The front ranges of Sierra Madre Oriental, Mexico, from Ciudad Victoria to Tamazunchale

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The Front Ranges of Sierra Madre Oriental, Mexico, from Ciudad Victoria to Tamazunchale.

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With 3 plates (XVI—XVIII) and 10 textfigures.

Contents.

I. Introduction.

The field-work on which this paper is based was undertaken for the Shell Group of oil-companies, between April and August, 1925. The directorate of the Bataafsche Petroleum Maatschappij at the Hague has generously invited me to publish the results not directly related to commercial production.

As a geologist of the Shell Group, J. M. Muir had the writer's reports at his disposal and has used certain data in his excellent book on the geology of the Tampico district (Muir, 1936). So far, only two brief notes have been published by myself on the Tampico region (Arn. Heim, 1926, 1934).

In addition, two valuable papers by W. Staub have been published in 1937 and 1939 on the Tampico region. The former one contains a series of complete sections in 1: 200 000 including Sierra Tamaulipas and Sierra Madre Oriental, the latter after my observations.

The region involved measures 300 kms from north to south and is 30—50 kms wide. The adjoining map is a reduction of twelve 1: 100 000 sheets. The work was hampered by bad weather, poor roads, slow transportation and untrustworthy base-maps. The northern and southern extremities of the area could not be studied as thoroughly as intended. The topography of the 1: 100 000 map of Mexico proved very unreliable. Much time was lost in the field over orientation and topographic correction.

North of Xicotencatl, the basalt-mesas were plane-tabled. The distance from this town to the mountain-front proved to be about 6 kms too short on the 1: 100 000 map. Hence, in such regions where the topographic contours are entirely false, we compromised by drawing the geological boundaries without regard to topography. In the reduced scale of the map, it was impossible to enter the strikes and dips, of which several thousands are indicated on the original sheets.

So long as the dry weather lasted, part of the work along the plain was done with the help of two Ford cars. But on the first days of heavy rain they stuck in the mud; even travelling on horseback became difficult. The hilly region was traversed partly on horses or mules, partly on foot, tents being used for camping.

The Front Ranges, especially in the north, are exceedingly difficult of access on account of dense jungle with cactus and thorny underbrush, as well as by lack of trails. No jungle known to the writer presents so many obstacles to geological work.

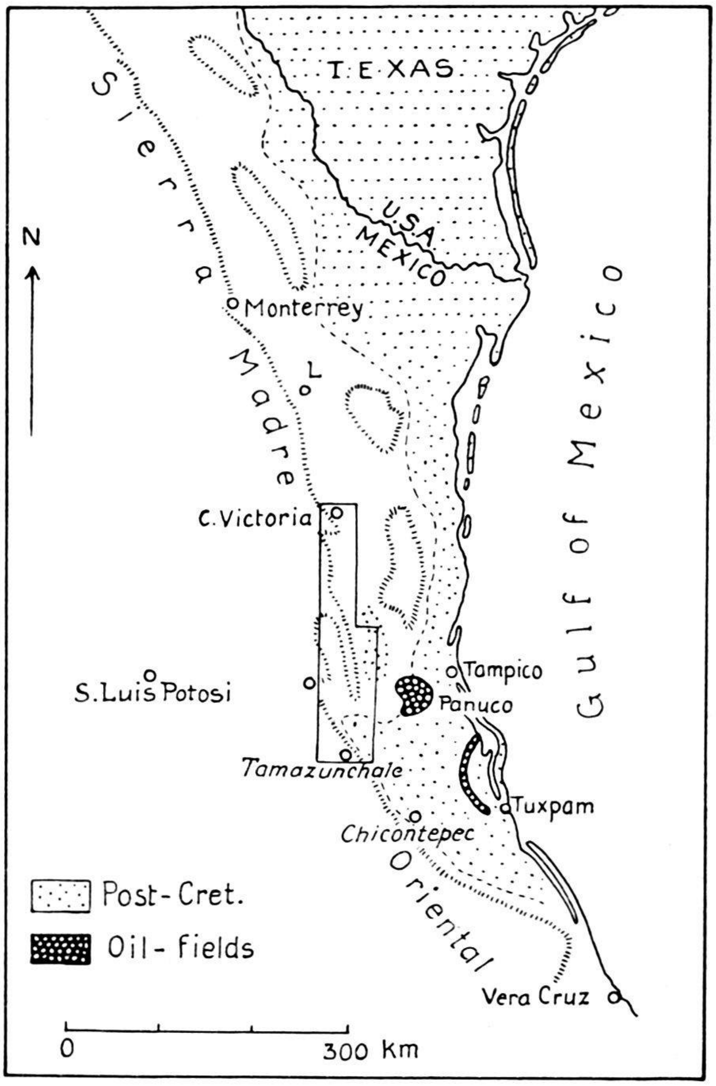

Fig. 1. *Index - Map.*

1:10000000.

The writer wishes to acknowledge the excellent and energetic collaboration of his assistents, Dr. H. Jenny † and Dr. W. Fehr. The map and the structural sections (Pl. XVI—XVIII) are joint work throughout.

Sincere thanks I ow to my colleague J. S. Turner, B.S.C., F.G.S., now professor at Rangoon College, Burma. He not only has encouraged me to prepare the original report for publication, but has kindly reviewed my complete manuscript.

II. Stratigraphy.

(a) General Observations.

The following formations are exposed in the mapped part of the Front Ranges:

Recent	Alluvium.	
	Caliche, Screes, Rock-Slides.	
Late-Tertiary? . . .	Basalt-flows and mesas.	
	Basaltic necks and plugs.	
Paleocene	Chalma Shale	Chicontepec Formation.
	Tanlajás Sandstone	
Cretaceous	Tamesí Formation.	
	Mendez Marls.	
	San Felipe Formation.	
	Xilitla Formation.	
	Tamabra Limestone.	
	Lower Cretaceous Limestones (in the northwest).	
Jurassic	Upper Jurassic Limestones and Shales (in the south).	
	Olvido Formation	in the north.
	Novillo Formation	
Permian?	Red Beds with basic intrusions.	
Carboniferous	Peregrina Formation.	
Pre-Carboniferous	Phyllites, Micaschists.	
	Gneiss and granite.	

The oldest rocks of the Front Ranges occur in the north, where two lateral valleys, west of Victoria, have exposed the crystalline core of the main anticline. This core is overlain unconformably by a thick series of Upper Palaeozoic strata, cut off by a second unconformity. Then follow more than 2000 metres of Mesozoic sediments, chiefly Cretaceous limestones and marls. The limestones, especially the thick-bedded Tamabra, dominate the Ranges. In the north, the Pre-Cretaceous sediments are partly terrestrial and brackish. In the south, at Tamazunchale, fossiliferous marine sediments of Jurassic age with ammonites occur.

(b) Region of Ciudad Victoria.

Gneiss.

Novillo and Peregrina Canyons have opened the crystalline core, formed of gneiss, gneissic granite and amphibolite. At Novillo, the gneiss is rich in red garnet. The foliation strikes NW and WNW, thus obliquely to the folds of the Cretaceous sediments. The crystalline rocks are cut by green diabase and serpentine and capped by gabbro (Pl. XVII, Section 1—2; Textfig. 2).

At Peregrina, the gneiss dips less steeply, generally to E or NE. In places, it is so slightly metamorphosed that one might call it a granite. Basic and metamorphic rocks are again associated with the gneiss, which is faulted against the Palaeozoic sediments (Pl. XVII, Section 1).

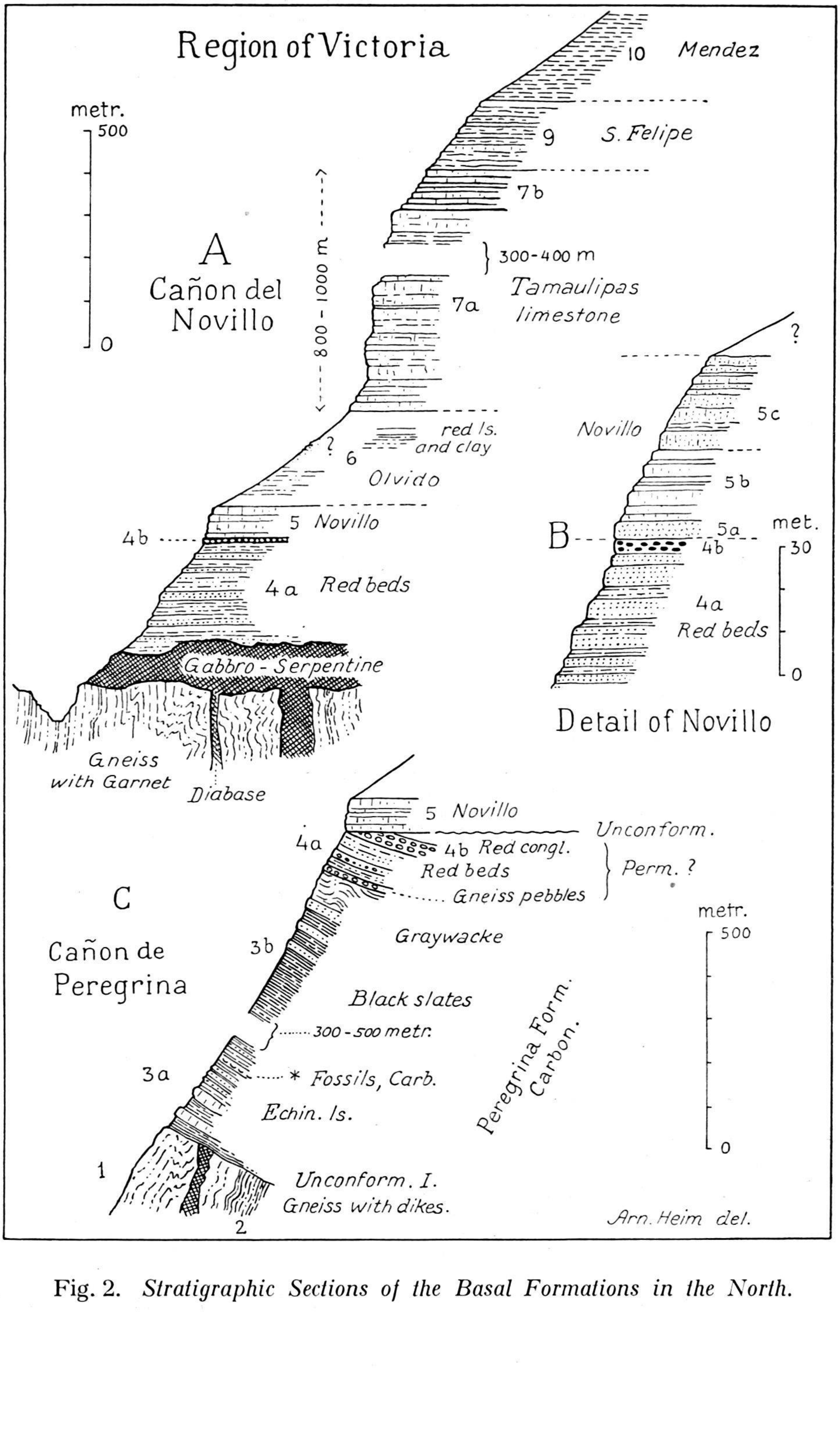

Fig. 2. *Stratigraphic Sections of the Basal Formations in the North.*

Phyllites (Pre-Mississippian).

