Studies of Some Early Tertiary Red Conglomerates of Central Mexico

By JOHN D. EDWARDS

A SHORTER CONTRIBUTION TO GENERAL GEOLOGY

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STUDIES OF SOME EARLY TERTIARY RED CONGLOMERATES OF CENTRAL MEXICO

By John D. Edwards

ABSTRACT

The Guanajuato conglomerate, typical of many other deposits of early Tertiary age scattered over the central and southern parts of Mexico, was studied in detail to learn something of its history and exact stratigraphic position. The study was under the auspices of the United States Geological Survey and the Instituto Nacional para la Investigación de Recursos Minerales, as part of the Technical Cooperation Program of the United States Department of State and the Mexican Government.

The Guanajuato conglomerate is bounded on the north and northeast by normal faults, on the west by alluvium, and on the south and east by capping volcanic rocks. Guanajuato lies in the largest outcrop area, and within 10 kilometers to the east and northeast are four smaller outcrop areas.

The conglomerate rests on lava of early Tertiary age, which in turn lies unconformably on deformed, intruded, and eroded Mesozoic rocks. Rhyolitic and andesitic tuffs, 600 meters thick, cap the conglomerate conformably at Guanajuato City. Post-volcanic faulting, accompanied or followed by gold-silver mineralization, produced tilted blocks and grabens.

Volcanic fragments form more than half the conglomerate; other major constituents are granite, diorite, limestone, and chert. Pebble samples from 10 horizons show that volcanic, limestone, and chert fragments decrease upward in the conglomerate, whereas granite fragments increase to a maximum of 35 percent.

The lower part of the conglomerate consists of red and brown sandstones, with some green and white beds, intercalated by andesitic and basaltic lavas and pebble beds; this is overlain disconformably by boulder beds that grade upward into pebble conglomerates. The entire sequence is about 1,500 meters thick at Guanajuato City and thins gradually to the northeast and southwest.

The source of the conglomerate was a highland northeast of Guanajuato City, composed of shales and of limestone of Cretaceous age intruded by granitic and dioritic rocks and capped by a thick series of silicic volcanic rocks.

Vertebrate remains found in the conglomerate during and after the field work indicate a late Eocene or early Oligocene age for the lower part of the formation.

Two other red conglomerates, at Taxco and Zacatecas, are comparable to the Guanajuato conglomerate and are believed to be of Oligocene age for the most part.

INTRODUCTION

PURPOSE AND SCOPE OF THE STUDIES

During the summer of 1948, while assistant to Dr. C. H. Behre, Professor of Economic Geology at Columbia University, the author had the opportunity to make a superficial reconnaissance of several areas in the central plateau of Mexico in which "red conglomerates" occur, and he became interested in the "red conglomerate" problem. This particular type of conglomerate is in many small, widely separated areas within the semi-arid Mesa Central (Ordóñez, 1936, p. 1289) of Mexico. Some areas known to contain such red conglomerates (by a review of the literature on this region and by reliable reports) are indicated on the index map (fig. 17), on which the three areas discussed in this report are also noted. The conglomerates are distinguished by their color and stratigraphic position. They contain beds of conglomerate with a reddish matrix, some volcanic materials, red sandstones, and red siltstones or claystones; they rest on deformed marine rocks of Mesozoic age or on early Tertiary volcanic rocks, and they are covered by thick volcanic deposits and late Pliocene conglomerates. Probably many similar conglomerates are now concealed beneath volcanic rocks in the isolated mountain ranges of the central plateau and under the alluvium that surrounds these ranges.

The purpose of these studies has been to obtain detailed information on at least one of the red conglomerates—information such as distribution, composition, texture, primary structures, mode of origin, environment of deposition, type and location of source, thickness, structure, stratigraphic position, and age. It was felt that by concentrating efforts in one area, criteria could be established for comparing and correlating other red conglomerates in central Mexico.

FIELD AND LABORATORY WORK

During the summer of 1949, 2½ months were devoted to brief field studies of the red conglomerate at Guanajuato, Gto.; Taxco, Gro.; and Zacatecas, Zac. (fig. 17). The months of July and August 1950 were spent in detailed mapping of the Guanajuato con-

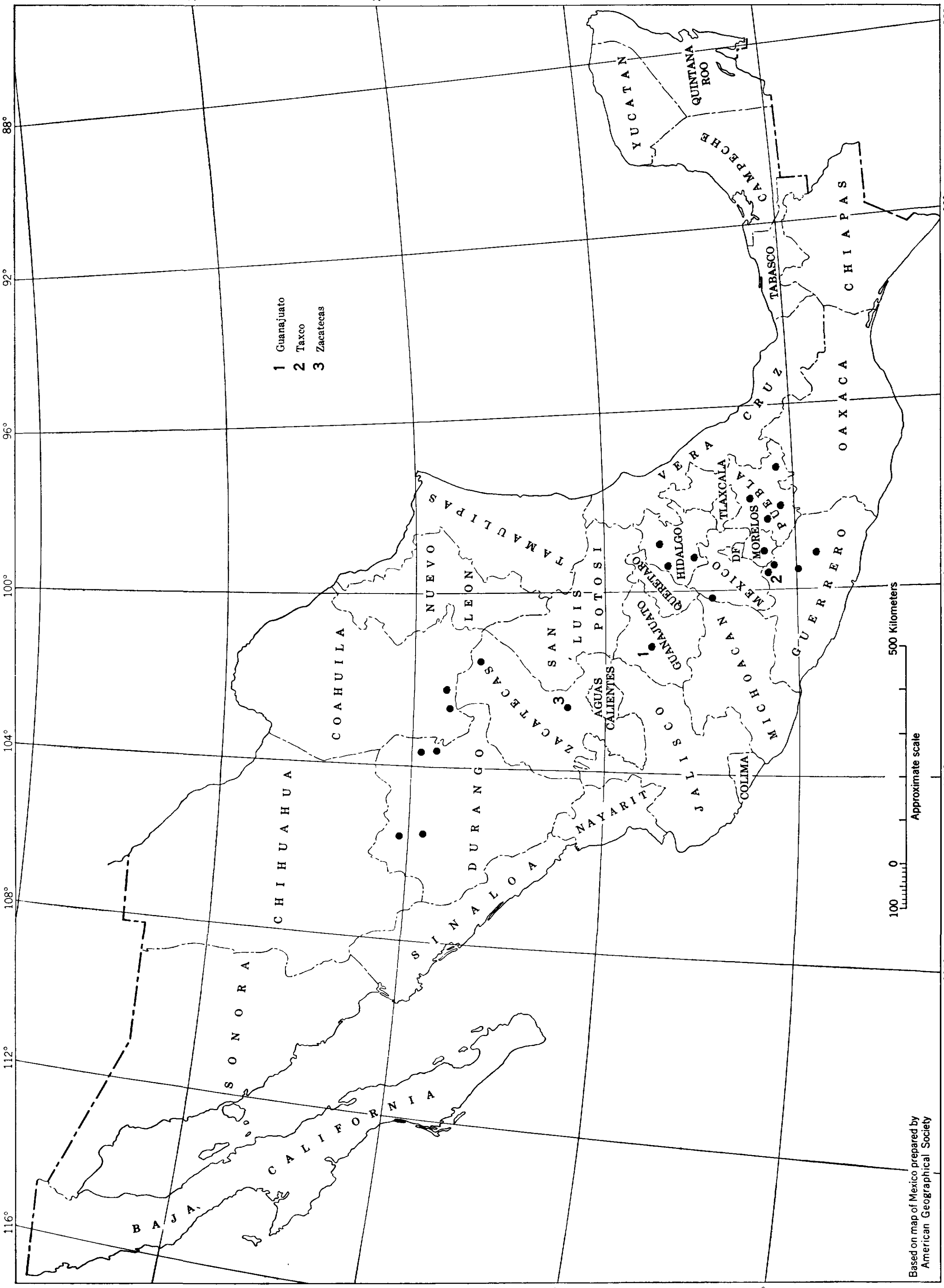

FIGURE 17.—Index map of Mexico showing locations in which red conglomerates are known to occur.

glomerate (Botsford, 1909, p. 691) using aerial photographs and an uncontrolled mosaic prepared by the Servicio Cartográfico of the Mexican Army. Gustavo Ortiz of the Instituto Nacional para la Investigación de Recursos Minerales assisted the writer and made it possible to complete the field work in the summer of 1950.

Parts of each of the geologic maps that appear in this report had already been prepared by preceding workers. On the Guanajuato map (pl. 45), most of the contacts northeast of a line between Santa Ana and Calderones were mapped by Reinaldo Guiza (1949, pl. 1). On the Taxco map (pl. 47), the contacts north of an east-west line through kilometer 152 on the Mexico-Acapulco highway were mapped by W. F. Foshag and Jenaro González Reyna.[1]

Ing. Teodoro Flores, Director of the Instituto de Geología of the Universidad Nacional Autónoma, placed the laboratory facilities of the Instituto at the disposal of the writer. Ing. Eduardo Schmitter prepared 30 thin sections of rocks collected near Guanajuato, and Ing. Alberto R. V. Arellano identified the Pleistocene vertebrate fossils found near Marfil, Guanajuato (1951, p. 614).

The first pre-Pleistocene vertebrate fossils found at Guanajuato were examined by G. E. Lewis, of the U. S. Geological Survey in Washington, D. C., and A. E. Wood, professor of Biology at Amherst College, Mass. Other material, found later, was studied by C. W. Hibbard, of the University of Michigan, and R. W. Wilson, of the University of Kansas.

The few invertebrates collected at Guanajuato were identified by J. S. Wells at Cornell University. Those collected at Taxco were reported on by R. W. Imlay, of the U. S. Geological Survey.

Fifty-five thin sections cut from rocks collected at Guanajuato and Taxco were studied by the writer during the winter of 1950–51 at Colorado College, in Colorado Springs, Colo., through the courtesy of Professor Donald Gould, chairman of the Geology department.

ACKNOWLEDGMENTS

The studies were carried on under the direct auspices and supervision of the U. S. Geological Survey, in cooperation with the Instituto Nacional para la Investigación de Recursos Minerales and the Instituto de Geología of the Universidad Nacional Autónoma, under a cooperative arrangement sponsored by the Technical Cooperation Administration of the U. S. Department of State and the Mexican Government. The enthusiastic support of Ing. Raúl de la Peña and Ing. Jenaro González Reyna, General Director and Chief Geologist, respectively, of the Instituto de Recursos Minerals, particularly in facilitating the services of Gustavo Ortiz in the field, is greatly appreciated. Most helpful were the continuous encouragement, suggestions, and counsel of Carl Fries, Jr., chief of the Mexico office of the U. S. Geological Survey.

Valuable constructive criticism and advice were received from Professor Marshall Kay of the Department of Geology of Columbia University. Professor Charles H. Behre, Jr., of the same institution, called the writer's attention to the subject of this report as a result of his extensive research in Mexico and his personal effort to further this research.

For many long calculations, and for the original typing of the manuscript, the writer is indebted to his wife.

THE GUANAJUATO DISTRICT

LOCATION

The city of Guanajuato, capital of the State of Guanajuato, is 475 kilometers by road northwest of Mexico, D. F., at an elevation of about 2,050 meters above sea level (see fig. 17). It is located on the southwest side of the Sierra de Guanajuato, which trends northwest-southeast, reaches an elevation of 2,500 to 3,000 meters, and forms one of the isolated mountain ranges of the Mesa Central physiographic province (Ordóñez, 1936, p. 1289). Southwest of Guanajuato lies the extensive plain known as the Bajío, on which are located the cities of Irapuato, Silao, and León. Drainage from the southwest side of the Seirra de Guanajuato passes southward through Irapuato to the Río Lerma. Drainage from the northeast side of this range is eastward and then southward by way of the Río de Las Lajas to the Río Lerma, which flows westward through a steep canyon to the Pacific Ocean. Farther north on the plateau, which varies in elevation from 1,200 to 3,000 meters, rivers flows into interior or intermontane basins, but in the southern part of the plateau the major rivers flow through steep canyons into either the Atlantic or Pacific Oceans.

Rainfall in this plateau region averages about 250 millimeters a year, most of it coming during the rainy season which is from June to October. Only the major streams are perennial, and most of the arroyos are dry even during parts of the rainy season.

MARINE ROCKS OF MESOZOIC AGE

The oldest rocks in the Guanajuato area consist principally of undifferentiated folded marine shales, which now appear in many places as phyllites or schists. Small quantities of limestone, sandstone, and volcanics are also in this series. These rocks are of unknown thickness and age, although they have been placed in

[1] Foshag, W. F., and González Reyna, Jenaro, 1946, Geology of the fluorspar deposits of the Taxco district, Guerrero, Mexico: U. S. Geol. Survey (unpublished report, p. 1-45).

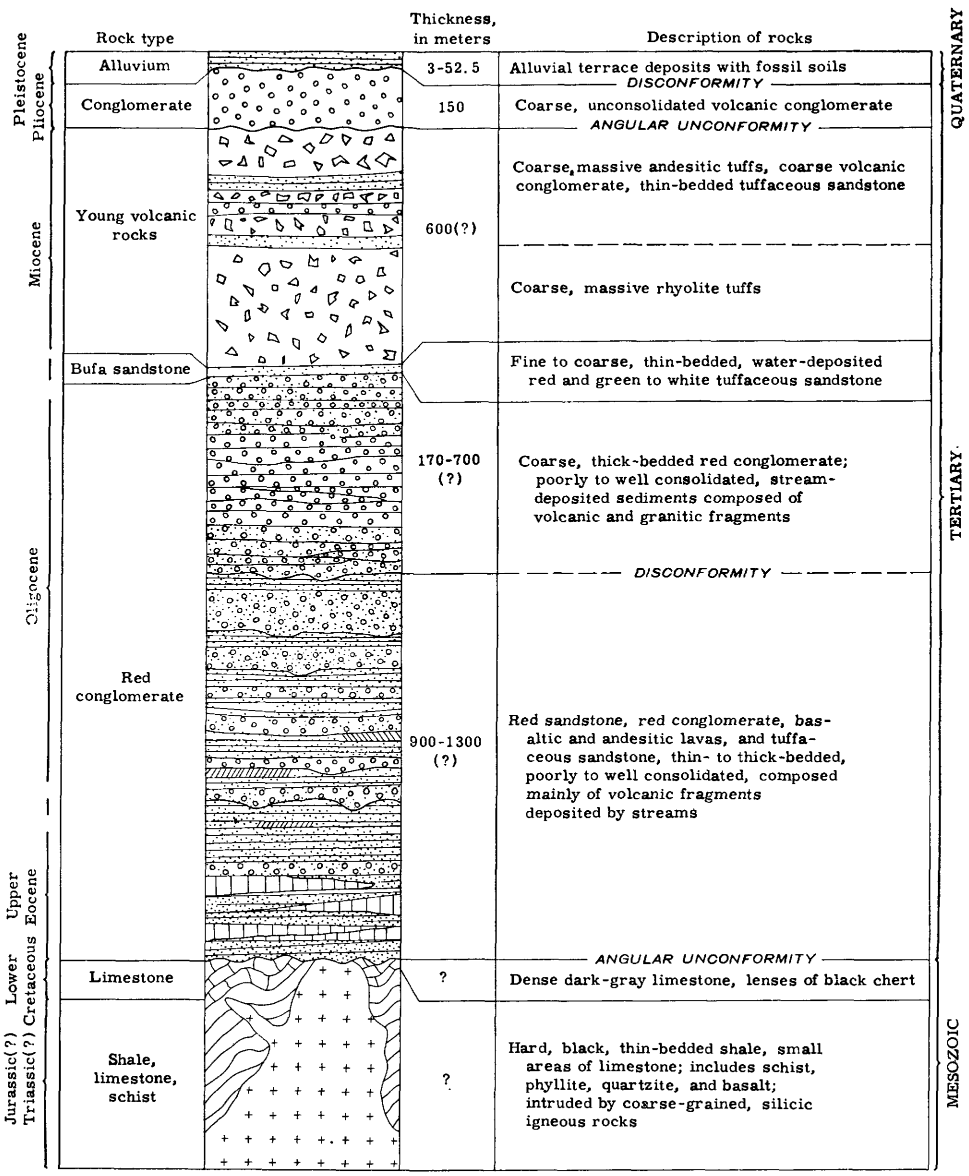

FIGURE 18.—Generalized stratigraphic column of the Guanajuato district. (The thickness of the Bufa sandstone ranges from 3 – 50 meters.)

part in the Triassic by Wandke (1928, p. 8) and Guiza (1949, p. 17) because of their lithologic similarity to Upper Triassic shales at Zacatecas, Zac., which were dated on faunal evidence by C. Burckhardt (1930, p. 2). Possibly, those at Guanajuato are representative of parts of the Triassic and also the Jurassic and Cretaceous (fig. 18).

