BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 49, PP. 1651-1694, 7 PLS., 6 FIGS. NOVEMBER 1, 1938

STUDIES OF THE MEXICAN GEOSYNCLINE

BY RALPH W. IMLAY

CONTENTS

ILLUSTRATIONS

ABSTRACT

The Melchor (San Pedro) Ocampo region lies on the boundary of Coahuila and Zacatecas in the central part of a broad belt of eastward-trending folds characterized by strong asymmetry. In contrast to the region farther north, the Jurassic limestone is extensively developed and forms the highest parts of the mountain ranges; the Cretaceous rocks form the foothills. About 100 square miles adjacent to Melchor Ocampo was studied intensively as a foundation for reconnaissance studies in adjoining areas.

During the Upper Jurassic and Lower Cretaceous epochs the distribution of marine facies of deposition was controlled by erosion from the Coahuila Peninsula to the north. The seaward margins of the clastic facies and the limestone reef facies approximately coincide with the southern side of the Sierras de Parras and Jimulco. Facies of Upper Cretaceous marine sedimentation were controlled by rising land masses in central Mexico, as shown by increasing thickness of clastics toward the south.

Folding in northern Zacatecas involves both the Jurassic and the Cretaceous beds and apparently occurred at the same time as that farther north. The Jurassic formations become progressively more elevated toward the south and in general are as intensely folded as the Lower Cretaceous formations of the Sierras de Parras and Jimulco in Coahuila.

The greater height of the ranges bordering the site of the Coahuila Peninsula (*e.g.*, Sierras de Parras, Jimulco, Rosario) than that of the ranges farther south, is ascribed (1) to the presence of the thick rudistid-bearing Aurora limestone, and (2) perhaps to less intense orogeny with consequent less effective erosion.

INTRODUCTION

The Melchor (San Pedro) Ocampo area in north-central Mexico on the boundary of Coahuila and Zacatecas was selected for study because of the extensive development of Upper Jurassic limestone which, in contrast to the region to the north, comprises the central and highest parts of the mountain ranges. The Cretaceous rocks form the foothills. An area of about 100 square miles adjacent to the village of Melchor Ocampo was

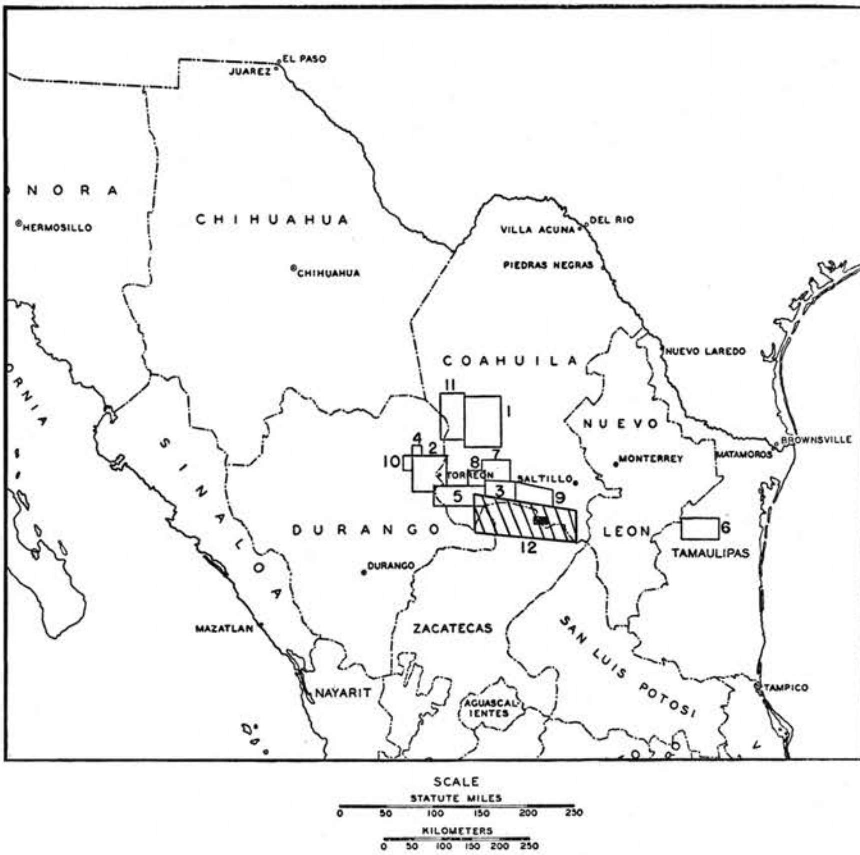


FIGURE 1.—*Index map of northern Mexico*

Hatched area covered in reconnaissance. Other blocked areas have been mapped.

(1) Mountains bordering the valleys of Acatita and Las Delicias,
(2) Mountains west of the Laguna District,
(3) Western part of the Sierra de Parras,
(4) Area northeast of Mapimi,
(5) Sierra de Jimulco,
(6) San Carlos Mountains,
(7) El Pozo-Boquillas area,
(8) Sierra de la Peña,
(9) Middle part of Sierra de Parras,
(10) Sierra del Rosario,
(11) Sierra de Tlahualilo,
(12) Melchor Ocampo Area.

studied intensively as a foundation for reconnaissance studies in contiguous areas of about 4000 square miles, between the Sierra de Parras on the north and Mazapil on the south. This large area was studied with particular regard to the distribution of the off-shore marine facies of the Jurassic and Cretaceous systems. The present paper gives the results of these studies and makes comparisons with the areas previously studied in southern Coahuila and eastern Durango. It is a summary contribution to the geological studies in northern Mexico which were started by Professor Lewis B. Kellum in 1932.

ACKNOWLEDGMENTS

The field work on which this paper is based was carried on during the summers of 1936 and 1937. It was supported by grants from The Geological Society of America and the Horace H. Rackham School of Graduate Studies of the University of Michigan. Laboratory work on the faunas and preparation of the manuscript were made in the Horace H. Rackham School of Graduate Studies. Recognition is made of the generous assistance of Mr. William Kane and Mr. Frank Narro of Saltillo, especially concerning the matter of proper introduction to local authorities. Thanks are due Mr. Carlos Rettich, an American miner near Melchor Ocampo, for his aid. To Professor Walter F. Hunt the writer is indebted for checking the rock determinations and for making the more difficult determinations. Mr. Richard Liddicoat served as field assistant in 1937 and receives credit for the identifications of the minerals.

EARLIER INVESTIGATIONS

Most of the present knowledge of the geology of the mountains near Mazapil and Concepción del Oro, Zacatecas, is due to the efforts of Carlos Burckhardt (1906a, b; 1930, p. 46-51). In the Sierra de Zuloaga the Upper Jurassic limestones were first recognized by Aguilera (1895, p. 19, 20). In 1910 and 1921 members of the Geological Institute of Mexico made a study of the phosphate deposits of the Sierra Zuloaga, and part of the information obtained was published by Burckhardt (1930, p. 49-50, figs. 16, 19a, b). The sections of the Upper Jurassic marly beds, called La Caja formation in this report, were carefully measured by Burckhardt along artificial trenches. Information concerning the hills near Symón and the low Sierra Ramirez is due to Böse (1923b; Burckhardt, 1930, p. 55, p. 127, figs, 17, 18). A summary of these earlier works was made by Burckhardt in 1930. The area north and northwest of the Sierra Zuloaga and south of the Sierra de Parras has not been previously described. The writer has spent some time in the region of Mazapil, Zacatecas, as well as at San Pedro del Gallo, Durango, and considers Burckhardt's field observations highly reliable.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

A belt of eastward-trending mountains and valleys constitutes the dominating topographic feature of southern Coahuila, northern Zacatecas, and adjoining parts of Nuevo León and Durango (Fig. 3). The physical features of the northern part of the belt have been described in previous papers (Böse, 1923a; Kellum, 1932, 1936; Imlay, 1936, 1937a; Jones, 1938). The present paper deals only with the southern part. The general features of the entire belt are similar, but south of the Sierras de Parras and Jimulco the mountains are lower, and the valleys wider than in the northern part, although altitudes remain high owing to increasing elevation of the Mexican Plateau toward the south. A bird's-eye view of this southern area would show a central group of eastward-trending mountains, separated from the Sierra de Parras on the north by a continuous plain of varying width, and bounded on the east and west by large northwestward-trending alluvial basins,—the Bolsones de Jalapa and Cedros—beyond which lie mountains that trend variously east-southeast to south-southeast.

In comparing the ranges of northern Zacatecas with the Sierras de Parras and Jimulco in Coahuila, it may be especially noted that the development of pediments has reached a more advanced stage in Zacatecas, which might imply a longer time for erosion or a drier climate toward the south. However, neither possibility seems likely. Uplift and folding apparently occurred at about the same time over the entire area, and the climate today is more humid toward the south. The greater height of the ranges bordering the site of the Coahuila Peninsula (*e.g.*, Sierras de Parras, Jimulco, and Rosario) than of the more distant ranges on the south is ascribed primarily (1) to the presence of the thick rudistid-bearing Aurora limestone, and (2) perhaps to less intense orogeny with consequent less effective erosion.

CULTURE

Farming, on a minor scale, is carried on in all northern Zacatecas, including the higher mountain valleys. Stock-raising is confined principally to goats and burros. It is said that before the Mexican revolution cattle ranged in vast numbers, but today they are uncommon, although pasturage is available. Mining is the main occupation in the vicinities of Mazapil, Concepción del Oro, Melchor Ocampo, and Trébol, in the mountains west of La Ventura, and in most of western Zacatecas. On the plains the principal occupations are the gathering of guayule for rubber, of candelilla for wax, and of istle for rope. Charcoal-making from mesquite is common on the plains of northwestern Zacatecas. In addition, various medicinal plants, growing in certain areas, constitute a minor source of income. A particularly choice variety of the plant used in making angostura bitters grows in abundance on Sierra Zuloaga.

TABLE 1.—*Correlation of Jurassic and Cretaceous deposits of north-central Mexico*

European Equivalents			Texas Groups	Northeastern Mexico	Mazapil & Melchor Ocampo Areas (R. W. Imlay)	Middle part of Sierra de Parras (R. W. Imlay)	Western part of Sierra de Parras (R. W. Imlay)	Sierra de Jimulco Cañones Alamo & San Pedro (R. W. Imlay & L. B. Kellum)	Mts. west of Laguna District (Modified after L. B. Kellum)	Unit
UPPER CRETACEOUS	Senonian	Maestrichtian	Navarro							
		Campanian	Taylor	Mendez shale	?	Difunta formation ?	Difunta formation ?			
		Santonian			Parras shale ?	Parras shale	Parras shale			
		Coniacian	Austin	San Felipe: Upper San Felipe limestone	Caracol formation	Caracol formation	Indidura formation			
		Turonian	Eagle Ford	San Felipe: Agua Nueva formation	Indidura formation	Indidura formation			Indidura formation	
		Cenomanian	Woodbine							
			Washita							
LOWER CRETACEOUS		Albian	Fredericksburg	El Abra and Upper Tamaulipas limestone	Cuesta del Cura limestone	Cuesta del Cura ls.	Cuesta del Cura ls.			
			Trinity			Aurora limestone	Aurora limestone	Aurora limestone	Aurora limestone	
		Aptian	?	Lower Tamaulipas limestone	La Peña formation ?	La Peña formation ?	La Peña formation ?	La Peña formation ?	La Peña formation ?	1
	Neocomian	Barremian			Cupido limestone	Cupido limestone	Parritas formation ?			
		Hauterivian	?				Las Vigas fm.	Las Vigas fm.	Las Vigas fm.	2
		Valanginian	Torcer formation		Taraises formation	Taraises formation ?	Taraises formation ?	Taraises formation ?	Taraises formation ?	3 4 A
		Berriasian	? Hiatus ?					Hiatus ?	Present (?) ?	
JURASSIC		Tithonian	Malone formation		La Caja formation	Hiatus	Hiatus	La Casita formation	La Casita formation	B
		Portlandian				La Casita formation	La Casita formation			
		Kimmeridgian	?						?	C
		Oxfordian			Zuloaga limestone	La Gloria formation	La Gloria formation	La Gloria formation	La Gloria formation	D E

SEDIMENTARY ROCKS

GENERAL DISCUSSION

The sedimentary rocks of northern Zacatecas and southern Coahuila are mainly of Upper Jurassic and Cretaceous age. In addition, red beds of Permo-Triassic age occur in the mountains west of La Ventura, and a few hundred feet of late Cenozoic deposits are found in the valleys. Upper Jurassic limestone crops out over wide areas and constitutes the main parts of all the mountain ranges. Lower Cretaceous strata occur mainly on the lower slopes of the mountains or as isolated erosional remnants on the plains. Upper Cretaceous strata have been found only in the broad, eastward-trending synclinal valleys south of the middle part of the Sierra de Parras but undoubtedly underlie the alluvium in some of the bolsons. The formations and their approximate thicknesses are as follows:

Formations in northern Zacatecas, Mexico

	Feet
Quaternary:	
Mayrán formation	800+
Upper Cretaceous:	
Parras shale	2000+
Caracol formation	3350
Indidura formation	560– 635
Lower Cretaceous:	
Cuesta del Cura limestone	830–1025
La Peña formation	260– 388
Cupido limestone	862–1123
Taraises formation	332– 463
Upper Jurassic:	
La Caja formation	140– 270
Zuloaga limestone	1800+
Total	10,934–11,854

JURASSIC SYSTEM

Zuloaga limestone.—The Zuloaga limestone (Pl. 3, fig. 3; Pl. 1, fig. 2) is the off-shore equivalent of La Gloria formation and is distinguished from the latter by the absence of sandstone and shale. It is overlain by a series of thin-bedded limestone, marl, and shale of Upper Jurassic age, defined later in the paper as La Caja formation. Its base is not exposed near Melchor Ocampo, but about 40 miles to the southeast in the mountains west of La Ventura it overlies red beds. The type locality is designated as the Sierra Sombreretillo north of Melchor Ocampo.