Boulders of mica-schists and spotted phyllites *(Knotenschiefer)* occur on the trail above Peregrina. The latter, with andalusite, are a typical product of contact-metamorphism. According to Mr. PARKER ROBERTSON, who accompanied me, they come from the higher valley-slope towards Molino (Section 1), and seem to overlie the gneiss; but they are certainly older than Mississippian.

Peregrina Formation (Mississippian).

The Peregrina ranch-houses stand on steeply and intensely folded, dark slates, about 1000 m thick, with beds of greywacke. To the east, in the upper part of the series, there are beds of conglomerate with gneiss-boulders up to the size of one's head, and red quartzite. The uppermost conglomerate-bed forms the base of the overlying Red Beds.

About 1 km west of Peregrina ranch occurs a rough, sandy limestone, dipping west, with echinoderm-fragments. Then follow greywacke and greenish quartzite, overlain by fossiliferous, black, sandy shale. The fossils collected in the creek by Messrs. P. ROBERTSON, J. M. MUIR and the writer were determined by Dr. L. W. STEPHENSON of the U. S. Geological Survey as *Productus semireticulatus* var. *hermosanus* GIRTY, *Spirifer, Orthothetes, Athyris, Spiriferina*, etc., and have been regarded as Pennsylvanian.

According to a letter from the late STUART WELLER (University of Chicago), however, fossils collected by Mr. C. L. BAKER, apparently at the same place, include *Productus, Syringothyris, Tetracema subtrigona* M. & W., *Spiriferina, Reticularia* cf. *pseudolineata* (HALL), *Chonetes, Athyris lamellosa* (LEV.), etc., which are definitely Lower Mississippian[1]).

The upper part of the Peregrina Beds may therefore be regarded as Upper Mississippian or Pennsylvanian.

Red Beds (Permian ?).

Red Beds have long been known. The writer found them also in the interior ranges of Miquihuana and Aramberri (p. 351). Some geologists have considered them to be Upper Jurassic. According to our observations, however, the Red Beds in the Victoria Range must be older. They consist of: (1) Red clay-shale, more or less sandy, with occasional layers of sandstone and conglomerate; (2) Red conglomerate (15 m thick), well exposed on the road west of Huizachal. On the Peregrina trail it is about 30 m thick and is badly crushed. The pebbles of gneiss and other metamorphic rocks attain the size of one's head. The crushing seems to have developed along the unconformity above the Red Beds, plainly visible west of Peregrina (Pl. XVII, Section 1). The dip is 0—30° higher than in the overlying Novillo Beds (Textfigs. 2c and 3). This unconformity explains the local absence of the conglomerate at El Nacimiento, about a mile east of Peregrina, where the red shale is found in contact with the Novillo Beds, both standing nearly vertically. It also explains the local reduction here of the Red Beds to less than 50 m.

North of Victoria, a thick body of Permian limestone has been described (*Diligenciaschichten*, HAARMANN 1913; HAACK 1914). Apparently this limestone fills the hiatus at the unconformity below or above the conglomerate.

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[1]) G. H. GIRTY also regards the fossiliferous horizon as Mississippian. See MUIR 1936, p. 7-9

Novillo Formation.

Formerly, this division was either regarded as the lower part of the Tamaulipas Limestone or completely ignored, but it is easily distinguished by its peculiar clay-ironstone facies. The name is taken from Novillo Canyon, west of Victoria, where the lower part, in contact with the red conglomerate, is exposed on the trail between the upper and lower ranches of Novillo (Fig. 2 B), as follows:

(c) Fine-grained, sandy limestone, resembling that of the Chicontepec Series	20 m
(b) Dark-bluish, dense to fine-grained limestone, resembling Tamaulipas Limestone	15—20 m
(a) Fine-grained ironstone, in compact beds up to 1 m each	4 m

The weathering is distinctly brownish and different from that of the Tamaulipas Limestone. A more complete exposure occurs on the road east of Huizachal, as follows (Textfig. 3):

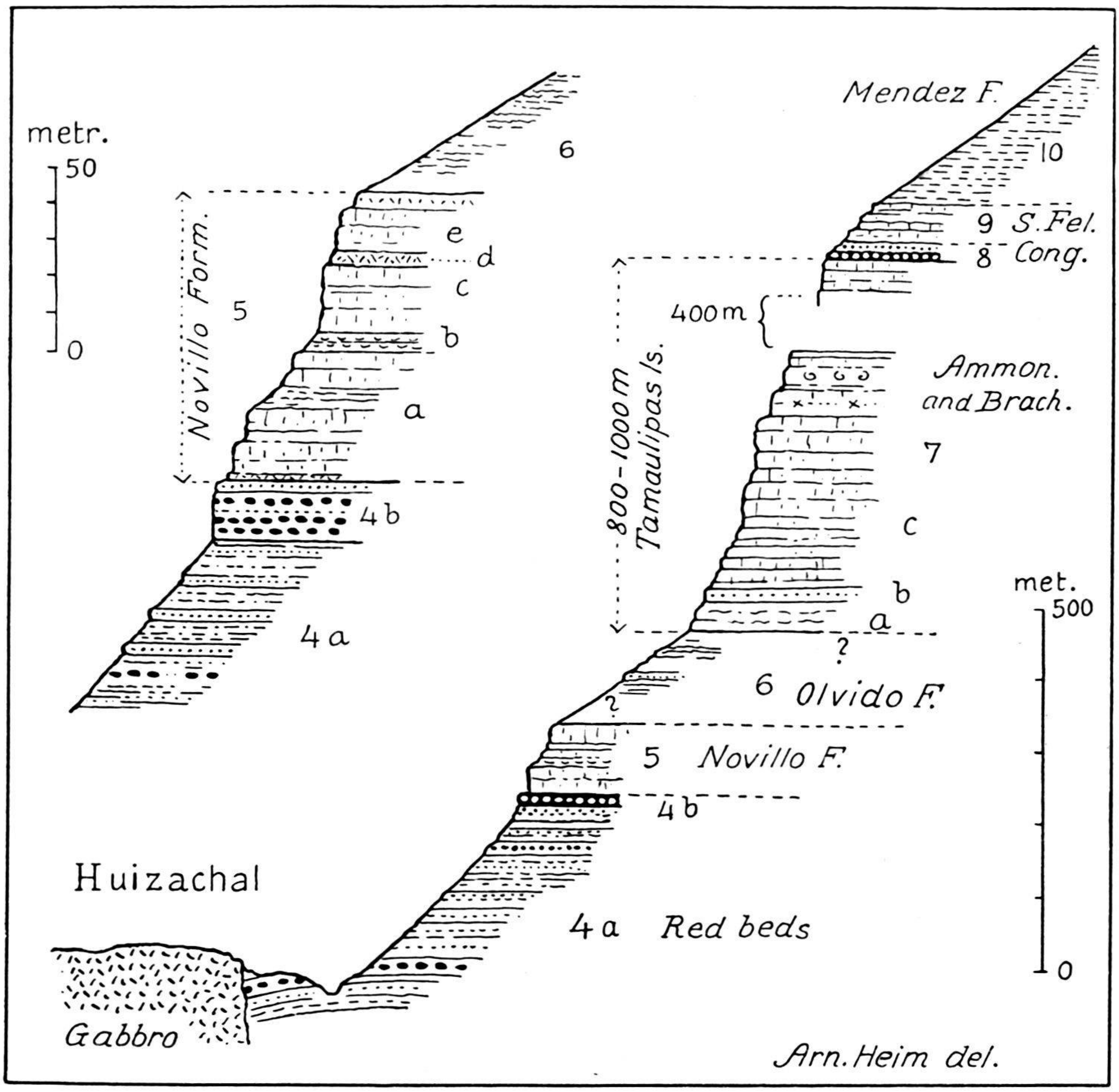

Fig. 3. *Stratigraphic Sections of Huizachal, SW of Ciudad Victoria.*

(e) Limestone and ironstone, like c and d, with grains of glauconite	20 m
(d) Ironstone, weathering brown	4—5 m
(c) Blue, dense to fine-grained limestone with algae	18 m
(b) Thin-bedded limestone with marls, weathering yellow-brown, with abundant *Exogyra* and *Rhynchonella multiformis*	5 m
(a) Dark limestone, weathering light grey, with basal ironstone	35 m

Here the Novillo Beds lie conformably on the Red Beds. A transition-facies a few metres thick, is probably due to reworking of the latter.

As a whole, the Novillo Beds are a distinct lithological unit, 50—100 m thick, of limestones with interbedded ironstone-layers. Fossils are poorly preserved. Dr. C. Burckhardt considered the *Rynchonella* to be a Neocomian species, but according to Schmittou (in Muir 1936, p. 13—14) the Novillo Beds would be Upper Jurassic or even older.

Olvido Formation (" Gypsum Beds").

No upper contact of the Novillo Formation was found. In Peregrina and Novillo Canyons, the Novillo Beds are separated from the Tamaulipas Limestone by a wide slope covered with boulders and " caliche " (surface-breccia), indicating a readily weathered substratum. Only in the Huizachal region have outcrops been found. The road west of Huizachal exposes warped beds of yellow to orange-weathering limestone and dolomite with interbedded green, red and violet clay and some sandstone (Textfig. 3). East of Huizachal, in the wild canyon of the abandoned Olvido Ranch, the variegated clays show fresh exposures with big blocks of gypsum. Thus, the general obscurity of this series at Novillo and Huizachal is explained. It is 50—300 m thick.

The writer nowhere found an exposure of the contact with the overlying Tamabra Limestone. In Peregrina Canyon, the lowest exposures of Tamaulipas Limestone seem to overlie the Gypsum Beds directly. The age is still problematical. Our observations are difficult to correlate with those of Schmittou (in Burckhardt 1930 and Muir 1936). It seems that he underestimated the thickness of our Olvido series, and that he did not separate it properly from the totally different facies of the Novillo Beds[2]).

Portlandian-Valanginian.