The most highly metamorphosed rock of this old marine series, the La Luz schist (Guiza, 1949, p. 30), crops out around the small mining town of La Luz, 10 kilometers northwest of Guanajuato. This schist includes several rock types, such as serpentine schist, sericite schist, quartzose sandstone, pebble conglomerate, and basalt. The amygdaloidal La Luz basalt, in many places highly sheared, is about 300 meters thick and rests conformably on black shale in the Tula and Asunción shafts in the La Luz district (Wankde, 1928, p. 8).

The shale, which constitutes by far the major part of the old rocks, is well exposed along the road from Guanajuato to Dolores Hidalgo between Valenciana and Santa Rosa. It shows tight folding locally, has dips of less than 45° usually, and contains silicic lava flows (Wandke, 1928, p. 8; Guiza, 1949, p. 30). Volcanic rocks occur in both the Lower and Upper Cretaceous of Sonora (R. E. King, 1939, p. 1676), and in the Upper Cretaceous of northern Zacatecas (Imlay, 1944, p. 1154) and east-central Mexico (Fries, personal communication). The occurrence of volcanic rocks in these argillaceous sediments does not date them, however, because volcanic rocks occur also in the Triassic and Jurassic in this part of Mexico.

The oldest rocks in the Guanajuato district occur in the footwall of the Veta Madre. They are principally dull-black carbonaceous shales, but in a few places some thin interbedded limestones and shales lie conformably above this argillaceous sequence (Guiza, 1949, p. 17). These erosion remnants of interbedded limestones and shales may represent transition beds that once passed upward into solid limestone.

The only evidence that limestone once formed extensive deposits in this region is the presence of limestone pebbles and cobbles in the overlying Guanajuato conglomerate of Tertiary age. The constituents of this conglomerate were probably derived in large part from bedrock outcrops not farther than 10 kilometers from the city of Guanajuato.

Three types of limestone occur in the conglomerate. In order of decreasing abundance, they are: a dense, massive, black calcilutite; a dense, massive, light-gray calcilutite; and a coarsely crystalline, light-gray, fossiliferous limestone that contains fragments of tuff. The first two types contain lenses of black chert ranging from 1 to 10 centimeters in thickness. The fossiliferous limestone is rare; only one cobble was found with fairly well preserved fossils of silicified corals. Several other fossiliferous limestone cobbles were found that contained eroded sections of corals, pelecypods, cephalopods, and bryozoa, none of which were identifiable generically or specifically. These are the first invertebrate fossils ever found in this part of the State of Guanajuato.

The silicified corals were identified by J. W. Wells at Cornell University as *Stylina* (*Heliocoenia*) sp. (nov.?), *Myriophyllia* sp. (group of *M. trinitatis*), and *Dendraraea*. All these genera range from Upper Jurassic through Lower Cretaceous. Wells stated that they are probably Early Cretaceous because they resemble forms of that age in Venezuela, although he states that they might possibly be as old as Late Jurassic. The dense, dark-gray limestone containing the lenses of black chert is correlated lithologically with the Cuesta del Cura limestone of Albion age in northern Zazatecas (Imlay, 1938, p. 1664) and the Tamaulipas limestone of eastern Mexico. The upper Albion, consisting of thin-bedded gray limestone with nodules and long lenses of black chert, is extraordinarily widespread over northern and central Mexico (Böse and Cavins, 1927, p. 65). It has been found in many parts of the States of Zacatecas, Neuvo León, Tamaulipas, Coahuila, San Luis Potosí, Hidalgo, México, Morelos, and Querétaro.

The information given above points to an Early Cretaceous age for most of the limestone fragments now included in the Guanajuato conglomerate, although as indicated by the corals, some Upper Jurassic limestone may also be included.

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LARAMIDE OROGENY

Subsequent to the deposition of the marine shales and Cretaceous limestones in this area, the Mexican geosyncline was destroyed by an orogeny, during which the sediments were folded and at the same time intruded by predominantly silicic igneous material (Guiza, 1949, p. 41). The main body of igneous rock exposed today is a deeply weathered granite intrusive into shales and schists in the area north of Guanajuato. The marginal phases of the intrusive are basic and range from diorite to granite-veined diorite. At Santa Rosa, dikes and sills of monzonite, quartz monzonite, and granite cut shales and phyllites, and diorite and granite cut the basalt at La Luz (Wandke, 1928, p. 12). Diorite is well exposed just north of a fault that is located 1.5 kilometers from the Guanajuato-Silao highway on the road to La Luz. Granite-veined diorite occurs north of the same fault 1.5 kilometers N. 22° W. of the Guanajuato railroad station (table 4, group G, No. 4). In places, blocks of diorite project down into the granite and some are surrounded by granite. These contact effects are visible in a zone almost 1 kilometer wide. Diorite was intruded first and was followed by the intrusion of differentiated granite (Wandke, 1928, p. 12).

Although the writer agrees with Wandke and Martínez in their interpretation of the sequence of intrusion, he does not agree on the age of intrusion. Because of the apparent genetic relationship between the granite and the gold-silver ores of the Guanajuato district, which occur in faults cutting the Guanajuato conglomerate and overlying volcanic rocks, they considered the granite to be of post-volcanic or late Tertiary age. The writer believes these intrusive rocks to be of post-marine, pre-Guanajuato conglomerate age, or of latest Cretaceous and earliest Tertiary age, because nowhere in the region around Guanajuato has granite or diorite been seen cutting either the conglomerate or the younger volcanic rocks. Granite and diorite fragments are abundant in the Guanajuato conglomerate, but their source could not be determined by Wandke and Martínez.

Uplift, faulting, erosion, and volcanism followed the orogenic movements in this area. A large volume of volcanic deposits must have been heaped upon the eroded surface before the accumulation of the next younger formation, the red Guanajuato conglomerate, because this formation has a high volcanic content.

THE GUANAJUATO CONGLOMERATE

DISTRIBUTION

The principal areas of Guanajuato-conglomerate outcrop are shown on the geologic map (pl. 45). One of the small exposures not included on the map is located in the valley 2 kilometers northeast of Presa de Mata, in which Monte de San Nicolás is situated. Volcanic red conglomerate occurs in a valley 9 kilometers north of Santa Rosa on the road to Dolores Hidalgo, between 23.5 and 28 kilometers northeast of Guanajuato city. A similar red conglomerate has been reported along the front of the mountains northeast of León, 48 kilometers northwest of Guanajuato. The first two areas are small and are surrounded by younger volcanic rocks, except on the west side of San Nicolás valley which is bounded by a normal fault. The area northeast of León was not visited.

The largest exposure of Guanajuato conglomerate, on which the city of Guanajuato is located, is about 8 kilometers long in a northeast-southwest direction and 3 kilometers wide. It is bounded on the northeast by a major northwest-trending normal fault, the great gold-silver-producing Veta Madre of Guanajuato (Guiza, 1949, p. 36). Volcanic rocks cap the conglomerate conformably to the east and southeast of the area. The southwestern side is covered by alluvial sands and gravels, and the northwestern side is cut off by a long northeast-trending normal fault.

Although the conglomerate crops out over only a small area, it is probably present beneath the thick younger volcanic rocks for a considerable distance to the northeast, east, southeast, and south of Guanajuato, because wherever it is exposed it is at least several hundred meters thick. Nowhere is its base exposed. However, it did not extend as an uninterrupted sheet over the entire region, as evidenced by its absence at Puerto de Santa Rosa, 10 kilometers northeast of Guanajuato where coarse tuffs rest on schist. The conglomerate is missing also on the crest of Cerro del Cubilete, 10 kilometers west of Guanajuato, where 100 meters of basalt rests directly on schist.

The conglomerate probably thickens and thins within relatively short distances, relative to deposition on a surface of either moderate or rugged relief.

COMPOSITION

Upon examination of any outcrop of the conglomerate, one is immediately impressed by the high proportion of volcanic fragments, which practically everywhere represent more than half the fragments of pebble size or larger. This is the only major factor that makes the Guanajuato conglomerate different from some other red conglomerates of a comparable stratigraphic position in central and southern Mexico. Of the volcanic fragments, rhyolitic and latitic types are much more abundant than andesitic and basaltic types. The other major constituents are granite, diorite, limestone, and chert. Calcite and quartz occur in very minor proportions.

The conglomerate matrix and the sandstone beds consist principally of the disintegration products of various volcanic rocks. A study of three sandstone thin sections showed that particles 0.02 to 1.58 millimeters in diameter included the following materials: rhyolitic, dacitic, and andesitic fragments, and the minerals albite, oligoclase, sanidine, quartz, biotite, calcite, aragonite, chlorite, serpentine, magnetite, and hematite. The matrix of some of the sandstones is tuffaceous and reveals shards in thin section. Much of the sandstone and conglomerate is cemented by secondary calcite, which is common as veinlets, vugs, and pebble incrustations. Red clay also acts as a binder. The small proportion of red clay in the matrix of the sandstones and conglomerates, and small quantities of hematite as thin particle coatings, cause most of the formation to be distinctly reddish. Many of the volcanic pebbles are red also, owing to the presence of small quantities of hematite disseminated through them. The presence of iron does not in itself make sediments red; the iron must be in the form of hematite or possibly of turgite. The origin of the red-colored clay will be discussed later.

To obtain quantitative data on the composition variations of the coarse pebbles throughout the formation,

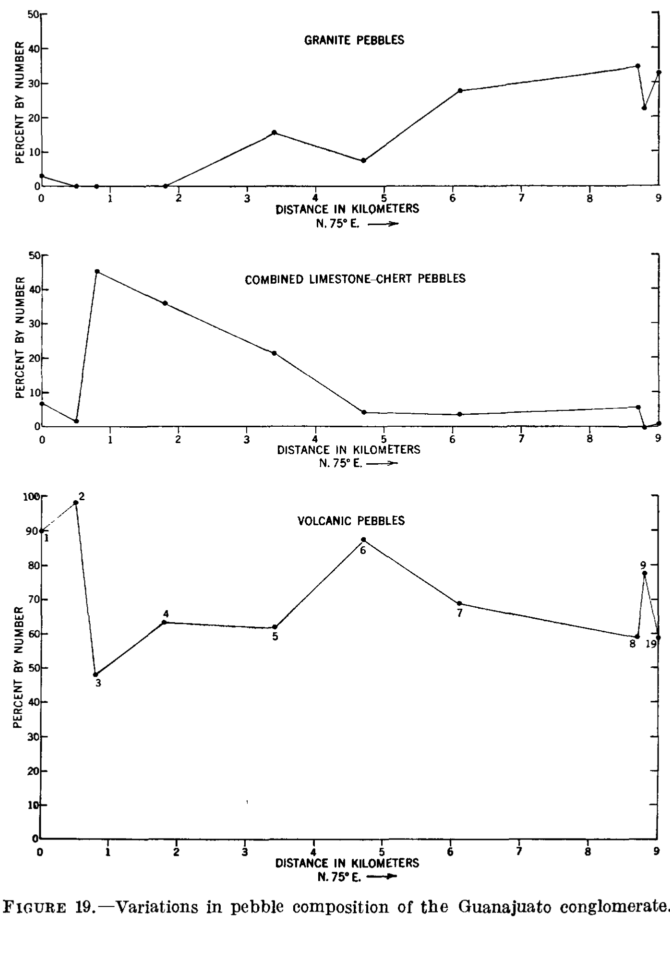


FIGURE 19.—Variations in pebble composition of the Guanajuato conglomerate.

12 spot samples of 300 pebbles each were collected. The localities where these samples were taken are indicated by numbers on the geologic map (pl. 45) and correspond to the numbered samples in table 1. The pebbles chosen for identification were between 2 and 10 centimenters in maximum diameter and were identified in the field by examination through a hand lens of a fresh surface obtained by breaking the pebble. Color, texture, hardness, and a dilute solution of hydrochloric acid were used in identifying limestone. The percentages shown in table 1 are based on the total number of pebbles in each sample. These figures are very close to those that would have resulted from determining the volume percentage of each constituent, as indicated by such a calculation for sample 6 (table 1).

The first nine samples in table 1 were chosen at random intervals in a direction normal to the general strike of the conglomerate and therefore they are from successively higher stratigraphic levels. The spacing is wide, and the samples are few; however, by comparing observations made at all outcrops studied with the results of these nine samples, the writer believes that the indicated variations in bulk composition are valid (fig. 19). Major faults were avoided in choosing successive sample localities, but because of innumerable small faults, the lack of marker beds, and the nonuniformity of the dip, the stratigraphic distance between samples was not used as the abscissa. Instead, the distances between the samples, projected onto a line trending N. 75° E., were used as the abscissa values.

TABLE 1.—*Composition of pebble samples taken from the Guanajuato conglomerate in 1949*
[Percentages shown are based on the total number of pebbles in each sample]

Constituent	Sample 1 [1]		Sample 2			Sample 3		Sample 4	
	Number	Percent	Number	Percent	Volume percent	Number	Percent	Number	Percent
Sediments	0	0. 0	0	0. 0	--------	18	6. 0	0	0. 0
Granite	9	3. 0	0	. 0	--------	0	. 0	0	. 0
Chert	8	2. 7	1	. 3	--------	46	15. 3	14	4. 6
Limestone	12	4. 0	5	1. 6	--------	84	28. 0	96	31. 3
Volcanic rocks	270	90. 0	305	98. 1	--------	144	48. 0	195	63. 5
Calcite	0	. 0	0	. 0	--------	1	. 3	2	. 6
Quartz	1	. 3	0	. 0	--------	0	. 0	0	. 0
Chalcedony	0	. 0	0	. 0	--------	7	2. 4	0	. 0
Total	300	100. 0	311	100. 0	--------	300	100. 0	307	100. 0
	Sample 5		Sample 6			Sample 7		Sample 8	
Granite	49	15. 6	22	7. 3	8. 2	74	24. 6	104	33. 6
Aplite	0	. 0	0	. 0	. 0	8	3. 0	3	1. 0
Chert	55	17. 5	4	1. 3	. 6	9	2. 7	10	3. 2
Limestone	13	4. 1	9	3. 0	1. 8	3	1. 0	8	2. 6
Volcanic rocks	194	61. 8	263	87. 7	86. 8	206	68. 7	183	59. 0
Calcite	3	1. 0	0	. 0	. 0	0	. 0	2	. 6
Quartz	0	. 0	2	. 7	2. 6	0	. 0	0	. 0
Chalcedony	0	. 0	0	. 0	. 0	0	. 0	0	. 0
Total	314	100. 0	300	100. 0	100. 0	300	100. 0	310	100. 0
	Sample 9		Sample 10			Sample 11		Sample 12	
Granite	67	22. 3	0	0. 0	--------	128	42. 7	39	12. 8
Aplite	0	. 0	0	. 0	--------	13	4. 3	12	3. 9
Chert	0	. 0	39	13. 0	--------	2	. 7	0	. 0
Limestone	0	. 0	23	7. 6	--------	0	. 0	0	. 0
Volcanic rocks	233	77. 7	238	79. 4	--------	155	51. 7	244	80. 0
Calcite	0	. 0	0	. 0	--------	1	. 3	0	. 0
Quartz	0	. 0	0	. 0	--------	1	. 3	7	2. 3
Chalcedony	0	. 0	0	. 0	--------	0	. 0	3	1. 0
Total	300	100. 0	300	100. 0	--------	300	100. 0	305	100. 0

[1] See sample localities in plate 45.

Pebble samples 10 and 11, taken from opposite sides of the fault that passes through the Guanajuato railroad yard, best illustrate the two extremes of composition in the conglomerate. Sample 10, which is characteristic of the lower part of the conglomerate, has 20.6 percent combined chert and limestone and no granite, whereas sample 11, which is characteristic of the upper part of the conglomerate, has 0.7 percent combined chert and limestone and 42.7 percent granite. The average composition of all samples taken in the upper part, lower part, and at the top contact are shown in table 2.

Note that the average compositions of the upper and lower parts of the conglomerate are distinctly different. Table 3 shows that the composition at the top contact remains essentially constant over a wide area; volcanic and silicic igneous pebbles are the principal constituents.

Certain pebble samples and some entire portions of the conglomerate have compositions quite different from the averages given in table 2. For example, sample 2 contains 98.1 percent volcanic rocks. The geologic map (pl. 45) shows, however, that it came from just above a lava flow within the conglomerate.

The Guanajuato conglomerate is divided into two distinct parts by the disconformity shown on the map in plate 45. This contact is very well exposed on the west slope of Cerro de La Sirena, where it is marked by a channel filled with boulder conglomerate, which cuts to a depth of 11 meters into thin-bedded red sandstone. South of Marfil the disconformity is marked by a sharp break in texture and composition, but in the central part of the map, immediately southwest of Guanajuato, the contact is gradational.

