUCSON, ARIZONA

MAP SHOWING THICKNESS OF THE FLOOD-PLAIN ALLUVIUM WHERE PRESENT, AND LATE PLIOCENE-EARLY QUATERNARY DEPOSITS AND OTHER FEATURES OF LATE PLIOCENE-EARLY QUATERNARY TIME.



GEOLOGY BY M.E. COOLEY, E.S. DAVIDSON, S.G. BROWN, & W.F. HARDT, U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION, TUCSON, ARIZONA

MAP SHOWING THICKNESS OF ALLUVIAL DEPOSITS. MOST DEPOSITS ARE PLIOCENE & QUATERNARY IN AGE, BUT LOCALLY THEY MAY INCLUDE MIDDLE & LATE MIOCENE(?) DEPOSITS. THESE DEPOSITS ARE THE ALLUVIAL AQUIFERS OF ARIZONA.



GEOLOGY BY M.E. COOLEY, E.S. DAVIDSON, S.G. BROWN, & W.F. HARDT, U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION, TUCSON, ARIZONA

MAP SHOWING GENERALIZED FACIES DISTRIBUTION AND DIRECTION OF SEDIMENT TRANSPORT DURING PLIOCENE (?) AND EARLY AND MIDDLE PLIOCENE TIME.

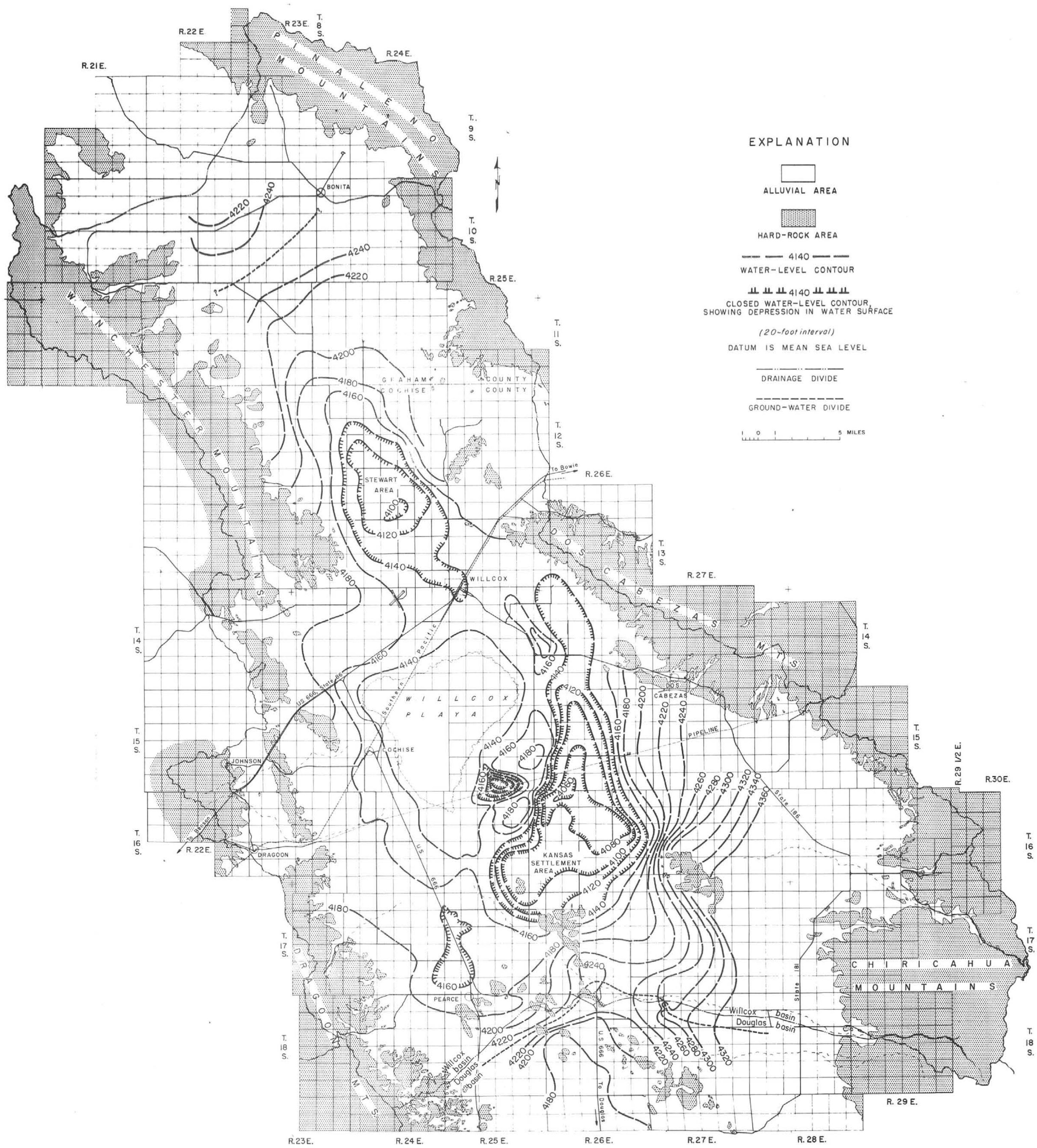
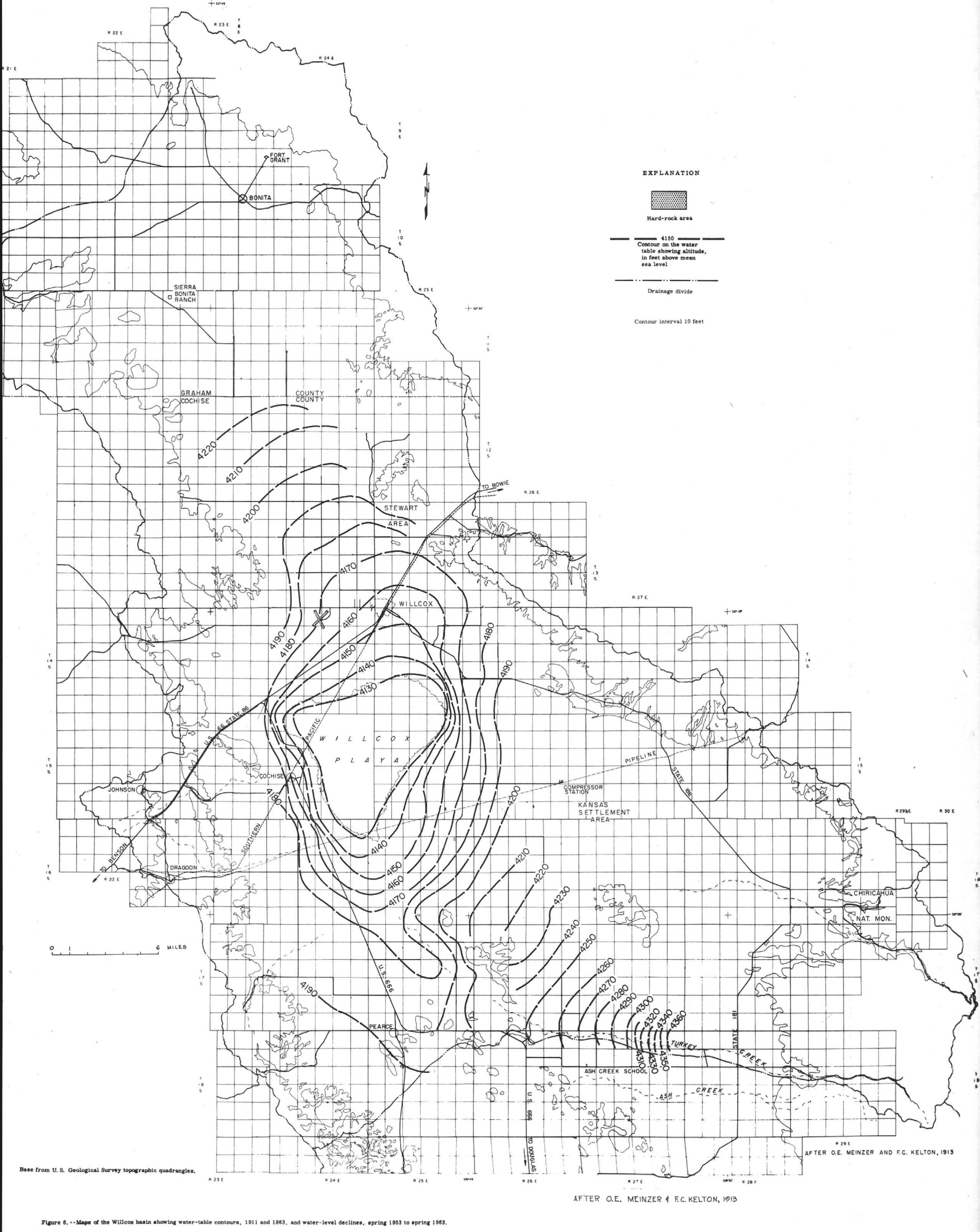