In Peregrina Canyon, only isolated outcrops of dense, grey limestones were noted directly under the walls of Tamaulipas Limestone, with patches of yellow, rose and red colour and some brachiopods. Later however, Schmittou seems

[2]) Compared with Muir's Fig. 3, p. 14, our main divisions seem to correspond to Schmittou's as follows:

	Rancho Molino	WSW of Huizachal	ESE of Huizachal
Olvido Formation	—	J—G	J—B
Novillo Formation	C	Q—L	O—K

to have found good exposures and the late Dr. BURCKHARDT identified his ammonites (MUIR 1936, p. 13—14, 22). Their result is as follows:

2. Valanginian, WSW of Huizachal: grey limestone alternating with marly chalk, and containing *Astieria schenki* UHL. non OPPEL, *Neocomites* aff. *paraplesius* UHL., *N. neocomiensis* (D'ORB.), and *Polyptychites* . . . . 10 m

1. Portlandian: marly limestones with shales and dark sandstones, containing *Perisphinctes and Holcostephanus* of the *stephanoides*-group . . . . 4—6 m

Tamabra Limestone (Lower and Middle Cretaceous).

This important limestone-division was originally called after Tamasopo Canyon, in the Inner Ranges along the Tampico–San Luis Potosí railway. After C. L. BAKER's discovery of a Senonian *Coralliochama* in the type-section, the name Tamasopo could no longer be used for the limestones which underlie the Turonian of the Front Ranges. Three names are introduced for different facies:

(a) Taninul Limestone, from a station on the San Luis Potosí railway in front of the El Abra Range: a reef-type with large rudistids and breccias.

(b) Abra Limestone, from the quarries of El Abra, 2 kms farther east on the same railway: rudistids have given place to miliolinids, which locally make up 50% of the rock (Textfig. 5).

(c) Tamaulipas Limestone, forming a great part of the Sierra de Tamaulipas and the Sierra Madre near Victoria: a well-bedded, dense, black to grey limestone with chert, weathering bluish-white, the beds frequently with stylolith-jointing.

White limestones with chert may be intercalated in the black Tamaulipas or in the Abra facies, and no sharp boundary can be drawn, one type passing into the other. According to H. ADRIAN, the normal Tamaulipas limestone with chert, in the Sierra Tamaulipas, is underlain " by pure white limestone without silex ", which has also been called Tamaulipas.

For the entire limestone-complex beneath the San Felipe or the Xilitla (Agua Nueva) Formations, the writer proposes the name Tamabra Formation, including the different facies.

Near Victoria, the Tamaulipas (Victoria) facies predominates (Pl. XVI). It is well exposed on the road to Huizachal, and is chiefly formed of distinct beds, 10—100 cm thick, of compact, dark and dense limestone with concretions and thin layers of dark chert. In hand-specimens and in the field, the resemblance to the Upper Jurassic *Hochgebirgskalk* or *Quintnerkalk* of the Swiss Alps is striking. The bedding-planes are often very uneven, suggesting submarine solution. Styloliths are common.

At Cumbre, 1200 m above sea-level (Pl. XVII, Section 3), and on the slope towards Huizachal, belemnites (*Belemnopsis minima*?), ammonites and *Terebratula* have been found. The shells have usually been dissolved and so are specifically indeterminable. According to Mr. W. S. ADKINS, they are Vraconnian (Middle Cretaceous) types. Their exact horizon at Cumbre is obscured by complicated folding and crumpling, but they clearly belong to the middle part of the Tamaulipas Limestone (Textfig. 3). This is confirmed on the western limb of the Huizachal Anticline, where ADKINS found the same fossils (*Desmoceras*, belemnites) at similar horizons.

The total thickness of the Tamabra Series at Victoria is about 1000 m (Textfig. 3), almost five times as great as in the Sierra Tamaulipas and at Pánuco (MUIR 1936, p. 37). In the Canyon del Novillo, the lower division forms huge walls of thick-bedded, white, dense limestone like that of the Sierra Tamaulipas itself. Higher up, the limestone is of Urgonian type (El Abra facies), and contains quartz-grains. Thus, even in this northern region, the Tamaulipas facies is locally mixed with the Abra type. The top of the Series, at Victoria, is a thin-bedded, black limestone, 80—100 m thick (7b in Fig. 2 A). Possibly, this horizon already belongs to the Turonian.

Xilitla (= Agua Nueva) Formation (Turonian).

Before 1925, no distinction was made of strata between the Tamaulipas Limestone and the San Felipe beds. In the region of Victoria, the Xilitla Formation is only locally represented. At the entrance to Novillo Canyon, the following succession is seen (dip 25° ENE):

4. Dense, speckled limestone-beds, weathering yellowish, with *Globigerina* (= San Felipe Beds), passing into
3. Thin-bedded, fine-grained, siliceous limestone with chert (= Xilitla Beds?) . . . . 5 m
2. Massive grey limestone, dense to fine-grained, with big chert concretions (Upper Tamaulipas). . . . . 5 m
1. Thin-bedded, dense, black Tamaulipas limestone.

While marine sedimentation seems to have been continuous near Victoria, conditions were different on the west side of the Huizachal Anticline. At La Mula, the Tamaulipas Limestone is covered by several metres of a coarse conglomerate or breccia with limestone-pebbles, resembling caliche. Above it follow some metres of calcareous sandstone with mica, which passes into the San Felipe series. Thus, west of Huizachal, the Xilitla Beds are lacking or represented by clastic sediments (8 in Textfig. 3).

San Felipe Formation (Coniacian).

The name San Felipe was formerly taken to include the Xilitla. At the type-locality on the San Luis Potosí railway, however, no Xilitla Beds are seen. Hence the writer proposes to use the name in a restricted sense, as has been done by Muir (1936, p. 58). The formation is easily recognised by the regular inter-stratifications of marl and dense, yellow-weathering limestone-layers and by the lumpy fracture, due to algae *(Fleckenmergel)*. With a lense, foraminifera can usually be observed, especially *Globotruncana* and *Globigerina*.

Typical San Felipe beds are present throughout the Victoria region, where they average from 100 to 200 m in thickness. West of the Huizachal Anticline, the San Felipe beds are only 50—80 m thick, and contain several thin layers of characteristic, intensely green, marine tuff (bentonite). South of Victoria, in the La Prada region, the thickness increases to over 300 m (Fig. 2; Pl. XVII, Sections 3, 4).

Locally, the San Felipe formation is entirely absent. This is the case on the eastern border of the El Abra front range, where the Mendez marls overlie the Tamabra with rudistids directly (Pl. XVII and Textfig. 4).

Wherever the formation is represented, it passes gradually upward into the Mendez Marls. Hence the stratigraphic boundary cannot be mapped properly in areas where the beds lie horizontally. The San Felipe division, as accepted by Muir (1936, p. 58) is Lower Senonian (Coniacian) in age.

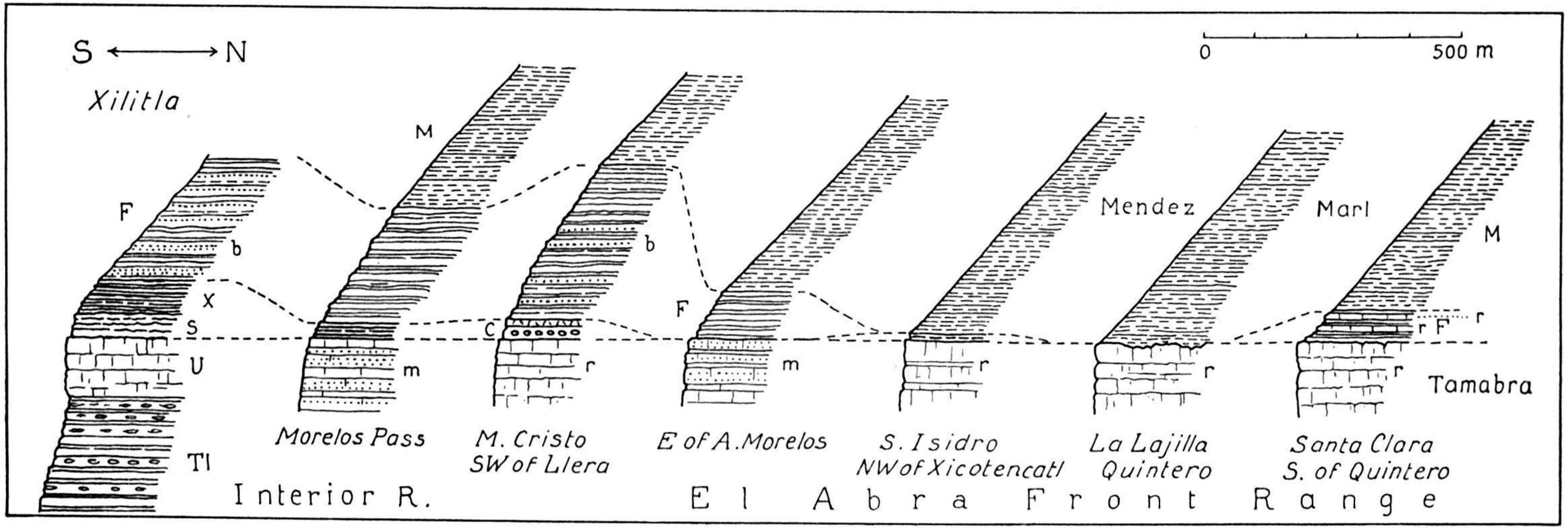

Fig. 4. *Stratigraphic Contacts between Tamabra Limestone and Upper Cretaceous.*

M: Mendez Marls (Middle Senonian);

F: San Felipe Formation; b: layers of bentonite tuff (points); r: limestone with rudistids;

X: Xilitla Formation, bituminous (Turonian); S: black limestone with chert; C: conglomerate and breccia;

Tamabra Formation (Middle Cretaceous): U: Urgonian facies with echinoderm fragments;

Tl: Tamaulipas- or Victoria facies with chert; m: Miliolinids (*Nummuloculina*); r: Rudistids.

Mendez Marls (Senonian).

The well-known Mendez Marls fill the great synclines of the Victoria and Jaumave valleys and are completely stripped off the flanks of the mountain ranges. They are dark grey to greenish and break up into angular fragments. Where calcareous layers are absent, the stratification is obscure. The resemblance in facies, micro-fauna and age to the *Amdener Mergel* of the Helvetic Alps is striking.

(c) Front Ranges South of Victoria.

Tamabra Limestone.