TABLE 2.—*Average composition of three parts of the Guanajuato conglomerate*

Constituent	Part of conglomerate					
	Lower (Samples 1, 2, 3, 4, 5, 6, and 10) [1]		Upper (Samples 7, 8, 9, 11, and 12) [1]		Top contact (Samples 13–22) [1]	
	Number of pebbles	Percent of total	Number of pebbles	Percent of total	Number of pebbles	Percent of total
Volcanic rocks	1, 609	75. 5	1, 021	67. 4	1, 426	56. 1
Granite	80	3. 8	412	27. 2	700	27. 5
Aplite	0	0. 0	36	2. 4	199	7. 8
Limestone	242	11. 3	11	. 7	21	. 8
Chert	167	7. 8	21	1. 4	15	. 6
Calcedony	7	. 3	3	. 2	46	1. 8
Quartz	3	. 1	8	. 5	18	. 7
Calcite	6	. 3	3	. 2	0	. 0
Miscellaneous	18	. 9	0	. 0	118	4. 7
Total	2, 132	100. 0	1, 515	100. 0	2, 543	100. 0

[1] See sample localities on plate 45.

The disconformity represents a hiatus of unknown, but probably considerable, time. The absence of channeling, or observable angular discordance, below the contact in the southwestern part of the area indicates that little or no erosion occurred; instead, this fact indicates that there was no deposition during the period that erosion was active to the northeast. The great influx of coarse granite conglomerate immediately above the disconformity is considered to be a result of rejuvenated normal faulting along the margin of the highland source that elevated the source and increased the stream gradients.

Volcanism must have occurred in the region near Guanajuato before, and during, deposition of the Guanajuato conglomerate, as evidenced by the high volcanic content throughout the conglomerate and the presence of interbedded lavas near its base.

The plane of the unconformity between the deformed marine rocks and these basal lavas or the conglomerate has not been found in the Guanajuato area; all of the known contacts are faults. The deepest part of the exposed section of the Guanajuato conglomerate contains calcic lavas and volcanic conglomerates (samples 1 and 2, table 1). For example, the first 222 meters of a 323-meter section measured in an arroyo flowing southwest from sample locality 3 (pl. 45) contained only volcanic pebbles and cobbles in the conglomerate beds of a predominantly red-sandstone sequence. Fifteen and one-half meters above the bed in which the first limestone pebble was found in place, sample 3 (table 1) was taken, which has 43.3 percent combined chert and limestone. No granite fragments occur in this 323-meter section, but granite is the next constituent to enter the conglomerate upward in the section.

TABLE 3.—*Pebble samples taken at the top contact of the Guanajuato conglomerate in 1950*

Sample no.[1]	Distance from top contact (in meters)	Distance N. 25° E. (in kilometers)	Radius (in cm) $\frac{A+B+C}{6}=R$	Roundness ratio[2] r_1/R	Flatness ratio[2] r_2/R	Flatness ratio $\frac{A+B}{2C}$	Silicic volcanic (in percent)	Intermediate to calcic volcanic (in percent)	Coarse silicic igneous (granite) (in percent)	Fine silicic igneous (aplite) (in percent)	Dark igneous (diorite) (in percent)	Limestone (in percent)	Chert (in percent)	Chalcedony (in percent)	Quartz (in percent)	Tuffaceous sandstone (in percent)	Miscellaneous (in percent)	Total each sample (in percent)	Number of pebbles $R, r_1 \div R, r_2 \div R, A+B \div 2C$	Number of pebbles used for comparison
13	3	0.0	2.26	0.077	0.287	1.75	48.8	17.6	16.4	8.0		2.0	2.8	2.4	0.4	1.6		100.0	100	250
14	4	1.2	2.42	.067	.261	1.95	35.1	17.2	36.3	3.1	1.6		.4	4.3	1.6		siderite 0.4.	100.0	100	256
15	2	2.6	2.13	.077	.280	1.96	31.6	14.0	49.2	1.2	1.6	.4	.4	.8	.8			100.0	100	250
16	4	3.8	1.83	.078	.254	1.88	46.2	19.3	18.9	6.4	3.0	2.3	.8	2.3		.4	conglomerate 0.4.	100.0	100	264
17	4	4.1	1.53	.095	.358	1.71	50.4	7.9	23.0	5.2	6.3	1.6		2.0	1.2	1.6	conglomerate 0.8.	100.0	100	252
18	3	4.2	1.74	.085	.294	2.14	31.7	21.6	24.7	12.7	5.8	.8	.4	1.5		.8		100.0	100	259
19	18	5.3	2.09	.079	.304	1.84	46.6	11.8	20.0	12.9	5.5		.8	.8	1.2	.4		100.0	100	255
20	16	6.8	2.51	.070	.251	2.41	29.8	9.4	32.2	14.5	10.2			2.0	1.9			100.0	100	255
21	6	6.9	2.98	.050	.204	1.85	32.5	34.1	22.2	4.8	4.4	1.2	.4			.4		100.0	100	252
22	5	12.1	3.44	.052	.242	1.72	39.2	15.6	32.8	9.2	1.2			2.0				100.0	100	250
Average			2.29	0.073	0.274	1.92	39.2	16.9	27.5	7.8	4.0	0.8	0.6	1.8	0.7	0.5	0.2	100.0	[3]1000	254

[1] See sample localities in plate 45.
[2] Wentworth, 1922, p. 93.
[3] Total number of pebbles.

Granite is a minor constituent in the lower part of the formation, but its percentage gradually increases until it averages 35 percent at the top contact. As the granite content increases, the chert, limestone, and volcanic content decreases correspondingly, although the latter retains its place as the principal constituent (fig. 19).

Cherty limestone must have been exposed to erosion near Guanajuato when the Guanajuato conglomerate accumulated. No outcrops of this rock are now known in this region. Conversely, the schist, shale, and shaly limestones that crop out north of Guanajuato are completely lacking as pebbles in the red conglomerate; therefore, they must have been buried during conglomerate deposition. Schist appears first as fragments in the volcanic tuffs above the conglomerate, but its occurrence there is rare. In the stream northeast of Peregrina, shale-bearing conglomerates are interbedded with volcanic breccias, tuffs, and lavas. Light-gray phyllite, black shale, and red shale are common in these conglomerates, as well as volcanic, chert, quartz, and granite fragments.

THIN-SECTION STUDIES

Information from a study of 44 thin sections of the rocks collected at Guanajuato is compiled in table 4. Group A contains eight typical coarse-grained intrusive igneous pebbles from the upper part of the conglomerate. Quartz-rich rocks predominate, although the principal feldspar may be orthoclase or sodic plagioclase. The diorite pebbles are rare except in the upper part of the conglomerate at the southwest extremity of its exposure.

TABLE 4.—*Thin-section data on rocks in, and associated with, the Guanajuato conglomerate*

[Pebble sample nos. refer to circled nos. in plate 45]

Group A. Igneous pebbles in the Guanajuato conglomerate

Specimen location	*Rock name*
1. Pebble sample 19	Soda granite
2. 1.9 km. S. 10° E. from pebble sample 5.	Granite
3. Pebble sample 11	Granite
4. Pebble sample 11	Soda granite
5. Pebble sample 11	Tonalite
6. 1.9 km. S. 10° E. from pebble sample 5.	Tonalite
7. 1.9 km. S. 10° E. from pebble sample 5.	Diorite
8. Pebble sample 12	Diorite

TABLE 4.—*Thin-section data on rocks in, and associated with, the Guanajuato conglomerate*—Continued

Group B. Volcanic pebbles in the Guanajuato conglomerate

1. 0.6 km. north from pebble sample 18	Rhyolite
2. Pebble sample 10	Rhyolite
3. Pebble sample 10	Rhyolite
4. Pebble sample 4	Rhyolite
5. Pebble sample 11	Rhyolite
6. 1.5 km. N. 85° W. from pebble sample 14.	Rhyolite
7. Pebble sample 3	Rhyolite
8. Pebble sample 3	Quartz latite
9. Pebble sample 11	Quartz latite
10. Pebble sample 11	Quartz latite
11. 1.65 km. N. 59° W. from pebble sample 21.	Quartz latite
12. Pebble sample 18	Quartz latite
13. Pebble sample 19	Andesite

Group C. Conglomerate and sandstone in the Guanajuato conglomerate

1. 1.3 km. due north from pebble sample 1.	Sand-pebble red congl.
2. 0.6 km. due north from pebble sample 18.	Sand-pebble red congl.
3. 1.3 km. S. 15° E. from pebble sample 5.	Coarse light-green tuffaceous sandstone
4. 1.3 km. S. 15° E. from pebble sample 5.	Coarse dark-gray sandstone
5. 1.5 km. N. 85° W. from pebble sample 14.	Pink rhyolitic tuffaceous sandstone
6. 1.35 km. N. 63° W. from pebble sample 21.	Coarse light-green tuffaceous sandstone

Group D. Lavas within the Guanajuato conglomerate

1. Roadcut midway between pebble sample 1 and 2.	Basalt
2. 0.4 km. N. 10° E. from pebble sample 1.	Basalt
3. 1.4 km. N. 19° W. from pebble sample 10.	Andesite
4. 1.05 km. due north from pebble sample 10.	Andesite
5. 0.95 km. N. 60° W. from pebble sample 1.	Andesite
6. 0.95 km. N. 60° W. from pebble sample 1.	Quartz latite
7. 0.65 km. S. 50° E. from pebble sample 4.	Rhyolite
8. 1.3 km. S. 27° E. from pebble sample 3.	Rhyolite

Group E. Intrusives into the Guanajuato conglomerate

1. 0.55 km. N. 68° W. from pebble sample 20.	Dacite dike rock
2. 46-meter-thick dike, (2-meter chilled border zone) .2 km. S. 20° E. from pebble sample 8.	Andesite dike rock

TABLE 4.—*Thin-section data on rocks in, and associated with, the Guanajuato conglomerate*—Continued

Group F. Lavas in the conglomerate Area North of Santa Rosa

1. Lava in stream bed below the conglomerate, 28 km. northeast of Guanajuato by road.	Andesite
2. Lava below the conglomerate and above the schist, 25.3 km. northeast of Guanajuato by road.	Andesite
3. Lava just above volcanic conglomerate, 28 km. northeast of Guanajuato by road.	Andesite

Group G. Igneous Rocks Older Than the Guanajuato conglomerate

1. Lava included in the La Luz schist, 3 km. north of Mexiamora on road to La Luz.	Basalt
2. 0.95 km. N. 75° W. from pebble sample 10.	Quartz latite
3. 1.5 km. N. 22° W. from pebble sample 10.	Diorite
4. 1.5 km. N. 22° W. from pebble sample 10.	Diorite intruded by Granite

Group B consists of representative volcanic pebbles from the conglomerate; seven rhyolites, five quartz latites, and one andesite are listed. Although this cannot be taken as the ratio among these types of pebbles, it does indicate that silicic volcanic rocks predominate over intermediate and calcic volcanic rocks. This conclusion is supported by many field observations.

In the conglomerate sections in Group C, the wide range of grain size, the heterogeneous composition, the calcite cement, and the small proportion of hematite were especially noted. The sandstones have been discussed under the section on composition.

Group D consists of eight thin sections of lavas interbedded with the conglomerate near Guanajuato, all of which occur in the lower part of the formation. The bulk of these flows are basaltic or andesitic and are located in the area bounded by the Silao-Guanajuato highway, the Rio de Santa Ana, and a long east-west fault (pl. 45).

Overlying these lavas immediately east of the bridge across the Rio de Santa Ana, a 112-meter section of fine- to coarse-grained tuffaceous sandstone was measured. These tuffs are pale red to white, very thinly bedded, underlain and overlain by pebble conglomerate, and dip 35° N. 34° E. This tuff sequence is not present 300 meters to the southeast on the south bank of the Rio de Guanajuato, and it extends only a few hundred meters to the northwest. It was probably deposited under water in a restricted topographic basin; however, no primary structures give evidence for a lacustrine origin.

Higher in the section to the northeast, but still in the lower part of the conglomerate, a 3.4-meter rhyolitic lava flow occurs within a 9.75-meter volcanic sequence composed predominanty of tuffaceous sandstone (table 4, group D, no. 7). This volcanic unit pinches out to the northwest. A 4.6-meter rhyolite in a red sandstone sequence was the only other silicic volcanic rock found in the conglomerate (table 4, group D, no. 8).

Group E shows the composition of two dikes that cut the conglomerate. Most of these dikes are located in El Cedro valley, and like those that cut the overlying volcanic rocks, they are andesitic. The 46-meter-thick dike at the northeast corner of Presa de La Olla and the dike just east of the Guanajuato baseball field are the only intrusives found in the conglomerate near Guanajuato (table 4, group E, nos. 1 and 2).

The major faults of the Guanajuato region are occupied by quartz-cemented breccia veins. Those that carry gold and silver tend to be northwest-southeast fractures parallel to the Veta Madre. The faults of small displacement carry only calcite.

As indicated by the three thin sections under Group F, the lavas immediately above and below the volcanic conglomerate in the valley north of Santa Rosa are andesitic.

Group G contains a basalt from within the La Luz schist, a quartz latite from the area of old rocks, which represents the volcanism prior to conglomerate deposition, and an igneous rock from the area of old rocks, which contains two phases of the same intrusive. Granite intrudes diorite. Both are of the type found to be intrusive into the La Luz schist and the shales north of Guanajuato. These are the same granite and diorite that appear as fragments in the Guanajuato conglomerate.

TEXTURE

The beds at sample localities 10 and 11 on opposite sides of the fault that passes through the Guanajuato railroad yard, best illustrate the two extremes of texture in the Guanajuato conglomerate. The beds at sample locality 10, which are characteristic of the lower part of the formation, are dark-red sandstones alternating with thin sand-pebble-cobble conglomerates. These beds vary from 0.1 to 1.0 meters in thickness, are well stratified, well-to-poorly sorted, and are commonly tuffaceous. The beds at sample locality 11 are characteristic of the upper part of the formation; they are sand-pebble-cobble-boulder conglomerates, containing boulders as large as 1.5 meters across. These coarse-grained beds are thick, irregular, lensing, and unsorted.

In the area traversed by the southwestern parts of sections A–A′ and B–B′ (pl. 45) the variations in texture within the lower part of the Guanajuato conglomerate are best exposed. The westernmost and most deeply exposed part of the formation consists of fine- to coarse-grained reddish-brown sandstone and coarse-grained green tuffaceous sandstone (fig. 20). Passing upward in the section, coarser-grained beds interfinger with these sandstones. At first, the sand-pebble-cobble beds are thin and of a minor importance, but higher in the section they are thicker and predominate over the sandstones, which become thinner and brick red. However, the coarse-grained green tuffaceous sandstones are still prominent, and in some places the conglomerate matrix is also green and tuffaceous. In the lower part of the conglomerate, the coarsest fragments are of pebble and cobble si e; the few boulders present are less than 50 centimeters in maximum diameter. The conglomerate beds, by field estimate, contain 25–50 percent sand, 25–50 percent pebbles, and 0–25 percent cobbles by volume. The proportion of conglomerate near the top contact of the lower part of the Guanajuato conglomerate increases from ¼, where section B–B′ cuts it, to more than ½, where section A–A′ cuts it (pl. 45). This northward coarsening of the lower part of the Guanajuato conglomerate occurs within 1.9 kilometers in a N. 5° W. direction and continues north of section A–A′ toward Marfil (pl. 45).

FIGURE 20.—Fine-grained reddish-brown sandstone in which vertebrate remains were found in the lower part of the Guanajuato conglomerate.

In the area south of Marfil, above a sharp, well-exposed disconformity, appears the upper part of the formation, which is a coarse-grained, massive, thick-bedded, poorly consolidated rock of high granite content (fig. 21). The conglomerate there, by field estimate, is composed of 25 percent sand, 50–75 percent pebbles, and 0–25 percent cobbles and boulders by volume. The largest boulders are volcanic and are less than 1 meter in maximum diameter.

The upper part of the Guanajuato conglomerate is free from sandstone beds over the whole region, but it becomes notably less coarse-grained toward the top. Table 3 shows the average radii of the coarsest 250 pebbles collected near the top contact at 10 places (shown in pl. 45 as sample localities 13–21). Boulders were found only at sample locality 22, which is off the map to the northeast.

FIGURE 21.—Typical sand-pebble-cobble beds in the upper part of the Guanajuato conglomerate.

