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GEOLOGICAL RECONNAISSANCE OF CENTRAL SONORA.

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The present paper is the result of reconnaissance geological work by the writer in the central part of the State of Sonora,

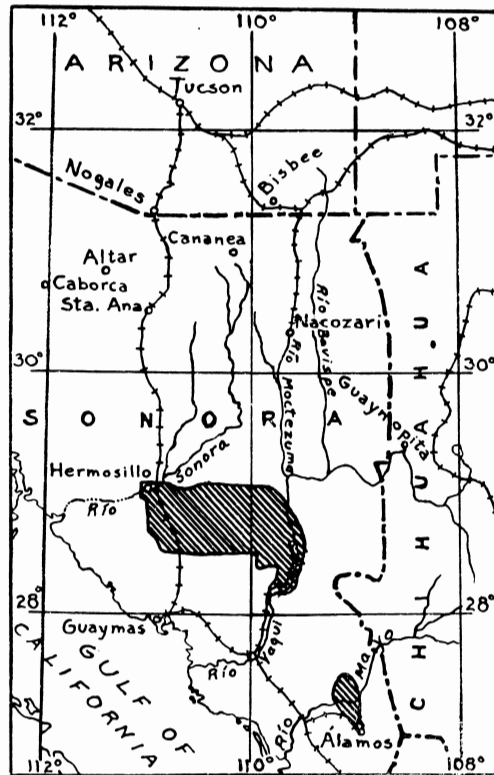


Fig. 1. Index map of Sonora, to show areas (shaded) described in the text.

Mexico, in 1931 and 1932, which had as its primary object the collection of data concerning the Paleozoic strata first noted in that region by Dumble¹ (Fig. 1). Dumble's observations

¹Dumble, E. T.: Notes on the Geology of Sonora, Mexico. Trans. Am. Inst. Min. Eng., 29, pp. 122-152, 1900.

were very sketchy, no map accompanied his report, and most of his localities can be found only on the most detailed state maps. Nothing further was written concerning the Paleozoic rocks of this region until the work of Teodoro Flores² appeared. As will be seen below, Flores assigned the Paleozoic strata of the vicinity to the Jurassic.

My field work was made possible by the generous financial assistance of Professor Charles Schuchert. I constructed a sketch map from pace traverses, doing all field work afoot or on horseback. The extent of the several areas of Paleozoic rocks was determined, and I attempted to establish the structural relations of the region. The present preliminary paper is being published in advance of further work in the same region and to the east of it.

The fusulinids collected were examined by Professor C. O. Dunbar, and his identifications are cited in the following text.

Area studied—The section of Sonora studied during the course of this work lies between 28°15' and 29° N. Lat., and extends from the Río Yaqui on the east to Hermosillo on the west. My own field observations are supplemented in the western part of the area by maps and data of Flores, which I have taken the liberty to interpret in the light of my own findings (Fig. 2).

GEOMORPHOLOGY.

The area studied lies in three large drainage basins—those of the Ríos Sonora and Yaqui on the west and east and of the Arroyo de Mátape in the center (Fig. 2). The western part of the area, lying west of the 110th meridian, has a pediment-inselgebirge topography like that described by Bryan in the Pápago country.³ There are three principal mountain massifs in this section. The western is that of La Colorada, a north-south chain of fault-block mountains separated from one another by pediments. East of this across the Mátape valley is the high east-west trending Sierra de Tecoripa, separated by a valley from the Sierra de Cobachi, which terminates to the north in the high Permian limestone mountain of Cerro Cobachi (Fig. 2). North-northeast of this is a broad round-topped granite mountain, the Sierra de Mazatán. Dividing the

² Reconocimientos Geológicos en la Región Central del Estado de Sonora. Inst. Geol. de México, Bol. no. 49. Mexico, 1929.

³ Kirk Bryan: Erosion and Sedimentation in the Papago Country, Arizona. U. S. Geol. Sur. Bull. 730, 1922.

different massifs from one another, and separating them from the high range east of the 110th meridian, is an extensive pediment plain eroded from granite thinly mantled with lavas.

In the eastern part of the area studied there is a north-south chain of high mountains, elongate about N. 25° W., and averaging 20 kilometers in width, lying along the west side of the Río Yaqui. This range is formed of Triassic quartzites intruded by igneous rock, and is believed to be an overthrust nappe. It terminates to the south of San Javier, and is succeeded in that direction by irregular metamorphic and igneous ranges separated from one another by narrow granite pediments.

Between the San Javier range on the west and the next parallel range to the east lies the north-northwest-trending intermontane valley which extends from La Dura on the south to beyond Rebeico on the north. South of Soyopa this valley is followed by the Río Yaqui. The width of the valley averages 10 kilometers. It is traversed by low north-south hog-back lava ridges, between which are low-lying strips underlain by agglomerate.

South of La Dura the Yaqui enters the region, above mentioned, of irregular ranges of metamorphic and igneous rock intruded by granite. Throughout its course the river loops back and forth from resistant rock into soft agglomerate, as if it had entrenched itself from a former period of meandering.