South of the Rio Guayalejo, the Tamabra constitutes the cores of the anticlinal mountain-ranges (Pl. XVII—XVIII). In the Monte Cristo-Carabanchel region (Pl. XVII, Section 6), it forms an immense anticline reaching an elevation of 2 100 m. At the village of Monte Cristo, the highest beds are full of rudistids. They overlie a massive, dense, white limestone with occasional corals, *Chamidae* and chert-nodules. But on the high plateau, the highest Tamabra consists of about 30 m of this dense limestone, while below are thick beds full of rudistids and *Chamidae*, yielding a strong smell of sulphuretted hydrogen under the hammer. In the narrow anticlines farther west (Sierra Prieto), the dark Victoria-facies with chert is interbedded with white limestone of Urgonian type, containing occasional rudistids and *Chamidae*.

Southwards from Gomez Farias, the eastern border of the Sierra del Abra consists of pure rudistid-limestone in thick, white, cavernous beds, intercalated with coarse breccia and conglomerates of rolled limestone-fragments. This facies extends beyond Taninul to the Rio Tampaon. Over this distance of 125 kms, the rudistid-facies only occurs in the eastern limb of the anticlinal mountain-range with a breadth of 1—3 kms. Westwards, it rapidly passes into the El Abra facies with benthonic foraminifera (*Nummuloculina*) and loses the big rudistids.

This change in facies is well seen between Quintero and Antigua Morelos, and again, 70 kms farther south, along the railway between Taninul station and El Abra (Pl. XVIII, Sect. 10; Textfig. 4). The eastern or main quarry at El Abra (Pl. XVIII, Sect. 13) exposes the upper 50 m of the Tamabra. Several interdigitating facies can be distinguished:

(a) Miliolina-limestone, resembling a white oolite and constituting a perfect " Miliolinite ". Dr. W. Leupold, of the University of Zurich, has kindly studied thin sections and prepared Textfig. 5. According to him, the genus is *Nummuloculina* Steinmann.

(b) Dense, light-coloured limestone with calcite in veins and patches.

(c) Echinoderm-limestone, of Urgonian type, partly crystalline, resembling the *Schrattenkalk* of the Alps.

(d) Subordinate rudistid-limestone-layers (Taninul facies).

(e) Irregular streaks and patches, a few metres thick, of black, bituminous limestone (recalling the Xilitla facies), 30—40 m below the top of the quarries.

In the next range inwards, that of Chamal, the facies is again mixed. On the trail from Chamal to Ocampo, only the upper Tamabra is visible in the Victoria (Tamaulipas) facies. In the deep cut at La Boquilla, 6 kms to the south, the following types occur in descending order: Tamaulipas; El Abra; Taninul; a chalky granular facies. The last, several hundred metres below the top of the Tamabra at La Cueva (Pl. XVIII, Sect. 9) is characterised locally by remarkable calcite-poikiloblasts *(Sammelkristalle)*. The rock is porous and cavitous and smells slightly of oil. The resemblance in facies to the Lebanon Limestone of Syria, of the same age, is striking. On the pass between Antiguo and Nuevo Morelos (Textfig. 4), the upper Tamabra is of the mixed type: perfect "miliolinite", black dense Tamaulipas facies with or without *Nummuloculina*, and light grey limestone of Urgonian type with *Chamidae*.

The Sierra Colmena, the next range west of Nuevo Morelos, also shows *miliolina*- and rudistid-limestones. Farther south, miliolinids occur all the way along it to its end at Tanchanaco, and rudistids are seen in many places south of the San Luis Potosí railway. The next Tamabra range still shows miliolinids on its eastern border, in the region between Aquismón and Tocomón.

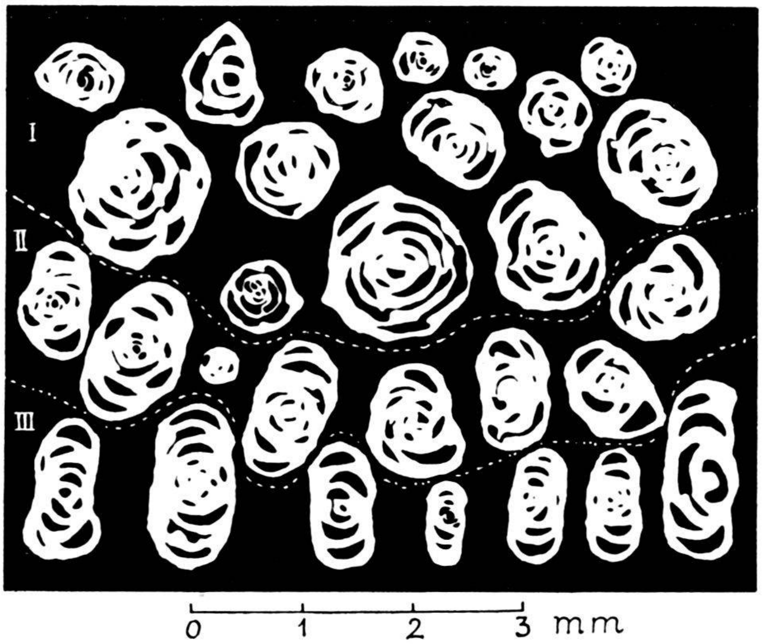

Fig. 5. *Nummuloculina* sp.

Sections through miliolinid-limestone from El Abra:

I, equatorial; II, oblique; III, approximately axial.

From a photograph by Dr. W. LEUPOLD, Zurich.

At Xilitla, the facies rapidly changes. North-west of this town, at Tlamaya, the Xilitla Beds are underlain by a huge mass of typical Taninul Limestone with abundant rudistids, at least 400 m thick. South east of Xilitla (Cruztitla), on the other hand, the Tamabra is made of dense limestone with chert, in well-defined beds with uneven joints (Tamaulipas type). It is several hundred metres thick and thrust over true San Felipe Beds east of Xilitla. Above it comes El Abra Limestone of massive Urgonian type, with chert. Thickness 100—200 m. In places, black bituminous shale is interbedded and resembles the lower part of the Xilitla Beds.

Thus the Tamaulipas, Taninul and El Abra Limestones are different facies of the same Tamabra Formation, interdigitating laterally and often repeated above one another at the same locality (mixed-facies). In addition to the five types of facies described from the quarries at El Abra (p. 324), we have to add:

(f) Tamaulipas or Victoria facies, dark, dense limestone,

(g) Chalky or granular, microcrystalline type (Boquilla, Micos Canyon, parts of the Pánuco oil-fields), with or without calcite crystals.

In the Inner-Ranges, west of Jaumave (p. 349) we have found:

(h) Limestone resembling an algal breccia,

(i) Oolitic limestones.

Apart from such irregular changes the main types are distributed as follows:

1. The Tamaulipas type predominates in the northern region of Victoria, but reappears to the south of Xilitla below the Abra type.

2. The border of the Front Range, for 125 kms between Gomez Farias and the Rio Tampaon, is represented entirely by the Taninul facies with rudistids.

3. This sub-reef type passes westward in 1—2 kms into the El Abra type, with miliolinids. These benthonic foraminifera, when developed abundantly, seem to be restricted to the upper 200 m of the Tamabra.

The thickness of the Tamabra, as a whole, seems to diminish to the south, from 1000 m to a few hundred metres at Tamazunchale.

Xilitla (Agua Nueva) Formation[3]).

The contact of the Tamabra with the Upper Cretaceous is very variable, the Xilitla Beds being locally absent or replaced by conglomerate and breccia. But as a whole, " by both lithology and fossils this horizon is easily identified all over northern and central Mexico " (Böse & Cavins 1927, p. 67). The typical Xilitla Beds are black to brown, flaggy shales or siliceous limestones, weathering light brown to pink, with a bituminous smell or even liquid oil, and containing numerous ganoid-scales. It is a true source-rock, though not of great commercial importance. Like the Californian Monterey Shales (Arn. Heim 1924), the Xilitla Beds are thought to be a coldwater, marine deposit. On the map, the formation is shown with a special colour where distinctly differentiated and widely distributed; elsewhere it is indicated with a black line or included with the San Felipe. Frequently, the outcrops are lacking.

Between Monte Cristo and La Libertad, the horizon is represented by conglomerates and breccia (Textfig. 4). An outcrop south of Monte Cristo village (Pl. XVI, Sect. 6) shows:

3. San Felipe Beds:

(c) Dense *Fleckenmergel* and yellow-weathered, sandy limestones containing beds of green sandstone,

(b) Blue limestone-breccia, cemented with limestone and containing chert. . . 3—4 m

(a) *Fleckenmergel*, limestones and sandstones, like (c) . . . . 15—20 m

2. Xilitla Breccia- Series:

(e) Conglomerate-breccia, resembling " caliche ", with large limestone-fragments and shell-fragments. . . . . 2—4 m

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3) The name Xilitla Flags was introduced by W. S. Adkins in a report for the Shell Group and treated as a separate formation in my report of 1925 (see also Arn. Heim 1926, p. 87). Subsequently, it was called after the Agua Nueva locality, in the Sierra Tamaulipas, by L. W. Stephenson (Muir 1936, p. 44). Priority apart, no better name can be found for a type-locality than Xilitla; this little town stands on well-developed, typical Xilitla Flags, of which it is built.

(d)	Black limestone of Tamaulipas facies with big chert-concretions at the top	6—8 m
(c)	Dark, dense limestone, resembling Tamaulipas facies	5—10 m
(b)	Massive, rough limestone-breccia, cemented with dense limestone	10 m
(a)	Dense, light-grey limestone (Top of Tamabra ?)	4 m

1. Tamabra Limestone with rudistids (Taninul facies).

Similar conglomerates were noted at La Libertad. On the Rio Sabinas, south of San Isidro ranch, is exposed a fine-grained, thin-bedded, dark-grey, impure limestone with fragments of echinoderms. Similar traces of the Xilitla Formation occur near Gomez Farias. Farther south, along the eastern border of the Front Range, the Xilitla and San Felipe beds are completely absent. Only at Salsipuedes, on the southern end of the El Abra front range, do typical Xilitla Flags recur.

In the second range, the Sierra Romana, the Xilitla Beds are well represented. They pass upwards into the San Felipe, but the lower contact with the Tamabra is well-marked. In the Chamal-Morelos region they are 20—40 m thick. The best outcrop is on Morelos Pass, between Antiguo Morelos and Nuevo Morelos (Textfig. 4; Pl. XVIII, Sect. 10). There is a sharp contact between Xilitla- and Abra Limestone with miliolinids. The Xilitla weathers in thin layers, recalling the Monterey Shale of California. It is crowded with fish-scales and smells bituminously, although no soluble oil could be extracted with chloroform. The lower part is thin-bedded (layers 5—30 cms thick); the upper part is more thickly-bedded and passes into San Felipe limestone with *Globigerina* and *Globotruncana linnei* (D'ORB.). The Xilitla extends eastwards to the west limb of the El Abra Range, where it dies out between the Abra Limestone and the San Felipe Beds. Similar conditions occur farther south.