Everywhere, the largest boulders are of one particular type of rhyolite, which probably came from a cliff-forming lava flow in the nearby source. In general, the boulders increase in si e to the east and northeast, but within the upper part of the conglomerate they increase to a maximum and then disappear before the top contact is reached. In the area south of Marfil the largest boulder observed was 88 by 44 centimeters in its exposed dimensions. Farther east, nearer Guanajuato, volcanic boulders of more than 1 meter in maximum diameter are common. The largest one found measured 235 by 200 by 90 centimeters. A volcanic boulder 200 by 160 centimeters was found on the west slope of Cerro de La Sirena, within the high-granite-content conglomerate that rests unconformably on thinly bedded red sandstone. This sandstone rests on thick sand-pebble-cobble conglomerates with interbedded green and red sandstones (fig. 22), similar to those occurring south of Marfil but not as thick or continuous. Although the largest granite boulders are also found to the east, near Guanajuato, they do not exceed 1 meter in maximum diameter.

PRIMARY STRUCTURES

Beds in the lower part of the formation are thin, persistent, and prominently displayed because of slight differences in color, texture, or weathering between adjacent beds (fig. 22). Beds in the upper part of the formation are thick, irregular, lensing, and poorly sorted, in which silt-to-boulder si es are mixed; they are visible as crudely sorted layers whose attitude can be determined readily (fig. 21).

Graded bedding and mud-cracked laminae are commonly seen in the red sandstones and green tuffaceous sandstones both south of Marfil and on the lower west slope of Cerro de La Sirena. Raindrop prints on thin silt beds were seen in a few outcrops. Crossbedding and channelling are rare in the conglomerate, especially in the coarse upper part. They are common in the particularly well exposed lower part of the formation on the western slope of the hills to the east of the road that leads south from Marfil. Crossbedding usually occurs in sand-pebble conglomerates and is present for only a few meters laterally. All the observed channels are formed by conglomerate cutting into sandstone beds

FIGURE 22.—Thick series of dark-red and light-green to white sandstones in the lower part of the Guanajuato conglomerate.

to depths of generally less than 1 meter. The largest channel found is 11 meters deep and 40 meters wide; it occurs at the disconformity between the upper and lower parts of the conglomerate.

No imbricate pebbles were found, probably because all the rocks contained in the conglomerate tend to break into equi-dimensional fragments, rather than into flat slabs.

ENVIRONMENT OF DEPOSITION

There is no doubt that the Guanajuato conglomerate was deposited under non-marine conditions, because only in such an environment could the following features occur together; mud cracks, raindrop prints, crossbedding, channels, poorly sorted boulder conglomerate, low pebble roundness, interbedded volcanic rocks, and vertebrate remains.

The orogenic movements of the Laramide revolution created many isolated interior basins of varying dimensions in the western United States and in Mexico. One of these was in the region around Guanajuato. The lower part of the Guanajuato conglomerate, in which red sandstones, lava flows, and volcanic conglonerates occur, probably was deposited in an interior basin in an area of continuing volcanism and of low to moderate relief. The increase in the average grade size upward in the formation indicates that the relief increased adjacent to the basin or that with the passage of time uplift affected land closer to the basin. The first hypothesis is more probable, considering the short distance of transportation involved, the increase in granite content upward in the formation, and the absence of conglomerate or sandstone fragments in the conglomerate.

The Guanajuato conglomerate was formed by a series of coalescing alluvial fans in a basin adjacent to a mountain range whose relief increased during the conglomerate accumulation as a result of repeated normal faulting along its margin. Seasonal torrential rains and adjacent high relief are probably responsible for the coarsest boulder conglomerates.

The climatic conditions under which the Guanajuato conglomerate was deposited were such that the red color was preserved. Red sediments deposited on a drained slope usually remain red in arid or semi-arid climates, but they also remain red if the climate is seasonally humid (Krynine, 1950, p. 150). The climatic significance of the scanty fauna or of the possible authigenic minerals contained in the conglomerate has not been studied.

RED COLOR

According to G. E. Dorsey (1926, p. 143), "Color of red beds is not due to a larger iron content than non-red rocks as they often contain less iron. Their color is not due to the presence of ferric rather than ferrous oxide since many non-red rocks contain more ferric oxide than do red rocks. The color is due to ferric oxide that has had time to dehydrate and turn to the red hydrate (turgite) and the red anhydride (hematite). This dehydration takes place most rapidly, not in deserts or in a semi-arid environment, but in warm, moist climates, conditions usually productive of a heavy vegetation. By coming to rest on continents where large scale reduction is not in progress, the sediments are able to retain this red color."

The total iron content in red beds need not be great, but it must be chiefly in the dehydrated ferric oxide state. For example, chemical analyses of five red slates from Washington County, New York, and from Western Vermont show an average of 5.26 percent Fe_2O_3, 1.21 percent FeO, a net Fe content of 4.62 percent, and a ferric to ferrous iron ratio of 3.91:1 (Dale, 1899, p. 259). Chemical analyses of eight green slates from the same area have an average of 1.35 percent Fe_2O_3, 5.21 percent FeO, a net Fe content of 4.99 percent, and a ferric to ferrous iron ratio of 0.23:1 (Dale, 1899, p. 232, 246, 252). These data show that a red-bed formation may contain less than 5 percent net iron; this is probably true for the Guanajuato conglomerate.

In a paper on the Pennsylvanian, Permian, and Triassic red beds of the United States, C. W. Tomlinson (1916, p. 252–253) states, "* * * the ferruginous matter of the Red Beds was transported and deposited almost, if not quite wholly, as a mechanical sediment both independently and as a coating upon grains of other material. The ferruginous matter which gives the Red Beds their color has been present in the series in very nearly its present distribution and arrangement since the time of sedimentation."

Because of the presence of interstitial red clay and red coatings on grains and pebbles in the Guanajuato conglomerate, the writer believes that the foregoing statements hold true for this formation. Inasmuch as this ferruginous material of the conglomerate was transported and deposited in essentially the same state in which it is now found, it follows that it must have been eroded from its source in this same state. This ferruginous material could not have come from the erosion of a red formation in the source area, because, if it had done so, coarse red-rock fragments as well as fine particles would be expected to occur in the conglomerate, and the red coloring matter would not be so uniformly distributed throughout the conglomerate section. Therefore, it seems reasonable that the red coloring matter of the conglomerate originated as red soils in the source area.

Red-colored sediments have long been thought to indicate an arid climate and high temperatures. This is not necessarily true for red beds that derive their color from red soils, because red soils themselves develop in warm, humid regions under oxidizing conditions with good subsurface drainage and subsequent leaching (Krynine, 1950, p. 145). These red soils may, along with other eroded materials, be transported and deposited within such a region. P. D. Krynine (1950, p. 143–154) presents a clear and well-documented discussion of the genetic significance of continental red beds.

A summary statement by C. W. Tomlinson (1916, p. 252) in his paper on the origin of the Red Beds has notable application to the specific case of the Guanajuato conglomerate. "The source of the Red Beds included uplands with in part rugged relief; they were therefore in all probability the sites of more abundant rain than fell upon the plains upon which the Red Beds were in large part deposited. The combination of well-watered highlands with less humid or semi-arid lowlands furnishes the conditions for the development of red soils, and at the same time provides for the transportation and deposition of the sediments derived from them, without extensive hydration or reduction of the ferric oxide constituent during the transfer."

The green color of the conglomerate that occurs in the mines along the Veta Madre may be explained as resulting from localized reducing conditions that were produced by hydrothermal alteration accompanying the mineralization.

SOURCE

Conglomerates, because of the composition of the pebbles they contain and the stratigraphic distribution of these pebbles, record more clearly than other sediments the history, composition, and location of their source. A brief review of the geologic history of this region prior to the deposition of the Guanajuato conglomerate will serve as a basis for a discussion of the source of the conglomerate. After the deposition of marine shales and limestones, these and other older rocks of this region were orogenically deformed and intruded by silicic igneous rocks. Uplift, erosion, and volcanism followed. The area that was later to become the source of the conglomerate was covered with rhyolitic and latitic lavas. This volcanic epoch continued into the time of conglomerate deposition, but at a diminishing rate, as evidenced by the several thick basaltic and andesitic lavas and tuffaceous sandstones in the lower part of the conglomerate and the absence of any known lava flow or tuffaceous sandstone in its upper part.

Figure 23 is an idealized and diagrammatic cross section of an area, which, if eroded by a stream with parallel retreating 30° slopes, would yield its various rocks in the sequence and percentages by volume shown on the three accompanying graphs. This is, of course, only one specific set of conditions, but the writer believes that the similarity between these curves and those in figure 19 is of correlative significance.

The graphs in figure 23 show that volcanic rocks are, at first, the sole constituents of any rock derived from a source such as that pictured. Limestone and chert are the next rocks that would enter the deposit. As their proportion increases, the proportion of volcanic rocks correspondingly decreases. Granite is the last rock to enter the deposit. As the proportion of granite increases at the expense of volcanic rocks the proportion of limestone and chert soon reaches a maximum and then begins to decrease. The three graphs in figure 19 show that the sequence in which the rock types enter the Guanajuato conglomerate and the relative changes in their proportions are strikingly similar to the idealized example in figure 23.

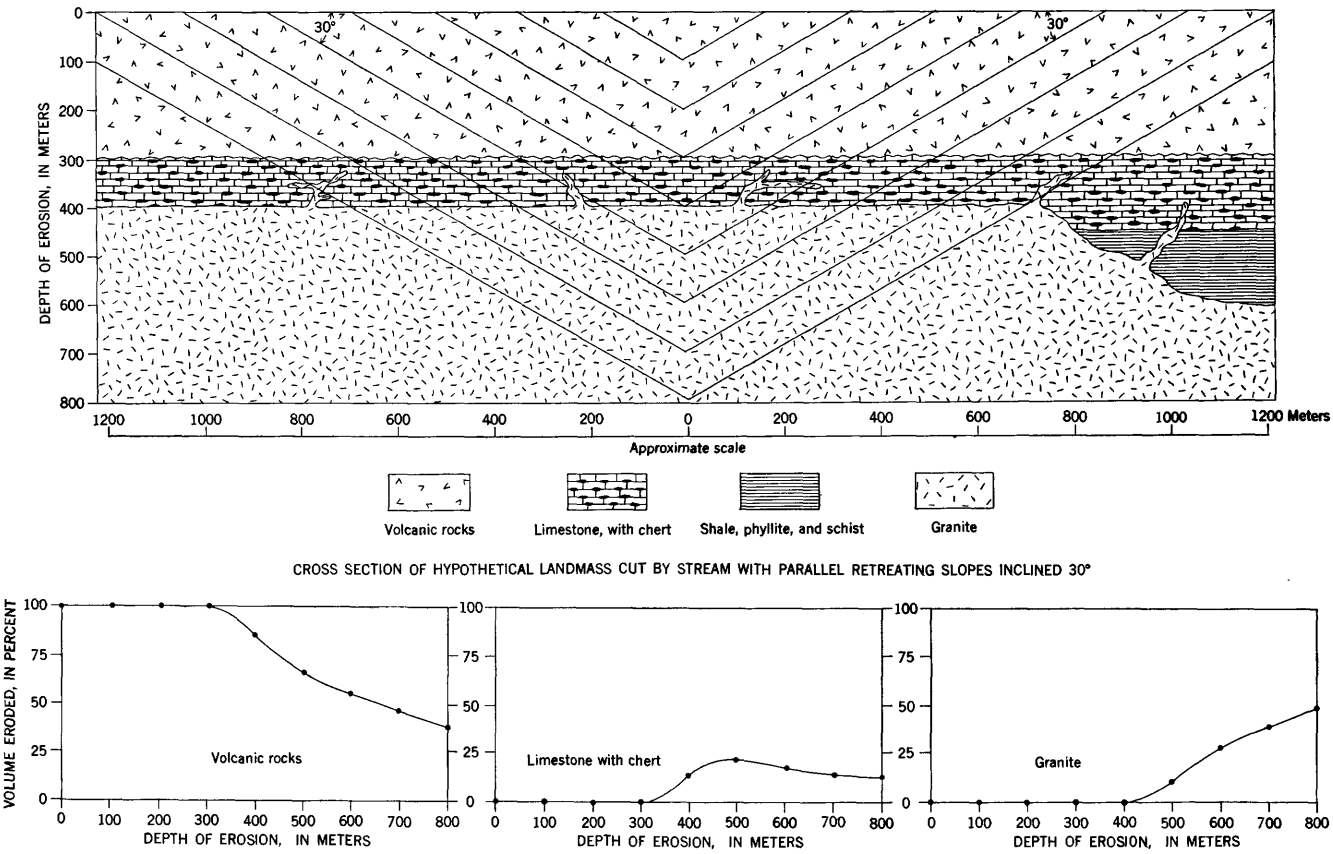


FIGURE 23.—Diagram indicating pebble composition of a conglomerate derived from erosion to different depths of a hypothetical land area of different rocks such as might have been present at Guanajuato.

It seems reasonable to conclude that the source of the Guanajuato conglomerate was a mountain range with a core of silicic rocks intruded into a cherty limestone sequence, which was covered by a thick series of predominately silicic lavas. Volcanism continued in the source area during at least a part of the period of deposition of the Guanajuato conglomerate and caused the sporadic influx of high-volcanic-content conglomerates. These volcanic rocks may have temporarily filled, or dammed, valleys in the source range, in which limestone or granite was exposed, thus decreasing the content of that rock in the conglomerate for short periods of time.

LOCATION OF SOURCE

Based on the coarseness and present distribution of the Guanajuato conglomerate, it is certain that the materials were derived from a nearby source, probably in large part from within 10 or 15 kilometers of Guanajuato city. In order to determine the source or sources of the debris now forming the Guanajuato conglomerate, several separate studies were made, each of which will be discussed briefly.

A facies change in this type deposit tends to take place within a short distance, but because of the present rough topography, high dips, abundant faults, and lack of any known marker beds, continuous strike exposures are needed to be certain of a facies change. Such an exposure was found in the lower part of the conglomerate and showed a remarkable decrease in average grade size in the direction S. 5° E. Within 1.9 kilometers, beds that contain 50 percent or more of pebbles and cobbles at the north, contain 25 percent or less at the south. Red sandstones take the place of the conglomerate beds. Southward thinning, which may also occur, could be neither proved nor disproved because the lack of marker beds prevented measuring similar sections. This area is discussed more fully under the section on texture.

On plotting the directions of 17 channels found in the lower part of the formation, an arithmetic mean azimuth of N. 23° E. was determined (fig. 24). The calculations of standard deviation, after Krumbein (1939, p. 691), and the modified chi-square test for estimating data significance, after Fisher (1932, p. 79), are shown in tables 5 and 6. A summary of the statistical data on channels in the Guanajuato conglomerate is shown in figure 25. Of these 17 channels, 16 were found along the same exposure that shows the striking decrease in average grade size discussed above.

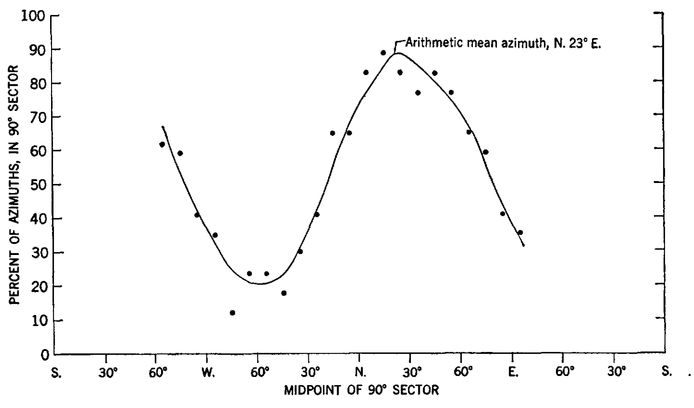


FIGURE 24.—Determination of the arithmetic mean azimuth for 17 channels in the lower part of the Guanajuato conglomerate.