Between La Dura and Soyopa the intermontane valley of the Yaqui is bordered on the east by a high range of quartzite and plutonic rock, a western ridge of the main Western Sierra Madre. The Yaqui cross-cuts this range north of Soyopa, and the continuation of the range toward the north-northwest of the Yaqui canyon is known as the Sierra de Soyopa. Through the area studied, the Río Yaqui makes an acute angle with the main structural trend of N. 25° W., its course being nearly due south. However, to the north, at Lat. 29°15' N., the river makes a right-angle bend to the east directly crossing the high ranges of the sierra. In the same strike valley which is occupied by the Yaqui below the great bend, the Río Moctezuma flows south from Nacozari (Fig. 1).

Alluvial fans are developed only on the flanks of fault-block mountains. The only large fans in the area examined border the Sierra de Cobachi, especially along the eastern fault scarp of that range. Where normal erosion processes have continued for a long period without interruption by uplift, broad

pediment surfaces are formed, more or less sheeted over by waste.

Several different levels of pediments are to be observed. A careful comparison of the levels would make possible their correlation from place to place, and the working out of the erosional history of the Quaternary, as was done by Kirk Bryan in the Pápago country.

The region is arid, though covered in most places with heavy brush, which is nearly impenetrable in most of the mountainous sections. The part of the area west of the Sierra de San Javier is covered with more or less grass, greasewood, mezquite, ironwood, sahuaro, pitahaya, cholla, palo verde, and other thorny trees and cacti such as are characteristic of southern Arizona. In the high mountains in the eastern part of the region there are tall trees, many of them thornless, and grass grows luxuriantly.

STRATIGRAPHY.

The following table represents the succession of sedimentary and volcanic rocks in the region :

Quaternary.	Alluvium, generally thinly mantling the pediments, rarely forming great fans.	
Tertiary.	Basalt, in western part of region. Agglomerate interbedded with thin flows of andesite and rhyolite; in the western part of the region capped by a thick flow of rhyolite. Total thickness over 1000 m.	
Cretaceous?	Lista Blanca formation of Dumble?	Dense dark-grey andesitic lava flows separated from one another by indurated agglomerate. Thickness over 1000 m.
Upper Jurassic?	Limestones near Willard station and Zubiata, assigned by Flores to Upper Jurassic on the basis of crinoid stems. May be late Paleozoic in age.	
Liassic and Upper Triassic.	Barranca group.	Two members of massive sandstone divided by a thin-bedded sandstone and shale member, containing coal and graphite. Thickness about 1500 m.
Permian.	Equivalent of upper Naco limestone of S. Arizona.	Crinoidal and fusulinid limestone. Thickness about 600 m.
Ordovician.	Dark-grey to black limestone, commonly cherty, sandstone, and one layer about 50 m. thick of massive white coralline limestone (late Ordovician).	

Lower Paleozoic.—Lower Paleozoic strata crop out in two areas. The eastern area lies on the east side of the highway between the towns of Mazatán and Tecoripa. The western lies about 12 kilometers to the west in the northern part of the Sierra de Cobachi (Fig. 2). In both areas dips are high and irregular, the hills formed by sediments being separated by strips of igneous rock, and the whole country being covered heavily by brush, making it difficult to work out the actual sequence. Dumble described northeast of La Casita a thick series of quartzite and marble of "Cambrian" age (but without fossils), succeeded unconformably by fossiliferous limestone of the "Silurian." I was unable to find any section as simply arranged as this.

The most persistent horizon in the lower Paleozoic is a very massive layer of blue-grey, white-weathering limestone, containing stringers of black chert in part. It is everywhere much pitted by solution. The thickness of this layer is about 50 meters. In the eastern area it forms low hills in the southern and southwestern part, northeast of the house known as La Casita, and in the western area it forms the Cerro Goyete, southwest of Cerro Cobachi. The limestone contains abundant corals of the genus *Palaeophyllum* and rare *Calapoecia*, *Streptelasma* and *Heliolites*. This is the "Silurian" fauna reported by Dumble, but the fossils indicate late Ordovician (Richmondian) age.⁴

Adjoining this big limestone in the southwestern part of the eastern area of lower Paleozoic, and either above or below, though probably below it, there is a confusing complex of dark-grey to black limestone containing brown and black chert layers and concretions and siliceous shale, interbedded with thin layers of quartzite and clayey buff-colored limestone. In places layers of angular chert-pebble conglomerate were seen, and at one locality there is a platy dark limestone which is brecciated in broad flat pebbles. The black limestone looks very much like that in the Marathon region of west Texas which there contains such a prolific fauna of graptolites, but none of those fossils could be found here. The dips are

⁴Schuchert originally reported the fossils to be *Cyathophyllum* and *Heliolites*, and they were so cited by Dumble. In 1909 he re-examined them, and in his notes wrote, "These fossils are now before me and I see that they are of the southwestern Richmond. The most abundant coral is *Palaeophyllum* but not *P. thomii* (Hall). Next a *Calapoecia* near *C. canadensis* and a small *Streptelasma*." The writer collected additional specimens of these species.

extremely irregular in angle and direction, but the strike has a general east-west trend. The sequence of the beds could not be worked out in this division, nor were any fossils found. These strata must be those which Dumble assigned to the "Cambrian," but their lithologic resemblance is greater to the Ordovician of Texas.