In the third range, the Sierra Colmena, the Xilitla Formation is exposed near Micos Falls, on the railway SE of Micos (Pl. XVIII, Sect. 12) and again farther south at Jopoy. Still farther south, at La Pila, the Xilitla Formation is absent, dying out with the San Felipe towards the Rio Tampaon. But it reappears in its greatest development in the regions of Tanchanaco and Xilitla, where the beds have seepages of oil and tar.

The town Xilitla stands at 570 m on the top of the middle part of the Xilitla Series which dips 20—25^0 NE. A quarry north-west of the town furnishes paving- and building-stones. Large impressions of fishes are seen on the pavements of the roads. BÖSE (1913, p. 26) cites *Inoceramus labiatus* SCHLOTH., a Turonian species, and C. L. BAKER further mentions *I. hercynicus* PET. and *Acanthoceras*. The following section was compiled from outcrops north-west of Xilitla (Textfig. 4; Pl. XVIII, Sect. 16):

3.	San Felipe Beds, unusually rich in green, argillaceous and tuffaceous beds (bentonite)	200—300 m
2.	Xilitla Formation	100—150 m
(d)	Black limestone beds, 10—30 cms thick, interbedded with shale and chert-layers and some bentonite	30 m
(c)	Shaly flags with streaks of green bentonite	15 m
(b)	Xilitla Flags: black, bituminous and thin-bedded, with thin chert-layers, fish-bones and scales and *Inoceramus labiatus* SCHLOTH. (Turonian), .	20 m
(a)	Black limestone with big chert-concretions, resembling Tamaulipas facies, in thick, nodular, uneven beds, 1—2 m thick, and limestone-breccia with occasional glauconite-grains (? Tamabra, Cenomanian ?)	50—80 m

— Sharp Contact —

1. Abra Limestone, massive, white and microcrystalline, with broken shells.

The upward passage into the San Felipe series is indicated by limestone-layers of San Felipe type with Globigerina in beds 2 (d) and by the occurrence of black layers at the base of 3[4]).

The bituminous layers, 2 (b), (c), resemble the Menilite Shales (BLUMER 1922, p. 112) in the Oligocene of the Carpathian oil-fields.

San Felipe Formation.

The San Felipe series is of secondary importance in the mountain-ranges. Throughout the Front Ranges, it passes directly into the overlying Mendez Marls. Its lower limit, however, is very variable and frequently shows a distinct unconformity (Textfig. 4). In places, the Mendez overlaps on to the Tamabra.

The thickness of the San Felipe at Llera–La Prada is 200—400 m, at Monte Cristo 200 m. In the latter region, the lower subdivision has thick beds of hard, greenish sandstone and tufflayers. At Fortunas ranch on the south end of Sierra Prieto (Pl. XVII), typical San Felipe limestones are still more than 200 m thick, but they diminish rapidly to the south-west and die out a few kilometres south of La Libertad. They are entirely absent along the eastern border of the Front Range but are constantly present in the second and third ranges. Where only gently folded, they may cover large areas, e. g., at Chamal, south of Antiguo Morelos and in the type-area of San Felipe, east of Valles, where the thickness is 200—300 m (Pl. XVI; Pl. XVIII, Sections 10—13).

Returning to the eastern border of the Sierra del Abra, we find the San Felipe Formation setting in again at Santa Clara, south of Quintero, but with a suprising change of facies. It includes several beds of coarse breccia and rudistid-limestone, ½—1 m thick, indistinguishable from the Taninul facies of the Tamabra (Textfig. 4). Dense red limestone with *Globigerina* is also interbedded, recalling the *Couches rouges* of the Alps (ALB. HEIM 1919—22, pp. 626—628), and whitish to greenish tuff (bentonite). Otherwise, the San Felipe is easily recognisable by its repetitions of marls and dense *Fleckenkalk*, although it is only 30—50 m thick. These observations were confirmed farther south, at El Choy, by Dr. FEHR. Still farther south, along the eastern border of the Sierra del Abra, the San Felipe beds again disappear and are entirely absent at Taninul.

The eastern limit of the San Felipe is a line coming from the north-east passing south of Llera to La Libertad, then turning southwards and following the crest of the Front Range for 70 kms. South of Quintero, the boundary undulates slightly along the eastern border of the Front Range, continuing southwards to Tampaon. East of this line, however, the San Felipe is again found in the plain, where it comes to the surface in small domes and anticlines (Pl. XVI). Drilling showed that it is well represented in the San Pedro Valley (Pl. XVIII, Sect. 15). Thus the San Felipe is absent along a narrow strip trending N–S along the Front Range.

Returning to the inner ranges, we find a similar dying-out south of La Pila. No exposure of the San Felipe–Tamabra contact was found. But at Urraca and on the Rio Tampaon, where the San Felipe must be considerably reduced, at least, not even boulders could be found on the slope. At the southern end of the

[4]) MUIR (1936, p. 60) says: " Southeast of Xilitla the Turonian (Agua Nueva) overlies Albian-Cenomanian rocks, and is itself overlain by the Tamasopo limestone ". This ought to oead: " South-west of Xilitla the Turonian is overlain by a thick mass of San Felipe rocks, rver which lies the Tamasopo Limestone ".

Sierra Colmena (Tanchanaco), and throughout the Sierra de Aquismón to Xilitla and Tamazunchale, the San Felipe is present, but in restricted thickness. A special facies at Xilitla is characterised by an abundance of green bentonite.

Mendez Marls.

In the region of Xicotencatl, east of the Front Ranges, the wide-spread Mendez Marls may be subdivided into:

2. Dark, greenish marls with cleavage and obscure bedding, many hundred metres thick.
1. Well-bedded, bluish-grey marls with occasional thin layers of limestone, 200—300 m.

The Mendez is purely marine and contains numerous microforaminifera. Two special facies have been observed:

(a) White layers of tuff in the middle Mendez at Buena Vista and Cerrito, NW of Xicotencatl. At Las Animas and Caimán, in the Antiguo Morelos Syncline, these are very hard and tough, forming well-defined beds, each 2 m thick and 25 m thick in all. They form broad mesas, several sq. kms in area and dip 0—5^0 E (Pl. XVI).

(b) South of the Rio Tampaon, a red variety of Mendez Marls occurs, especially in the middle and upper parts of the series, resembling the reddish shale of the type-locality on the railway from Tampico to Valles (Muir 1936, p. 69). The northernmost exposure of red shale was found at Paliguau. At San Pedro, in the creek near La Labor well, the shale is partly blood-red, partly violet, greenish and yellowish. The best exposure of red Mendez beds is along the trail east of Cerro Guajolote, between Aquismón and Tancanhuitz.

With increasing colour, the Mendez develops sandy and indurated horizons. This is the case between Huichihuayan and Matlapa, NW of Tamazunchale. It is often difficult to distinguish this facies of Mendez from the overlying Tamesí beds.

The total thickness of the Mendez could not be measured in the northern region on account of interrupted outcrops and obscure stratification. It is believed to be about 1000 m (part of the Tamesí possibly included).

In the south, definite data are obtained from drilling at San Pedro. Well No. 1 commenced in the upper part, reaching the San Felipe at 3650 ft. The total thickness is thus about 1300 m. The only question is whether the uppermost part should not be regarded as Tamesí. Farther south-west, towards Tocomón and Tamazunchale, the Mendez Series thins by more than half.

The age of the Mendez is Santonian-Campanian (Middle Senonian). A great number of foraminifera have been determined recently by different specialists (see Muir 1936, pp. 69, 73).

Tamesí Formation.

In my 1925 report I termed Barrancón Beds the series overlying the Mendez in the San Pedro Valley and vicinity, from the fine outcrop at El Barrancón from which J. B. Dorr has recently determined 82 species of foraminifera (Muir 1936, p. 86—88). The name Tamesí having been agreed upon by Tampico geologists, the name Barrancón, as a formation, can be dropped (Muir 1936, p. 78). In former reports the Tamesí was grouped either with the underlying Mendez or with the overlying Chicontepec. Our mapping establishes its wide distribution and individuality.

In the north the Tamesí has been observed:

1. About 2 kms NE of Llera, as a greenish shale resembling a special facies of the Mendez, but interbedded with ripple-marked, sandy flags (Pl. XVII, Sect. 5).

2. In the bed of the Rio Guayalejo at Xicotencatl (Pl. XVII, Sect. 7), where shale of Mendez type is interbedded regularly with calcareous sandstone in beds 1—20 cms thick. Farther south, the Tamesí also occurs below the great plain.

At El Barrancón (San Pedro Valley), the creek has cut a high bank, the lower part of which consists of blue-grey marls with extremely thin, nodular layers of calcareous, micaceous sandstone at intervals of about 20 cms. They are full of tracks of animals resembling *Helminthoides* and plant-fragments. This series, of which about 50 m are exposed, dips 10° SW and is overlain by calcareous sandstone of the Tanlajás Series (Lower Chicontepec). Another excellent exposure, in steeply upturned strata, showing the full thickness, is seen along the trail north of Tancanhuitz, at La Cuesta. The Tamesí beds give place abruptly to the overlying Tanlajás sandy limestone. The Tamesí Formation was mapped continuously from San Pedro round the Chicontepec Mountains, by Tancolol and Tancanhuitz down to Tamazunchale. The thickness averages 100—200 m (Plate XVI).

From the foraminifera, the age is considered to be Upper Senonian-Danian.

Tanlajás Series (Lower Chicontepec).

The Chicontepec, generally regarded as Lower Eocene, is about 2000 m thick and is subdivided into:

3. Upper Chicontepec or Jaco Sandstone
2. Middle Chicontepec or Chalma Shale
1. Lower Chicontepec or Tanlajás Sandstone.

Again commencing in the north: From Lavin station, south-east of Victoria, along the railway down to San Francisco, Forlon, Xicotencatl and beyond to Magiscatzin and El Naranjo, the wide synclinal plain consists of gently undulating Tanlajás Beds and is covered with slabs of calcareous sandstone, 5—30 cm thick, with uneven surfaces and weathering brown, like basalt. They are equivalent to the Tanlajás of the San Pedro Valley.

The most interesting outcrops are found east of Magiscatzin, north-west of the imposing volcanic plug of the Bernal de Horcasitas, 1111 m high (Arn. Heim 1934). The unfossiliferous slabs dip gently east. Two km from the abandoned ranch of San Juan, blocks of rough sandy limestone and *lumachelle* contain abundant *Serpula*, brachiopods, single corals, bryozoa, shark-teeth and a small *Nummulina* (2—3 mm in diameter, with central pillar). An extraordinary aspect is given to this rock by huge calcite-poikiloblasts, enclosing grains and fossils (*Sammelkristalle*).