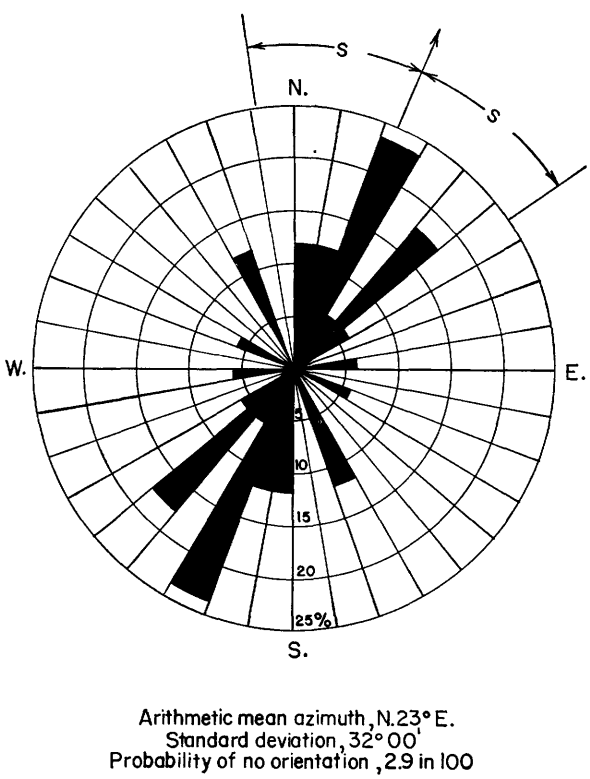


FIGURE 25.—Summary of statistical data on 17 channels in the lower part of the Guanajuato conglomerate.

Therefore, flow in these channels was from the northeast. No channels were found in the upper part of the formation.

Only 10 exposures of unquestionable crossbedding were found. The number of observations is too small to permit a statistical analysis. However, on plotting the sparse data, a mode of S. 20° E. shows prominently (fig. 26). This indication of southeast-flowing streams should not be entirely discounted.

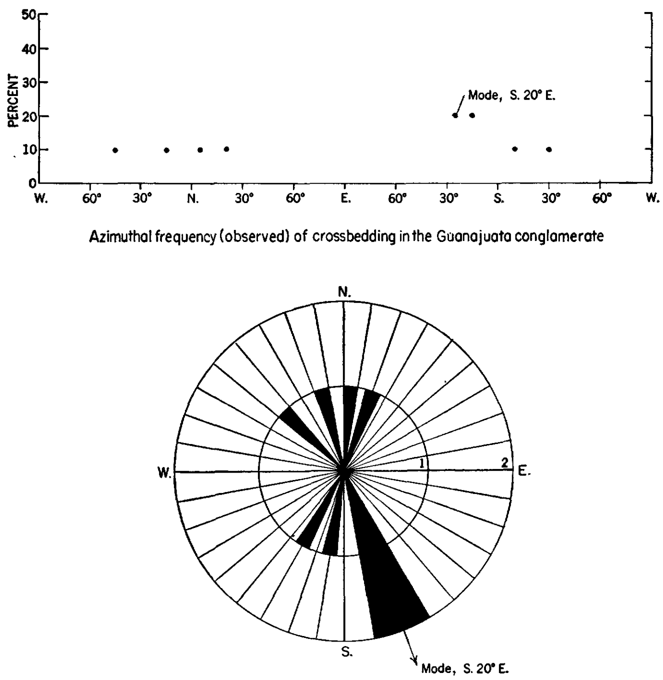


FIGURE 26.—Direction of flow as indicated by crossbedding in the lower part of the Guanajuato conglomerate.

Calculations of arithmetic mean azimuth by plotting directions of 17 channels in lower part of Guanajuato conglomerate [1]

Class limits 10° interval	Azimuthal frequency (observed)	Azimuthal frequency (percent)	Midpoint of 90° sector	Percent azimuth in 90° sector
N. 80°–90° W.	0	0	85° W.	35. 3
70 –80	0	0	75	11. 8
60 –70	1	5. 9	65	23. 5
50 –60	0	0	55	23. 5
40 –50	0	0	45	17. 6
30 –40	0	0	35	29. 4
20 –30	2	11. 8	25	41. 2
10 –20	0	0	15	64. 7
0 –10	0	0	5	64. 7
N. 0 –10 E.	2	11. 8	5 E.	82. 3
10 –20	2	11. 8	15	88. 2
20 –30	4	23. 5	25	82. 3
30 –40	1	5. 9	35	76. 4
40 –50	3	17. 6	45	82. 3
50 –60	1	5. 9	55	76. 4
60 –70	0	0	65	64. 7
70 –80	0	0	75	58. 8
80 –90	1	5. 9	85	41. 2
Total----	17	100. 1	----------	----------

[1] See figure 24.

Maximum boulder size increases to the northeast in the upper part of the conglomerate in the Guanajuato outcrop area (pl. 46). Maximum pebble size at the top contact increases to the northeast (fig. 27 is a plot of data from table 3). Pebble roundness at the top

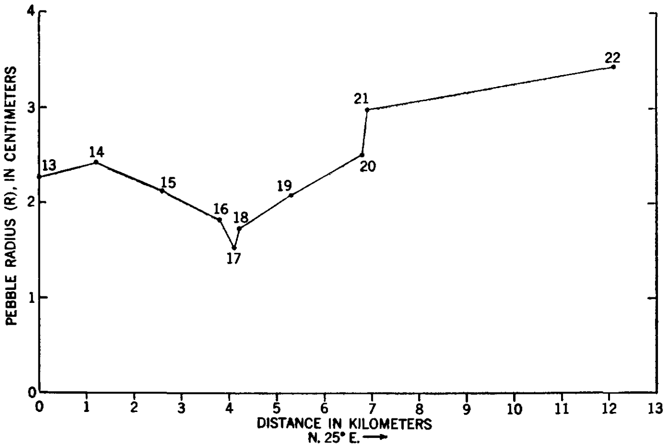


FIGURE 27.—Variation in maximum pebble size at the top contact of the Guanajuato conglomerate.

TABLE 5.—*Calculation of standard deviation*

Class limits 20° interval	Azimuthal frequency 20° interval f	Arbitrary scale d (20°=1)	fd	d	fd^2
N. 77°–87° W. N. 67°–77° W.	0	+4	0	+16	0
N. 57°–67° W. N. 47°–57° W.	1	−4	−4	+16	+16
N. 37°–47° W. N. 27°–37° W.	0	−3	0	+9	0
N. 17°–27° W. N. 7°–17° W.	2	−2	−4	+4	+8
N. 7° W.– N. 3° E. N. 3°–13° E.	2	−1	−2	+1	+2
N. 13°–23° E. N. 23°–33° E.	6	0	0	0	0
N. 33°–43° E. N. 43°–53° E.	4	+1	+4	+1	+4
N. 53°–63° E. N. 63°–73° E.	1	+2	+2	+4	+4
N. 73°–83° E. N. 83° E.– N. 87° W.	1	+3	+3	+9	+9
Total	17	--------	−1	--------	+43

Standard deviation S=class interval $\sqrt{\Sigma fd^2/\text{total}\, f-(\Sigma fd/\text{total}\, f)^2}$

$S=20\sqrt{43/17-(-1/17)^2}=32°$

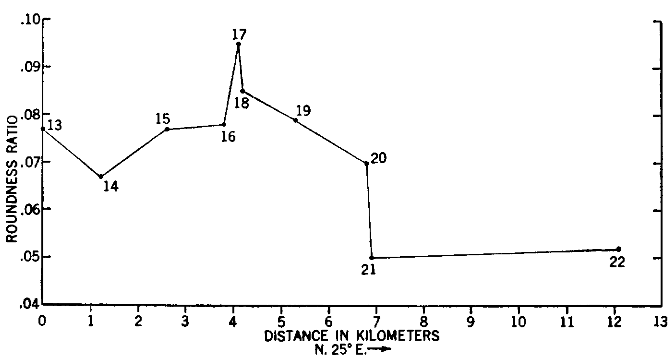


FIGURE 28.—Variation in pebble roundness (r_1/R) at the top contact of the Guanajuato conglomerate.

TABLE 6.—*Modified chi-square test for estimate of data significance*

Class limits 90° interval	Azimuthal frequency fo (observed)	Azimuthal frequency fa (average)	fo-fa	$(fo\text{-}fa)^2$
N. 22° W.–N. 68° E.	13	8.5	4.5	20.25
N. 68° E.–S. 22° E.	4	8.5	−4.5	20.25
Total	17	17	--------	40.50

NOTE:
$X^2=\Sigma(fo-fa)^2$=cell frequency
$X^2=\frac{40.5}{8.5}=4.76 \quad X=2.18$
$V=n-K$, where n is number of classes, K is number of independent linear constraints.
$V=2-1=1$, degrees of freedom
Therefore, $P=2.9$, percentage points of the X^2 distribution.

Conclusion: the chances of getting this degree of deviation from a random sample are only 2.9 in 100. Thus it has been indirectly shown that an orientation exists.

contact decreases to the northeast (fig. 28 is a plot of data from table 3). Roundness was measured by the roundness ratio as defined by Wentworth (1922, p. 93).

All these data indicate a northerly or northeasterly direction for the source of the conglomerate now present near Guanajuato. Therefore, the source of the Guanajuato conglomerate was a northwest-trending mountain range whose southwestern edge probably was less than 10 kilometers northeast of the city of Guanajuato.

THICKNESS

The thickness of the conglomerate is indicated in cross sections AA′ and BB′ in plate 45. Similar deposits, the Triassic of New Jersey for example, have attained great thicknesses within short distances from their source because of normal faulting along the edge of the source during their deposition.

In a like manner, normal faulting along the margin of the source at Guanajuato caused the basin to subside and thus provided space for the great thickness of this deposit in so short a distance from its source. The total thickness of the conglomerate can only be estimated, because the base of the conglomerate is not exposed. The relatively steep dips and the wide unfaulted downdip exposures along the lines of section make certain, by reconstruction, that the conglomerate is at least 1,500 meters thick in the vicinity of Guanajuato and has a probable maximum thickness of 2,000 meters (fig. 29).

The upper part of the conglomerate thins southwestward in section B–B′, from 650 meters to 180 meters, and thins northeastward in section A–A′, from 700 meters to 170 meters. The lower part of the conglomerate near Guanajuato is about 1,000 to 1,300 meters thick. Note that the upper part of the formation is 650 meters thick in the eastern part of section BB′, but it is only 170 meters thick in the eastern part of section A–A′.

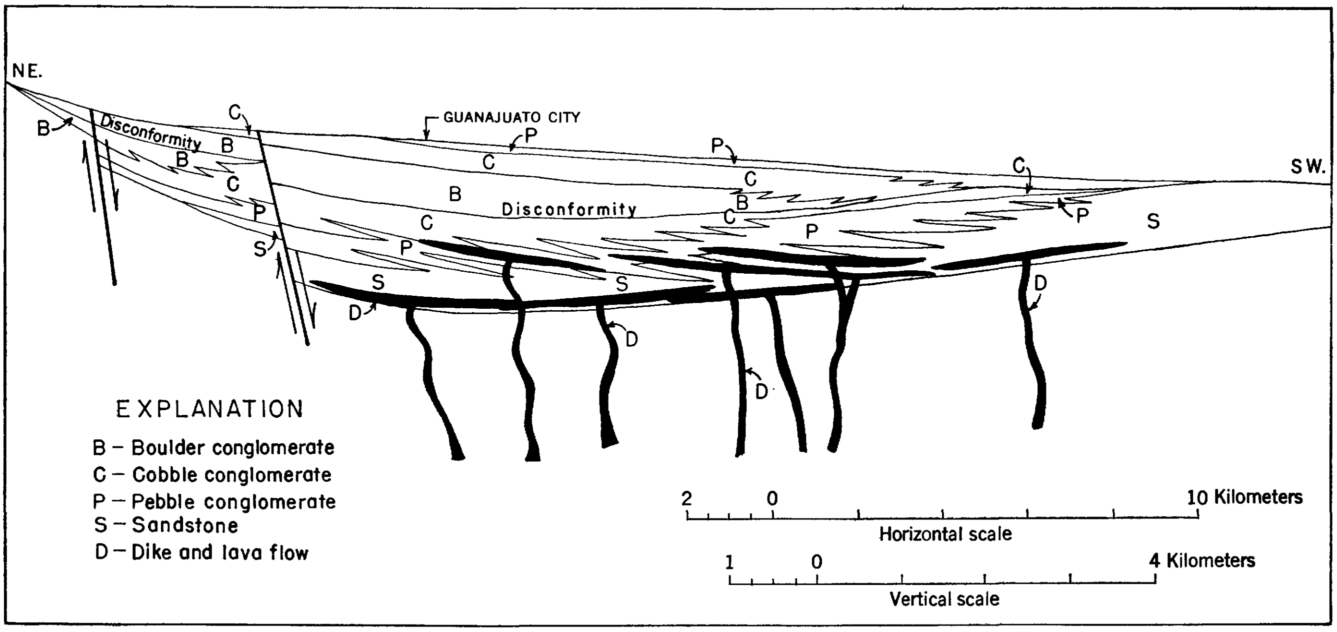


FIGURE 29.—Restored section at close of deposition of the Guanajuato conglomerate.

On the map in plate 45, the Veta Falla del Amparo, a normal fault that dips about 60° S. 30° E., divides these thick and thin areas. The northeast end of this fault cuts the Bufa sandstone on the north slope of Cerro del Meco, but the throw is less than 30 meters. Therefore, there must have been movement along this fault during conglomerate deposition, and the side away from the source (the southeast side) moved downward possibly as much as 500 meters. Other and similar faults were probably active during conglomerate deposition (fig. 29).

AGE

No fossils had been found in the Guanajuato conglomerate until the summer of 1950 when the writer and Gustavo Ortiz collected several small vertebrate bones from thinly laminated siltstones within the lower part of the formation (pl. 45, fossil locality; fig. 20). A study of these fragmental remains by G. E. Lewis of the U. S. Geological Survey in Washington, D. C., and by A. E. Wood, associate professor of biology at Amherst College, provided no age assignment because none of the material was complete enough to be diagnostic.

In the spring of 1951, Carl Fries, Jr., chief of the office in Mexico of the U. S. Geological Survey, returned to the locality and searched further for fossil materials. Only a few tiny unidentifiable bone fragments had been uncovered by the rains since 1950. In March 1952, Fries again visited the locality, accompanied by Kenneth Segerstrom, geologist of the Geological Survey, and was fortunate in finding a part of a skull of a tiny rodent, apparently identical with material found by Fries in the summer of 1950 and subsequently lost in transportation. This new material was prepared and examined by C. W. Hibbard, of the University of Michigan, and R. W. Wilson, of the University of Kansas, and is described in detail by Fries, Hibbard, and Dunkle (1955). The find was mentioned in a short article by Arellano (1952). For the purpose of assigning an age to the Guanajuato conglomerate the following quotation from Wilson is here presented:

"In many ways this rodent is similar to but somewhat more advanced than *Sciuravus powayensis* of the early late Eocene (on the v. p. [vertebrate paleontology] time scale) of southern California. In one presumably fundamental character, however, it is more like *Taxymys* (middle Eocene) than any other described sciuravine. This is the structure of the paracone-protocone crest which is continuous rather than composed of a short, oblique, inner crest, and a largely independent paracone.

"I cannot be certain of its geologic age for two reasons: (1) it is not clearly on any known line of descent and (2) it is far enough removed geographically from its allies so that survival to a later date than elsewhere becomes a possibility. The known range of sciuravines, however, is such as to imply strongly a middle Eocene to early Oligocene age . . .

"Geographically, certainly sciuravine species are known from the Bridger and Uinta Basins of the Rocky Mountains, and from San Diego, California. If the Mexican species had been found in beds of unknown age, but within the general geographic area indicated above, I would expect the age to be one of the following (arranged in order of decreasing probability):

(1) Uintan-Duchesnean (late Eocene-latest Eocene): most likely, and more probably late than early.
(2) Chadronian (early Oligocene): in facies not normally represented in White River.
(3) Bridgerian (middle Eocene).
(4) Post-Chadronian (post-early Oligocene): with decreasing probability the higher in the Tertiary.
(5) Later Wasatchian (later early Eocene): almost certainly not this age or older."

In view of the fact that Guanajuato lies about 1,200 kilometers farther south than the most southern locality in which sciuravine remains have been found and described in the United States, an exact age assignment does not yet seem to be possible for the Guanajuato material, but an early Tertiary age is at least certain, and a late Eocene to early Oligocene age seems most probable. Fries (personal communication) feels that such an age assignment accords well with known data on the tectonic history of this part of Mexico, as recorded in the folding of the latest Cretaceous and earliest Tertiary marine sedementary rocks along the eastern margin of the plateau to the east of Guanajuato.

CONTACT OF THE GUANAJUATO CONGLOMERATE AND OVERLYING ROCKS

Conformably above the Guanajuato conglomerate lies the Bufa sandstone, a water-laid, silicic tuffaceous sandstone (Botsford, 1909, p. 692). It rests on a plane surface formed by the top of the conglomerate and is thin but cliff-forming (fig. 30). Thin, continuous laminae, good sorting, graded bedding, crossbedding, and the presence of some ripple-marked beds and small channels in this sandstone (fig. 31) suggest that it was deposited in a shallow-water environment, such as a shallow lake.