The western area of lower Paleozoic strata is about 10 kilometers long, extending as a range of low-lying rugged hills elongate from north to south. Some Pennsylvanian or Permian strata are probably included in this complex. The dips and strikes here, as in the Casita area, are very irregular, and the interpretation of the structure and stratigraphy is difficult. In many places it is impossible even to determine the dip, because the strata are completely broken down along numerous joint planes, leaving only angular fragments on the surface. Aside from the fossiliferous limestone of Cerro Goyete and a limestone containing crinoids and bryozoans 3 kilometers north of Cerro Goyete, the area consists of brown and red sandstone and quartzite and cherty and siliceous limestone.

Permian.—Limestones of this age are much more widespread than lower Paleozoic strata. They seem to be a southern extension of the upper or Permian portion of the Naco limestone of southeastern Arizona. Generally, the limestone is almost made up of crinoid stems and fusulinids. Great reefs of massive limestone similar to those of West Texas form high mountains such as Cerro Cobachi and Cerro San Francisco north of Zubiata (Fig. 2). In intervening areas the limestone is darker in color, thinner bedded, and made up of small waterworn fragments of crinoid stems, and rarely fusulinids.

Brachiopods were found in only one place, south of the belt of massive coralline limestone lying northeast of La Casita. These were poorly preserved, but a *Linoproductus* was distinguished. North of there, in the same Paleozoic area, the hills east of Las Arrastras, composed of east-dipping light-grey massive limestone, contain *Parafusulina* of about the same age as that in the limestone of Cerro Cobachi.

Cerro Cobachi is a high hogback dipping to the south, formed of bluish-grey limestone, probably 500 meters thick. The limestone appears to be a reef mass, and to the west it breaks up into thinner limestone beds. In this region it contains many crinoid columnals and an abundance of fusulinids of two species. One is a *Paleofusulina* very near to, if not

identical with, *P. gümbeli* of the Leonard horizon of west Texas. The other form is larger and not yet identified. The limestone appears to thin considerably east and west from Cerro Cobachi, and is either cut off by intrusive granite or faulted off. The limestone dips toward the older Paleozoic on the south, and is probably downfaulted against it.⁵

West of the Arroyo de Mátape, Paleozoic sediments appear again in the northern part of the Sierra de la Colorada. They were assigned by Flores almost entirely to the Oxfordian division of the Upper Jurassic on the basis of stems of *Apio-crinus* in the Cerro de Sonora, and of *Millericrinus* in the hills east of Willard station, identified by Burckhardt. I did not visit these exact localities, but in the Cerro de San Francisco a few kilometers east of the Cerro de Sonora I found abundant fusulinids in crinoidal limestone, and in the Cerro de la Flojera north of Willard I found a few fusulinids in granular crinoidal limestone. These finds throw grave doubt on the correlation of crinoidal limestones in the same vicinity with the Jurassic on the basis of such doubtful fossils as crinoid stems, even by so eminent a paleontologist as Dr. Burckhardt.

In the La Colorada mining district there are quartzite and limestone which are much altered, shattered, and intruded. They are probably of Paleozoic age, though no fossils were found. The Cerro San Francisco, northeast of Zubiata, is made up of hundreds of meters of massive light-grey limestone, forming a reef nucleus which grades laterally into thin-bedded cherty, granular, crinoidal limestone bearing fusulinids. Cerro Zubiata, southwest of Zubiata, is likewise formed of a massive reef limestone. A number of other hills in the same vicinity

⁵ Dumble stated that the eastern face of Cerro Cobachi is formed by Cambrian rocks, consisting of "banded quartzites, marbles, etc., standing at a very high angle with the Cretaceous beds, having a comparatively gentle dip toward the west, resting upon their strongly-eroded edges. In the foothills southeast of this place the Silurian rocks succeed the Cambrian, but the contact was not observed. . ." The Cretaceous limestones containing supposed silicified hippuritids "are unconformable with all underlying rocks. . . Further south, on the western face of the main mountain, the limestones rest upon the upturned edges of a series of marbles and quartzites, which are provisionally referred to the Cambrian. Along the southern and eastern faces little was seen except the Cretaceous beds, which, in some places, are worn into great caves."

In my reconnaissance study of the region I did not find the unconformity mentioned by Dumble in the above quotations. However, I proved by fossil evidence that the supposed Cretaceous is really Permian, and if, as Dumble states, there is a profound angular unconformity below what he called "Cretaceous," the unconformity really represents the break below the Permian—an unconformity which is widespread throughout Arizona, New Mexico, and west Texas.

are evidently formed of Permian limestone. West of the Southern Pacific Railroad and south of Hermosillo there are several ranges of seemingly Permian limestone (though regarded by Flores as Upper Jurassic). The principal one is the Sierra de Doña Marta, along the south side of the Río Sonora. It is formed of crystalline limestone, standing nearly vertically and intruded by granite.