In the San Pedro district, the Chicontepec Formation is well-known and was not studied systematically by the writer. The lower part of the Tanlajás Sandstone is fine-grained and unfossiliferous. Coarse-grained calcareous sandstone with small nummulites occurs 100—200 m above the Tamesí Beds. These sandstones also contain a *Discocyclina* and occasional glauconite-grains. In the creek at Tanlajás, marls are interbedded with the sandstone, which here includes pebbles of ironstone, apparently derived from the Novillo Formation, and of limestone with algae resembling *Lithothamnium*. Between San Antonio and Tancanhuitz, the upper part of the Tanlajás Series contains interbedded layers of dense, yellow-weathering dolomite.

The Tanlajás Series may be 1000 m thick or more.

Chalma Shale (Middle Chicontepec).

On the north side of the Bernal de Horcasitas and in the Axtla region, the Tanlajás Sandstone seems to be overlain by a grey to greenish sandy shale, somewhat resembling the Tamesí. It probably corresponds to the Chalma Shale (Plate XVI). No Upper Chicontepec Beds are known in the region.

Quintero Limestone.

South-east of Quintero, outside the El Abra Range, lies the conical, flat-topped Cerrito del Campo Santo, reaching an elevation of 170 m. The top is formed of a yellowish limestone with approximately horizontal bedding, about 40 m thick. The texture is dense but cavernous, and the general appearance that of a fresh-water limestone, possibly of Upper Tertiary age. Nothing similar is known in other parts of the Front Ranges. On the map (Plate XVI) it is indicated as *ls* with horizontal hatching.

Caliche (Recent).

This is a surface-conglomerate or breccia, cemented with lime into a hard pan and is distributed especially in the semi-arid region around Victoria. The same type is found in North Africa, wherever the soil contains sufficient lime for cementation. Sometimes it is so hard that it covers the subjacent formations like a coat of mail.

(d) Cretaceous of the Inner Ranges.

The type-locality of the Tamasopo Limestone is Tamasopo Canyon on the San Luis Potosí Railway, 45 km due west of Valles. The sharply-folded limestones are over 1000 and probably nearly 2000 m thick. They are dense, light-coloured, thick-bedded limestones with interbedded argillaceous layers. Occasional rudistids occur, including a Senonian *Coralliochama*, discovered by Mr. C. L. Baker. Eastwards the limestone extends to the longitudinal valley of the Rio Frio (Rio Gallinas), whose east side shows anticlines overturned eastwards in Tamabra, covered normally by Xilitla and San Felipe Beds.

Is this sudden change of facies due to a regional overthrust of the Tamasopo Limestone to the east? On the east side of the valley, at Ingenio Rascón, the Xilitla Formation consists of white, dense limestone resembling the Tamasopo. It seems that a change in facies occurs rapidly, but not abruptly, so that there may not be a regional thrust here.

But at Xilitla an overthrust is hardly disputable. At the same time the stratigraphic relations seen at Ingenio Rascón are confirmed; within the thrust series, a transition occurs from Lower Xilitla (black limestone) to the overlying white Tamasopo Limestone, which forms the peaks of the Sierra de Xilitla (Pl. XVIII, Sect. 16). At Miramar, 1200 m, above Xilitla, Dr. Jenny noted typical San Felipe limestones *(Fleckenkalk)* within the main body of the Tamasopo limestone, 200—300 m above the base of the Xilitla Series. These facts confirm the paleontological conclusions of BÖSE, BAKER, ADKINS and others, obtained at Tamasopo Canyon in 1923/24, that the Tamasopo Limestone represents the upper part of the Xilitla Beds and the entire San Felipe Formation, possibly including part of the Mendez. It thus belongs chiefly to the Lower Senonian. The Tamasopo Limestone of the Sierra de Xilitla is quite typical. At the base of the Peña de San Antonio, chert-nodules occur which are usually absent higher in the series.

At the western end of Tamasopo Canyon, the Tamasopo Limestone is overlain by a thin conglomerate-bed, followed by 200—300 m of Mendez Beds, which are succeeded by the thick series of the Cárdenas Beds (BÖSE, 1906 A). These are well exposed along the railway, where the following approximate section was observed from Cárdenas eastwards to Escontria (Textfig. 6):

Upper Cárdenas Beds, 2000 m:

13. Yellow limestone, interbedded with marls.
12. Greenish marls, resembling Mendez Beds, 500 m.
11. Sandstone and sandy-marly limestone with oyster-beds: *Gryphaea vesicularis* LAM., *G. costata* SAY, *Ostrea gigantica*.
10. Well-bedded limestone with marls.

(The relations of the above beds to the underlying strata are obscured by folding and lack of exposures.)

9b. Cárdenas Red Clay, several hundred metres.
9a. Red and green clay-shale, resembling Tamesí Beds.

Lower Cárdenas Beds, about 1300 m:

8. Very fossiliferous marls and sandstones with corals, *Coralliochama g.-boehmi* BÖSE, *Exogyra costata* SAY, etc.
7. Hard grey, calcareous sandstone with gastropods: *Conus*, *Turritella*, etc.
(Gap, covered by caliche.)
6. Marls and nodular limestones full of oysters; *Gryphaea*.
5. Grey shale with limestone, 200—300 m.
4. Marls and nodular limestones full of oysters, *Cardium*, *Pholas*, etc.
3. Grey shale with beds up to 1 m thick of yellow limestone full of *Pseudorbitoides*, 100—200 m.

Mendez Marls:

2. Grey, more or less sandy shale, 200—300 m.
1. Conglomerate, 1 m.

Tamasopo Limestone.

Thus the Cárdenas Beds, Upper Senonian in age, represent a shallow-water-facies of the Upper Mendez of the Front Ranges. They are confined to the Inner Ranges, where they were observed as far north as Tula, west of Carabanchel.

(e) The Jurassic of Tamazunchale.

In the south, the Jurassic is well-developed and subdivided into fossiliferous formations from Lias to Upper Jurassic. MUIR (1936, pp. 9—11) gives full details of the Lias. So far as studied by me, only Upper Jurassic is present in the gorges of the Rio Moctezuma above Tamazunchale. Part of the results having been already published (ARN. HEIM 1926), a short resume will suffice.

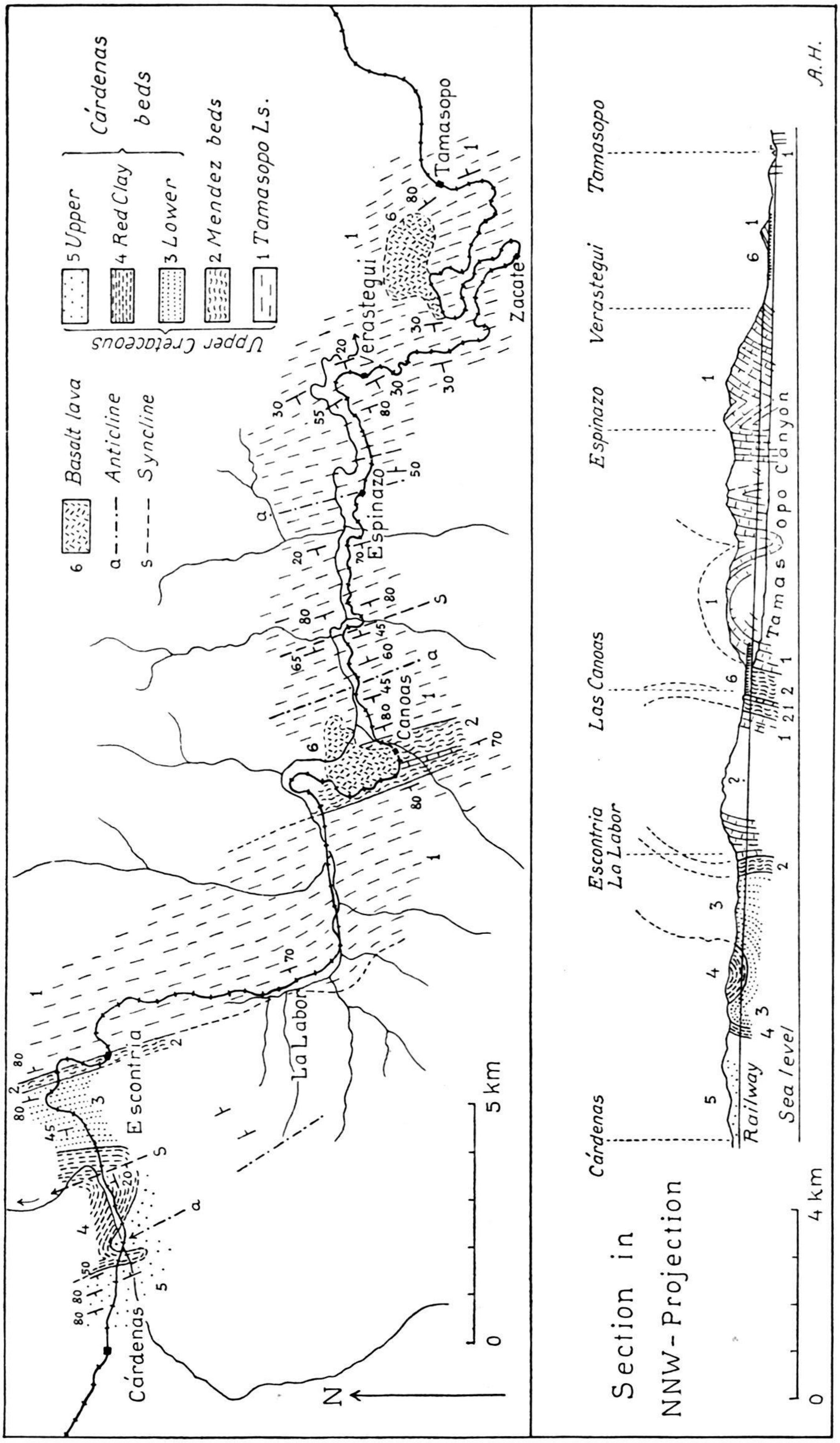

Fig. 6. *Section of Tamosopo Canyon along the Railroad.*

Tamán Formation.

Well-bedded, black, fine-grained and microcrystalline limestones, alternating with black shales and forming an anticlinorium in the centre of which is the village of Tamán. For nearly 10 km the river flows through this series of over 1000 m thickness. The fossils were determined by the late Dr. C. BURCKHARDT as Upper Kimeridgian: *Haploceras fialar* (OPP.), *H. transatlanticum* BURCKH., *Perisphinctes cyclodorsatus* MOESCH in FONTANNES, *Aspidoceras* of the *longispinum*-group, *A.* cf. *polysacrum* FONT., *A. eligmoptychum* FONT., and abundant *Aulacomyella lata* sp. nov. and *A. heimi* BURCKH.