The Zuloaga limestone is the main mountain-forming limestone south of the Sierras de Parras and Jimulco. In the belt of eastward-trending mountainous folds between Mazapil and the Sierra de Parras the formation occupies the central and highest parts of the mountains. In the southward-trending folds west of La Ventura the formation comprises

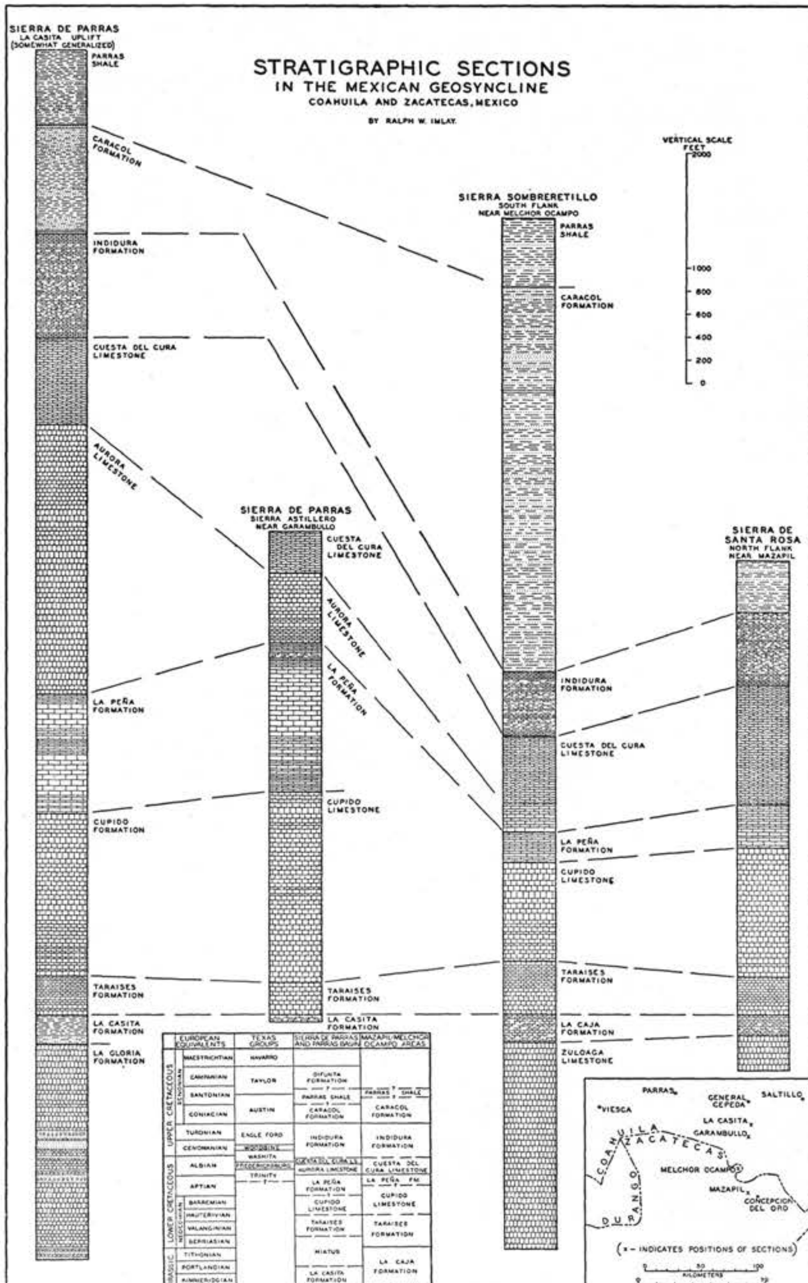


FIGURE 2.—*Stratigraphic sections in the Mexican geosyncline*

almost the entire mountain mass. It constitutes the bulk of the Sierra Yeso and the eastern part of the Sierra Jimulco, as well as the ranges toward the south, whereas the Lower Cretaceous rocks in most places are reduced to low hills.

The Zuloaga limestone is mainly thick-bedded. Beds as thick as 10 feet have been observed, and beds from 3 to 5 feet thick are common. The dominant color is dark gray, but some beds in the middle and lower parts of the formation are medium to light gray. In most sections the upper 20 feet contains a few black chert nodules. Locally some beds contain poorly preserved bivalves or gastropods or corals. On Sierra Sombreretillo about 1800 feet is exposed. On the east slope of the mountain, 6 miles southwest of La Ventura, the complete formation above the red beds is about 1200 feet thick. At this locality certain limestone beds in the lower 450 feet are pinkish gray. The underlying red beds, exposed along the axis of an anticline, are about 20 feet thick and consist of red shale, red sandstone, and conglomerate. The conglomerate consists of angular masses of red shale, red sandstone, and yellowish quartzite. The pieces of shale and sandstone range from small particles to more than a foot in diameter. Their size and poor rounding suggest slightly reworked mantle rock.

The Zuloaga limestone is apt to be confused with the Lower Cretaceous limestones but is somewhat darker, generally contains more calcite veinlets, and is thicker-bedded.

The Zuloaga limestone is of Upper Jurassic age and probably belongs in the Oxfordian. It is correlated with La Gloria formation of the Sierra de Parras (Imlay, 1936, p. 1105). It was called "the *Nerinea*-bearing limestone" by Burckhardt (1930, p. 46).

La Caja formation.—La Caja formation (Pl. 1, fig. 2; Pl. 3, fig. 3) consists mainly of thin-bedded limestones and marls and is the off-shore equivalent of La Casita formation, although its highest beds may be somewhat younger. Its contacts are sharply demarcated from the thick limestones of the underlying Zuloaga limestone and of the overlying Taraises formation. The type locality is designated as the Vereda del Quemado, on the Sierra de la Caja, north of Mazapil, Zacatecas (Burckhardt, 1930, fig. 14).

La Caja formation occurs in narrow strips around the outcrops of the Zuloaga limestone and is coextensive with the latter except at the western end of the Sierra de Atajo where it is replaced by the gypsiferous shales and sandstones of La Casita formation. La Caja formation weathers rapidly and exposures are poor except on the divides between canyons.

Numerous sections in the Sierras de Santa Rosa, La Caja, Canutillo, and Zuloaga were measured and described by Burckhardt (1930, p. 47-54, figs. 13-16, 19). Sections near Symón and in the Sierra Ramirez, Zacatecas, were measured by Böse and described by Burckhardt (1930, p. 55, 58). The thickness ranges from 140 to 300 feet.

The type section of La Caja formation on the Vereda del Quemado, Sierra de la Caja, was studied by Burckhardt (1906a, 1930). In 1936 the writer rechecked the section and collected fossils from the various beds. Burckhardt's description (1930, p. 52) of the section, from top to bottom, may be translated as follows:

Unit	Meters
1. Limestones, marly and shaly, brownish and whitish, with intercalated beds of black chert and gray limestone. *Kossmatia* cf. *richteri* Oppel, *Berriasella* gr. of *calisto* d'Orbigny, *Harpoceras* sp.	8±
2. Marls and shales, brownish, and intercalated gray limestone	3
3. Bed of grayish, phosphoritic limestone with *Cucullaea phosphoritica* Burckhardt	?
4. Limestones, phosphoritic, grayish, and intercalated with breccia-like limestone. *Pseudolissoceras subrasile* Burckhardt, large *Perisphinctes* (above)	3
5. Marls and shales, brownish, with a bed of black limestone. *Oppelia mazapilensis* Burckhardt	3
6. Limestones, phosphoritic, reddish with black spots. *Phylloceras apenninicum* Canavari, *Mazapilites zitteli* Burckhardt, *M. fissilobatus* Burckhardt, "*Perisphinctes*" *aguilari* Burckhardt, "*P.*" cf. *nikitini* Michalski, *Aspidoceras cyclotum* in Steuer, *A. fallax* Burckhardt, *A. phosphoriticum* Burckhardt, *A. cajense* Burckhardt, *A. zacatecanum* Burckhardt, *Cucullaea,* bivalves	1½
7. Shales, brownish, with one bed of limestone	30
8. Limestone, black, with "*Haploceras*" *fialar* Oppel, *Haploceras costatum* Burckhardt, "*Craspedites*" *mazapilensis* Burckhardt, "*C.*" *praecursor* Burckhardt, *Phylloceras* aff. *consanguineum* Gemmellaro	1
9. Beds with *Idoceras.* Marls, shales, and marly limestone, brownish and yellowish, with nodules of fossiliferous, compact, black limestone. Contains *Oppelia boesei* Burckhardt, "*Perisphinctes*" aff. *cyclodorsatus* Moesch, *Aspidoceras quemadense* Burckhardt, *A. bispinosum* Quenstadt, *A. mazapilense* Burckhardt, *Idoceras* cf. *zacatecanum* Burckhardt, *I.* cf. *hospes* Neumayr, *I. laxevolutum* Fontannes, *I. cajense* Burckhardt, *I. inflatum* Burckhardt, *Aulacostephanus* sp., *Lytoceras* sp.	30±
10. Limestone, reddish and black, compact, with lustrous surfaces. Contains *Trigonia* aff. *hudlestoni* Lycett	2
11. Marls and marly shales, gray and brownish. A few cm.	
Total	82± (269 feet)

Progressively upward in all sections of La Caja formation the deposits become finer and more calcareous. In adjoining areas the lithologic divisions appear similar, but Burckhardt (1930, p. 47-49) has shown that they cut across the paleontologic horizons and become younger toward the south. The highest unit of whitish shaly and marly limestones, containing *Substeueroceras,* is very distinctive lithologically because of the peculiar ashy appearance of many beds. This lithologic type occurs over wide areas, being noted in the Sierra Ramirez, the Sierrita del Chivo, the

FIGURE 1. NORTHERN FRONT OF SIERRA SANTA ROSA
Valley of Mazapil in foreground.

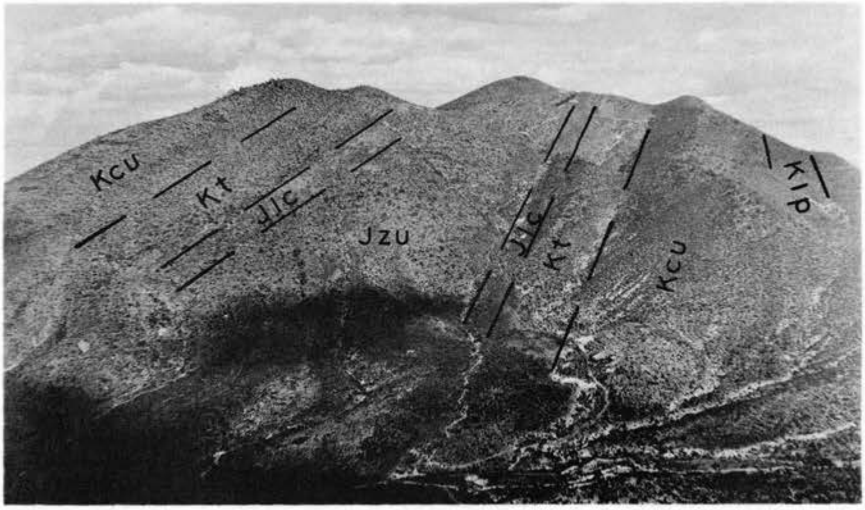


FIGURE 2. EAST WALL OF CAÑÓN SAN FRANCISCO
Jzu, Zuloaga limestone; Jlc, La Caja formation; Kt, Taraises formation; Kcu, Cupido limestone; Klp, La Peña formation.

MOUNTAINS

FIGURE 1. PORPHYRY—LA PEÑA FORMATION FAULT CONTACT
Slightly south of crest of Sierra Zuloaga due south of Cañón San Francisco. Hammer indicates direction of fault contact. La Peña formation on right.

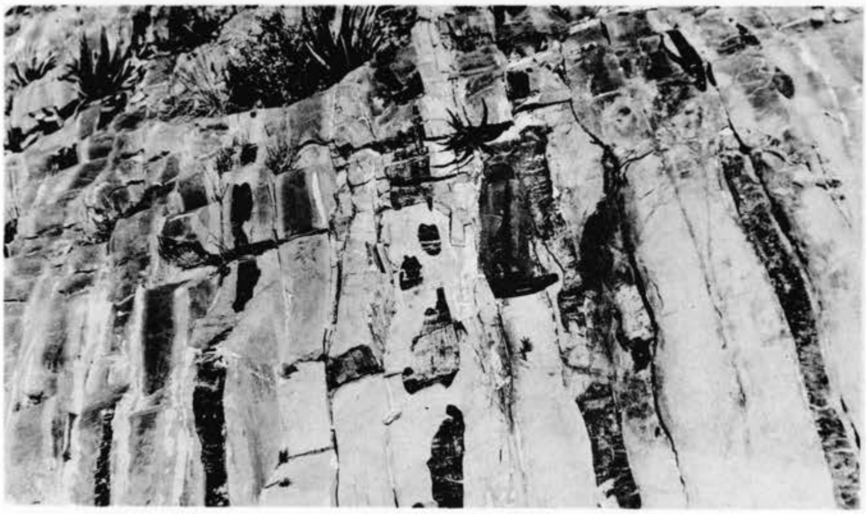


FIGURE 2. CUESTA DEL CURA LIMESTONE AND CHERT
Vertically dipping beds on south flank of Zuloaga Anticline on trail south of Cañón San Francisco.

FORMATIONS AND FAULTS

mountains near Melchor Ocampo and Mazapil, the mountains west of La Ventura, and even in the Sierra Madre Oriental of the State of Tamaulipas. Burckhardt (1930, p. 55-59, 74-75) has discussed in considerable detail the phosphatic limestones of upper Kimmeridgian and Portlandian age. He shows that from the Sierra Zuloaga southward the facies diminishes in thickness and appears at successively higher horizons. The facies diminishes rapidly toward the east in the vicinity of Concepción del Oro, and on the west is practically absent in the Sierra de Ramirez. Burckhardt believes that the abundance of bivalves in the former and the richness of cephalopods in the latter indicate that the phosphatic facies was deposited in slightly shallower water than the adjacent nonphosphatic beds. He conjectures that the phosphatic beds were formed when there was a submarine ridge which appeared first in the north and then spread southward. This explanation accords with the facts observed in the Sierras de Parras, Atajo, and Jimulco. The gypsiferous and carbonaceous beds in the Upper Jurassic of those areas imply lagoonal conditions and therefore some sort of barrier to the south.

Fossils found by the writer at localities not previously described are here listed. In the Sierras Zuloaga and Sombreretillo, La Caja formation is not rich in fossils except in the horizon of *Glochiceras fialar* (Oppel). In other horizons the material is scarce and very poorly preserved. About 2 miles south-southeast of Melchor Ocampo just south of the crest of Sierra Zuloaga, a collection made about 100 feet from the base of La Caja formation included *Glochiceras fialar* (Oppel), *Haploceras zacatecanum* Burckhardt, *H. transatlanticum* Burckhardt, H. aff. *mexicanum* Burckhardt, and *Involuticeras* n. sp. ind. About 2 miles northwest of Melchor Ocampo on the east side of the head of Cañón Sombreretillo, a collection made 50 feet from the base of the formation includes the above-mentioned species and *Haploceras costatum* Burckhardt. At the top of the formation at the same locality was found a specimen of *Berriasella* sp. Three miles northeast of Melchor Ocampo in Cañón del Escorpión, the highest unit of La Caja formation consists of whitish-gray, platy limestone about 25 feet thick. In the highest beds were found several species of *Parodontoceras* and *Substeueroceras.* The lower part of the unit contains black limestone concretions from which were obtained *Proniceras subpronum* Burckhardt, *P.* cf. *torresense* Burckhardt, and *P.* n. sp.

On the east front of Sierra de la Ventura about 6 miles southwest of La Ventura, Coahuila, La Caja formation crops out extensively. About 900 feet south of the Mina de San Francisco and 40 feet above the base of the formation were collected *Idoceras tuttlei* Burckhardt, *I.* cf. *balderum* Loriol, and *Glochiceras fialar.* A few feet higher in the section a limestone concretion yielded many specimens of *Glochiceras fialar* (Oppel), *Haploceras costatum* Burckhardt, *H. felexi* Burckhardt, *H. transatlanticum* Burckhardt, *H. zacatecanum* Burckhardt, and *H. mexicanum* Burckhardt. About a mile south of Mina de San Francisco on the northern slope of an eastward-trending spur from the main range, the same horizon occurs about 40 feet above the base of the formation. Certain crumbly limestone concretions furnished a large collection of well-preserved ammonites, including *Glochiceras fialar* (Oppel), many species of *Haploceras,* several perisphinctoid forms, and *Subneumayria* aff. *ordoñezi* Burckhardt.

Correlation.—La Caja formation is of Upper Jurassic age and, on the basis of Burckhardt's (1930, tables 4, 5, 6) work, belongs in the Tithonian, Portlandian, Kimmeridgian, and perhaps upper Oxfordian stages.