There are many other scattered areas of limestone and other sediments north and east of Hermosillo in the region of Ures, beyond the area I studied. Many of these probably are of Paleozoic, and mostly Permian age, though Liassic and Neocomian fossils have been found in several places.

"Juratrias" (Barranca group).—This is a thick group of clastics, largely of fresh- or brackish-water origin, containing beds of coal and graphite. Because of its excellent exposures in the vicinity of La Barranca, east of San Javier, Dumble named it the Barranca group. As indicated by Dumble (*op. cit.*, pp. 139-140), the group is divided by a thin-bedded sandstone and carbonaceous shale. It is the most widespread sedimentary unit of the region.

The type region of the Barranca group is the Sierra de San Javier, the high range lying along the west side of the Río Yaqui (Fig. 2). The sedimentary sequence there is obscured by the complex faulting, shattering, and intrusion which the beds have undergone. There are two places where the succession of beds is relatively unbroken through a great thickness of section—in the valleys draining east from La Barranca and in the high Aguja chain of peaks between San Javier and La Barranca. In those places the sequence is well over 1,000 meters in thickness, comprising grey, buff-weathering massive sandstone, generally quartzitic, which contains members of shale and thin-bedded sandstone, having seams of coal and graphite. The coal is soft and crumbly, but has been mined for use at the silver mines of San Javier.

The Sierra de Soyopa, the high range east of and parallel to the Sierra de San Javier, is almost wholly composed of the Barranca group, intruded by granitic rock. A number of small patches of badly shattered sandstone and quartzite, generally intruded by granite, occur in the Yaqui valley between the Sierras de Soyopa and San Javier, as well as south of the southern end of the Sierra de San Javier in the vicinity of Suaqui Grande. No fossils were found there, but lithologically the rock resembles the Barranca beds. The Sierra de

Tecoripa west of San Javier is a high range formed of thick, massive quartzite. The occurrence of graphite reported from there is evidence for placing it in the Barranca group.

The graphite area south of La Colorada was studied by Flores (op. cit., pp. 105-109). The lower members of the "Juratrias" succession there are black, grey, and yellow-brown shale, marl, sandstone, and quartzose and quartzitic conglomerate. The upper part is limestone or marly limestone, somewhat metamorphosed either by alteration to wollastonite or silicification of the limestone.

There are many ranges of quartzite and thin limestones north of Hermosillo near Santa Ana, from some of which Liassic fossils were collected by Flores.

I collected a number of cycad leaves in shaly beds of the formation in the Sierra de Soyopa east of Ónavas. These were determined by Professor Wieland to belong to a widely-distributed species, collected also by Wieland in the Rhaetic of Oaxaca. The coal-bearing member of the Barranca east of San Javier, in the type region of the group, contains abundant plant remains in certain layers. Twenty-four species of plants were identified by Newberry and listed by Dumble (op. cit., p. 139). Their age is said to be Rhaetic. West of San Marcial (Flores, op. cit., p. 107) there have been collected *Panope rémondi*, said to be of Rhaetic age, and species of *Pecten* referable to the lower or middle Lias. South of Santa Ana (Fig. 1) Flores found pectens, crinoids, bryozoans, and gastropods of Liassic age.

The Barranca group is the continental facies of Upper Triassic-Liassic sediments which probably were deposited over nearly the whole of Sonora, southern Arizona, and western Chihuahua. There is a gradual transition northwestward from the type area of the Barranca to a more marine facies. As noted above, limestones come into the section in the graphite mining area south of La Colorada, and marine or brackish water pelecypods are found there. North of Hermosillo, crinoids, bryozoans, and gastropods are also present. In the northwestern part of the State of Sonora, 45 kilometers west of Caborca (Fig. 1), the Permian limestone is overlain by 1,150 or more meters of sandstone and quartzite containing some layers of shale and limestone, from which was collected a prolific fauna of Karnic ammonoids, pelecypods, gastropods, *Spiriferina*, "*Orthoceras*," *Belemnites*, and ichthyosaurs. Above this lies 1,500 to 2,000 meters of

red micaceous sandstone, grey massive quartzite, and clayey sandstone and limestone. The limestone contains *Arietites*, *Belemnites*, *pectens*, *Mediola*, *Lima*, *Trigonia*, and *Pentacrinus*, of Lias age.⁶ This is evidently a transition to the typical marine facies of the "Juratrias."