The transition between the conglomerate and tuffaceous sandstone is everywhere only a few centimeters (fig. 30). No pebbles occur in the Bufa sandstone. Thin sections show that it is composed of mostly angular, but some subrounded, grains of quartz and plagioclase, together with a large proportion of altered silicic volcanic rocks cemented by calcite. Its thickness of 10 to 20 meters is fairly constant over the entire length of its outcrop, but as a result of thickening of individual beds, it varies, for example, from 16.6 meters to 21.3 meters within 400 meters along its outcrop east of Presa de La Olla in Guanajuato City. These sections were measured in two adjacent quarries where the sandstone is mined on a small scale for building stone. This same unit on the east side of El Cedro valley, 2.5 kilometers due east of the 21.3-meter section, is 52.5 meters thick, coarser grained, and not so thinly bedded. Just north of San Nicolás del Monte, 15.5 kilometers northeast of Guanajuato by road, the tuffs are coarser and thicker than at Guanajuato. Although the sandstone is present continuously to the southwest of Guanajuato, it tends to be finer grained and thinner; it is only 3 meters thick at one locality (pl. 45, sample 14).

The surface of the Guanajuato conglomerate at the time of deposition of the Bufa sandstone must have been almost in the form of a plane with only a slight primary dip. The tuffs were deposited by water as a thin flat layer; their source seems to have been to the northeast of Guanajuato. This formation marks the

FIGURE 30.—Bufa sandstone conformably overlying the Guanajuato conglomerate.

FIGURE 31.—Detailed view of Bufa sandstone, showing sedimentary structures characteristic of shallow-water deposition.

initial explosive phase of a great volcanic epoch that followed the deposition of the conglomerate. Still essentially a tabular body, the sandstone has been tilted to the east by post-volcanic faulting, as have all the rocks of the region. Between the two streams feeding Presa de La Olla, its average dip is 19° S. 84° E., which indicates the direction and degree of tilting caused by the southeast continuation of the Veta Madre, on the western side of El Cedro valley.

Conformably overlying the Bufa sandstone is a series of coarse-grained, massively bedded tuffs that are more than 500 meters thick, and vary from rhyolitic to andesitic upward in the section (Guiza, 1949, p. 25–29). These younger volcanic rocks are probably mainly of Miocene age. They consist principally of massive tuffs but also contain volcanic breccias, thin conglomerate layers, and various types of lavas; the basal part contains isolated fragments of pink rhyolite, tuffaceous sandstone, gray granite, and schist (fig. 32). In the same part of the stratigraphic column, 28 kilometers northeast of Guanajuato on the road to Dolores Hidalgo, are pitchstone, pink rhyolite, and tuffs. During this age of volcanism, andesite dikes cut both the conglomerate and the overlying volcanic rocks; they probably acted as feeders for overlying andesite lava flows and ash beds. These dikes, the only intrusives in the conglomerate, are most numerous in El Cedro valley, 6 kilometers southeast of Guanajuato (pl. 45).

FIGURE 32.—Coarse-grained massive tuff conformably overlying Bufa sandstone.

Following this great volcanic epoch, a period of normal faulting occurred which produced the most striking structural features seen in this area today. The ores of the district were emplaced at that time. The dip slip on several of the northwest-striking normal faults that bound tilted blocks and grabens is as much as 1,000 meters (Guiza, 1949, pl. 2).

Derived principally from the younger volcanic rocks and overlying them, a younger conglomerate spreads toward the southwest from the faulted and uplifted Sierra de Guanajuato. It now forms the hills that separate Guanajuato from Silao and Irapuato to the west and southwest, respectively. This same conglomerate appears 40 kilometers (by road) northeast of Guanajuato, where it was derived from the volcanic crest of the Sierra de Guanajuato and deposited to the northeast in the broad open valley of the Río de Las Lajas. By analogy with other deposits of this kind in Mexico and the United States, this younger conglomerate is probably middle to late Pliocene in age.

After the deposition of the younger conglomerate, the streams were superposed on all the older rocks. The Río de Guanajuato, which flows through the city and then toward the southwest, began to develop a flood plain at the end of this downcutting period. This was followed by some aggradation and during this time, at least five soil horizons were formed in the flood-plain deposits and were, in places, buried successively. Downcutting began again and has continued to the present time. This period of erosion, deposition, and soil formation occurred in part during late Pleistocene time, because typical late Pleistocene vertebrate remains have been collected from the flood-plain deposits of the Río de Guanajuato.

Volcanism did not cease in this region after the eruption of the great quantity of younger volcanic rocks; instead, it continued intermittently at a decreasing rate to the present day. Flows near the base of Cerro del Cubilete between Guanajuato and Silao evidently cover gravels of Quaternary age. Other basalt flows are scattered over the Bajío region. The year 1874 marked the most recent strong earthquake in this vicinity. Hot springs with temperatures of 90° to 93° C. are found today near Silao, Apaseo, and Celaya (Wandke, 1928, p. 5). In the vertical arroyo banks that are located about 2 kilometers southwest of Marfil, a fine-grained, white, rhyolitic ash layer, 1 to 3 centimeters thick, occurs from 3 to 4 meters below the terrace surface. A horse mandible was found 3.5 meters below the surface in fine-grained sandy beds immediately below the ash layer. An elephant molar was found at a depth of 4.3 meters in an old stream gravel in this area. These were probably in the local equivalent of the Becerra formation of the Mexico City Basin, of late Pleistocene age (Arellano, 1951, p. 614).

THE TAXCO DISTRICT

LOCATION

The town of Taxco, located 163 kilometers southwest of Mexico City on the Mexico-Acapulco highway (fig. 17) at an altitude of 1,783 meters, is at the south end of a mountain range that extends from the Mesa Central into the north-central Balsas Basin physiographic province (Ordóñez, 1936, p. 1294). This range is locally called the Sierra de Taxco.

GEOLOGIC SETTING

A tightly crinkled, usually step-folded, buff-colored sericite schist is the oldest rock in this region (fig. 33). It is exposed in a relatively small area and can readily be seen south of kilometer 155 (pl. 47) and at kilometer 162 on the highway. This rock is thought by some geologists to be pre-Cambrian, but it may be Paleozoic or even early Mesozoic. Very little is known of the thicknesses, exact sequence, and ages of the Mesozoic rocks overlying this schist because of the complexly folded structures and lack of detailed mapping.

Fowler, and others (1948, p. 5), state that the schist is overlain unconformably by a series of massive, thick-bedded gray limestone of Cretaceous age overlain by shale. They estimated the maximum thickness of the limstone at more than 250 meters and the minimum thickness of the shale at 300 meters. They believe that the contact between the schist and overlying rocks of Cretaceous age is the plane of an overthrust. In both the Remedios and La Concha mines the schist-limestone-shale sequence is confirmed. At the La Concha mine, 10 kilometers southwest of Taxco, the limestone is about 200 meters thick, lies against schist, and is overlain by an unknown thickness of shale (Snow, personal communication).

Eight kilometers east of Taxco, the limestone forms a low range of mountains with well-developed karst topography, which extends south towards Iguala from the divide through which the highway passes at kilometer 147 (pl. 47). This limestone is a dense, thick-bedded, light-gray calcarenite that contains small lenses and nodules of gray to black chert. Certain beds are highly fossiliferous, but the fossils have been recrystallized during deformation to the extent that specific identification is difficult. From field observation of this limestone and its contained fossils, the formation is believed to be equivalent to the Tamaulipas or El Abra limestone of middle to late Early Cretaceous age in eastern Mexico (Fries, personal communication).

At kilometer 150 on the highway, several limestone cobbles containing numerous silicified fossils were found within the conglomerate. At this place, the conglomerate is thin and rests on limestone of the same type as the cobbles. The following faunal list was prepared by R. W. Imlay and J. W. Wells from a study of these fossils:

Mammites sp.	*Ostrea* sp.	*Serpula* sp.
Scaphites? sp.	*Plicatula* sp.	*Trocharea* sp.
Anisoceras? sp.	*Nemodon*? sp.	*Lophosmilia* sp.
Calliomphalus? sp.	*Corbula* sp.	*Ovalastrea*? sp.
Cerithium? sp.	*Hippurites* cf. *H. mexicana* Barcena	*Heliopora*? sp.
Phacoides? sp.		*Cladophyllia*? sp.
Exoygra sp.		

Imlay states that these fossils are of early Late Cretaceous age and probably represent the lower part of the Turonian stage. This age determination is based on the presence of ammonites, probably belonging to *Mammites* and *Scaphites*, and on the rudistid *Hippurites*. These fossils appear to have come from the upper part of the limestone sequence, mainly from the thin-bedded limestone on top of the massive-bedded Tamaulipas limestone. Wells, of Cornell University, assigned the poorly preserved corals to the upper part of the Lower Cretaceous (Mexican Middle Cretaceous), somewhat older than Turonian.

Dark-gray to black fissile shale, which contains numerous limestone beds as much as 30 centimeters thick, is well exposed in the many road cuts in the valley between Taxco and Iguala (fig. 34). This shale is tightly folded, in common with the underlying limestone; the axial planes usually strike about north-south and stand vertically, but they may be slightly overturned to the east or southeast.

A few diabase dikes cut these marine rocks. A dike, 24 meters thick, cuts the shale along the road 1.5 kilometers southwest of the Victoria Hotel in Taxco. These are the only intrusive rocks exposed in this area that are older than the few dikes found cutting the red conglomerate of Tertiary age.

Following the deformation and uplift of the rocks of Cretaceous age in latest Cretaceous and earliest Tertiary time, erosion must have developed a rugged surface with karst topography where the limestones were exposed. A basin of interior drainage was formed in this region, probably as a result of faulting, and it was filled with material eroded from the surrounding highlands.

THE RED CONGLOMERATE

The red conglomerate at Taxco is like many of the formations of early Tertiary age on the plateau of Mexico. It lies on a rugged surface truncating deformed marine rocks of Mesozoic age, has textures varying from silt to boulder conglomerate, is red, changes thickness in short distances, and is associated with volcanic rocks that become abruptly predominant at the top and conformably cap the formation to great thicknesses.

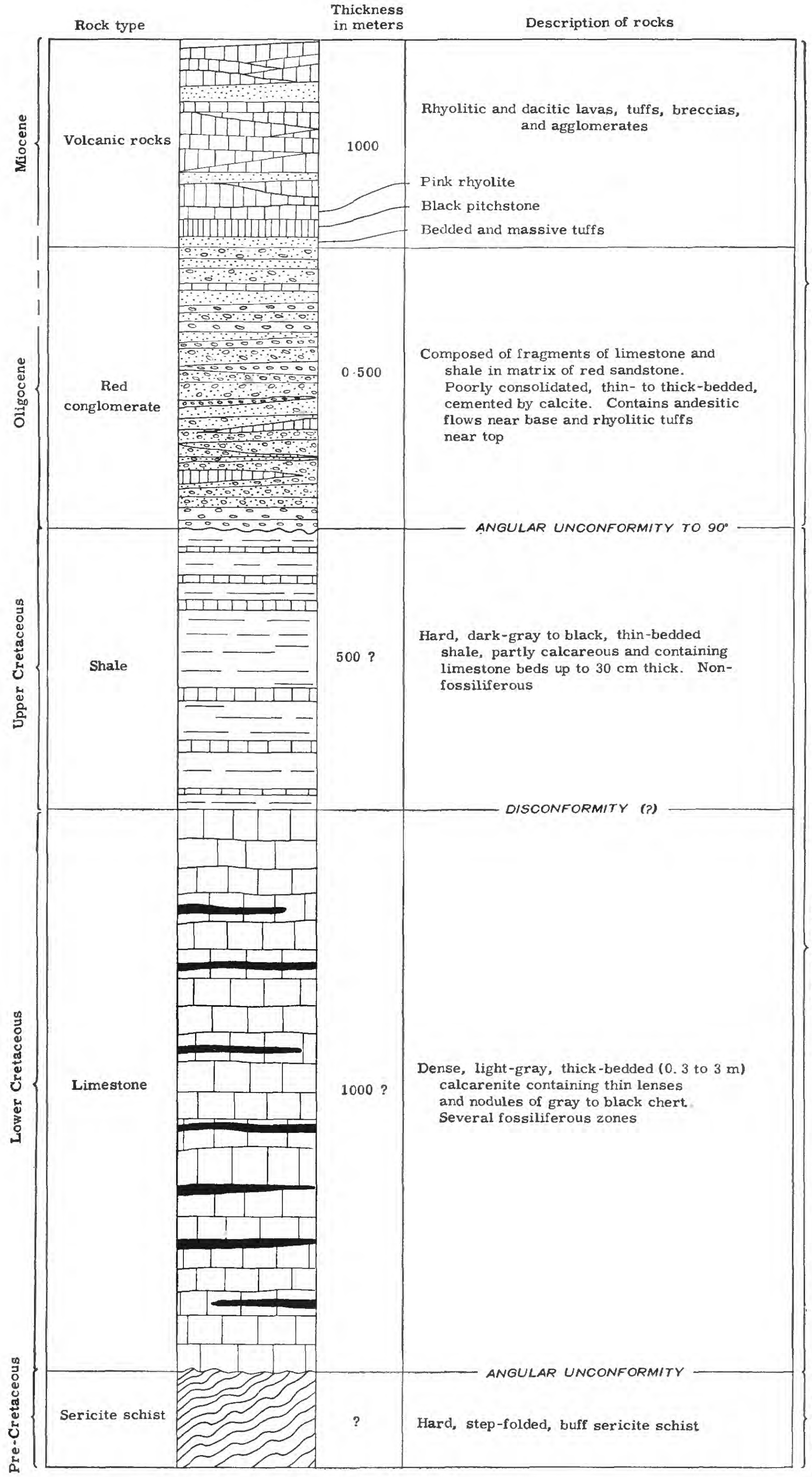


FIGURE 33.—Generalized stratigraphic column of the Taxco district.

FIGURE 34.—Fold in shale and limestone beds, looking west at kilometer 163.5 on the Mexico-Acapulco highway.

DISTRIBUTION

The conglomerate is exposed in most of the road cuts along the highway between kilometer 149.8 and kilometer 155.3 (pl. 47). The top contact of the conglomerate between these points lies just west of the highway and is marked by cliff-forming volcanic rocks. Fifty meters south of the road, at kilometer 155.3, the conglomerate is cut off by a major normal fault trending N. 66° W., which brings the sericite schist against the conglomerate (pl. 47). The conglomerate reappears on the south side of this fault 2.5 kilometers to the west, between kilometer 159.6 and kilometer 160, at the north edge of Taxco. The outcrop belt then extends southwestward up the side of Cerro Atache, through the town of Taxco, and around the south side of this mountain into the valley to the west, where it extends for an undetermined distance.

The largest area of exposure of this conglomerate is in the valley to the east of the highway between kilometer 153 and kilometer 155, in which the towns of Acamixtla and Las Juntas are situated (pl. 47).

COMPOSITION

The principal constituents of the conglomerate are limestone and shale, but close inspection of most exposures throughout the formation disclose very minor quantities of andesite, milky quartz, red sandstone, calcite, and black chert. Some conglomerate beds contain only fragments of shale or limestone. These tend to be situated low in the section and they tend to rest on the type of rock whose fragments they contain. A rare occurrence of conglomerate at Coaponga, consisting largely of an altered iddingsite basalt, is cited by Foshag and González (1946, p. 14). Within 35 meters of the top contact, and above a unique tuff sequence (fig. 35), rhyolitic and dacitic lavas and tuffs appear as pebbles and cobbles in the conglomerate.

No pebble samples were taken in the Taxco area. An estimate of the proportion of each constituent of pebble size or larger in the conglomerate follows: 90 percent combined limestone and shale (limestone greater than shale), 8 percent lavas (calcic greater than silicic), and 2 percent combined red sandstone, chert, quartz, and calcite, in order of decreasing abundance. The limestone fragments are of the type exposed in the area east of Taxco. The shale fragments in the conglomerate, which include quartzose, silty, black fissile, and highly calcareous shales, are all represented in the shale exposed in the area today. No fragments of the sericite schist have been recognized in the conglomerate. Therefore, it is almost certain that the schist was not exposed in this region during the accumulation of the conglomerate and was probably uncovered much later, possibly in Pleistocene time.

Thin-section studies show that the sandstones are formed, in part, of angular to subrounded grains of quartz, calcite, albite, sanidine, and biotite. Calcite as veinlets, pebble incrustations, and cavity fillings binds most of the conglomerate. A very low percentage of red clay as thin coatings on particles gives the formation its red color. The red color of this conglomerate is considered to result from the development of red soils in the source area.