Pimienta Series.

The Tamán Beds seem to pass upwards into a series of black or black and white, thin-bedded, dense limestones with many layers of black chert, 100—200 m. thick. The age is supposed to be Portlandian.

Tenestipa Limestone.

White, dense, massive limestone with chert, about 100—200 m thick, at the village of Tenestipa, and several hundred metres thick at Pimienta, on the opposite side of the great anticline. The relation of this limestone, which may be Cretaceous, to the overlying Upper Cretaceous of the Xilitla region could not be studied. Possibly, the Tenestipa Limestone is a facies of Tamabra.

III. Igneous Rocks.

Igneous extrusions and intrusions took place in Eastern Mexico at various dates (see MUIR 1936, W. STAUB 1922, 1937, 1939). The following types were found in the region mapped, or its immediate surroundings:

1. Granite and basic intrusions, more or less metamorphosed, in Novillo and Peregrina Canyons: Pre-Mississipian.
2. Gabbro, serpentine, diabase, etc., intruded into the Red Beds at Huizachal and Novillo Canyon (Textfigs. 2, 3; Pl. XVII, Sections 2, 3): Pre-Cretaceous, probably pre-Jurassic.
3. Green tuffs (bentonite), interstratified with the Xilitla- and San Felipe Formations: Turonian to Coniacian.
4. White tuffs in the Mendez Marls: Upper Senonian.
5. Basic necks or cones at widely separated localities:

   (a) Bernal de la Purisma, 400 m high, overlooking the mesa of that name (Pl. XVII, Sect. 5).

   (b) Bernal de la Clementina, at the village of that name, south of the Rio Guayalejo.

   (c) Bernal de Horcasitas, 1111 m, SE of Magiscatzin, visible on a clear day from Tampico, 100 km away. A basalt column 1 km thick and 600 m high, rising above a flat, basaltic lava-shield of Hawaiian type, 6—8 km in diameter (ARN. HEIM 1934).

   (d) Cerros Morcielago and Nopal, north of the San Luis Potosí railway and 30—37 km NW of Guerrero (Pl. XVI), connected with basalt dykes and lava-flows.

(e) Cerro Guajolote, the southernmost neck, 500 m in diameter, on the Aquismón-Tancanhuiz trail. The rock seems to be a gabbro or diorite and has metamorphosed the Mendez Marls at the eastern contact.

All these necks and plugs are later than the Mendez and probably than the Chicontepec. Judging from their state of preservation, they may be younger Tertiary or Quaternary, and partly seem to be related to the basalt mesas.

6. Basalt Mesas. They are widely developed in the region between Xicotencatl and Lavín, near Ciudad Victoria. Their average elevation is 350 m, or 250 m above the plain. The mesas are indicated approximately on our map, and in Pl. XVII, sections 5—6, but extend farther east near the Victoria railway. (On the topogr. map 1:100000 of Mexico, these flat mesas are drawn like folded mountains.) The thickness of the basalt at Mesa Josefeña was estimated at about 50 m. It usually lies on a eroded surface of Mendez Shale. The extrusion and erosion may be placed near the end of the Tertiary. Since then, slight uplift must have occurred to allow dissection of the mesas and to aggrade the present alluvial plain, 200—250 m below, processes which probably took place chiefly during the older Quaternary.

7. Basalt Streams. Two long but narrow streams of subrecent basalt have been encountered (Plate XVI).

One follows the small Rio Boquilla which crosses the two eastern ranges and ends, after several interruptions, in the eastern Tamabra gorge. In the cascades of the western or Chamal Range, the lava has slightly metamorphosed the immediately underlying Tamabra limestone.

The other stream probably derived from the same source west of Sierra de Chamal. It followed the synclinal valley of Nuevo Morelos through the channel of Rio Mesillas which now runs along the western side of the lava stream. This stream has been followed for more than 50 km upwards of its termination. The lava must have been extremely hot and liquid to flow on such a distance in a valley so slightly descending. These lava streams are much younger than the basalt of the mesas and may have flown in historic time.

IV. Structure.

The structure is reviewed by natural divisions:

The Huizachal Anticline.

The main structure of the first range between Victoria and the broad Jaumave Valley is the gentle Huizachal Anticline, 15—20 km wide and 2—3 km in structural height. At Huizachal Ranch, on the crest of the Anticline, erosion has stripped the sedimentary mantle down to the gabbro. In the next canyon to the north, that of Novillo, west of Victoria, even gneiss is exposed. While the main anticline's axis runs N-S, the vertical layers of the gneiss and amphibolite strike NW to WNW, thus making an angle of 45—75° with the later folding. At Peregrina, the gneiss seems to be cut off by a pre-Cretaceous NNW-SSE fault from the fossiliferous Peregrina Beds.

The anticline is associated to the east with numerous minor anticlines, with local contortions and steep dips. They are secondary folds on the easterly limb of the main anticline and dye out like waves towards the great synclinal plain of Ciudad Victoria. These secondary anticlines change rapidly:

Anticline *a* (Pl. XVII, Sect. 3), well exposed in Juan Capitan Canyon, forms a regular arch; the western limb dips 55°, the eastern limb 80°. Anticline *b*, on the north side of the same canyon, is less symmetrical. Anticline *c* has a steep easterly dipping limb south of El Tenagón; it is overturned slightly, north of Tenagón. Anticline *e*, of the Sierra de la Boca, is the most prominent of these minor folds traversed by the Arroyo Juan Capitan. The top of the anticline forms a regular arch. Anticline *f* occurs at the land-mark of El Tecolete (a prominent white rock in a syncline overturned to the east).

The common feature of all these minor folds is the steeper eastern limb. Anticlines *a*, *b*, *c* strike NNW, flattening to the north. Anticlines *e* and *f* strike N and pitch 5—12° in that direction, disappearing under the plain, 4—5 km north of Arroyo Juan Capitán, before reaching Victoria. The steep westerly dip of the Mendez Beds, east of the church of Guadalupe, proves that the folding continues there at greater depths.

The Front Folds north of Llera.

Passing southwards, the bend in the railway at Victoria (Pl. XVI) is caused by the projection of the mountains into the plain for more than 20 km. It was formerly thought that this projection is due to a sharp change in the fold-axes. Our observations show that the principal cause is a general axial rise of the minor folds east of the Huizachal Anticline (Pl. XVII, Sect. 4).

The anticlinal axis of the Sierra de la Boca rises to the south and then pitches again south at about 10° towards the Rio Guayalejo. Nearer the plain follow smaller brachy-anticlines. That of La Mina is the most easterly one and shows a core of Tamaulipas Limestone. Then follow five anticlines in San Felipe strata in the Prada-Las Cruces region, pitching north or south from an axial centre WSW of Lavin. Finally there is the Santa Juana Anticline in Mendez Marls, near the station of Lavin.

This general axial rise of the frontal folds has no equivalent in the Huizachal Anticline. It rather corresponds to an axial depression of the latter.

The Front Folds south of Llera.

The Rio Guayalejo, west of Llera, crosses the ranges in a general axial depression of the folds, also indicated by the re-entrant angle of the plain and by Chicontepec Beds within the mountains at Llera, 15—20 km inland from Lavin.

At Guadalupe, on the trail from Llera to the abandoned ranch of Las Adjuntas, a perfect, upright anticline in San Felipe Beds, is exposed on the south bank of the Rio Guayalejo (Pl. XVII, Sect. 5). Going inland, the next anticline forms a range with an irregularly folded core of Tamaulipas Limestone (800 m elevation), the Adjuntas Anticline. It pitches gently to the north and is replaced by the anticline of the Sierra de la Boca north of the Rio Guayalejo. The broad region of gently folded San Felipe Beds, west of Las Adjuntas, was not studied.

Following these frontal folds southwards, the Guadalupe Anticline forms a long chain of hills, before pitching beneath the Mendez at San Antonio. The next fold to the west continues farther south. At Monte Cristo, on the west flank of the Front Ranges, and in the San-Juanito-Carmen region on the east flank, the mountains are no more inaccessible. The Sierra Prieto, the highest of the Front Ranges rises to 1200 m. As shown in Pl. XVII, Sect. 6, it consists of four folds:

(a) The eastern one is overturned to the east and disappears on the eastern slope owing to a southerly pitch. (b) The second one, at Fortunas, some 10 km away, is the highest, but also pitches to the south. (c) The two western anticlines were only mapped approximately, but it is certain that at Libertad, farther south, the third anticline also pitches south, at an angle of 5—10^0.

Thus, we have a repetition of the type of structure found north of Llera, viz., a second culmination of the frontal folds. At Lavin, however, the outermost folds do not rise again to form mountains, being indicated only by dips in scattered outcrops of San Felipe beds in the vast expanse of Mendez Marls (El Terrero, La Flor, Cerrito, Poza).

The Foreland from Xicotencatl to Guerrero.

To pass outside the region equivalent tectonically to the front folds of Lavin, one must go as far as Xicotencatl, which stands on a gentle syncline of Tamesí Beds (Pl. XVII, Sect. 7). The persistence of deeper folding around Xicotencatl is indicated by dips up to 45^0 in Mendez Marls, like those west of Lavin.

The most important anticline in the region north of Xicotencatl is that of Poza (sect. 9 on Pl. XVIII), which possibly extends southwards to the Mendez of Peñita. In a similar position is the Canoas or San Juarez Dome, situated in the great alluvial plain which, in the rainy season, becomes an almost impassable swamp. The lower Mendez and upper San Felipe rise with a maximum of 10^0 to a low hill, 15—20 m high. On the whole, the surface corresponds with the structure.

West of Canoas, on the Rio Mante, another dome-like structure of San Felipe rises above the plain. Finally, there is a small outcrop of San Felipe Beds, dipping 5—7^0 SE, at Huiches, 4 km east of Guerrero.

The region from Xicotencatl to Guerrero, outside the Sierra Madre, is therefore a plain of denudation and widespread alluvial deposition: but it does not imply an unfolded basement.

The Main Anticline from Monte Cristo to Chamal.

The front folds of the Sierra Prieto are paralleled on the west by the deep syncline of Mendez Marls on which stand the ranches of La Flor and La Soledad (Pl. XVII, Sect. 6). From here, the main mountain-range rises with a uniform slope to at least 2100 m. The top of the flat summit can only be reached along a trail from Monte Cristo village (elevation 500 m) to Jaumave. Four kilometres before reaching Carabanchel, a huge plateau of Tamabra with rudistid-beds is traversed. It is due to an extremely broad warping, which may be called the Carabanchel Anticline, apparently the southern extension of the Huizachal Anticline (Pl. XVII, Sect. 6).