CRETACEOUS SYSTEM

Taraises formation.—The Taraises formation has recently been discussed in detail by the writer (1938, p. 541-544). Only additional information will be added here. North of Melchor Ocampo in the Sierra Sombreretillo and on the divide east of the head of Cañón Sombreretillo, the section, measured from top to bottom, is as follows:

Unit	Feet
1. Limestone, thin-bedded and marly, light gray; some beds pinkish gray; weathers light yellowish gray; some thin beds of black chert near base. Contains *Olcostephanus* sp., *Bochianites* ? sp., and *Distoloceras* ? sp.	215
2. Limestone, thick-bedded, light to medium gray	248
Total	463

Fossils can be found in the upper member of the Taraises formation wherever it is well exposed. About 2 miles from the east end of Sierra Zuloaga were found *Olcostephanus raricostatus* Böse and *Olcostephanus* sp. At the top of the west wall of Cañón San Francisco, about 4 miles southwest of Melchor Ocampo, the upper member yielded *Olcostephanus symonensis* Böse and *Neocomites* ? sp.

The Taraises formation is of Lower Neocomian age, and in northern Zacatecas appears to represent the Berriasian, Valanginian, and lower Hauterivian stages.

Cupido limestone.—The Cupido limestone in northern Zacatecas crops out widely along the lower slopes of the Sierras Santa Rosa, La Caja, Canutillo, Zuloaga, and Sombreretillo. It was not observed in the mountains west of La Ventura, or in the Sierras de Atajo and Yeso along the Coahuila-Zacatecas border. It occurs in the Sierrita del Chivo, northeast of Symón, Zacatecas.

The Cupido limestone of northern Zacatecas differ from the same formation in the Sierra de Parras only in being somewhat thicker-bedded.

The section on the Sierra Sombreretillo north of Melchor Ocampo, measured from top to bottom, is as follows:

Unit	Feet
1. Limestone, thick- to medium-bedded, medium gray; some beds pinkish or yellowish gray; some beds contain yellowish brown chert nodules which weather reddish	193
2. Limestone, thick-bedded, light gray	307
3. Limestone, medium- to thin-bedded, light gray	362
Total	862

The section on the north slope of Sierra de Santa Rosa north of Puerto Blanco (Burckhardt, 1906a, geologic maps), from top to bottom, is as follows:

Unit	Feet
1. Limestone, thick-bedded, light gray, contains nodules of reddish-gray chert which weathers reddish brown. Many beds 3 to 5 feet thick	525
2. Limestone, medium- to thick-bedded, medium gray	506
3. Limestone, medium- to thick-bedded, dark gray, weathers yellowish gray; contains pyrite concretions near base; many short lenses and nodules of black chert	92
Total	1123

No fossils have been found in the Cupido limestone, but it is probably of upper Hauterivian and Barremian age. In Zacatecas the youngest beds may be of lower Aptian age.

La Peña formation.—La Peña formation (Pl. 2, fig. 1) crops out in the same ranges as the Cupido limestone and forms the topographic depressions.

In northern Zacatecas, La Peña formation ranges from about 250 to 400 feet in thickness. At the top it consists of thin-bedded and platy limestone interbedded with thin lenses of black chert. This grades downward into somewhat thicker limestone interbedded with thick beds of black chert. The formation is easily distinguished from the Cuesta del Cura limestone by the absence of wavy bedding and the many platy beds.

The section on Sierra Sombreretillo, at the head of Cañón Sombreretillo, from top to bottom, is as follows:

Unit	Feet
1. Limestone, thin-bedded and platy, with shaly parting, yellowish gray; interbedded with many thin beds of black chert. Becomes thicker-bedded toward base	160
2. Limestone, thin- to medium-bedded, yellowish gray, interbedded with lenses of black chert. Some limestone and chert beds as much as 8 inches in thickness	100
Total	260

The section on the north flank of Sierra de Santa Rosa north of Puerto Blanco, from top to bottom, is as follows:

Unit		Feet
1.	Limestone, thin-bedded and platy, with shaly partings; dark gray to black, weathers yellow to buff, interbedded with many thin lenses of black chert	50
2.	Limestone, thin- to medium-bedded, with many thick lenses of black chert. Some limestone beds as thick as 18 inches, and many chert bands as thick as 8 inches	332
	Total	382

In most sections the thin-bedded limestones at the top of La Peña formation contain fragments of poorly preserved ammonites similar to those figured by Burckhardt (1906c, p. 191-195, pls. 42, 43). Most of the ammonites probably belong to the genus *Parahoplites* and indicate an upper Aptian or lower Albian age. No fossils were found in the lower part of the formation which may possibly be younger than the lower part of La Peña formation in the Sierra de Parras.

Burckhardt's studies (1925, p. 49-53) of the Rio Nazas in eastern Durango indicate that the marly beds below the middle Cretaceous limestone and chert represent both the upper Aptian and the basal Albian (Clansayes horizon). Kellum (1936, p. 1071) noted the same marly beds near Puerto Soldados and in the Puerto de San Isidro, near the southern end of the Sierra de Mapimí in eastern Durango. Along the northern front of the Sierra de Parras the marly beds below the Aurora limestone contain only upper Aptian fossils. Farther south in the Sierra de Parras the upper beds of La Peña formation contain a fauna slightly different from that along the northern front, but apparently of upper Aptian age. Burckhardt (1906c, p. 197-198) studied similar beds near Mazapil and concluded (1925, p. 53; 1930, p. 134) they were of early Albian age. It seems likely that at many localities the highest marly and thin-bedded limestones of La Peña formation may be of early Albian age. This point might be proved by a careful study of the fossil collections now available.

Cuesta del Cura limestone.—The Cuesta del Cura limestone was originally noted (Imlay, 1936, p. 1125) in the Sierra de Parras. From there it extends southward at least as far as Mazapil. To the west it has been observed by the writer along the southern side of the Sierra Jimulco and in the Sierrita del Chivo northeast of Symón. Böse (1923b, p. 30) noted similar beds near Camacho, Zacatecas, and Burckhardt (1910, p. 330-331) described similar beds in the Mesa del Cardenche southeast of San Pedro del Gallo, Durango. It has not been observed in the Sierras Hispaña or Mapimí in eastern Durango, or along the northern part of the Sierra Jimulco in Coahuila, or in the mountains west of La Ventura in southeastern Coahuila. It corresponds, at least in part, to the deep-water facies of the middle and upper Albian described by Böse and Cavins (1927, p. 64-65, 89-90, pl. 19) and Burckhardt (1930, p. 166-173). The best section observed by the writer is on the south slope of Sierra Zuloaga south of Cañón San Francisco (Pl. 2, fig. 2).

In northern Zacatecas the Cuesta del Cura limestone consists of two members transitional into each other. The upper member is identical lithologically with the Cuesta del Cura limestone of the Sierra de Parras section—*i. e.*, it consists of thin-bedded limestones that are wavy-bedded, dark gray to brownish black, and contains many bands of black chert. The lower member consists of units of medium-bedded limestones (Pl. 2, fig. 2) becoming somewhat thicker-bedded toward the base and containing nodules and lenses of black chert, which alternate with units of thin-bedded limestones and chert like those in the upper member, with less wavy bedding.

On the south flank of Sierra Sombreretillo, north of Melchor Ocampo, the section, from top to bottom, is as follows:

Member	Feet
1. Limestone, thin-bedded, wavy-bedded dark gray to brownish black, contains many thin lenses and bands of black chert	580
2. Limestone, medium- to thin-bedded, medium to dark gray. Units of medium-bedded limestone containing nodules and lenses of black chert alternate with units like member 1, but wavy-bedded. Lower 50 feet thicker-bedded than overlying beds	250
Total	830

On the north flank of Sierra de Santa Rosa north of Puerto Blanco, the Cuesta del Cura limestone is about 1025 feet thick and is similar to the section just described. Most of the limestone beds are thin, but some, especially toward the base, are as much as 14 inches thick.

The Cuesta del Cura formation has yielded no fossils but it lies between La Peña formation, which contains upper Aptian and perhaps basal Albian fossils, and the Indidura formation which presumably represents the same time equivalent as in the Sierra de Parras. Therefore, the age of Cuesta del Cura limestone in northern Zacatecas is mainly Albian, although the highest beds may belong in the Cenomanian. It is considered equivalent to both the Cuesta del Cura limestone and the underlying Aurora limestone of the Sierra de Parras section.

Indidura formation.—The Indidura formation crops out along the margins of the eastward-trending synclinal valleys in northern Zacatecas between Melchor Ocampo and Mazapil. Sections are fairly well exposed on the divides between arroyos.

The Indidura formation is sharply differentiated from the underlying Cuesta del Cura limestone at all localities. Its upper contact is placed at the base of the tuffs characterizing the Caracol formation. The complete section at the southern base of Sierra Sombreretillo, northwest of Melchor Ocampo, is 560 feet thick and consists of thin-bedded, platy, and shaly limestones, which are light gray to yellowish gray and weather yellowish gray to gray. The section becomes a little more shaly toward the top.

The complete section at the northern base of Sierra de Santa Rosa, southeast of Mazapil, from top to bottom, is as follows:

Unit	Feet
1. Shale, buff, containing a few beds of buff limestone from 1 to 8 inches in thickness	87
2. Limestone, shaly, mostly brownish black, some pinkish, weathers light yellowish gray to buff; contains a few beds of black limestone which weather orange	171
3. Limestone, platy to thin-bedded, dark gray to brownish black, thinly laminated	144
4. Limestone, platy, and shale, dark-gray to brownish black, thinly laminated	233
Total	635

The Indidura formation of northern Zacatecas is lithologically almost indistinguishable from the Indidura formation of the Sierra de Parras section. It occupies the same stratigraphic position and is probably of the same age.

Caracol formation.—The Caracol formation occurs in the large eastward-trending synclinal valleys from the middle part of the Sierra de Parras southward to Mazapil. It has not been observed in Zacatecas south of the Sierras Jimulco and Yeso and probably does not occur there. Its eastern and southern limits are not known. Excellent exposures of the complete section may be found northwest of Melchor Ocampo in the large valley between Sierra Sombreretillo and Sierra Zuloaga.

The section northwest of Melchor Ocampo, from top to bottom, is as follows:

Unit	Feet
1. Shale, mainly; some interbedded tuff as in unit 2	536
2. Tuff, and some shale. Tuff gray, friable, fairly coarse-grained, weathers yellowish gray	180
3. Shale, dark gray, predominant, but containing many thin beds of yellowish-brown tuff; some tuff beds as thick as 6 inches; several lenses of deep yellow limestone about 180 feet from top	1090
4. Shale and tuff interbedded in about equal amounts; tuff rather coarse-grained	182
5. Shale, dark gray and yellowish gray, but containing considerable yellowish-brown tuff which weathers deep red	425
6. Shale, dark gray and yellowish gray; contains many thin beds of yellowish-brown and brownish-black tuff which weather respectively brownish red and yellowish; some tuff beds as thick as 3 inches	825
7. Shale, dark gray; contains some beds of red and brownish-black tuff; a few thin lenses of deep yellow limestone in lower 70 feet	112
Total	3350

Examination of thin-sections of the tuffs from the above section revealed about the same composition as the tuffs of the Sierra de Parras section (Imlay, 1937a, p. 617-618). The groundmass consists of calcite

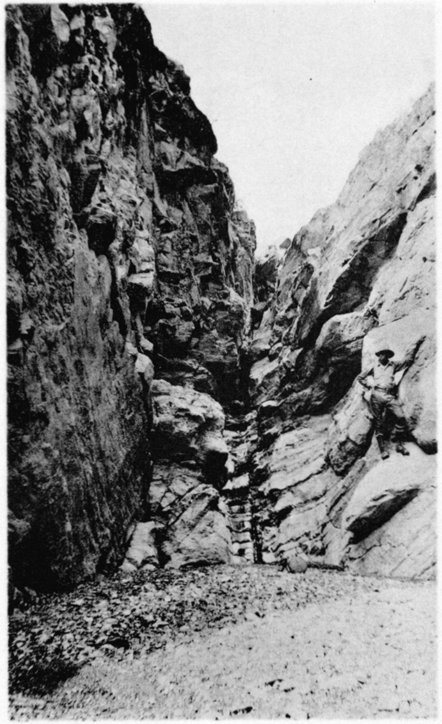


FIGURE 1. ALTERED CARACOL FORMATION
At falls in Arroyo San Pedro. Small fault in middle of arroyo bed.

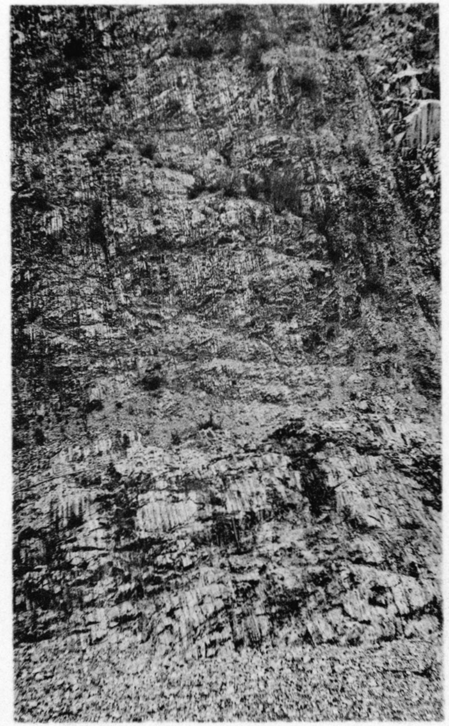


FIGURE 2. ALTERED CARACOL FORMATION
In Arroyo San Pedro two-thirds of a mile northeast of Melchor Ocampo.

FIGURE 3. LA CAJA FORMATION
On north wall of Cañón Toboso, near Symón, Durango. Man shown in circle. Jzu, Zuloaga limestone; Jlc, La Caja formation; Kt, Taraises formation.

FORMATIONS

FIGURE 1. EASTERN END OF SIERRA JIMULCO
South of Viesca.

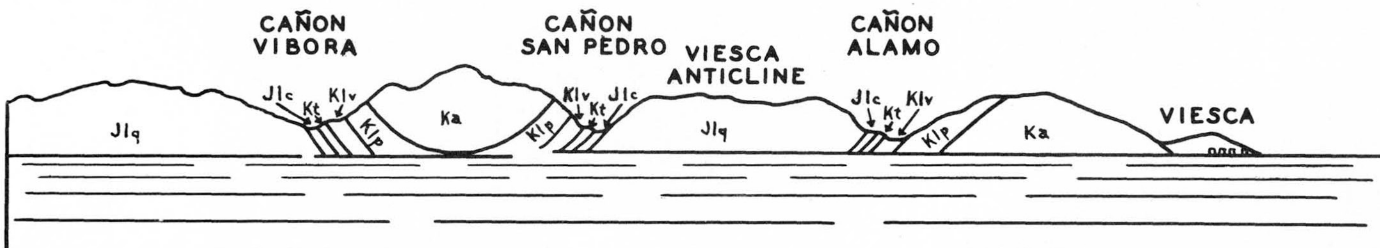


FIGURE 2. DIAGRAM OF STRUCTURE AND FORMATIONS
Shown in Figure 1. (Somewhat generalized.) Jlg, La Gloria formation; Jlc, La Casita formation; Kt, Taraises formation; Llv, Las Vigas formation; Klp, La Peña formation; Ka, Aurora limestone.