IGNEOUS ROCKS IN THE CONGLOMERATE

Several andesitic lava flows occur within the conglomerate (table 7, nos. 1 and 2). The only other volcanic rock found in the conglomerate was a unique tuff sequence near the top (fig. 35), which is described in table 8 and in the paragraph preceding it. Two thin,

FIGURE 35.—Unique tuff sequence near the top contact of the red conglomerate at kilometer 154.1 on the Mexico-Acapulco highway.

dark, basic dikes, both shown on the map in plate 47, were the only intrusive rocks found in the conglomerate.

TABLE 7.—*Thin-section data on rocks from the Taxco district*

No.	Description	Rock name
1.	Lava most common as pebbles in the conglomerate and a flow in the conglomerate in Taxco	Andesite.
2.	Amygdaloidal lava near base of the conglomerate in bed of the Rio Acamixtla, 1.6 kilometers southeast of kilometer 155 on the highway	Andesite.
3.	24-meter-thick spheroidal-weathering dike cutting shale and overlain by conglomerate, 1.5 kilometers southwest of Victoria Hotel, Taxco	Diabase dike.
4.	Conglomerate within 5 meters of top contact at kilometer 154 on the highway. MATERIALS IN HAND SPECIMEN: Rhyolite, red sandstone, limestone, quartz. MATERIALS IDENTIFIED: Red sandstone, rhyolitic and dacitic lavas and tuffs, quartz, sanidine, albite, calcite, calcite 2nd, hematite. GRAIN FORM: Angular to subround. CEMENT: Calcite. GRAIN SIZE IN THIN SECTION (MM): 0.005–18.24	Cobble conglomerate.

TEXTURE

Individual beds show a complete variation in texture from siltstone to boulder conglomerate. The finest beds occur near the base of the formation east of kilometer 155 and at the top of the formation to the southwest of Taxco. The thickest and most persistent fine-grained beds observed occur in the upper half of the conglomerate section immediately southwest of Taxco. Boulders are scarce; the largest boulder found (at kilometer 154.5) was only 50 centimeters in maximum diameter. The average diameter of fragments in the coarsest part of the conglomerate is 5 centimeters, or less (fig. 36).

BASAL RELATIONS

The red conglomerate everywhere lies with angular unconformity on shale or limestone; it has not been seen overlying schist in the Taxco region. Shale underlies the conglomerate at Taxco, whereas in the area mapped, limestone lies beneath it to the north and shale lies beneath it to the south. The basal contact of the conglomerate changes elevation rapidly, in part because of later faulting and tilting, but primarily because it is the trace of an ancient erosion surface.

TABLE 8.—*Description of volcanic-tuff marker beds near the top of the Taxco red conglomerate*

[Thickness in meters]

Km 152.4	Km 154.05	Km 155.15	400 m west of km 159.6	1 km N. 77° W. of Taxco church	Description
(Top)					
1. 0	9. 0	3. 0	[1]	9. 0	Volcanic tuff.
15. 70	21. 40	33. 10	[1]	(absent)	Red conglomerate.
. 10	(absent)	. 07–. 20	[1]	(absent)	Soft, coarse, red tuff.
[2] . 09	. 08	. 08	[3] . 09	. 10	Hard, fine, red tuffaceous sandstone.
. 24	. 24	. 23	[1]	. 10–. 15	Coarse, soft, red tuffaceous sandstone.
[2] . 13	. 13	. 14	[3] . 26	. 28	Hard, fine, red tuffaceous sandstone.
. 03	. 04	. 05	[1]	. 03	Soft, coarse, red tuff.
. 03	. 03	. 04	[1]	. 03	Hard, dark, coarse tuffaceous sandstone.
. 60	. 55	. 54	[1]	1. 20	Coarse volcanic tuff.
(Bottom)					

[1] Beds not exposed.
[2] These are the most conspicuous beds and are easily recognized in several road cuts between kilometer 152.4 and kilometer 155.15.
[3] Recognized from float.

THICKNESS

The red conglomerate is not present between the younger volcanic rocks and the limestone north or east of kilometer 149, but it comes in between these formations at a point 150 meters north of the highway at kilometer 149.3 and thickens rapidly southward, as indicated both on the map and in section B—B′ in plate 47. By constructing section A–A′ (pl. 47) the thickness at kilometer 154.5 was estimated to be 475 meters. At kilometer 159.4, a red-conglomerate section of 268 meters was measured, with the base not exposed; the total thickness is probably about 350 meters. A complete section of 140 meters was measured 1 kilometer west of Taxco. Figure 37 shows the relationship between these sections.

SOURCE AND DIRECTION

As indicated by the fragments contained in the red conglomerate, the source was composed of limestones and shales similar to those cropping out today in the region east and south of Taxco. No schist or intrusive igneous rocks were exposed in the source area while the conglomerate was accumulating. The small quantities of calcite and quartz fragments in the conglomerate must represent vein fillings in the fractured and folded rocks of the source range. Inasmuch as the volcanic

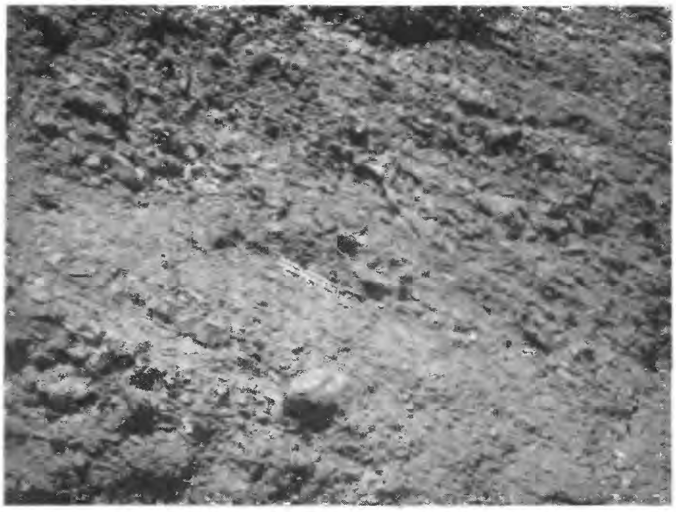


FIGURE 36.—Sand-pebble-cobble red conglomerate composed of limestone and shale at kilometer 154.9 on the Mexico-Acapulco highway.

pebbles in the conglomerate are of the same composition as the lava flows interbedded with it, volcanism must have occurred in the source area before, or during, the deposition of the conglomerate.

The variations in both texture and thickness give evidence of the direction of the source. From east to west the texture becomes finer, especially in the upper half of the conglomerate. The variations in thickness have been discussed and are shown in figure 37. The points pertinent to source direction and position are briefly these: the conglomerate is absent north and east of kilometer 149 because of non-deposition; from there, it thickens rapidly to a maximum at a point 3 kilometers S. 25° W., and then it thins gradually to the west.

The fence diagram in figure 38 shows that the pebble conglomerate at the top of the formation along the highway between kilometers 152 and 155 is absent at Taxco to the west. Note also that it is only in the east that thin conglomerate beds near the base of the overlying volcanic rocks are present. This diagram was constructed on the basis of unique marker beds of volcanic tuff (fig. 35), which are remarkably uniform over a broad area (table 8).

Between kilometer 150 and kilometer 155 on the highway, 10 conglomerate-filled channels, 0.3 to 1 meter deep, were found cut into the well-bedded tuffaceous sandstone that overlies the main body of the red conglomerate (fig. 38). The arithmetic mean azimuth of these channels was determined to be N. 15° W. (fig. 39). The calculations of standard deviation, after Krumbein (1939, p. 691), and of data significance, after Fisher (1932, p. 79), are shown in tables 9 and 10.

A summary of the statistical data is shown in figure 40.

The position of the source of the red conglomerate near Taxco, based on the information given above, was 7 to 10 kilometers east of Taxco, barring the indication of north-south trending streams (fig. 40), which may be closely related to the position of the first volcanic rocks overlying the conglomerate. The source was probably elongated northwest-southeast. This would account for the absence of conglomerate north of kilometer 149 and for its westward decrease in average grade size.

AGE

No dating on fossil evidence is now possible for the red conglomerate at Taxco. The only fossils found in the conglomerate were meager, fragmental, carbonized plant remains. The red sandstone in the upper half of the formation west of Taxco seems best suited for further search for plant and animal remains. Based upon stratigraphic position, tectonic history, composition, and environment of deposition, this red conglomerate is believed to have the same general age as the Guanajuato red conglomerate and is probably of Oligocene age.

TABLE 9.—*Calculation of standard deviation*

Class limits 20° interval	Azimuthal frequency 20° interval *f*	Arbitrary scale *d* (20°=1)	*fd*	*d*	*fd*²
N. 80°–90° W N. 70°–80° W	0	−4	0	+16	0
N. 60°–70° W N. 50°–60° W	1	−3	−3	9	9
N. 40°–50° W N. 30°–40° W	2	−2	−4	4	8
N. 20°–30° W N. 10°–20° W	2	−1	−2	1	2
N. 0°–10° W N. 0°–10° E	4	0	0	0	0
N. 10°–20° E N. 20°–30° E	0	+1	0	1	0
N. 30°–40° E N. 40°–50° E	1	+2	+2	4	4
N. 50°–60° E N. 60°–70° E	0	+3	0	9	0
N. 70°–80° E N. 80°–90° E	0	+4	0	+16	0
Total	10	--------	−7	------	23

NOTE: Standard deviation = S = class interval $\sqrt{\Sigma fd^2/\text{total } f-(\Sigma fd/\text{total } f)^2}$

$$S=20\sqrt{\frac{23}{10}-\left(\frac{-7}{10}\right)^2}=26.9^\circ=26^\circ 54'$$

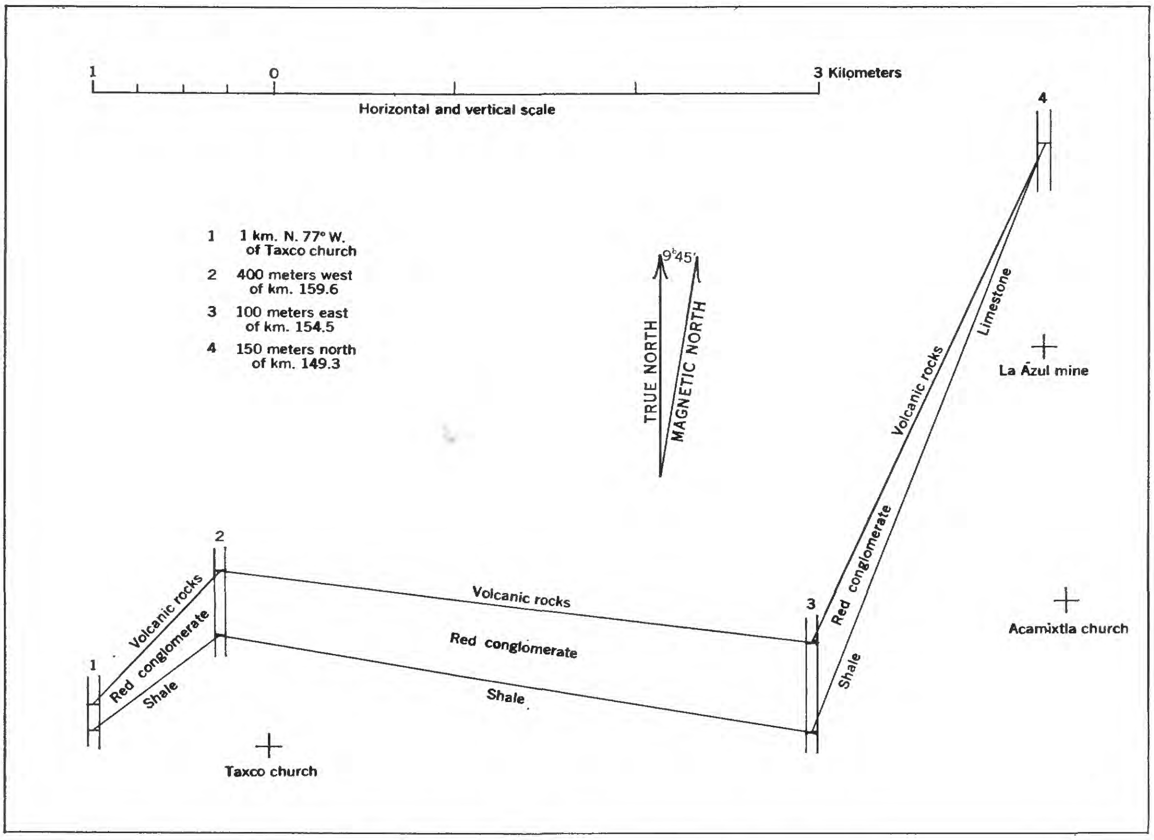


FIGURE 37.—Fence diagram of the red conglomerate near Taxco, Guerrero.

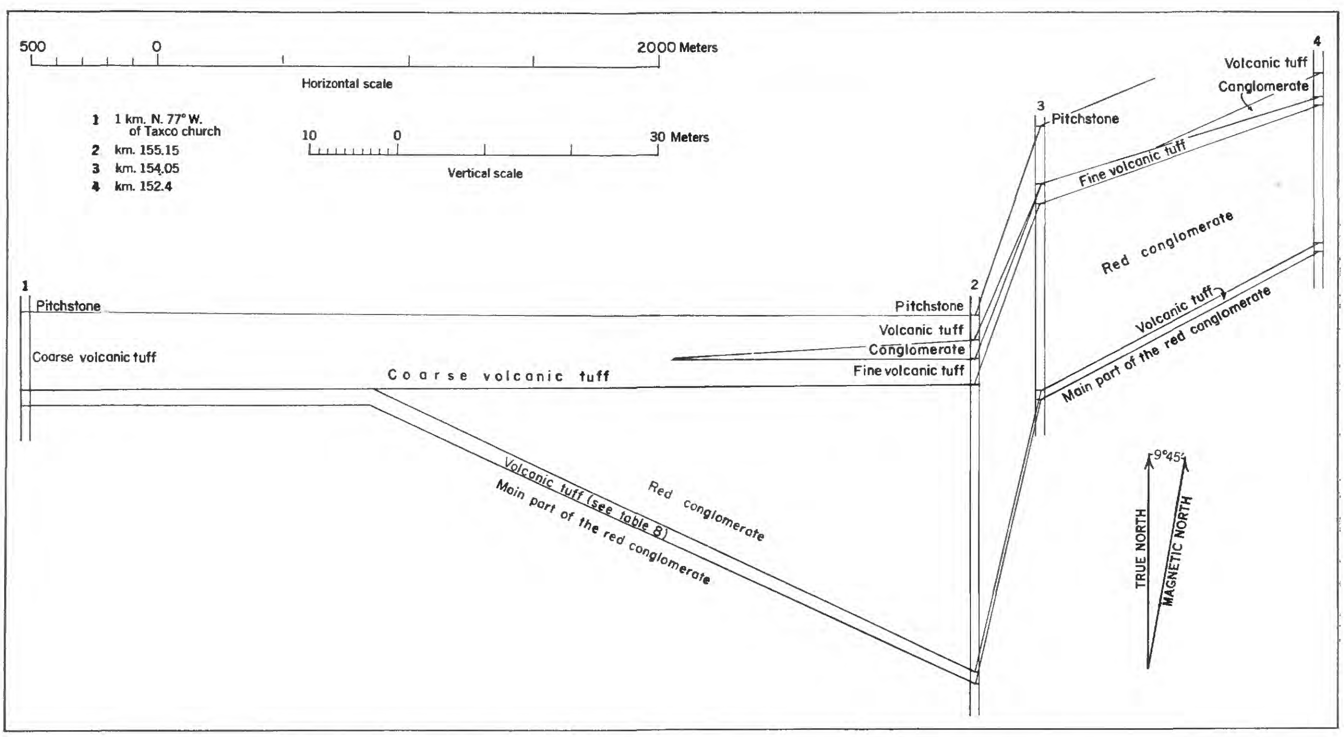


FIGURE 38.—Fence diagram of the uppermost units of the red conglomerate near Taxco, Guerrero.

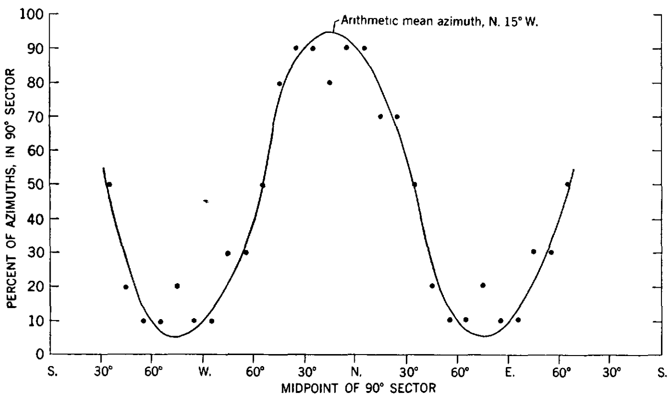


FIGURE 39.—Determination of the arithmetic mean azimuth of 10 channels at the top contact of the red conglomerate between kilometers 150 and 155, near Taxco, Guerrero.