In view of the great lithologic similarity and similar stratigraphic position upon the Permian limestone (though the middle Cretaceous limestone is absent in Sonora), it seems reasonable to correlate the Barranca group and its equivalents in Sonora with the Glance and Morita formations of the Bisbee district (Fig. 1), though these have always been placed in the Lower Cretaceous simply because there is no apparent break between them and the overlying Cretaceous Mural limestone. The aggregate thickness of the Glance and Morita formations is 7,500 feet, comprising red breccia and conglomerate grading upward into red and buff sandstone and red shales. No fossils have been found in them. Though no fossil evidence can be brought forth to support such a correlation, the abundance of Upper Triassic and Liassic fossils in a similar thick group of strata not far to the south and southwest in Sonora strongly indicates that these beds are referable to that age.

Cretaceous? andesitic lava and agglomerate (Lista Blanca formation of Dumble?).—The Barranca sedimentary succession is overlain by dense dark-grey lava flows of andesitic composition separated from one another by indurated agglomerate. The lava commonly shows spheroidal structure, which may be due in part to pillow structure in submarine flows, though it is probably generally only the result of onion-skin exfoliation. In two places limestone layers were found interbedded in the lavas, but no fossils could be found there. The andesite is intruded by the granite batholiths of the region. Its thickness exceeds 1,000 meters, and in places may be much more. The andesite and agglomerate form high mountains contrasting strongly with the soft Tertiary agglomerate and porous andesites overlying it, which at most form low hills. In their typical expression it is easy to distinguish the two, but where only small areas of andesite occur it is difficult to know for sure to which group they belong, and the classification given on the accompanying map is in many places arbitrary. It is believed, though not proved, that the older group is intruded by the granite, while the younger was formed after the solidification of the batholiths.

⁶ Information from unpublished letter by C. L. Baker to J. P. Smith, dated 16 August, 1925.

Dumble (op. cit., pp. 143-144), on the basis mainly of the section exhibited by the Lista Blanca range west of San Marcial (Fig. 2), concluded that the Barranca graded upward into the igneous group, which he termed the Lista Blanca formation and likewise assigned to the Jurassic. I did not study the San Marcial section, and at no place did I observe a transition between the formations, but because of the presence of limestone in the andesite and agglomerate group, I believe that it probably was formed during the Mesozoic marine cycle.⁸

There is Cretaceous limestone east of the area studied near Arivechi in the Sierra Madre. This is a southward extension of the Mural limestone of southeastern Arizona, for it contains fossils of the same type. Such limestone is not to be found west of the Río Yaqui.⁹ Evidence has been brought forth in two other places in the Western Sierra Madre of this part of Mexico which tends to support my conclusion that this volcanic sequence is of Cretaceous age. Hovey¹⁰ found at Guaynopita (Fig. 1) that the Cretaceous (?) limestone was overlain by an older group of andesite and breccia which had been folded conformably with it; these older folded formations were in turn overlain by nearly flat-lying younger dacite, rhyolite, and basalt. In the Cabullona basin of northeastern Sonora, Taliaferro¹¹ reports up to 800 feet of tuff and agglomerate which overlies more than 7,000 feet of Upper Cretaceous limestone, sandstone, and shale, and apparently forms a part of that practically conformable sequence.

Tertiary and Quaternary.—In most of the low-lying valleys in the eastern part of the region, between the sierras, there are belts of soft agglomerate, generally tilted at angles of 10-15°, which probably was laid down after the mountains had attained more or less their present form. It is doubtful if the mountain masses themselves were covered by agglomerate. However, in

⁸ Flores (op. cit., pp. 114-115) states without explanation that the hornblende andesites in the region of La Colorada are all intrusive. While part of this rock is probably intrusive, the greater part appears to be definitely extrusive.

⁹ Dumble records two localities of Cretaceous fossils in the central Sonora region—Cerro Cobachi and east of Zubiata. I visited both places, and could find no Cretaceous fossils, but in the beds which Dumble apparently considered to be of that age there were Permian fusulinids. North of Hermosillo near Santa Ana (Fig. 1) there is Cretaceous limestone, but this is of Neocomian age and therefore much older than the Mural.

¹⁰ Op. cit., pp. 421-423.

¹¹ Taliaferro, N. L.: An Occurrence of Upper Cretaceous Sediments in Northern Sonora, Mexico. *Jour. of Geol.*, 41 (1933), pp. 16, 31-32.

the west, in the Sierras de la Colorada and Cobachi, the agglomerate occurs within the range on the down-slope of tilted fault cuestas, and must there have been sheeted over the entire area. This agglomerate-lava group appears to be that which Dumble (op. cit., pp. 126-128) named the Báucari division after its exposures in the valley of the Cedros. However, he referred most of the agglomerate of the Yaqui valley near Tónichi to his "Nogales division," which he states lies unconformably beneath the Báucari there. I did not see the evidence for such subdivision.

The fault block cuestas in the region of La Colorada-Torres-Zubiate are formed of volcanics of this age (Fig. 2). The thickness seems to be variable. Around the mines of La Colorada the Paleozoic? metamorphic rocks are overlain by a flow of hornblende andesite, 30 meters of agglomerate, and 50 meters or more of rhyolite, the youngest flow of the region. This sequence seems to occur in the same order throughout the surrounding region, but appears to be much thicker in some of the ranges, such as the Sierra del Chivato south of La Colorada.