SIERRA JIMULCO

and less abundant cryptocrystalline quartz in which are embedded sharply angular grains of quartz, feldspar, biotite, and muscovite. Many quartz grains show wavy extinction. The feldspar is probably oligoclase. There is some chlorite derived from biotite. Hematite, limonite, and organic matter are common, and their varying proportions determine the color of the rock. The size of the grains ranges from small to fairly large in the various specimens examined.

The Caracol formation is exposed in the synclinal valley at Mazapil but is so highly folded that measurements are useless. Probably at least 1500 feet of the formation occurs in the valley. Examination of thin-sections showed that the tuffs have about the same composition as those near Melchor Ocampo.

The Caracol formation near Melchor Ocampo differs from the sections in the Sierra de Parras by being much thicker and containing a greater proportion of tuff. The shale is highly calcareous, mostly dark gray, but more abundant than the tuff. The contact with the Parras shale is drawn where beds of tuff become relatively scarce and inconspicuous, but there is no sharp line. In fact, unit 1 of the Melchor Ocampo section might almost as readily be placed in the Parras shale.

The Caracol formation of northern Zacatecas is correlated with the upper part of the Indidura formation near Parras, Coahuila, and is probably of Coniacian age. Its greater thickness toward the south is probably due to its proximity to the source of the tuff rather than to longer time of deposition.

Parras shale.—The Parras shale crops out in the valley at Melchor Ocampo, around the west end of Sierra Jasminal, along the southwest side of Sierra Gerónimo, and an unknown distance along the southern side of the Sierra de Parras east of the national railroad.

The Parras shale in northern Zacatecas is similar to that in the Parras Basin of Coahuila, although thin beds of tuff, or sandstone, are somewhat more abundant. In the synclinal valley at Melchor Ocampo the formation is about 2000 feet thick, and the lower 600 feet contains thin beds of tuff grouped in zones at irregular intervals. The upper part of the formation consists almost entirely of shale, excellently exposed in the arroyos immediately west of Melchor Ocampo.

In northern Zacatecas the Parras shale is the youngest Cretaceous formation exposed and probably represents only the lower part of the same formation in the Parras Basin.

QUATERNARY SYSTEM

Mayrán formation.—Limestone conglomerates and tufas of late Cenozoic age in the Sierra de Parras have been assigned by the writer (1936,

p. 1135; 1937a, p. 620) to the Mayrán formation. Similar conglomerates, associated with ash beds, along the southern side of the Sierra Jimulco (Kellum, 1932, p. 551) and in the mountains of eastern Durango (Kellum, 1936, p. 1073-1074), have been assigned by Kellum to the late Cretaceous or Tertiary. The writer suspects that these various conglomerate deposits were formed during the same humid cycle of erosion and that their locally steep dips are probably due in part to deposition on steep slopes.

The conglomerates along the south side of the Sierra Jimulco were restudied by the writer in the vicinity of Ahuichila at the southeast corner of the Sierra Jimulco. At this place (Kellum, 1932, fig. 10), the conglomerates are about 800 feet thick, form a cliff nearly as high, and rest unconformably (Pl. 6, figs. 2, 3) on ash beds about 100 feet thick. Most of the pebbles consist of limestone, but some consist of sandstone, chert, or volcanic rock. With the exception of the latter, all the rock types are found in the marine formations of the Sierra Jimulco to the north or of the Sierra Ramirez to the south. The average size of the pebbles is one to two inches, but some are as large as boulders (Pl. 6, fig. 1). Most of them are rather angular; others show a little rounding. Their interstices are filled with calcite and sand grains.

Between the cliffs and the Sierra Jimulco proper, about a mile to the north, the conglomerates form a shallow syncline. Traverses by the writer west and east of Cañón Ahuichila have shown that along the southern flank of Sierras Jimulco and Yeso the conglomerates rest unconformably, but nearly horizontally in most places, on the sandstones and limestones of the strongly folded La Gloria formation. Kellum (1932, p. 552) found the conglomerates extending along the southern side of the Sierra Jimulco for 25 miles. He also noted their occurrence in valleys in other parts of the range where they are associated with an underlying "shale" and ash series and apparently folded with the underlying formations. However, the conditions at Ahuichila show that folding of the conglomerates is minor compared with the folding of the Jurassic-Cretaceous formations and that local steep dips are due to initial slope of deposition. Possibly the apparent slight folding of the conglomerates is due in part to deposition on slopes. Whatever folding exists must have occurred during the latest stage of orogeny and presumably much later than the end of the Cretaceous. That the conglomerates have not undergone a period of strong deformation is shown by the character of the ash beds at Ahuichila.

At Ahuichila the ash beds are nearly horizontal. Their upper limit is irregular and bears a thin layer of carbonaceous material containing impressions and fragments of plant stems. Their lower limit was not observed but presumably is unconformable, as the underlying marine beds

FIGURE 1. LA CASITA FORMATION
At Cuchillo del Calvario, northwest end of Sierra de Atajo. Taraises formation caps hill at right.

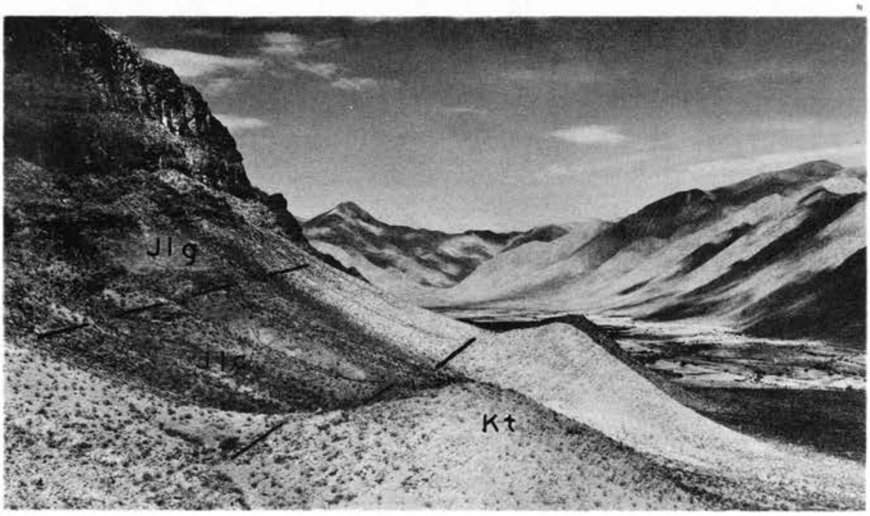


FIGURE 2. SOUTH WALL OF CAÑÓN ALAMO
South of Viesca. Jlg, La Gloria formation; Jlc, La Casita formation; Kt, Taraises formation; La Peña formation on right of canyon; center of canyon eroded in Las Vigas shale and shaly limestone

CONTACTS

FIGURE 1. CONGLOMERATES AT AHUICHILA
Some particles as large as boulders.

FIGURE 2. CONGLOMERATE—ASH CONTACT AT AHUICHILA
Beds nearly horizontal. Contact very irregular.

FIGURE 3. CONGLOMERATE CLIFFS NEAR AHUICHILA
View northwest from Rancho de los Indios.

MAYRAN CONGLOMERATES

are strongly folded. The ash deposits are stratified and consolidated, but not strongly indurated. Certain layers are not sufficiently compacted for the making of thin-sections. Some layers consist of fine particles and resemble shale; others consist of coarse material and resemble a coarse grained sandstone. Some of the latter contain tiny pebbles of limestone and chert. The color ranges from white, through shades of gray, and grayish brown, to green. Gray shades predominate toward the top of the deposits, green shades toward the base. In the upper fourth of the ash beds fibrous white gypsum occurs as thin layers lying mainly parallel to the bedding, but also in part along vertical joints. At the base of the ash emerges a large spring of alkaline water.

Specimens of the volcanic ash were examined in thin-section. A specimen of light-green shaly ash from the lower part of the deposit shows all the characteristics of an ash. The groundmass consists of colorless to brownish glass. Quartz and feldspar occur as small sharply angular splinters. There is some chlorite derived from biotite, a little limonite, and a few minute grains of zircon. The most conspicuous mineral, however, is glauconite,[1] which is abundant as greenish to brownish-green masses and as rounded bodies with a radiating structure. Some of the latter have a brownish core and a greenish border; others are green throughout. In addition to the above-mentioned minerals there is much interstitial calcite.

The presence of glauconite in the ash deposits is interesting as it is one of the first undoubted occurrences of the mineral in nonmarine sediments. The origin of glauconite as an alteration product of biotite in marine sediments has recently been discussed by Galliher (1935), who points out that the controlling factors of formation are an alkaline solution and conditions of oxidation. These factors seem to exist in the ash deposits at Ahuichila. The spring issuing from the foot of the ash deposit is decidedly alkaline. The absence of organic matter in the ash, except on its upper surface, and its porous character would suggest oxidizing rather than reducing conditions. That the alkaline waters come from the ash beds rather than from the overlying limestone conglomerates is indicated by the presence of considerable gypsum in the upper part of the ash deposits and by its absence in the lower part. The presence of gypsum suggests that the waters percolating downward through the conglomerates are neutral. The sulphur of the gypsum might have been derived from pyrite which occurs in the Jurassic and Cretaceous limestones as concretions and as vein material. The gypsum held in neutral solution would be deposited if the solution became alkaline, as seems to have occurred in the upper part of the ash beds. The increasing propor-

[1] Identified by Professor Walter F. Hunt.

tion of glauconite toward the base of the ash beds suggests that the factors favoring its formation become more dominant downward—*i. e.*, the ground waters probably become more alkaline.

A specimen resembling gray sandstone and containing a few small pebbles was examined under the microscope and shows the characteristics of volcanic ash except for the absence of a glassy groundmass. Quartz and feldspar occur as sharply angular fragments. Biotite is fairly common and is partly altered to chlorite. Green hornblende is uncommon. Magnetite, hematite, and grains of zircon are present. There is considerable calcite in which one "radiolarian-like" body was noticed. The pebbles consist of limestone and chert, and there are some grains of the same materials. The rock is interpreted as a slightly reworked ash in which pebbles and grains from the nearby mountains have been incorporated.

The softness of the ash beds, the presence of glassy material, and the appearance of the quartz grains in thin-section show that the ash beds in the Sierra de Jimulco have not been subjected to a period of intense orogeny, as have the Mesozoic formations outcropping in the same range. Rather, their condition suggests relatively late formation in the Cenozoic era. Their age must be about that of the conglomerates which overlie them, as they would soon have been washed away unless covered with a protecting cap. In fact, in the Sierras de Hispaña and Mapimí, Kellum (1936, p. 1073-1074) found similar conglomerates interbedded with volcanic ash. Some of the ash may have been deposited in small lakes, but much of it was probably deposited subaerially, as extensive lakes probably would not exist on the upper parts of pediments. Showers of the ash must have occurred at sufficiently short intervals to prevent vegetation from taking a foothold. At times, rain waters reworked the ash somewhat and washed in foreign particles.

The writer has not studied the ash beds in the Sierras de Hispaña and Mapimí, but Kellum (1936, p. 1072-1074, pl. 10) observed that they dip steeply away from the overthrust front of the Sierra de Hispaña. He concluded that they had been subjected to one period of folding. These ash beds may be of different age from those in the Sierra de Jimulco, or they may have been affected by a local uplift. These possibilities seem unlikely to the writer, but the solution of the problem depends on more field studies.

IGNEOUS AND METAMORPHIC ROCKS

In southern Zacatecas, igneous rocks are common in limited areas, In the vicinities of Mazapil and Concepción del Oro occur many igneous bodies which were studied by Rosenbusch (Burckhardt, 1906b, p. 23-28). Igneous rocks of several types are common on Las Coapas upland, and several porphyry sills occur in the Sierra Ramirez, but these have not been studied. Attention will be confined here to the igneous and the metamorphosed sedimentary rocks in the vicinity of Melchor Ocampo.

Near Melchor Ocampo are two areas of igneous intrusion (Pl. 7). The less important area lies south of the city in the Sierra Zuloaga along the highest part of the Zuloaga anticline. Small, nearly vertical porphyry sills occur from Cañón San Francisco eastward for 2 miles. The best exposures are in Cañón San Francisco. Along the ridge east of the canyon igneous rocks have been found in several mines. The intrusions occur in the thin-bedded or incompetent formations—*i. e.*, La Caja, upper member of Taraises, and La Peña formations. Along Cañón San Francisco the sills are distinctly offset by a cross-fault. The porphyry is rotten at all surface exposures, but a specimen from the San José Mine (No. 7 shaft) was fresh enough to be identified as a felsite. The thin-bedded limestones and marls adjacent to the porphyry have been considerably altered and are cut by many rather highly mineralized veins, especially in the vicinity of the north-south fault zone where brecciation is common.

The most important area of igneous intrusion lies north and northeast of Melchor Ocampo from Cerro Voladero northward to the base of Sierra Sombreretillo. It comprises about 5 square miles and is confined to the outcrops of the Caracol and Indidura formations on the north flank of the Melchor Ocampo syncline. The intrusions occur as vertical, or nearly vertical, thin sills whose positions are commonly marked by zones of indurated metamorphosed sediments (Pl. 3, figs. 1, 2) that form ridges. In the central part of the area of intrusion, sills are so common that the outcrop of the Caracol formation is nearly twice its normal width. Only the larger sills are indicated on the accompanying geologic map, as the inclusion of many small sills would obscure the general picture; however, the positions of most of the small sills are denoted by the zones of metamorphosed sediments. The igneous rocks are of at least two kinds. Andesite porphyry forms the sills at the eastern end of Cerro Voladero, part of Cerro del Oro, and the small body half a mile west-southwest of Cerro del Oro. A light colored porphyry, probably a felsite, is equally as common and crops out extensively throughout the area. These sills probably mark the position of a fairly large igneous body at depth, as the Sombreretillo Anticline to the north curves around the intruded area, suggesting that the latter acted as a relatively stable mass. The curvature of the anticline around the north side of the intrusive area might suggest that outward pressures were generated from the intrusion, but, on the contrary, the anticline is strongly overturned toward the south, which implies that the intrusive mass acted merely as a buttress. Intrusion probably occurred toward the end of folding, but before the final overfolding. This is shown in the area south of Melchor Ocampo where the cross-fault along Cañón San Francisco offsets the porphyry sills (Pl. 2, fig. 1). The cross-fault was probably formed during the final overfolding.

The calcareous tuffs and shales adjacent to the sills have been altered considerably, and, in addition, zones several hundred feet thick have been more or less strongly metamorphosed by hot solutions or even by injection of thin sheets of magma along the bedding planes. The resulting rocks are much lighter in color and harder than the original rocks. Some resemble limestones, others appear to be igneous, and the general term "contact rock" is perhaps appropriate.