Figure 17.-- Map of Willcox basin (northern Sulphur Spring Valley), Cochise and Graham Counties, Ariz., showing altitude of the water level, Spring 1963.

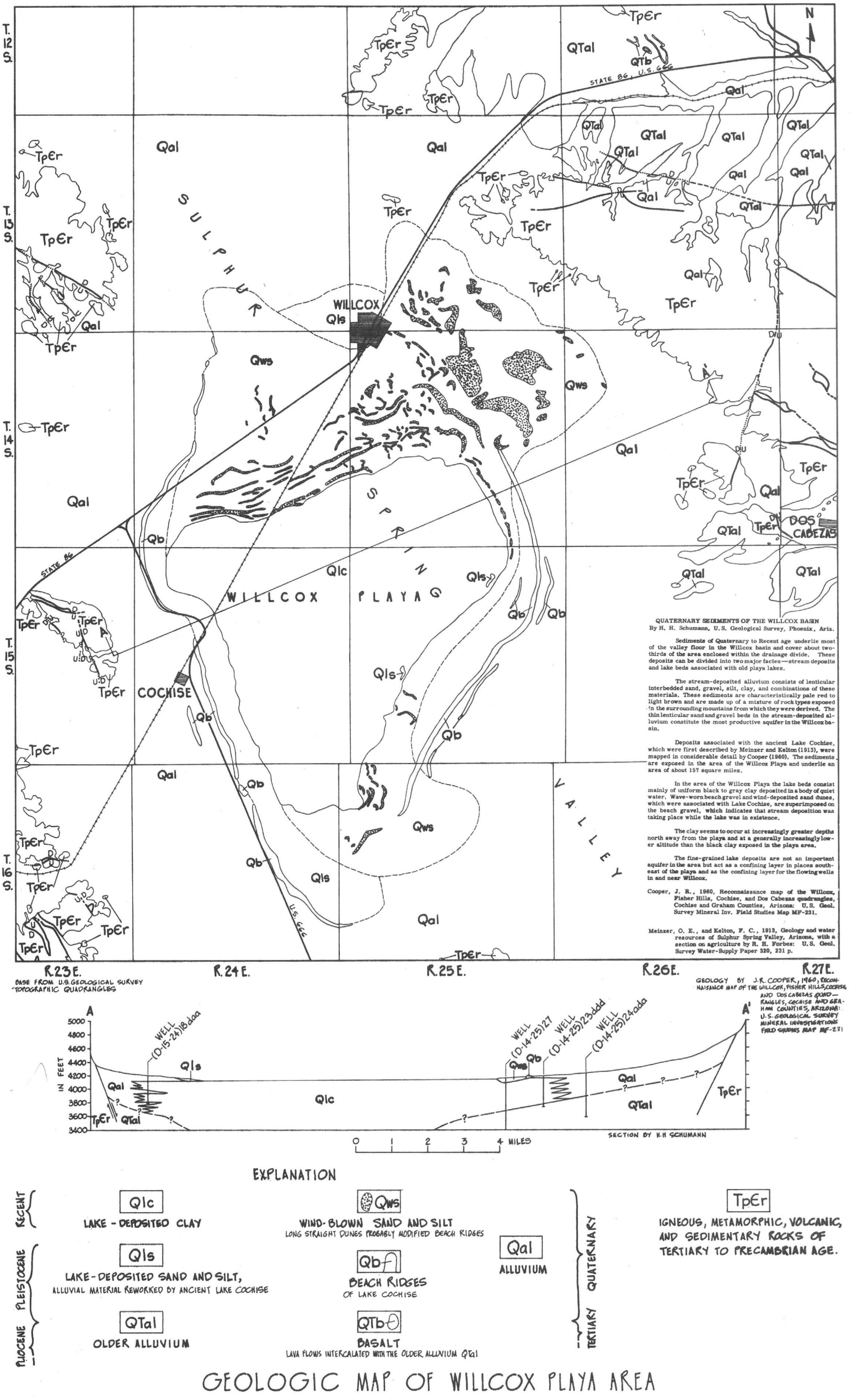


Base from U. S. Geological Survey topographic quadrangles.

AFTER O.E. MEINZER & F.C. KELTON, 1913

Figure 6.--Maps of the Willcox basin showing water-table contours, 1911 and 1963, and water-level declines, spring 1953 to spring 1963.

A. Water-table contours, 1911.



QUATERNARY SEDIMENTS OF THE WILLCOX BASIN

By H. H. Schumann, U.S. Geological Survey, Phoenix, Ariz.

Sediments of Quaternary to Recent age underlie most of the valley floor in the Willcox basin and cover about two-thirds of the area enclosed within the drainage divide. These deposits can be divided into two major facies—stream deposits and lake beds associated with old playa lakes.

The stream-deposited alluvium consists of lenticular interbedded sand, gravel, silt, clay, and combinations of these materials. These sediments are characteristically pale red to light brown and are made up of a mixture of rock types exposed in the surrounding mountains from which they were derived. The thin lenticular sand and gravel beds in the stream-deposited alluvium constitute the most productive aquifer in the Willcox basin.

Deposits associated with the ancient Lake Cochise, which were first described by Meinzer and Kelton (1913), were mapped in considerable detail by Cooper (1960). The sediments are exposed in the area of the Willcox Playa and underlie an area of about 157 square miles.

In the area of the Willcox Playa the lake beds consist mainly of uniform black to gray clay deposited in a body of quiet water. Wave-worn beach gravel and wind-deposited sand dunes, which were associated with Lake Cochise, are superimposed on the beach gravel, which indicates that stream deposition was taking place while the lake was in existence.

The clay seems to occur at increasingly greater depths north away from the playa and at a generally increasingly lower altitude than the black clay exposed in the playa area.

The fine-grained lake deposits are not an important aquifer in the area but act as a confining layer in places southeast of the playa and as the confining layer for the flowing wells in and near Willcox.

Cooper, J. R., 1960, Reconnaissance map of the Willcox, Fisher Hills, Cochise, and Dos Cabezas quadrangles, Cochise and Graham Counties, Arizona: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-231.

Meinzer, O. E., and Kelton, F. C., 1913, Geology and water resources of Sulphur Spring Valley, Arizona, with a section on agriculture by R. H. Forbes: U.S. Geol. Survey Water-Supply Paper 320, 231 p.