TABLE 10.—*Modified chi-square test for estimate of data significance*

Class limits 90° interval	Azimuthal frequency (observed) *fo*	Azimuthal frequency (average) *fa*	*fo-fa*	$(fo-fa)^2$
N. 60° W.-N. 30° E.	8	5	3	9
N. 30° E.-S. 60° E.	2	5	−3	9
Total	10	10		18

NOTE:
$X^2=\Sigma(fo-fa)^2$=cell frequency
$X^2=\frac{18}{5}=3.6$ $X=1.90$
$V=n-K$, where n is number of classes, K is number of independent linear constraints.
$V=2-1=1$, degrees of freedom
Therefore, $P=5.8$, percentage points of the X^2 distribution.
Conclusion: The chances of getting this degree of deviation from a random sample are only 5.8 in 100. Thus, it has been indirectly shown that an orientation exists.

OVERLYING VOLCANIC ROCKS

The rock that immediately overlies the red conglomerate is everywhere a volcanic tuff. This is followed conformably by about 1,000 meters of silicic volcanic rocks, the bulk of which are rhyolitic tuffs and flows. All the high parts of the Sierra de Taxco to the north and west of Taxco are formed or capped by a great thickness of volcanic rocks, most of which are probably of Miocene age. The volcanic section west of the highway at kilometer 153 is representative of the thicknesses and sequence of volcanic rocks immediately overlying the red conglomerate on the west side of the Río Acamixtla valley (table 11).

In late Tertiary time, this entire conformable Tertiary sequence, as well as the older rocks, was cut into huge blocks by normal faults.

THE ZACATECAS DISTRICT

LOCATION

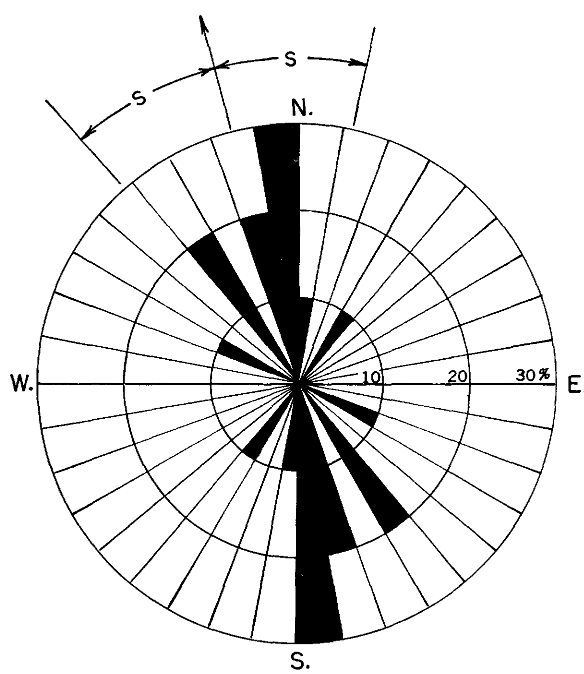
The city of Zacatecas, capital of the State of Zacatecas, is at the southwest end of the Sierra de Zacatecas at an elevation of 2,560 meters (fig. 17). According to Ordóñez (1936, p. 1289), it is in the Mesa Central physiographic province.

TABLE 11.—*Volcanic section overlying the red conglomerate 100 meters west of kilometer 153 on the Mexico-Acapulco highway*

Thickness (meters)	Rock type	Description
(Top) 30+	Rhyolite	Dense, massive, many large phenocrysts, pink.
5. 5	Rhyolite	Dense, flow-banded, fine-grained, red to orange.
18.6	Pitchstone	Dense, glassy, black, conchoidally fractured, well-jointed, many incipient phenocrysts.
14.6	Tuff	Friable, coarse-grained, massively bedded, light-green, silicic.
2.7	Conglomerate	Hard pebble conglomerate with red matrix; shale, limestone, and tuffaceous sandstone fragments.
1.0	Tuffaceous sandstone.	Pale-green, thin-bedded, fine-grained sandstone, volcanic fragments.
(Bottom)	Red conglomerate.	(Main body of formation.)

GEOLOGIC SETTING

The oldest rocks in the region are phyllites, sericite schists, limestones, and conglomerates, which crop out 3 kilometers west of the city in Arroyo de La Pimienta. These rocks are probably of Paleozoic age and have



Arithmetic mean azimuth, N. 15° W.
Standard deviation, 26°54′
Probability of no orientation, 5.8 in 100

FIGURE 40.—Summary of statistical data on 10 channels at the top contact of the red conglomerate between kilometers 150 and 155, near Taxco, Guerrero.

been intensely folded. They are overlain unconformably by greenstones and phyllites of Upper Triassic age (Burckhardt, 1906, p. 10; Mapes, 1949, p. 10). Small outcrops of rocks of Jurassic age, lying unconformably on the pre-Triassic schists, are recognized by Mapes (1949, p. 11); no fossils verify this dating. The upper part of the "roca verde", of Burckhardt, is a green rock, extending essentially as a sheet over all of the older rocks. Ordóñez (1900, p. 26) called this green rock an andesite that grades into a diabase and gabbro. At Zacatecas, a terrestrial red conglomerate lies unconformably above the upper "roca verde."

THE RED CONGLOMERATE

DISTRIBUTION

The red conglomerate crops out in an area only 8 kilometers long from east to west and 2 to 4 kilometers wide, with the city of Zacatecas at its western limit. It is cut off to the north by the Veta de La Cantera, the main silver-producing vein of the Zacatecas mining district, which strikes N. 78° W. and dips 50° to 60° SW. The vein occupies a fault and is about 20 meters wide and 11 kilometers long. The conglomerate is covered by alluvium in the valley to the east, goes beneath the volcanic rocks of Mesa del Cerrillo to the south, and lies on the upper "roca verde" to the west.

An isolated patch of conglomerate was found 5.5 kilometers southwest of Zacatecas. No other conglomerate is reported in this region (Burckhardt, 1906, Carte Geologique).

COMPOSITION

The red conglomerate is heterogeneous in composition. Its constituents are listed in table 12. Pebbles of sedimentary rock are most abundant and probably represent most of the various deformed marine rocks now exposed west of Zacatecas. The green igneous pebbles were derived from the upper "roca verde", which directly underlies the conglomerate at Zacatecas. Although no other pebble counts were made, the same constituents of pebble and cobble size were seen in other exposures.

CHANGES IN COMPOSITION AND TEXTURE

Based on the information from these two pebble counts and from recorded composition variations in nearby arroyos, the following generalizations seem to be valid. Passing upward in the conglomerate, the percentage of pebbles of sedimentary rock increases; the percentage of volcanic rock, including the "roca verde", decreases; and the percentage of granite increases. Although a few 30-centimeter volcanic and granite cobbles were found near the base of the conglomerate at Zacatecas, most of the lower beds contain only 5- to 10-centimeter pebbles. Upward in the conglomerate section, fragments 30 centimeters in diameter become more abundant.

BASAL RELATIONS

The upper "roca verde" lies beneath the conglomerate wherever its basal contact is exposed near Zacatecas. The relief on this unconformity is at least 25 meters at kilometer 749.75 on the highway. The unconformity rises to the south from Zacatecas toward a source, or an island inlier, that has since been truncated and buried by volcanic rock. In the area 5.5 kilometers southwest of Zacatecas, the base of the conglomerate is not exposed. Beneath a covered zone, tightly folded, thin-bedded argillites crop out, upon which the conglomerate probably lies.

TABLE 12.—*Pebble samples from the red conglomerate at Cacatecas*

Constituents [1]	Pebble sample 1		Pebble sample 2	
	Number	Percent	Number	Percent
Sediments:				
Argillaceous	28	9.3	185	61.7
Siliceous	53	17.5	36	12.0
Granite	58	19.1	30	10.0
Volcanic rocks [2]	36	11.9	8	2.6
Green igneous	64	21.1	35	11.7
Miscellaneous	64	21.1	6	2.0
Total	303	100.0	300	100.0

[1] Each rock name used in the pebble-count tabulations includes a variety of more specific rock types.
[2] The volcanic pebbles range from andesitic to rhyolitic.

Note: Pebble sample 1 was taken 34 meters from the base of the conglomerate, in a bed containing pebbles 2 to 10 centimeters in maximum diameter, near the mouth of the arroyo flowing south from between the two "bufas" northeast of Zacatecas.
Pebble sample 2 was taken 182 meters from the base, or 212 meters from the top of the conglomerate, in the same arroyo as 1. These pebbles also were 2 to 10 centimeters in maximum diameter.
"Miscellaneous" in sample 1 includes, in order of decreasing abundance, the following unit constituents: silicic volcanic, 23; tuffaceous sandstone, 12; volcanic breccia, 6; quartz, 6; chalcedony, 5; chlorite schist, 3; calcite, 2; limestone, 1; and sandstone, 1.
"Miscellaneous" in sample 2 consists only of quartz-veined shale.

RELATIONS WITH THE OVERLYING VOLCANIC ROCK

On the south side of Cerro de La Bufa, 1 kilometer northeast of Zacatecas, coarse-grained massive rhyolitic tuffs and volcanic breccias, which contain lava fragments as large as 30 centimeters in maximum diameter, rest with slight disconformity on the red conglomerate. Only pyroclastic material, consisting of angular silicic lava fragments imbedded in coarse tuffs, occurs above this contact. These rhyolitic volcanic rocks and the conglomerate terminate northward against the Veta de La Cantera, toward which they dip about 14°. The north slope of Mesa del Cerrillo, southeast of Zacatecas, has the same sequence as that just described, except that the volcanic section rests with slight angular unconformity on the conglomerate and upper "roca verde."

ISOLATED OUTCROP AREA

The conglomerate located 5.5 kilometers southwest of Zacatecas is different in several ways from that exposed at Zacatecas. It rests on deformed shale and is conformably overlain by 89 meters of massive to thin-bedded tuffaceous sandstone. A 9.6-meter cliff-forming rhyolite caps these tuffs. The only pebbles in the red conglomerate at this site are volcanic rock, shale, and quartz. The first two types are found throughout the exposed section, whereas the milky vein-quartz pebbles are rare and occur only near the top. Volcanic pebbles, largely in a tuffaceous matrix, are most common; the largest was 47 by 16 centimeters in exposed dimensions. Loose sands and gravels and well-cemented sandstones and conglomerates occur close together stratigraphically. The tuff beds and sandstones can be traced for several hundred meters and therefore they are useful as markers for measuring thickness. Faulting has affected these beds only slightly; however, dips of less than 5° occur in various directions.

THICKNESS

One 418-meter section of conglomerate was measured at Zacatecas; the location was discussed under pebble sample 1, table 12. The conglomerate pinches out to the south beneath the volcanic cap of Mesa del Cerrillo, 2 kilometers south of Zacatecas. The conglomerate section 5.5 kilometers southwest of Zacatecas is 58 meters thick, but the base is not exposed. Its total thickness, assuming no faulting, is 133 meters or about one-third of that at Zacatecas. It should be remembered that the conglomerate is absent for a distance of 4 kilometers between these two areas.

PRIMARY STRUCTURES

The beds range from a few centimeters to several meters in thickness and average ½ meter or less. The degree of sorting varies from very poor to good. Cross-bedding and channeling were seen in a few places, and fluviatile graded bedding is common. Most of the individual beds of sand or conglomerate can not be traced laterally for more than 50 meters because the beds are lenticular.

SOURCE AND DIRECTION

The source areas that provided materials to form this conglomerate must have had as many types of rock exposed as were reported in the pebble samples, plus other types not recognized. All rock types contained in the conglomerate in considerable quantity, except some of the (included) volcanic rocks and the granite, can be found today in the region north and west of Zacatecas. The nearest granite intrusive known to the writer is 40 kilometers northeast of Zacatecas (Mapes, 1949, p. 15). Closer granite bodies may now be buried by volcanic rock. Volcanic fragments are much more abundant in the conglomerate southwest of Zacatecas, where nearby volcanism must have occurred before and during conglomerate deposition.

These, and other areas of conglomerate accumulation, were probably intermontane basins. The two preserved outcrop areas were not connected, as evidenced by differences in composition and by their present isolation.

The source of the conglomerate was not limited to only one side of each basin. The area between the two conglomerate basins, which contains shales and volcanic rocks, probably provided material to both basins. Several small channels in the conglomerate beds near the pebble sample localities trend from due north to N. 20° W. The granite seems to have come from the north, because it is present in the northern basin and absent from the southern one. Thus, it appears that the principal source of this red conglomerate was north of Zacatecas. The pyroclastic debris that blankets the conglomerate also had a source north of Zacatecas because it becomes finer to the south.

AGE

Only fossils of Upper Triassic age have been found in the Zacatecas region. The sequence of the post-marine rocks at Zacatecas is the same as that at Guanajuato and Taxco. Volcanic rocks precede and succeed the red conglomerate. Ordóñez has assigned the red conglomerate at Zacatecas to the Miocene epoch; he states that the overlying rhyolitic volcanic rock is of Pliocene age (1900, p. 26). By analogy with the Guanajuato area, however, the conglomerate seems more likely to be principally of Oligocene age, and the volcanic rock may in large part be of Miocene age.

CONCLUSIONS

The stratigraphic sequence is essentially the same in the three widely separated areas discussed in this report. Strongly deformed and deeply eroded marine rocks of Mesozoic age are overlain unconformably by red conglomerates or by pre-red-conglomerate volcanic rocks. The conglomerates have lavas or tuffs interbedded with them and are abruptly and conformably overlain by volcanic rocks. The other known areas of red conglomerate in Mexico (fig. 17) have the same general stratigraphic relationships. This does not mean that similar stratigraphic units in different areas are time equivalents, but it does mean that the sequence of geologic events in all these areas in post-marine time was essentially the same.

No soundly based age had previously been determined for any of the pre-Pliocene non-marine rocks of Tertiary age of central Mexico. A fossil-vertebrate locality found in the Guanajuato red conglomerate during the course of this study has yielded material indicating a late Eocene or early Oligocene age for the lower part of this conglomerate, and it has made possible, for the first time, a sound interpretation of the general age of these old red terrestrial deposits.

Upon cessation of marine sedimentation in central Mexico, which occurred before the end of Late Cretaceous time (Imlay, 1938, p. 1692), terrestrial conditions were established and have continued uninterruptedly to the present time. The retreat of the sea from central Mexico preceded the Laramide orogeny, which affected all the rocks in the Mexican geosyncline. The culmination of this orogeny and the main folding of the eastern Sierra Madre occurred in early and middle Eocene time (Böse, 1927, p. 142). The main folding in the central plateau west of the Sierra Madre may have occurred somewhat earlier, beginning in latest Cretaceous or earliest Tertiary time. This was followed by general uplift, block faulting, volcanism, and conglomerate deposition in late Eocene and early Oligocene time.

A very different climate from that of today prevailed in central and northern Mexico during early Tertiary time. Fossil plants in the basal tuffs that unconformably overlie rocks of Upper Cretaceous age in the Barrilla Mountains of Trans-Pecos Texas indicate that during early Eocene time a warm temperate climate with abundant precipitation prevailed in that region (Berry, 1919, p. 3). The red color of the conglomerates discussed in this present report is further evidence of a humid temperate climate in the source areas of the conglomerates, because their red color is due to eroded and redeposited red soils that typically develop in such a climate.

From the nature and angularity of the unconformities between the marine rocks of Mesozoic age and the volcanic rocks or conglomerates that rest on them, it is certain that enormous quantites of rock were removed during early Tertiary time. These great quantities of debris must have been carried in large part to the sea, probably eastward to the Gulf of Mexico, because no known deposits in central Mexico can account for more than a small part of the material, although some of it probably was removed in later Tertiary time. Volcanism accompanied this early Tertiary erosion cycle over large parts of Mexico, as evidenced, for example, by the pre-red-conglomerate volcanics at Zacatecas, Zac., Guanajuato, Gto., and Taxco, Gro.

Either by uplift and block faulting or by volcanic damming of drainage systems, or both, interior drainage basins were formed in central Mexico by late Eocene time. As a result of continuous volcanism, red conglomerates accumulated in these basins. In Oligocene and Miocene time, volcanism broke out on a huge scale over large parts of Mexico, thus causing quick burial and preservation of the red conglomerates. Later block faulting helped to preserve these conglomerates in the down-faulted blocks. This later faulting and a probable general uplift have contributed to the formation of the present topographic surface.

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