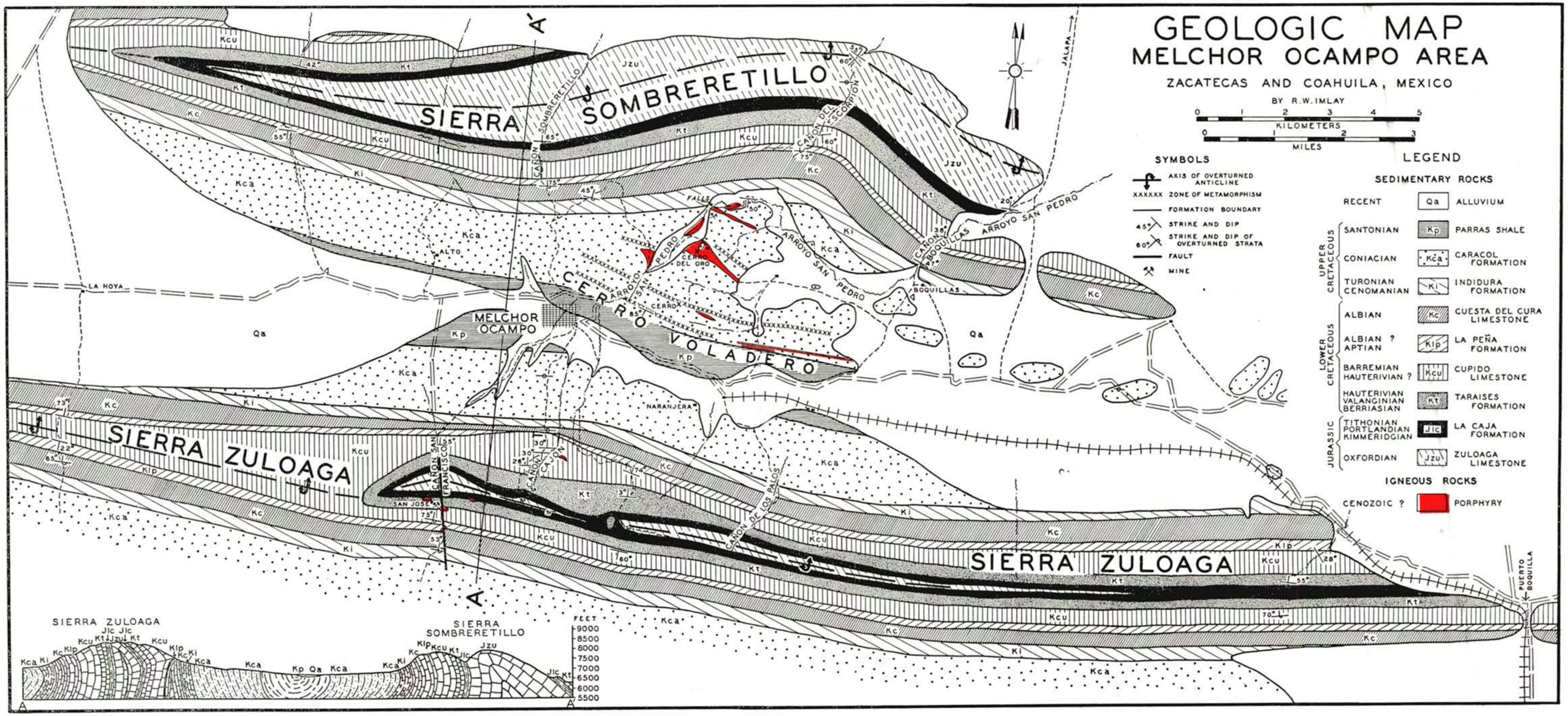
STRUCTURAL UNITS IN NORTHERN ZACATECAS AND SOUTHERN COAHUILA

GENERAL FEATURES

A broad belt of major asymmetrical folds extends eastward across southern Coahuila and northern Zacatecas (Fig. 3). Toward the west in southwestern Coahuila and eastern Durango the structural trend changes to the northwest, and toward the east in Nuevo León, southeastern Coahuila, and eastern Zacatecas, it changes to the southeast parallel to the folds of the Sierra Madre Oriental. The turning of the tectonic strike on the east may be defined by a line drawn about S 45° W from Monterrey. The greatest length of the east-west folded belt is more than 250 miles (Kellum, Imlay, Kane, 1936, p. 995-996) measured in an east-west direction through southern Coahuila, but in northern Zacatecas the belt is much less extensive. The greatest width of the belt of east-west folding lies on a north-south line drawn through Mazapil. Westward and eastward from this line in Zacatecas, northward-trending folds become more common. The appearance of many folds trending at an angle to the east-west major trend possibly indicate a return toward the south of the normal northwest trend of the Rocky Mountain Cordillera. Most of the structural units of southern Coahuila have been described in previous papers (Kellum, 1932, 1936, Imlay, 1936, 1937a), and the present paper will deal only with those south of the Sierras de Parras and Jimulco.

FOLDS

Atajo Anticline.—The Atajo anticline is represented topographically by the Sierra de Atajo which lies due south of Parras about 20 miles and by the southern mountainous ridge of the Sierra del Capadero (Imlay, 1936, p. 1100). Its axis trends east-southeast at least 35 miles and is probably continued toward the east in the Sierra Gerónimo. At its west end the anticline is strongly overturned toward the north, but farther east



GEOLOGIC MAP OF THE MELCHOR OCAMPO AREA

becomes less overturned and lower. An excellent section of the anticline is exposed northeast of Rancho Manchuria where the west end of the Sierra de Atajo ends abruptly at the plain of the Laguna de Viesca. Directly east of Rancho Manchuria extends the synclinal valley of Cañón del Mimbre in which are exposed reddish gypsiferous sandstones and shales of La Casita formation. North of the canyon the rugged Sierra de Atajo is composed of Zuloaga limestone which is folded strongly toward the north. Then, along the front of the range, follows a recumbent syncline containing La Casita formation and the Taraises formation, both excellently exposed at the northwest end of the range which is called the Cuchillo del Calvario (Pl. 5, fig. 1) and is about 4 miles north of Rancho Manchuria. These formations plunge north at the base of the range, thereby forming an anticline which is probably the continuation of the Capadero Anticline (Imlay, 1936, p. 1143) to the west.

Yeso Anticline.—The Yeso Anticline begins in the southern part of the Sierra Jimulco south of the Praderones Anticline (Kellum, 1932, p. 560) and extends eastward from Cañón Ahuichila for about 50 miles as a major fold parallel to the Atajo Anticline. It is represented topographically by Sierra del Mimbre (Gaban) for about 15 miles, then by a low mountain directly north of Trébol. In the vicinity of Rancho Manchuria the fold is several miles broad but contains several minor folds, and the north flank is overturned. The Sierras de Yeso and Mimbre are composed mainly of Upper Jurassic limestone, but northeast of Trébol exposures of Lower and Upper Cretaceous rocks occur around the plunging nose of the anticline. East of the Bolsón de Jalapa the same line of folding may be represented by the Sierra de Jasminal where the overfolding is toward the north.

Sombreretillo Anticline.—The Sombreretillo Anticline, directly north of Melchor Ocampo, is represented topographically by the Sierras Sombreretillo and Trébol. In these mountains the fold is broad, strongly overturned toward the south, and closes toward the west. Its trend is slightly south of east but is marked by a flexuous curve in the area northeast of Melchor Ocampo. This curve seems to reflect the presence of the igneous body to the south. Toward the west a remnant of the south limb of the anticline is represented by the Sierra Trébol. Toward the east the anticline may be continued across the Bolsón de Jalapa, east of the Zacatecas-Coahuila railroad, in the Sierra de la Ventura which parallels the eastern end of the Sierra Jasminal for about 6 miles and then swings to the southeast for many miles. In the area southwest of La Ventura, Coahuila, the range is broad and high and bears at least three lines of folding which trend from northwest to southeast.

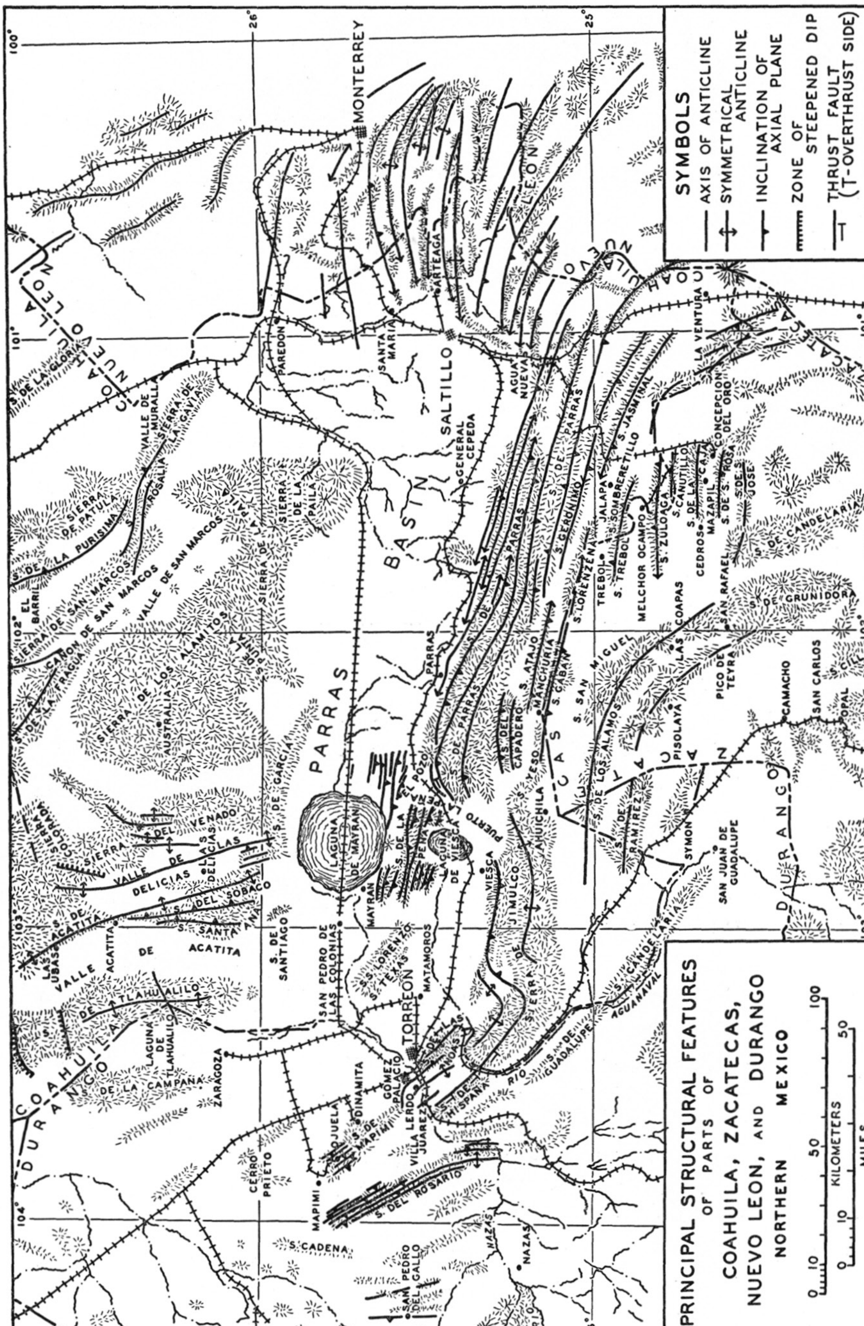


FIGURE 3.—*Principal structural features*

Zuloaga Anticline.—The Sierra Zuloaga is the topographic reflection of a fairly large anticline which trends sinuously in an east-west direction and is more or less strongly overturned toward the south. The anticline is highest in the region south of Melchor Ocampo and from there closes gradually toward the east and the west. The highest part of the structure is marked by small igneous intrusions, especially at the head of Cañón Cajón and in Cañón San Francisco, and by a zone of high-angle thrust faulting along the northern base of the mountain. Along the zone of faulting, La Peña, Cuesta del Cura, and basal Indidura formations are extremely contorted, broken, and mashed, and are greatly reduced in thickness. Near the mouth of Cañón Cajón the competent Cupido limestone lies nearly horizontal on vertical beds of the upper part of the Cuesta del Cura formation, showing that most of the Cuesta del Cura and La Peña formations have been faulted out. South of the fault the Cupido limestone locally forms a small gentle anticline on the north flank of the major anticline.

Canutillo, La Caja, and Santa Rosa Anticlines.—Three short eastward-trending mountains south of the Sierra Zuloaga, representing local folds, have been adequately described by Burckhardt (1906a, b). These folds terminate on the west and east in broad northwestward-trending synclines which are bounded by northwestward-trending folds.

Los Alamos Anticline.—Several miles south of Ahuichila a series of low hills—Sierra de los Alamos—composed of Upper Jurassic limestone parallel the eastern end of Sierras Jimulco and Yeso and gradually become higher toward the east. These hills mark an eastward-trending anticlinal fold which passes east-southeast through the Sierra Iglesias, a few miles southwest of Puerto Yeso, then swings southeast along the mountainous (Sierra San Miguel) eastern edge of Las Coapas upland, and plunges into the plain about 10 miles southwest of Cedros, which is at the western end of Sierra de la Caja. A few miles to the southeast rise some low ridges which trend southeast and pass into a large eastward-trending fold in the Sierra de San José. The anticline, where observed, is somewhat overturned toward the north or northeast.

Ramirez Anticline.—The Sierra Ramirez marks the position of a broad fold which is overturned toward the north and trends eastward for at least 35 miles parallel to Los Alamos Anticline. The Ramirez Anticline probably continues west of the National Railroad but was not traced. It is probably continued toward the southeast by a fold along the mountainous western edge of Las Coapas upland just east of Pisolaya.

FAULTS

Faulting becomes more common southward from the Sierras de Parras and Jimulco but is still much subordinate to folding. In the low ranges immediately south of the Sierra de Parras and in western Zacatecas, faults are difficult to trace because of the widespread alluvium and the advanced stage of erosion. However, minor faults with displacements of a few feet are common, and it seems safe to infer that some of the alluviated valleys trending at wide angles to the ranges were developed along major fault zones. For example, Puerto Yeso, south of Rancho Manchuria, and the western edge of Sierra de Atajo probably mark the position of a fault zone.

The most highly faulted area in the belt of east-west folding is that of Mazapil and Concepción del Oro, studied by Burckhardt (1906a, b). He has mapped some high-angle thrust faults and many short cross-faults. Many of the faults appear to be related to nearby intrusive bodies. Along the northern side of the Sierra Canutillo, Burckhardt (1930, fig. 11) found a high-angle thrust fault. In the Sierra Zuloaga, the writer found two significant faults. The northern front of the range north of the highest part of the Zuloaga Anticline is marked by a zone of high-angle thrust faulting about 4 miles long involving mainly the contact beds of the Lower and Upper Cretaceous. A cross-fault with a displacement of about 60 feet was traced from the head of Cañón San Francisco across the southern slope of Sierra Zuloaga. It distinctly offsets some porphyry sills (Pl. 2, fig. 1) and therefore is younger than their intrusion. Its course is marked by topographic depressions.

MINERAL DEPOSITS

The mines and minerals of the Melchor Ocampo area have been briefly studied by Richard T. Liddicoat, Jr., who has kindly contributed the following note and chart.

"Melchor Ocampo is an interesting mining locality, both for its colorful history and for its present mineral wealth. The earliest mining is said to date back to the Spanish conquest of Mexico in the sixteenth century, making it one of the first mining operations in North America. Several buildings still stand as monuments to the Spaniards who constructed them over three centuries ago. The mines have been alternately exploited and abandoned during most of their history, the latest revival being only five years old. As in numerous ancient mining districts, many of the people believe that the earliest workings were fabulously rich and, having been lost, will be rediscovered some day.

"The principal production is silver and gold, but lead is very important and zinc occurs in such quantities as to be undesirable in smelting. The manganese and iron content is relatively high. Most of the collecting was done from dumps of mines that had not penetrated through the oxidized zone, but the San José and several other smaller mines did yield some sulphide zone material. The scope of the work was not nearly complete, but gives some idea of the minerals present. At present the ores of the district are argentiferous galena, chalcocite, and sphalerite, with some free gold. The gangue material consists mainly of carbonates, but includes some quartz and gypsum. The majority of the minerals are carbonates, oxides, sulphates, and silicates, but a few sulphides were collected at mines that had reached the sulphide zone. Near the San José mine occur several small dikes, and a fault cuts through the mine producing a zone of brecciation which has been well mineralized. The region in general was probably mineralized by solutions ascending from the igneous bodies near Melchor Ocampo."