GEOLOGIC MAP OF WILLCOX PLAYA AREA

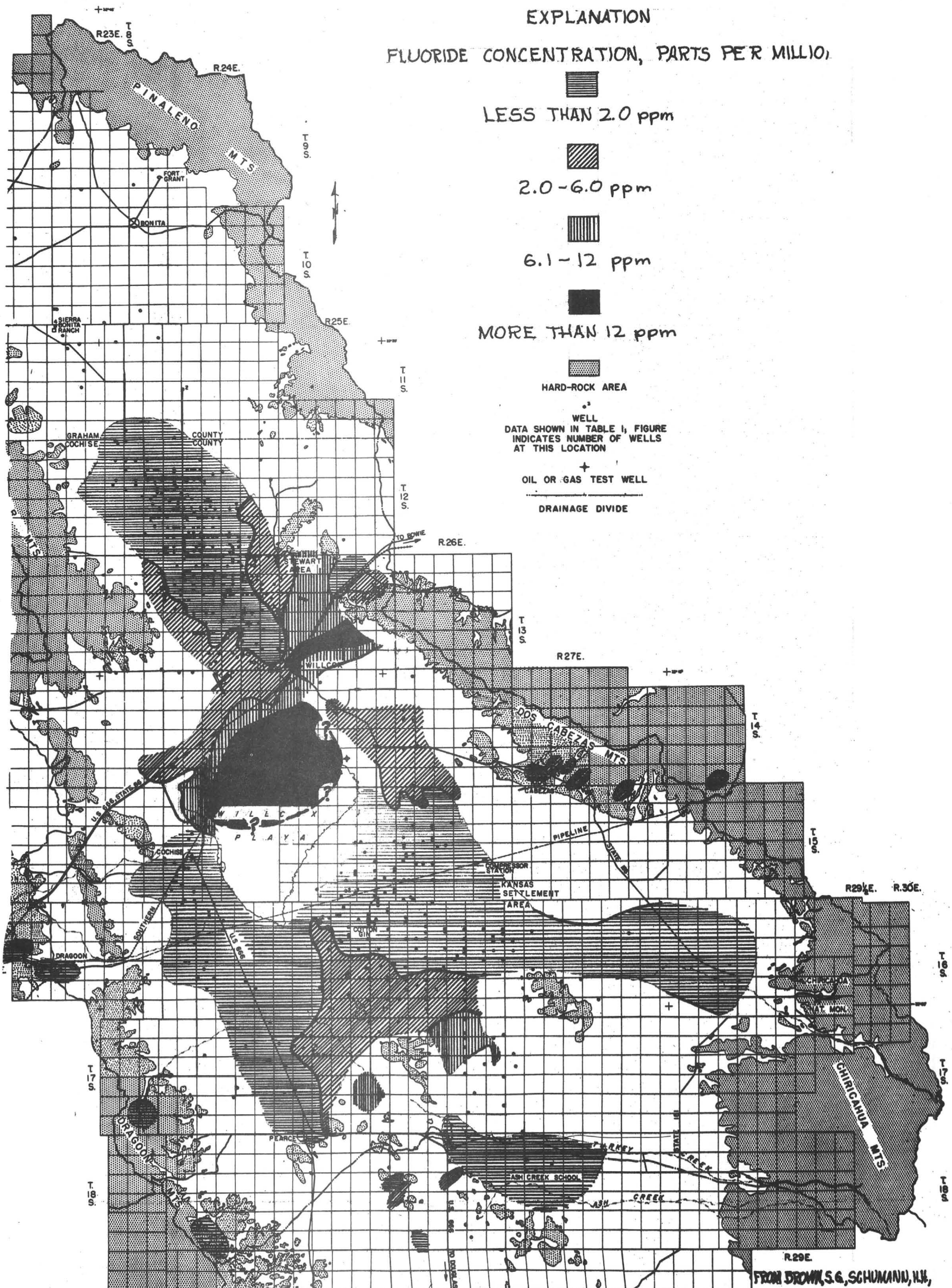


Figure 3.-- Map of Willcox basin, Cochise and Graham Counties, Ariz., showing the location of selected wells.

FROM BROWN, S.G., SCHUMANN, H.H., KISTER, L.R., & JOHNSON, P.W., 1963, BASIC GROUND-WATER DATA OF THE WILLCOX BASIN GRAHAM & COCHISE COUNTIES, ARIZONA: ARIZ. STATE LAND DEPT. WATER RESOURCES REPORT 14.