A still later phase of vulcanism is represented in a small basalt hill between Torres and Luján on the east side of the Southern Pacific line. In many parts of Sinaloa, Sonora, and southern Arizona similar basalts were poured out over the eroded scarps of the andesite ranges after the block-faulting of the region. They were emitted at such a late date geologically that their original surfaces are in many places preserved in their entirety (as between Ortiz and Guaymas, southwest of the region studied).

The several pediment levels are capped by coarse gravels, but these rarely exceed 10 meters in thickness. In valleys of graben origin, such as that north of Tecoripa, the alluvial fill may attain great thicknesses. Similarly, fault-block mountains like the Sierra de Cobachi are bordered by great alluvial fans. Proboscidean(?) bones were reported to me by the inhabitants from south of San José de Pimas (Fig. 2) and from Tepaguaje between Ónavas and Toledo. I did not have an opportunity to visit these places.

Dumble (op. cit., p. 125) observed Quaternary raised beaches in the Valle de Guaymas, extending within 15 kilometers of Ortiz, southwest of the area studied.

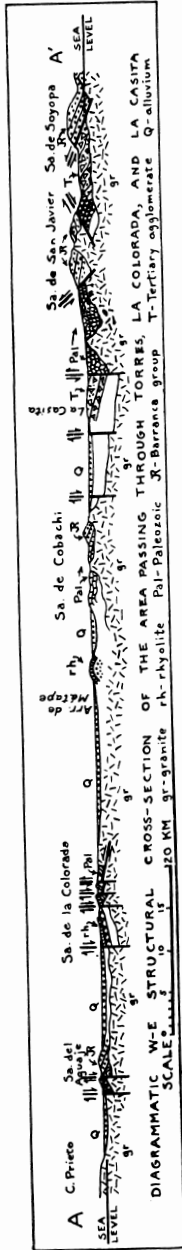


Fig. 3. Geologic sketch map of part of the Alamos district. For legend, see Fig. 2.

INTRUSIVE ROCKS.

The ranges of sedimentary and effusive igneous rocks are separated from one another by, and have their roots downward in, a vast batholith or group of coalescing batholiths of granite, of late Mesozoic or Tertiary age. This granite underlies most of the broad pediments of the region, such as that between La Colorada and Mazatán, and it also makes its appearance in the midst of the ranges of other rock (Fig. 2). Size of crystals and mineral composition are highly variable. Generally it is a coarse-grained rock consisting predominantly of quartz and feldspar, with a small amount of biotite. In the southwest part of the town of Mazatán the granite contains much muscovite. Along contacts there is a great deal of metamorphism.

Most of the other types of intrusive rock are probably to be regarded as differentiation products of the granite. A variety of igneous types is to be found in the vicinity of the mining districts, and it is probably in areas of much differentiation that the magma gave rise to mineralizing solutions.

As the granite is intruded into all formations older than the Tertiary agglomerate, it is believed that it is of early Tertiary or late Cretaceous age, the time of the Laramide orogeny.

STRUCTURE.

The ranges of sedimentary and extrusive igneous rocks are only detached roof-pendants in a vast granite batholith or group of coalescing batholiths (Fig. 3), probably representing the lowest parts of the roof of the batholith at the end of the period of intrusion, the higher parts having been removed by erosion. Nearly all the ranges of non-granitic rock are cut by apophyses of granite. The granitic intrusions have done much to complicate the pre-granite structure of the sediments and extrusives, giving rise to metamorphism and shattering along the contacts as well as a great deal of jointing and minor faulting at a distance from the contacts. It is probably for this reason that only the most massive, resistant formations, such as the Barranca formation, separated by 500 meters or more from the nearest granite contact, show the structure clearly. Successions of alternating competent and weak strata, such as the Paleozoic and parts of the Barranca (Jura-Triassic), show such a confusion of dips and are cut by so many small faults

that the working out of the structure and stratigraphy is extremely difficult.

In the eastern part of the area studied are the two longest unbroken ranges—the Sierras de San Javier and Soyopa. Both are made up mainly of Barranca quartzite, which is intruded by granite and its differentiation products. The Sierra de San Javier ends south of San Javier, and is succeeded in that direction by irregular andesitic mountains. The Sierra de Soyopa either ends or swings to the east between Ónavas and La Dura, being likewise succeeded to the south by andesitic mountains. These ranges extend north between the Ríos Sonora and Moctezuma apparently without interruption into the Bisbee district of southeastern Arizona, and may be regarded as western flanking ranges of the Western Sierra Madre, in contrast to the detached ranges to the west. Their termination toward the south suggests an echelon relation to the main Sierra Madre.