TABLE 2.—*Minerals of the Melchor Ocampo area*

Minerals	Mines							
	1	2	3	4	5	6	7	8
Quartz	X	...	X	X	X	X	X	...
Calcite	X	X	X	X	X	X	X	X
Aragonite	...	...	X	X	X	...	X	...
Galena	X	X	...	...	...	...	...	X
Cerussite	X	...	X	X	X	X	X	...
Mimetite	X	...	...	...	...	...	...	...
Pyrite	X	X	...	...	...	...	X	X
Limonite	X	...	X	...	...	...	...	X
Fluorite	X	X	...	X	...	...	X	...
Crysocolla	X	X	X	X	...	...	X	...
Malachite	...	...	X	X	X	X	...	...
Smithsonite	...	...	...	X	X	X	X	...
Azurite	X	X	X	...	...	X	...	...
Gypsum	X	...	...	...	X	...	X	...
Pyrolusite	X	X	...	X	...	...	X	...
Barite	...	X	...	...	...	...	...	...
Sphalerite	X	X	...	...	...	...	...	...
Gold	X	X	...	...	...	...	...	X
Chalcocite	X	...	...	...	...	...	...	...

1. San José mine, near head of Cañón San Francisco, about 2 miles southwest of Melchor Ocampo, in lower part of upper member of the Taraises formation.
2. San Francisco mine, about 400 feet south of San José mine in basal Cupido limestone.
3. Cajón mine, head of Cañón Cajón south of Melchor Ocampo, in Taraises formation and Zuloaga limestone.
4. Voladero mine, south of crest of Sierra Zuloaga south of Cañón Cajón and in the Zuloaga limestone.
5. Vomitivo mine, about 900 feet east of Voladero mine at contact of Zuloaga limestone and La Caja formation.
6. Candelaria mine, south of crest of Sierra Zuloaga about half a mile east of Vomitivo mine at contact of Zuloaga limestone and La Caja formation.
7. Mine on mountain top 2 miles south-southeast of Melchor Ocampo in Zuloaga limestone.
8. Perla de San Pedro mine, about 1½ miles northeast of Melchor Ocampo in Caracol formation.

COMPARISON OF FACIES IN MEXICAN GEOSYNCLINE

UPPER JURASSIC

La Gloria formation and Zuloaga limestone.—La Gloria formation was originally defined from the Sierra de Parras section to include "the com-

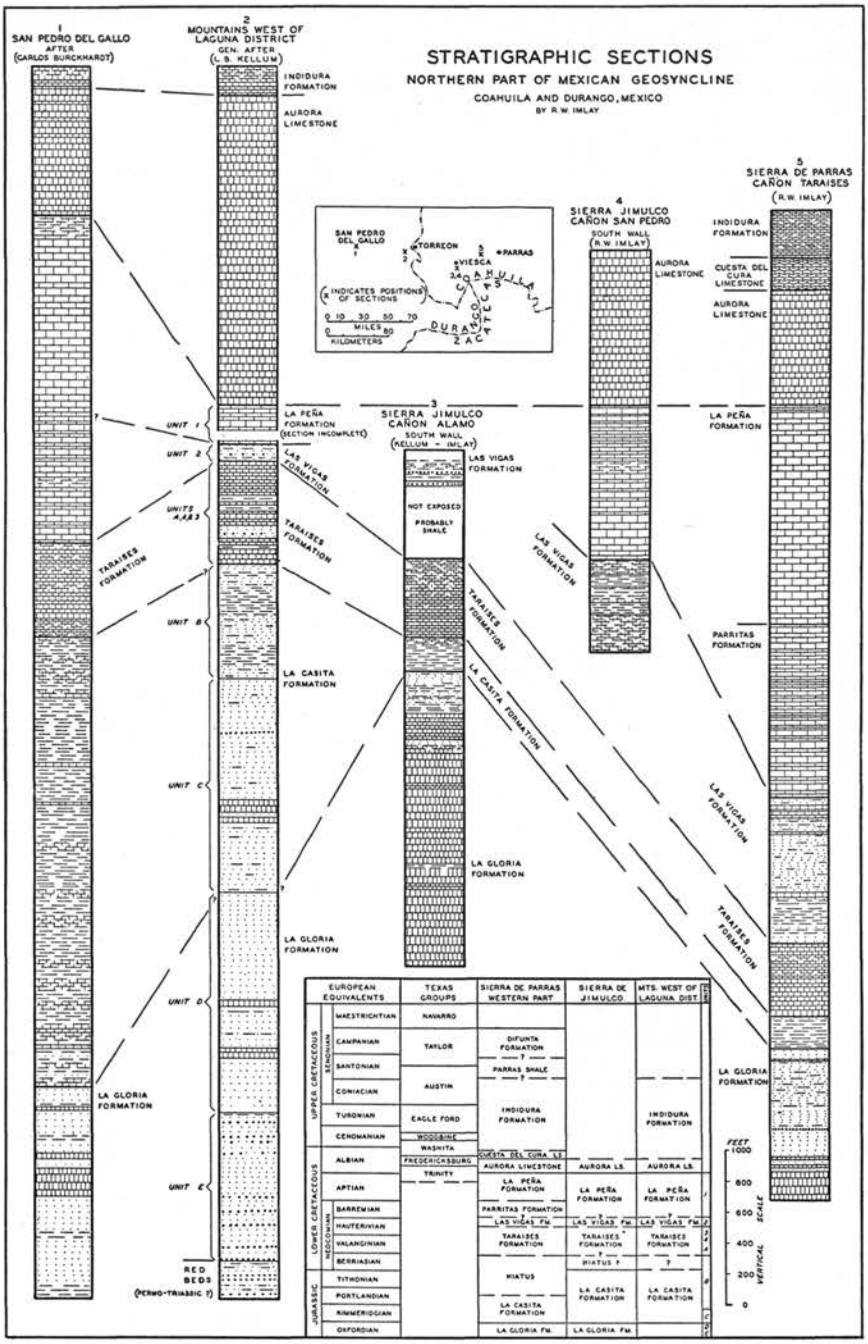


FIGURE 4.—*Stratigraphic sections along northern part of the Mexican geosyncline*

pact limestones and sandstones of Upper Jurassic age, lying beneath La Casita formation and constituting the oldest rocks exposed" (Imlay, 1936, p. 1105). At the type locality the formation consists mainly of thick- to medium-bedded limestone but is characterized by sandstone and minor amounts of conglomerate. La Gloria formation is now more exactly defined to include only those near-shore deposits which contain coarse clastic materials, although limestone may be the predominating material. The sands of the formation were deposited in lenses fringing the Coahuila Peninsula and interfingered seaward with lime muds. The off-shore, nearly pure limestone equivalent of La Gloria formation is defined in this report as the Zuloaga limestone. Outside the area of the Sierra de Parras, La Gloria formation includes the lower 600 meters of limestone and quartzite in Cerro de Volcán near San Pedro del Gallo (Burckhardt, 1912, p. 203), units D and E of the section near Villa Juárez, Durango (Kellum, 1936, p. 1065-1067), and a thick section in the Sierra de Jimulco.

In the Sierra de Jimulco, La Gloria formation crops out widely along the Praderones Anticline and the east end of the Viesca Anticline east of Las Boquillas. Excellent exposures occur along Cañón Ahuichila and along the south side of the Sierras Jimulco and Yeso near Ahuichila.

A structure section (Pl. 4, figs. 1, 2) drawn northward from the south wall of Cañón de la Vibora, about 5 miles south of Viesca, shows a succession of three valleys and mountains and a syncline and an anticline. The bottom of Cañón de la Vibora is worn along La Casita formation. Its south wall is composed of La Gloria limestones on the north flank of the Praderones Anticline. Its north wall rises into a narrow synclinal mountain capped with at least 1,000 feet of Aurora limestone and exposing on the lower slopes La Peña, Las Vigas, and Taraises formations. Cañón de San Pedro, which follows to the north, is developed along La Casita formation. North of this canyon is an unnamed mountain consisting mainly of La Gloria formation and marking the axis of the Viesca Anticline. Along the northern base of the mountain is exposed an excellent section of La Gloria, La Casita, and the Taraises formations. The bottom of Cañón Alamo is eroded in the soft beds of Las Vigas formation. The mountain to the north represents the overturned flank of the Viesca Anticline and consists of Lower Cretaceous formations.

Sections of La Gloria formation were measured on the mountain between Cañones Alamo and San Pedro. The upper part of the formation, consisting of interbedded sandstones and limestones, was measured on the north slope of the mountain south of Puerto Santiago. From top to bottom it is as follows:

Unit		Feet
1.	Sandstone, thick-bedded, yellowish gray; directly underlies La Casita formation	12
2.	Sandstone, medium-bedded, gray	10
3.	Sandstone, medium-bedded, compact, yellow	26
4.	Shale, sandy, pinkish to dark gray, some thin beds of yellowish sandstone near base	52
5.	Sandstone, yellowish gray	15
6.	Limestone, medium-bedded, medium gray	46
7.	Sandstone, brown, gray, and yellowish gray, some layers conglomeratic	47
8.	Limestone, medium- to thin-bedded, dark gray; thicker beds contain black chert nodules; thinner beds nodular, and contain fragments of bivalves	230
9.	Sandstone, medium-bedded, yellowish gray, weathers brownish gray	5
10.	Limestone, gray, medium-bedded at top but becoming thin-bedded at base	16
11.	Shale, sandy, yellowish gray	2
12.	Limestone, compact, light gray	1½
13.	Sandstone, shaly, gray	8
14.	Sandstone, thin-bedded, medium-grained, brownish gray, contains fragments of bivalves	2
15.	Limestone, shaly, light gray. Top of thick-bedded limestone forming mountain south of Cañón Alamo	20
	Total	492+

The sandstones of the above section are similar in composition to the sandstones of La Gloria formation of the Sierra de Parras (Imlay, 1936, p. 1108-1109) and were undoubtedly derived from the same landmass. A thin-section of sandstones from unit 14 consists of subangular to well-rounded grains of quartz, microcline, plagioclase, and chert cemented with calcite. Feldspar and chert grains are uncommon. The quartz contains some apatite. A specimen of sandstone from unit 9 is very similar in composition but contains a little organic matter, some of the calcite occurs as concentric bodies (öolites?), and many quartz grains show undulatory extinction.

In a thin-section of yellow sandstone from unit 7, the grains are mostly quartz and feldspar, but a few are chert. They are subangular to well rounded and have an interlocking texture. The feldspar consists of microcline and plagioclase. Most of the quartz grains show undulatory extinction. There is some interstitial calcite. Minor constituents include limonite, organic matter, ilmenite, leucoxene, zircon, rutile, and tourmaline.

The lower part of La Gloria formation measured across the southern half of the mountain between Cañones Alamo and San Pedro, starting at the base of the sandstones, from top to bottom, is as follows:

Unit		Feet
1.	Limestone, nodular, gray	70
2.	Limestone, thick-bedded, medium to light gray	152
3.	Limestone, thin-bedded, nodular, contains nodules of dark gray chert	38
4.	Limestone, thick-bedded, medium gray, contains many small nodules of dark gray chert	250

Unit	Feet
5. Limestone, medium-bedded, alternating with nodular, thin-bedded, dark gray. Some dark gray chert nodules in the thicker beds	234
6. Shale, calcareous, fissile, red to grayish red	20
7. Limestone, nodular, marly, gray, traces of shells	10
8. Limestone, thick-bedded, medium gray, many small nodules of dark gray chert which weather reddish	62
9. Limestone, medium- to thin-bedded, gray	66
10. Limestone, thick- to medium-bedded, dark to medium gray	538
Total	1440

In the mountains west of the Laguna District, near Villa Juárez, a section of Upper Jurassic rocks was studied by Kellum (1936, p. 1063-1069) and included in his Torcer-Las Vigas series. The lower part of this series, comprising units D and E, are now assigned to La Gloria formation on the basis of stratigraphic position and lithologic similarity. The stratigraphic evidence consists, in part, of fossils of late Jurassic or early Cretaceous age in the upper part of unit B, which will be discussed under the next heading. Their presence clearly shows that the underlying beds are of Jurassic age. Unit C is not considered part of La Gloria formation for reasons to be discussed later. Unit D is probably of Oxfordian age as indicated by some large ammonites collected 580 feet above the base of the unit (Kellum, 1936, p. 1066). Collection A-16 contains fragmentary specimens which are provisionally referred to *Pseudopeltoceras* (U. M. 19401), *Subgrossouvria* (U. M. 15948, 19308), and *Indosphinctes* (U. M. 15960, 19306, 19309, 15961, 19307, 19400, 15950). These genera indicate a Lower Oxfordian age. Lithologically the sandstones of units D and E are very similar to the sandstones of La Gloria formation of the Sierra de Parras, and certain types are identical. The most common characteristic type in both areas is a grayish-white quartz sandstone spotted with yellowish-brown limonite. Conglomeratic layers are common in both areas.

Thin-sections of sandstones from units D and E were examined under the microscope and showed essentially the same characteristics as the sandstones of La Gloria formation of the Sierra Jimulco and the Sierra de Parras. (Imlay, 1936, p. 1108-1109; 1937a, p. 600). A specimen of yellowish-gray calcareous sandstone from a small knoll 1½ miles southwest of Las Cuevas contains fragments of bivalves and belongs in unit D. A thin section showed fairly well rounded grains of quartz, microcline, and plagioclase cemented with calcite. Many quartz grains have undulatory extinction. Minor constituents include limonite, apatite, zircon, tourmaline, ilmenite, and leucoxene.

Another specimen (Coll. A-13) of brownish-black sandstone of unit D was collected on a knoll about 2 miles southwest of Las Cuevas. It consists of grains of quartz, plagioclase, and chert in a matrix of organic matter and some calcite. The feldspar and chert are uncommon, and limonite is abundant. Minor constituents include zircon, apatite, and tourmaline.

Sandstone specimens of unit E were collected about 3 miles southwest of Villa Juárez on the road to Picardillas. A grayish-white quartz sandstone flecked with limonite stains was examined under the microscope. The grains consist of quartz, microcline, and rare plagioclase and chert. Other constituents are limonite, calcite, organic matter, and apatite. Many of the quartz grains show undulatory extinction. Most of the grains are held together by an interlocking arrangement, and calcite is of minor importance as a cementing material. Another specimen of grayish sandstone from the same locality shows a similar interlocking arrangement of quartz, feldspars, and chert grains, and bears limonite, magnetite, zircon, tourmaline, apatite, and rutile as minor constituents.

At San Pedro del Gallo, Durango, the lowest beds exposed consist of thick- to medium-bedded limestones and quartzitic sandstones which, according to Burckhardt (1930, table 6), are at least 600 meters (1970 feet) thick. Some of the sandstones, spotted with limonite, are similar to types in the Villa Juárez and Sierra de Parras sections. The sandstones at San Pedro del Gallo are more indurated, as the region has undergone more intense deformation.