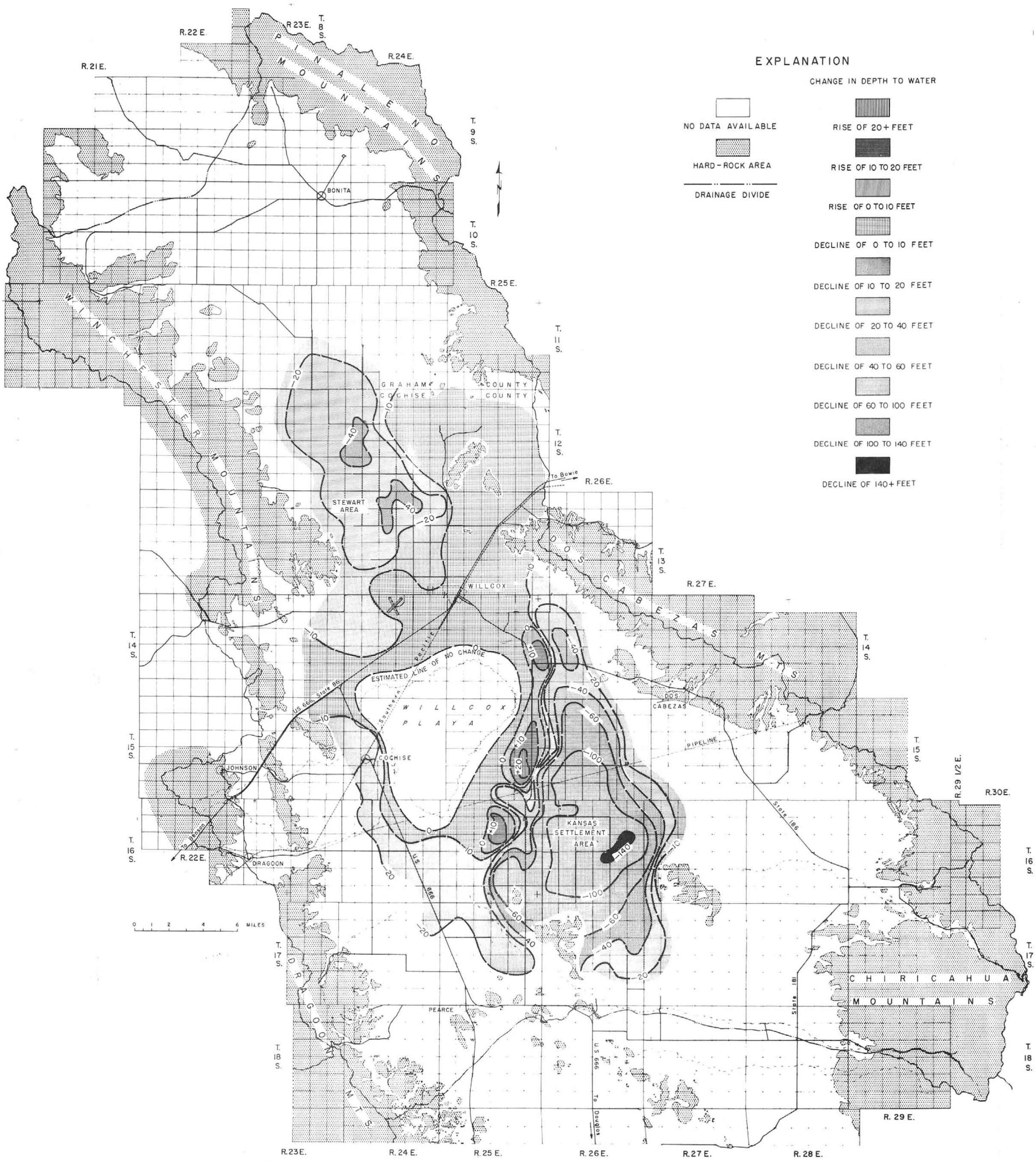


Figure 18.-- Map of Willcox basin, Cochise and Graham Counties, Ariz., showing change in ground-water level from spring 1953 to spring 1963.