Along the borders of these ranges the Barranca group and the Cretaceous (?) andesite and agglomerate lie in contact with the Tertiary andesite and agglomerate, and for a distance of 25 kilometers with the Paleozoic rocks of the Casita area. These contacts are not overlaps, for the Tertiary agglomerate in many places is dipping at low angles toward the greatly deformed Barranca beds. It is believed that the ranges are bordered by faults (Figs. 2 and 3). Patches of the Cretaceous (?) andesite and agglomerate group occur anomalously within the Sierra de San Javier, entirely surrounded by Barranca quartzite yet seemingly unrelated to it structurally, and tongues and outliers of Barranca quartzite occur beyond the borders of the range, where they show no relation to the structure of the surrounding rock. These seem to be explicable only as windows in, and outlying klippen of, an overthrust nappe.

If the structures of the Sierras de San Javier are explained by overthrusting, one is faced with several difficulties. Instead of an asymmetrical structure, with the overthrusting on one side and the roots on the other, the evidence of thrusting seems to be equal on both sides, and there are what seem to be windows in the very middle of the range. On the other hand, if it is postulated that the entire sierra is an outlier of a nappe with its roots to the east, this would necessitate a horizontal displacement of as much as 22 kilometers from the west side of the Sierra de Soyopa. To the west there is no range that could be regarded as the roots of such a nappe.

Overthrusts are known in the northern continuation of the same ranges on the north side of the Cabullona Basin near the Arizona border (Taliaferro, op. cit., pp. 35-36, Fig. 7). There the Naco, Glance, Morita, and Mural are overthrust to the southwest upon the Upper Cretaceous. Thrusting in the same direction is known in the Whetstone Mountains north of the international boundary. However, in the Bisbee district of Arizona, only 25 miles from the Cabullona Basin thrusts, there is strong thrusting from southwest to northeast. Determination of the direction and amount of movement on the thrusts in the Sierras de Soyopa and San Javier must await further field studies.

The areas west and south of the Sierras de San Javier and Soyopa are characterized by block-faulting, which took place probably after the intrusion of the granite. They are subdivided at about parallel $28^{\circ}30'$ into two regions of unlike geologic constitution. North of that line the ranges are predominantly sedimentary, comprising Paleozoic and Mesozoic strata. South of that latitude, beyond the area mapped as far as the coast, there are only a few patches of highly altered quartzite in a region dominantly igneous. The following are the main structural features of the northern area:

Tecoripa graben.—The straightest and longest valley in the region is that which extends from La Casita to Tecoripa, Suaqui Grande, and Cumuripa, where it reaches the Río Yaqui. North of Tecoripa it is mostly filled with alluvium, but near and south of that town it contains low-dipping Tertiary agglomerate in a belt averaging 4 kilometers in width, on each side of which are granite pediments and quartzite and andesite hills. On each side of the valley near Tecoripa there are hot springs along the granite-agglomerate contact. It is fairly certain that the valley has a graben structure. The bordering faults may extend north along the east side of the Sierra de Mazatán.

The Sierras de Cobachi and Tecoripa are divided from one another by a strip of granite pediment. On the east side of both ranges, facing the Tecoripa graben, there are fault scarps: on the west they seem to be tilted toward the Mátape valley.

Sierra de la Colorada.—From the La Colorada mining district north to Aguajito and beyond, there is a range of complex structure and great diversity of surface formations. The most striking structural feature of this range is revealed only beneath the surface in the mines of La Colorada and Minas

Prietas.¹² At depths of 800 to 1,000 feet in all the mine workings, granite is encountered below the quartzite, diorite, quartz porphyry, and metamorphic rock which contain the mineralized veins. It is separated from the overlying rocks by a plane of shearing, dipping about 15° to the southeast, along which there is much brecciation (Fig. 4). Where this granite comes to the surface north and northeast of Minas Prietas the fault plane can hardly be recognized as such at the surface exposures. Granite of the same composition also occurs above the fault plane southeast of Minas Prietas. The direction of movement along the fault plane is not known, though, lacking evidence to the contrary, it is presumed to be most likely from the direction in which the plane dips, that is, from the southeast toward the northwest.

The whole Sierra de La Colorada is cut by a number of block faults, formed after the extrusion of the rhyolite flow which is the youngest rock of the range. Block faults displace the plane of the overthrust in the mines at La Colorada. Most of the fault blocks are tilted toward the west, their scarps facing eastward. The range was up-arched in the last orogenic movement affecting the region, and the arch broken by normal faults. The ranges south of La Colorada are likewise westward-dipping fault cuestas.

Structural history of the region.—Dumble reported a structural break between the Lower Paleozoic and the Permian, but I was unable to locate this. In late Triassic and Early Jurassic time the State of Sonora was the site of a continually-sinking geosyncline in which several thousand meters of clastic sediments were deposited. It grades from a purely continental facies in the Yaqui valley to one with marine members in central and northwestern Sonora. Upon the sediments were poured a great thickness of andesitic lava, much of which probably solidified under the water. In Late Cretaceous time the whole region was folded and along the Río Yaqui nappes were developed. Probably at about the same time a great granite batholith or series of batholiths intruded the sediments and lavas. The portion of the area west of the Sierra de San Javier probably had low relief in Tertiary time, for it was sheeted over by agglomerate, finally capped by a flow of rhyolite. Then it was broken by normal faults, trending generally N. 15-20° W., forming fault blocks mostly tilted to the west.