La Gloria formation was deposited around the margin of the Coahuila Peninsula. Comparing La Gloria formation at the various localities, the coarsest and thickest deposits are in the Villa Juárez uplift and progressively finer grained facies are found in the western part of the Sierra de Parras, the middle part of the Sierra de Parras, San Pedro del Gallo, and the Sierra Jimulco. The coarseness and thickness of clastic materials may indicate the degree of proximity of the landmass. On the other hand, the much greater thickness and extent of the Upper Jurassic west of the Coahuila Peninsula than south of it can easily be explained by assuming that the principal drainage was to the southwest.

The La Gloria and Zuloaga formations are considered of Oxfordian age on the basis that the overlying Jurassic beds contain upper Oxfordian, Kimmeridgian, Portlandian, and Tithonian fossils. In the Cerro del Volcán (Burckhardt, 1910, pl. XLIX) near San Pedro del Gallo, Durango, fossils of upper Oxfordian age (Burckhardt, 1912, p. 5-39) occur in beds directly overlying La Gloria formation. In the section near Villa Juárez, Durango, unit C and the top of unit D contain a pelecypod fauna which Albritton (1937, p. 259) would place in the Kimmeridgian. However, on the basis of lithology and contained ammonite fauna, unit D must be placed in La Gloria formation, and the question of the age of unit C may be held in abeyance pending further paleontological studies.

La Casita and La Caja formations.—La Casita formation includes the shales, sandstones, and limestones of Upper Jurassic age above La Gloria formation (or Zuloaga limestone) and below the Taraises formation. All sections contain carbonaceous shales, and some contain coal beds. Gypsum occurs in most sections south of the Coahuila Peninsula and is very abundant in some. The formation, comprising near-shore clastic, carbonaceous, and gypsiferous beds, was deposited along the margin of a landmass and grades seaward into more calcareous, less clastic beds, which form La Caja formation of this report. La Casita formation has been observed in the middle and western parts of Sierra de Parras, at the eastern end of Sierra de Atajo (Pl. 5, fig. 1), in Sierra Yeso, in Sierra Jimulco, in the vicinity of San Pedro del Gallo, and in the mountains west of the Laguna District. Similar deposits have been studied by Böse (1923a, p. 196-209) in the Sierra Madre Oriental southeast of Saltillo and, by various workers (Burckhardt, 1930, p. 84-91), farther south in Nuevo León, and Tamaulipas.

In the Sierra Jimulco, La Casita formation is excellently exposed along the south side of Cañón Alamo, south of Puerto Santiago. The section at this place was measured by Kellum (1932, p. 547), who gave a generalized description. The writer remeasured the section in 1936 and found the younger Taraises formation lying below (Pl. 5, fig. 2) La Casita formation, thereby proving that the section is inverted by strong overfolding toward the north. The section as measured by the writer, from top to bottom, is as follows:

Unit	Feet
1. Shales and limestone, poorly exposed; a bed of marly limestone 7 feet from top contains *Substeueroceras, Proniceras, Aulacosphinctes, Hildoglochiceras, Micracanthoceras,* and *Parodontoceras*	101
2. Limestone, medium-bedded, yellowish gray	31
3. Limestone, thin-bedded to shaly, brownish black, weathers dark brown. Limestone resembles sandstone but consists of bodies of Foraminifera preserved as cryptocrystalline quartz in a matrix of calcite, limonite, and organic matter	46
4. Shale, gypsiferous, pink, gray, and buff; contains dark gray arenaceous concretions and thin lenses of limestone	45
5. Shale, sandy, gray to pinkish, contains a few thin beds of gray sandstone	25
6. Shale, fissile to sandy, dark gray	17
Total	265

The same section, measured by Kellum, is somewhat more detailed and will be given from top to bottom as follows:

Unit	Feet
1. Shale	6
2. Limestone, red, shaly, with *Substeueroceras, Proniceras, Aulacosphinctes, Micracanthoceras, Parodontoceras,* and *Hildoglochiceras*	1
3. Shale, tawny, with calcareous nodules	13
4. Limestone, shaly, with *Durangites* n. sp. ind.	2
5. Talus slope with debris of shale and flaggy limestone layers	28

Unit	Feet
6. Shale, gypsiferous	24
7. Limestone, black, nodular, shale partings	4
8. Shale, large ferruginous lime concretions at top	27
9. Limestone, dark gray, nodular; ammonites	2
10. Unexposed	7½
11. Limestone, dark gray, nodular	1
12. Shale, gypsiferous; ferruginous lime concretions at top	17
13. Shale, blocky, tawny to pink, gypsiferous	43½
14. Shale, blocky, gypsiferous, pinkish	20
15. Unexposed	5
16. Limestone stringers	2
17. Shale, gypsiferous	13½
18. Sandstone, ashy, dark gray, nodular; partings of gray and black shale	8½
19. Shale, pink and gray, sandy; passing at base into shaly sandstone containing partings of ferruginous brown shale	11
Total	236

La Casita formation is excellently exposed along the southern base of the Sierra de Atajo in Cañón del Mimbre and, also, at its northwestern end at the Cuchillo del Calvario (Pl. 5, fig. 1), where about 250 feet of sandy shales and gypsiferous or carbonaceous shales of various shades of red, yellow, and gray occurs. Compared with the section in Cañón Taraises at the western end of the Sierra de Parras, the beds are less carbonaceous and more gypsiferous.

In the mountains west of the Laguna district, near Villa Juárez, La Casita formation is probably represented by unit B previously referred tentatively to the "Torcer-Las Vigas series" (Kellum, 1936, p. 1067). At the northwest end of the bluffs east of Cuesta del Carbonera and at the same horizon as Kellum's collection A-4, the writer found several species of corals and ammonites in addition to the more common *Vermetus, Plicatula,* and *Gryphea.* The ammonites include several fragments of gigantic forms, of which one (U. M. 19415) is a *Thurmannites* close to *T. novihispanicus* Imlay (1937b, p. 563, pl. 78, figs. 8, 9; pl. 79, fig. 6) from Miquihuana, Tamaulipas. One fragment (U. M. 19414), not identifiable generically, suggests *Blanfordiceras.* Several small pieces (U. M. 19419, 19417) of whorls probably represent *Berriasella.* In addition to these forms Kellum found some large ammonites (collection A-34) on the western side of the Sierra de Mapimí, about half a mile south of Puerto Soldados, associated with the same bivalve fauna as in collection A-4. One of the ammonites (U. M. 19413) is similar to *Thurmannites miquihuanensis* Imlay (1937b, p. 564, pl. 76, fig. 1; pl. 77, fig. 7), and another (U. M. 15832) to *Thurmannites* sp. (Imlay, 1937b, p. 565, pl. 80, figs. 3, 4) from the Miquihuana region. The resemblances of these *Thurmannites* to those from Miquihuana are striking, but just as noticeable are the resemblances of two excellently preserved species of *Exogyra* to *Exogyra reedi* Imlay and *Exogyra putnami* Imlay (1937b, p. 566). The association of the ammonite genera indicates a Tithonian or Berriasian age, and the resemblances to the Valanginian fauna of the Miquihuana region favor an early Cretaceous age. Other evidence indicating that the Jurassic-Cretaceous boundary is in the middle of unit B consists of an external mold of the outer whorls of an ammonite which is probably either *Spiticeras* or *Proniceras.* Kellum's field label states that the fossil comes from black shale below limestone on the hill east of Cuesta del Carbonera. Another bit of evidence pointing toward the early Cretaceous age of the upper part of Unit B consists of an ammonite (U. M. 16132), probably *Kossmatia,* found as float just north of Cuesta del Carbonera, on the trail to Las Cuevas ranch (Kellum, 1936, p. 1069). This ammonite suggests a Portlandian age and must have come from the bluffs to the east which are formed of the middle part of unit B. If the upper part of unit B is of Cretaceous age, it should not be placed in La Casita formation. Neither could it be placed in the Taraises formation, as it consists principally of shales. If the upper part of unit B is of early Cretaceous age, then the Jurassic-Cretaceous boundary might be drawn at the base of the thick unit of sandstone in the middle of unit B. That would leave about 400 feet in the lower part of the unit to be placed in La Casita formation, which, considering the great thickness of the formation at San Pedro del Gallo about 40 miles to the west, seems surprisingly thin. Therefore, it may well be that most, if not all, of unit C should be placed in La Casita formation, which assignment would conform with the age determinations of Albritton (1937, p. 359) in his studies of the Malone fauna. Before such conclusions can be drawn, the fossils of unit C should be restudied and carefully checked with the type specimens of the Malone fauna. If future work shows that the Jurassic-Cretaceous boundary should be placed lower than the above evidence indicates, then the quartz conglomerate occurring 368 feet below the top of unit C (*see* Kellum, 1936, p. 1054, 1067) might be a possible significant horizon marker.

In the vicinity of San Pedro del Gallo the Upper Jurassic formations were carefully studied by Burckhardt (1910, 1912). The writer visited the area in 1936, made a large collection of fossils, and checked the general geology. Burckhardt placed more than 3000 feet of shales and marls in beds now assigned to La Casita formation. This thickness is a composite of many small sections and, as such, is apt to be excessive as the various sections cannot be fitted together exactly. La Casita formation, in the vicinity of San Pedro del Gallo, is mostly covered with alluvium and, where exposed, is commonly much contorted and broken by minor bedding faults. This condition can be best seen along Arroyo Aguajito which trends east from the city. In only a few places is it possible to measure a section of a few hundred feet, and even there one cannot be certain that there has not been some duplication. This condi-

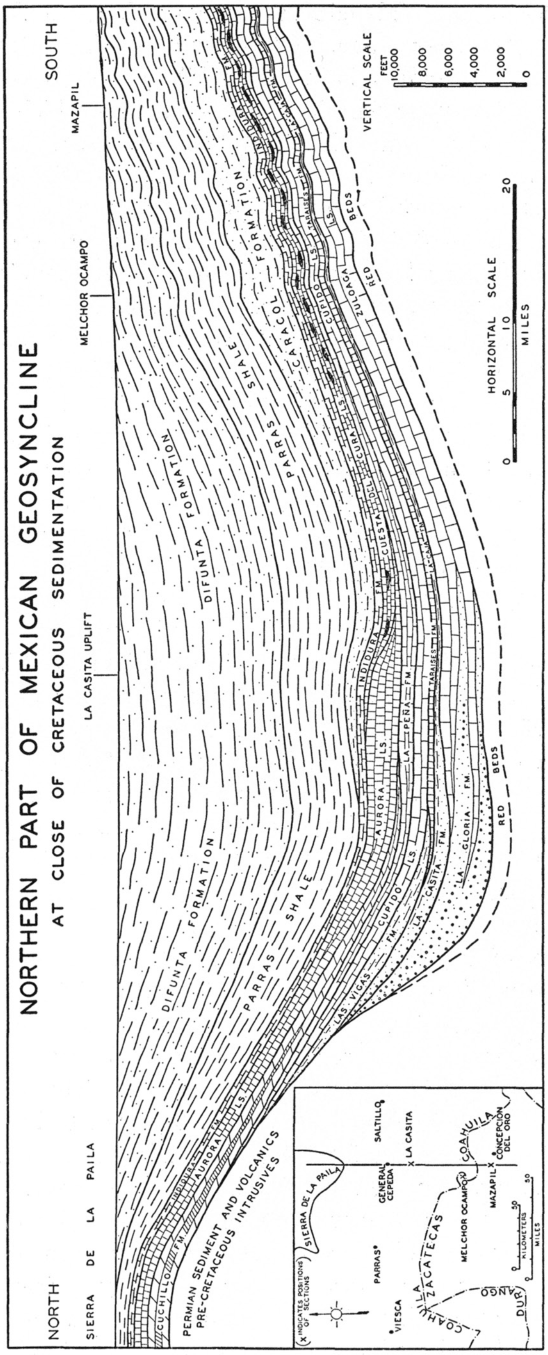


FIGURE 5.—*Northern part of Mexican geosyncline at close of Cretaceous sedimentation*

tion of the shales is explained by the strong deformation which the region has undergone. The anticline, which trends roughly north-south through San Pedro del Gallo, has been strongly overturned toward the east and broken by a number of cross-faults into a mosaic of blocks. The nearly recumbent east flank is well shown in the Mesa del Cardenche southeast of the city. During the folding, considerable readjustment of the beds must have taken place along the axial plane of the anticline, and much of this readjustment occurred in the relatively soft beds of La Casita formation. Considering the poor exposures and the amount of deformation of La Casita formation in this area, the thickness can only be estimated. The 3000 or more feet given by Burckhardt may be nearly correct, but the writer would estimate the thickness to be between 700 and 1500 feet.

Comparing La Casita formation at the various localities, the coarsest and thickest deposits occur west of the former Coahuila Peninsula, and the most carbonaceous and gypsiferous deposits occur south of the peninsula. These relationships show that the main drainage of the land was toward the west and that south of the landmass lagoons existed in which circulation of sea waters was feeble and sedimentation slow.

CRETACEOUS

Taraises formation.—This formation has been adequately discussed elsewhere (Imlay, 1938, p. 541-544), except for the near-shore equivalent in the mountains west of the Laguna District (Kellum, 1936, p. 1069-1070). Units 4 and 3 on the western flank of the Sierra de Mapimí and equivalent units on the east flank of the Villa Juárez uplift bear lithologic resemblances to the Taraises formation and occupy about the same stratigraphic position. No fossils have been found in these units, but they probably belong in the Neocomian as the underlying unit B (and 5) contains ammonites which indicate a late Jurassic or early Cretaceous age. The lower unit, A and 4, like the lower member of the Taraises formation, tends to form bluffs but differs from the latter in being more siliceous and in containing beds of sandstone and arkose. The upper unit 3 (Kellum, 1936, p. 1058) is similar lithologically to the upper member of the Taraises formation and, similarly, weathers easily to form depressions. The same unit is well exposed in the first canyon about half a mile east of Cuesta del Carbonera (Kellum, 1936, pl. 14). It is overlain at this locality, and also on the west side of the Sierra de Mapimí, by sandstone and shale which resemble Las Vigas formation of the Sierra de Parras section.

Las Vigas, Parritas, and Cupido formations.—Las Vigas formation includes the clastic facies deposited around the margin of Coahuila Peninsula during upper Neocomian and possibly lower Aptian times. The time represented by the formation may not be the same at all localities, but its stratigraphic position is similar. In the western part of the Sierra de Parras and in the Sierra Jimulco, Las Vigas formation overlies the Taraises formation which contains lower Hauterivian fossils. In the mountains west of the Laguna district the same relationship seems to exist. Unit 2 of the section on the west side of Sierra de Mapimí (Kellum, 1936, p. 1058, 1070) is lithologically similar to Las Vigas formation of the Sierra de Parras and overlies units which are probably near-shore equivalents of the Taraises formation. The same unit occurs in Cañón de los Cabritos about 2 miles south of Las Cuevas ranch on the east side of the Villa Juárez uplift (Kellum, 1936, p. 1070). Las Vigas formation in the western part of the Sierra de Parras is 945 feet thick, in the eastern part of the Sierra Jimulco about 800 feet thick, and on the west side of the Sierra de Mapimí 112 feet thick, thus varying considerably in thickness within rather short distances. The incomplete section on the south wall of Cañón de San Pedro in the Sierra Jimulco about 4½ miles south of Viesca, from top to bottom, is as follows:

Unit	Feet
1. Limestone, shaly, and some gray shales	96
2. Shale, light gray to pinkish, contains some shaly limestone near top and grades into overlying unit	77
3. Limestone, shaly, light gray	9
4. Shale, pink, somewhat indurated	3
5. Shale, papery, ashy gray to pinkish	64
6. Limestone, shaly, and shales, light gray	26
7. Shale, papery, ashy gray	17½
8. Shale, light gray and pinkish, contains some thin beds of light gray limestone	62
9. Limestone, shaly, light gray	243
	597+

The lowermost unit of Las Vigas formation is exposed on the south wall of Cañón Alamo, about 4 miles southwest of Viesca. It consists mainly of shale, which includes two benches of ground shell conglomerate, and grades downward into the shaly limestones of the upper member of the Taraises formation.

The Parritas formation includes the yellowish, thin- to thick-bedded limestones directly over Las Vigas formation in the western part of the Sierra de Parras (Imlay, 1936, p. 1117). Yellowish limestones occur near the base of the Cretaceous section in the mountains of eastern Durango and in the Sierra del Ramirez and Sierrita del Chivo in western Zacatecas. Perhaps detailed mapping in these areas would show the desirability of extending the formation name, but at present it is applied only locally.

The Cupido limestone comprises the thick- to thin-bedded gray limestones between the Taraises and La Peña formations (Imlay, 1937a, p.

606) and is the off-shore equivalent of Las Vigas and the Parritas formations of the western part of the Sierra de Parras. It has been identified in the middle part of the Sierra de Parras and in many places in northern Zacatecas. It will probably be found over large areas in the central part of the Mexican geosyncline.

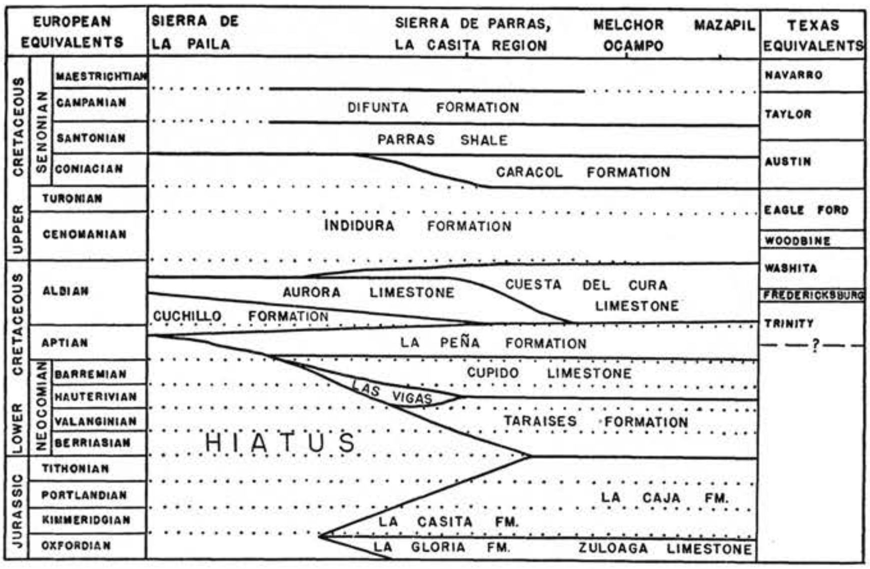


FIGURE 6.—*Time relations of facies in the Mexican geosyncline*

La Peña formation.—In the mountains bordering the site of the Coahuila Peninsula (*i.e.*, Sierra de Parras, Mapimí, Rosario, and Jimulco), La Peña formation includes the lower and middle parts of the mountain-forming limestones below the Aurora limestone. It varies from thick- to thin-bedded, and some sections contain considerable amounts of shale and shaly limestone. These units of shaly to thin-bedded limestone characterize La Peña formation and distinguish it from the contiguous formations. The top of the formation in all sections is marked by a unit of thin-bedded limestone and marl, or shale, which commonly contains upper Aptian fossils. The base of the formation is not sharply demarcated in most sections. In the Sierra Jimulco and the Sierra de Mapimí it is extended down to the top of Las Vigas formation because there is no lithologic or faunal basis for subdivision at a higher horizon. At these localities, therefore, the formation probably includes older beds than in the Sierra de Parras. La Peña formation has a considerable range in thickness—in the middle part of the Sierra de Parras from 1000 to 1270 feet; in the western part, from 1420 to 2260 feet; in the eastern part of the

Sierra de Jimulco, 1000 feet. In the Sierra de Mapimí, Kellum (1936, p. 1057, 1070) measured only 248 feet, but the complete formation is much thicker.

The complete section on the south wall of Cañón de San Pedro in the Sierra Jimulco about 4½ miles south of Viesca, from top to bottom, is as follows:

Unit	Feet
1. Limestone, shaly, gray	10
2. Limestone, thick-bedded, dark gray	48
3. Limestone, shaly and thick-bedded alternating, medium gray	66
4. Limestone, thin-bedded and nodular at base, becoming more shaly toward top	48
5. Limestone, compact, gray	2
6. Limestone, thin-bedded, nodular, gray, contains traces of oyster shells	192
7. Limestone, shaly, medium gray	53
8. Limestone, thick-bedded, gray	6
9. Limestone, shaly, gray	18
10. Limestone, medium- to thin-bedded	268
11. Limestone, mainly thick- to medium-bedded, some thin-bedded, gray	195
12. Limestone, thin- to medium-bedded, becomes thicker-bedded upward, dark gray	94
Total	1000

La Peña formation in the Sierra de Parras becomes thinner-bedded toward the south. In northern Zacatecas it is a rather thin formation consisting of thin-bedded to platy limestone separated by shaly parting and many thin beds of black chert. This black chert represents the beginning of a type of sedimentation which continued nearly uninterruptedly until the end of Albian time in Zacatecas, but which along the northern front of the Sierra de Parras was confined to the upper Albian. The upper beds in the vicinity of Mazapil, Zacatecas, contain fossils which Burckhardt (1930, p. 126, 134) considers of basal Albian age. If this is so, the highest beds of La Peña formation in northern Zacatecas are equivalent to the basal Aurora limestone of the Sierra de Parras section.

Aurora and Cuesta del Cura limestones.—The Aurora limestone is a reef facies of lower and middle Albian age which apparently covers areas that were landmasses in Upper Jurassic, or Neocomian times, or that were only slightly submerged adjacent to landmasses. Thus, the Aurora limestone crops out on the site of the Coahuila Peninsula as well as in the high mountains which border the former peninsula. A strip of reef facies of approximately the same age seems to be fairly continuous along the Sierra Madre Oriental from the region of Saltillo southward. South of the Coahuila Peninsula the Aurora limestone ends in the Sierras de Parras (Imlay, 1937a, p. 611) and Jimulco and is replaced by a series of chert-bearing limestones scarcely distinguishable from the Cuesta del Cura limestone. West of the Coahuila Peninsula the Aurora limestone is present in the Sierra del Rosario but absent in the Mesa del Cardenche southeast of San Pedro del Gallo.

The Cuesta del Cura limestone was originally defined (Imlay, 1936, p. 1125), from the western part of the Sierra de Parras, to include the thin-bedded limestones and black cherts between the Aurora limestone and the Indidura formation. At the type locality it is about 210 feet thick and probably of upper Albian age. In the middle part of the Sierra de Parras the Cuesta del Cura limestone thickens southward from about 250 feet along the northern front of the range to about 1000 feet along the southern margin. This thickening is coincident with thinning of the underlying Aurora limestone (Imlay, 1937a, p. 614-615). In the vicinity of Melchor Ocampo the Cuesta del Cura limestone is about 828 feet thick, and the Aurora limestone facies has disappeared. However, the lower 250 feet of the formation is somewhat thicker-bedded than the upper part and is possibly the equivalent of the Aurora limestone. In the vicinity of Mazapil the Cuesta del Cura limestone is about 1024 feet thick and is not noticeably thicker-bedded toward the base. Thus, the Cuesta del Cura limestone represents a facies which includes nearly the entire Albian in the region of Mazapil and only the upper Albian along the Sierra de Parras front.

Indidura, Cuesta del Cura, and Caracol formations.—The Indidura formation was originally defined (Kelly, 1936, p. 1028-1029) for about 100 feet of shales, rubbly limestones, and platy limestones directly overlying the Aurora limestone at the southern end of the Sierra de Santa Ana southwest of Las Delicias, Coahuila. The type section contains fossils of upper Albian, Cenomanian, and Turonian ages (Jones, 1938, p. 86-93). The same facies and fauna directly overly the Aurora limestone in the Sierra de la Peña (Jones, 1938, p. 83-86) and in the Sierra de Tlahualilo (Robinson). All these areas overlie, or are on the margin of, the Coahuila Peninsula of Upper Jurassic time. South of the site of the peninsula in southern Coahuila and northern Zacatecas the Indidura formation becomes more calcareous and very unfossiliferous. In the western part of the Sierra de Parras it is of Cenomanian, Turonian, and Coniacian age and is underlain by the Cuesta del Cura limestone which is probably equivalent to the basal Indidura at its type locality. In the middle part of the Sierra de Parras and farther south in Coahuila and northern Zacatecas the Indidura is underlain by the Cuesta del Cura limestone and overlain by the Caracol shale and tuff. The latter thickens greatly southward and is equivalent to the upper part of the Indidura formation of the western part of the Sierra de Parras. Thus, the Indidura formation in central Coahuila passes southward in Coahuila and Zacatecas into three distinct facies. In central Coahuila, over the site of the Coahuila Peninsula, deposition went on very slowly in a shallow sea from Upper Albian until Coniacian time and the environment remained very favorable for bottom-living organisms. South of the peninsula, deposition occurred in fairly deep waters during the upper Albian and in shallow waters during Cenomanian to Coniacian time, but the bottom conditions were unfavorable to organisms probably due to the rapid accumulation of sediments derived from the rising landmasses in central Mexico. The maximum thickness of the Indidura formation on areas overlying Coahuila Peninsula is only a few hundred feet. The thickness of equivalent formations in northern Zacatecas is more than 4000 feet. Comparing the highly fossiliferous Indidura formation in central Coahuila with the unfossiliferous so-called Indidura formation in areas off-shore from the Coahuila Peninsula, the question arises as to whether they should be recognized by the same name. Perhaps future studies of the formation will show the desirability of restricting the name to the deposits overlying the Coahuila Peninsula and of giving a different name to the deeper-water facies.

Parras shale and Difunta formation.—During the Senonian the positive areas of central and western Mexico began rising, at first slowly and later rapidly, as shown by the increasing coarseness and quantity of sediments deposited in the Mexican geosyncline. At first, dark calcareous muds were deposited with considerable quantities of volcanic ash which was showered widely at frequent intervals. Later, enormous quantities of sands were swept from the lands into the rapidly sinking geosyncline and, although deposition of calcareous muds continued at a great rate, gave rise to characteristic coarse deposits known as the Difunta formation. The earlier deposits, known as the Parras shale, crop out along the southern part of the Parras Basin as well as at many places in Zacatecas. The younger Difunta formation, on the other hand, has not been found south of the Parras Basin.

WORKS TO WHICH REFERENCE IS MADE

Aguilera, J. G., and Castillo, A. (1895) *Fauna fósil de la Sierra de Catorce, San Luis Potosí,* Inst. Geol. México, Bol., num. 1, 55 pages, 24 plates.

Albritton, C. C. (1937) *Faunal diversity in Malone Mountains Beds, Texas,* Pan-Am. Geol., vol. LXVIII, p. 257-262, 1 figure.

Böse, Emil (1923a) *Vestiges of an ancient continent in northeast Mexico,* Am. Jour. Sci., 5th ser., vol. 6, p. 127-136, 196-214, 310-337, 4 figures.

——— (1923b) *Algunas faunas cretácicas de Zacatecas, Durango, y Guerrero,* Soc. Geol. México, Bol., num. 42, 219 pages, 19 plates.

———, and Cavins, O. A. (1927) *The Cretaceous and Tertiary of southern Texas and northern Mexico,* Univ. Texas Bull., no. 2748, p. 7-142, 1 plate (paleogeographic map).

Burckhardt, Carlos (1906a) *Géologie de la Sierra de Concepción del Oro (Mexico)*, 10th Intern. Geol. Cong., Mexico, Guidebook 24, 24 pages, 1 map.
——— (1906b) *Géologie de la Sierra Mazapil et Santa Rosa (Mexico)*, 10th Intern. Geol. Cong., Mexico, Guidebook 26, 40 pages, 2 maps.
——— (1906c) *La Faune jurassique de Mazapil, avec un appendice sur les Fossiles du Crétacique inférieur*, Inst. Geol. México, Bol., num. 23, 216 pages, 43 plates.
——— (1910) *Estudio geológico de la región de San Pedro del Gallo, Durango*, Inst. Geol. México, Parergones tomo III, no. 6, p. 307-357, chart, 1 plate, geologic map.
——— (1912) *Faunes jurassiques et crétaciques de San Pedro del Gallo (Etat de Durango, Mexico)*, Inst. Geol. México, Bol., num. 29, 260 pages, 46 plates.
——— (1925) *Faunas del Aptiano de Nazas (Durango)*, Inst. Geol. México, Bol., num. 45, 71 pages, 10 plates.
——— (1930) *Etude synthétique sur le Mésozoïque mexicain*, Soc. Paléont. Suisse, Mem., vols. 49-50, 280 pages, 11 tables, 32 figures.
Galliher, E. Wayne (1935) *Glauconite genesis*, Geol. Soc. Am., Bull., vol. 46, p. 1351-1366, pls. 109-110, 1 figure.
Imlay, R. W. (1936) *Geology of the western part of the Sierra de Parras*, Geol. Soc. Am., Bull., vol. 47, p. 1091-1152, 10 plates, 3 figures.
——— (1937a) *Geology of the middle part of the Sierra de Parras, Coahuila, Mexico*, Geol. Soc. Am., Bull., vol. 48, p. 587-630, 14 plates, 4 figures.
——— (1937b) *Lower Neocomian fossils from the Miquihuana region, Mexico*, Jour. Paleont., vol. 11, no. 7, p. 552-574, pls. 70-83, 8 figures.
——— (1938) *Ammonites of the Taraises formation of northern Mexico*, Geol. Soc. Am., Bull., vol. 49, p. 539-602, 15 plates, 4 figures.
Jones, T. S. (1938) *Geology of Sierra de la Peña and paleontology of the Indidura formation*, Geol. Soc. Am., Bull., vol. 49, p. 69-150, 13 plates, 4 figures.
Kellum, L. B. (1932) *Reconnaissance studies in the Sierra de Jimulco, Mexico*, Geol. Soc. Am., Bull., vol. 43, p. 541-564, 15 figures.
——— (1936) *Geology of the mountains west of the Laguna district*, Geol. Soc. Am., Bull., vol. 47, p. 1039-1090, 14 plates, 2 figures.
———, Imlay, R. W., and Kane, W. G. (1936) *Relation of structure, stratigraphy, and igneous activity to an early continental margin*, Geol. Soc. Am., Bull., vol. 47, p. 969-1008, 3 plates, 3 figures.
Kelly, W. A. (1936) *Geology of the mountains bordering the valleys of Acatita and Las Delicias*, Geol. Soc. Am., Bull., vol. 47, p. 1009-1038, 13 plates, 2 figures.
Robinson, W. I.: *Geology of the Sierra de Tlahualilo, Durango, Mexico*. (In manuscript.)

UNIVERSITY OF MICHIGAN, ANN ARBOR, MICH.
MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, APRIL 4, 1938.
READ BEFORE THE GEOLOGICAL SOCIETY, DECEMBER 30, 1937.
PROJECT GRANT 167-36.