¹² Information from Mr. W. C. Taylor, Jr., of La Colorada.

Probably from the fissures formed during this normal faulting basalt was poured out locally, as the last volcanic event in the region. At the same period the intermontane valleys between the high ranges in the Yaqui valley were filled with agglomerate alternating with some andesitic flows.

ECONOMIC GEOLOGY.

In the region studied there are hundreds of mineralized veins. The main commercial developments have been in the heart of areas with a great variety of igneous rocks—La Dura, San Javier, and La Colorada. Silver and copper values predominate in the ores, though La Colorada is an exception, gold values having been greatest during the period of operation. In 1932 no mine of any importance was being worked.

There are a number of places where placer gold occurs in arroyos and in the gravel terraces bordering the arroyos and the Río Yaqui. They are worked by crude methods by the natives of the region, but yield scarcely a living wage to them.

Coal was mined from the coal fields east of San Javier for operation of the silver mines. The ranges south of La Colorada contain seams of high-grade amorphous graphite which have played an important part in the world's production of that mineral.

Limestone of the Permian (?) is quarried east of Hermosillo for use in the manufacture of cement.

NOTES ON THE OCCURRENCE OF PALEOZOIC STRATA IN THE DISTRICT OF ALAMOS.

Paleozoic strata were first reported in the district of Alamos (Fig. 1) by Dumble (op. cit.), and were again studied by Angermann,¹³ who fell into the natural error of believing that the Casita of Dumble was the ranch of that name on the bank of the Cedros, which lay on Dumble's route and is a place of much more importance than the Casita near which Dumble collected his "Silurian" fossils, and which lies between San Javier and Mazatán.

Paleozoic (?) rocks.—There are two principal areas of probable Paleozoic rocks in this region, one around El Trigo and

¹³ Parer. Inst. Geol. de México, 1, No. 3, pp. 81-90, 1904.

the Trigo mine, and the other in the headwaters of the Arroyo Arenoso between Conocarit and Macoyahui (Fig. 4). At the first locality there are outcrops of quartzite interbedded with a lesser amount of altered limestone, so intensely shattered that bedding planes cannot be made out. I found no fossils here, but Angermann reported a poorly preserved brachiopod that seemed to be a *Spirifer*. At the head of the Arroyo Arenoso there is a range of hills trending northeast-southwest, made up

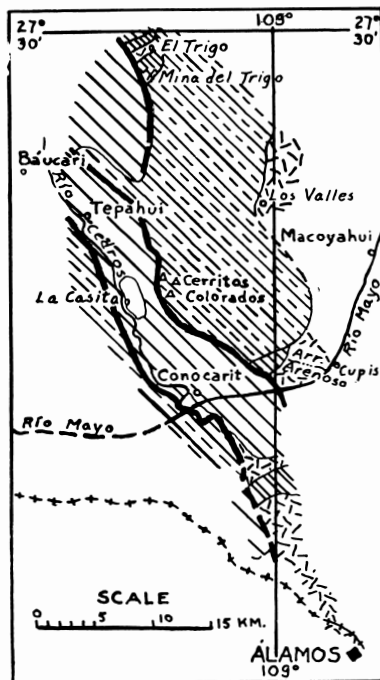


Fig. 4. Structural cross section along line A-A' of Fig. 2.

of quartzitic sandstone and hard, granular limestone. In the float below this range there are abundant boulders of crinoidal limestone. About 4 kilometers northeast of the ranch La Casita, and midway between the Trigo and Arroyo Arenoso areas are the Cerritos Colorados, small outliers of altered limestone that may be assignable to the Paleozoic. They overlie a porphyritic intrusion. Angermann reports another locality from south of La Casita on the west side of the Cedros valley, where there are vertical limestone, quartzite, and quartzitic con-

glomerate. The few imperfect fossils in these altered strata do not permit exact age determination, but it is reasonably certain that they are Paleozoic.

Barranca (?) formation.—Northwest of Alamos there is an east-west range of red quartzite at the Piedras Verdes mine, intruded by granite. Lithologically it resembles the Barranca formation in a general way, and Angermann and Aguilera so assigned it, but Dumble regarded it as Archean.

Igneous complex.—A high massif between the Ríos Mayo and Cedros is composed of andesitic lava and agglomerate resembling the supposed Cretaceous volcanics of central Sonora.

*Tertiary agglomerate*¹⁴ fills the valley of the Cedros, probably in a graben structure similar to that of the valley of Tecoripa in central Sonora.

Structurally this area is very similar to the western part of the region studied in central Sonora. The Cedros valley is a graben, bordered on both sides by older rocks. The western side of the valley is a range of andesitic rock. To the east is the high volcanic massif, around the borders of which are the three areas of probable Paleozoic strata, accompanied by more extensive areas of intrusive granite.

¹⁴ Identified by Dumble as Triassic Lista Blanca but by Angermann as late Tertiary.

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