As seen by telescope from Carabanchel ranch, the entire mountain-range seems to be formed by this huge anticline. It is more than 20 km wide, and shows a dip-surface pitching a few degrees north. On the trail south of La Flor, on account of the pitch of the adjacent Soledad Syncline, the westernmost anticline of the Sierra Prieto appears to amalgamate with the great Carabanchel Anticline. But this syncline is well exposed again at Gomez Farias, separated from the plain of

Xicotencatl by the Tamabra of the Sierra Pequeña Anticline (Pl. XVII, Sect. 7). The latter pitches 5—10° S, flattens out and disappears, so that the eastern slope of the Carabanchel Anticline now forms the border of the mountains.

In the Chamal region, most interesting changes in structure occur. The wide syncline at this village lies exactly on the southern prolongation of the Carabanchel Anticline. The wide Tamabra-built mountain gradually descends to the south, the anticlinal crest being transformed into a syncline,

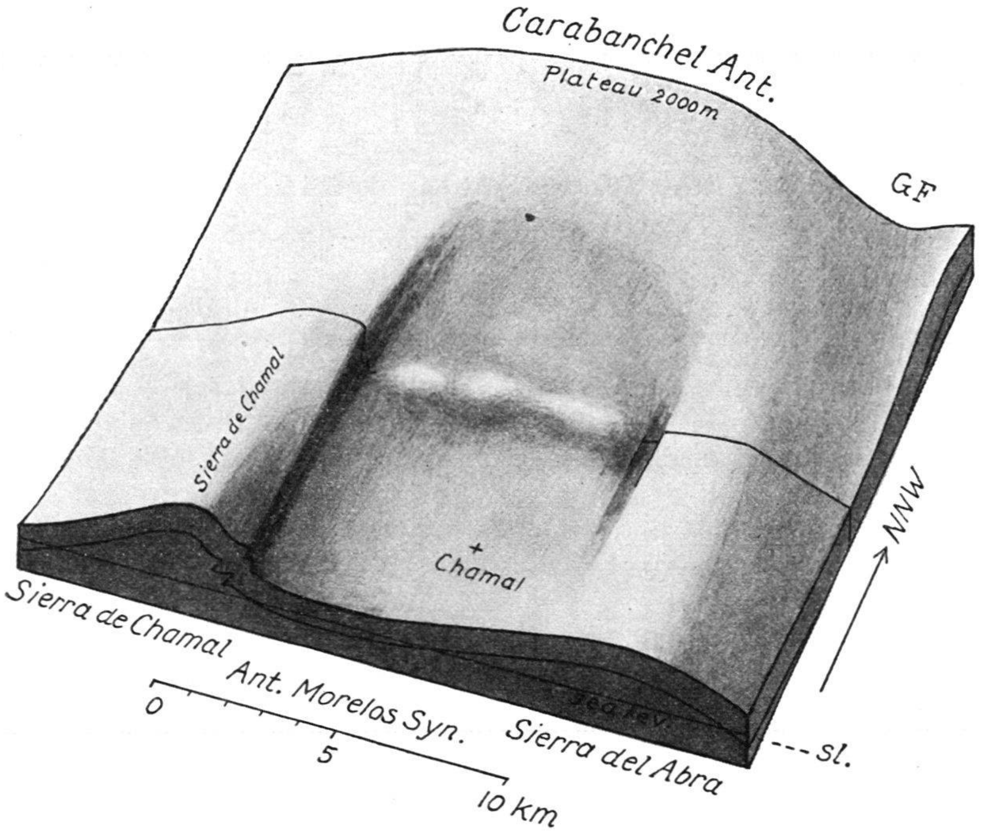

Fig. 7. *Replacement of the Carabanchel Anticline by the Antiguo Morelos Syncline.*

Block-diagram in natural proportions drawn after a model of the reconstructed Tamabra surface.

GF: Gomez Farias syncline.

and the flanks into lateral anticlines. But the transformation is complicated by a distinct cross-fold, just where this transformation takes place. It is an anticlinal barrier of Tamabra (Textfig. 7). A third structural peculiarity in this locality is the little synclinal peak, called Chamalito, with its basalt-cap overlying folded Mendez Beds, and the little graben to the south-east of it (Pl. XVIII, Sect. 8). But Chamalito is not only situated on a faulted syncline of normal trend. A N-S section also shows a synclinal structure. Thus, tectonically, Chamalito is on a faulted structural basin.

The Sierra del Abra from Chamal to the Rio Tampaon.

The road to Chamal crosses a low symmetrical anticline in Tamabra, developed from the eastern limb of the Carabanchel Anticline (Pl. XVIII, Sect. 8, 9). From here, the monotonous El Abra front-range extends for 110 km, with an average elevation of only 300 m and a maximum of 500 m. The El Abra Range, however, is not a single, simple anticline, but is composed of several secondary folds which merge into one another. Beauitful springs issue from the cavernous rudistid-limestone all along the east side of the range. The largest, north of Quintero, is the source of the Rio Mante (Pl. XVI).

A complete cross-section is afforded by the Rio Boquilla, where the crest is slightly faulted. The trail from Quintero to Antiguo Morelos crosses a structure similar to that of Chamal (Pl. XVIII, Sect. 10). Thereafter, the Anticline widens and its western limb is thrown into secondary folds, while the eastern limb steepens to 30° and, at Nombre Dios, even to 50 and 80°. At Taninul station, the eastern dip is again very gentle (Pl. XVIII, Sect. 13), but it steepens once more on approaching the Rio Tampaon. Here the folded Abra Limestone pitches 5—10° southward under the river.

Instead of giving a good section of the Tamabra structure, the Rio Tampaon escapes from the mountains through an axial depression in the Front Folds. South of the river, the Abra Limestone again comes to the surface, but in separate domes. The first and widest lies between the Rio Tampaon and Tantobal, is flat-topped and has peripheral dips of 5—10°. The next is at Salsipuedes[5]). It has a gently dipping, western slope, but a steep dip (60° NW) along Salsipuedes river, due to a cross-fold, plainly visible above the big spring. No fault was seen. A third dome is represented by the San Felipe Beds of the Santa Isabel well (Pl. XVIII, Sect. 14).

In earlier reports the eastern border of the Sierra del Abra from Quintero to beyond the Rio Tampaon was mapped as a fault. Such a fault may be present locally, e. g., at Quintero, between Mante and Cantón. But wherever there are good outcrops, no such fault was visible, the Tamabra dipping normally under San Felipe or Mendez Beds. The absence of the San Felipe in the latter case is a stratigraphical phenomenon.

The Antiguo Morelos Syncline.

The little town of Antiguo Morelos lies in a synclinal valley between the first and second ranges of that region. It is 10—12 km wide. As a rule, the synclines of this region are much broader than the anticlines. Along the Rio Boquilla, the San Felipe Beds, or those passing into the Mendez, reach the surface, showing that the syncline is very shallow (Pl. XVIII, Sect. 9—10). South of Antiguo Morelos, secondary folding with low dips becomes more general (Pl. XVIII, Sect. 11). The deepest part of the Syncline gradually moves westwards, until at Valles it is 13 km away from the El Abra Anticline.

The Sierra Nicolas Perez.

This long mountain-range starts NW of Chamal as the Sierra de Chamal. Anticlinal structure is developed in the Tamabra along the road to Ocampo. Here the eastern limb is intensely crumpled, while farther north, west of Coahuila,

[5]) The name means " Pass if you can ". Once, indeed, we could not and lost a day.

this eastern limb has a sharp, right-angled knee, with high, vertically stratified walls (Pl. XVIII, Sect. 8).

South of Ocampo Pass, the range mapped as the Sierra Nicolas Perez culminates in twin peaks called the Peña Romana (approximately 1300 m). The structure of the eastern foot of this range is complicated, minor anticlines pitching north. The prominent white wall north of Peña Romana, ending west of Caimán, consists of overturned Tamabra Limestone, dipping 45° W, and underlain by Xilitla and crumpled San Felipe Beds. The corresponding normal limb forms the twin summits of Peña Romana. The crest of the Sierra Nicolas Perez is thus a Tamabra anticline overturned towards east (Textfig. 8; Pl. XVIII, Sect. 9).

For several kilometres east of Peña Romana there runs a rough ridge of broken Tamabra Limestone which was identified as a large rock-slide (Pl. XVI). From Peña Romana, the Sierra Nicolas Perez Anticline swings off to the SSW, and pitches under the valley of Nuevo Morelos, another anticline rising from the western part of the syncline at Peña ranch. A few kilometres to the south, the eastern limb becomes vertical. In places, the San Felipe Beds are even overturned, while the dip of the western limb remains very gentle. This anticline may be called the Morelos Anticline, since it forms the pass between Antiguo and Nuevo Morelos (Pl. XVIII, Sect. 10). The eastern limb is associated with several minor anticlines in San Felipe and Mendez Beds, with dips reaching over 70°. The largest is traversed by the Morelos trail, the N-S axis pitching away from it in both directions.

South of this Pass, Tamabra miliolinid-limestone outcrops on both flanks of the Range, the top being capped by Xilitla and San Felipe Beds. Between Benadito and Tanchachil, the anticline bends abruptly, first plunging to the south-east and then swinging sharply SSW. From here on, the Range is a broad anticline in San Felipe Beds (Pl. XVIII, Sect. 11), ending finally at the hills of Chantol, NW of Valles. There the structure plunges under the plain of Mendez Beds, as is seen from San Mateo railway-station (Pl. XVIII, Sect. 12). Thus the two great synclines of Antiguo and Nuevo Morelos become joined (Pl. XVI).

The Nuevo Morelos Syncline.

Like that of Antiguo Morelos, the Nuevo Morelos Syncline is broad and asymmetric, the deepest part lying to the west where secondary folding occurs (Pl. XVIII, Sect. 10—11). One of the most prominent features of the flat, synclinal valley is the extremely long, sub-recent, basalt lava-stream which follows the Rio Mesillas for more than 50 km.

The Sierra Colmena and its Continuation.

At Colmena, west of Nuevo Morelos, Dr. Jenny reported the structure to be a complex anticline, overturned to the east (Pl. XVIII, Sect. 10). In Section 11 he shows a complicated thrust of folded Tamabra over a sharp fold in San Felipe Beds, which is still overturned farther south.

The fine section along the Micos River (Pl. XVIII, Sect. 12) is incorrectly described by Böse (1906 B, p. 13) as follows: "Tout près de la sortie se voit une fracture." Actually, there is an unfaulted, inverted series of beds. The Tamabra of the high walls above Micos Falls dips 80° W and must be overturned, for farther west it is underlain by the complete Xilitla-San Felipe-Mendez series, dipping 40—60° WSW (Pl. XVIII, Sect. 12). South of the railway, between Jopoy and

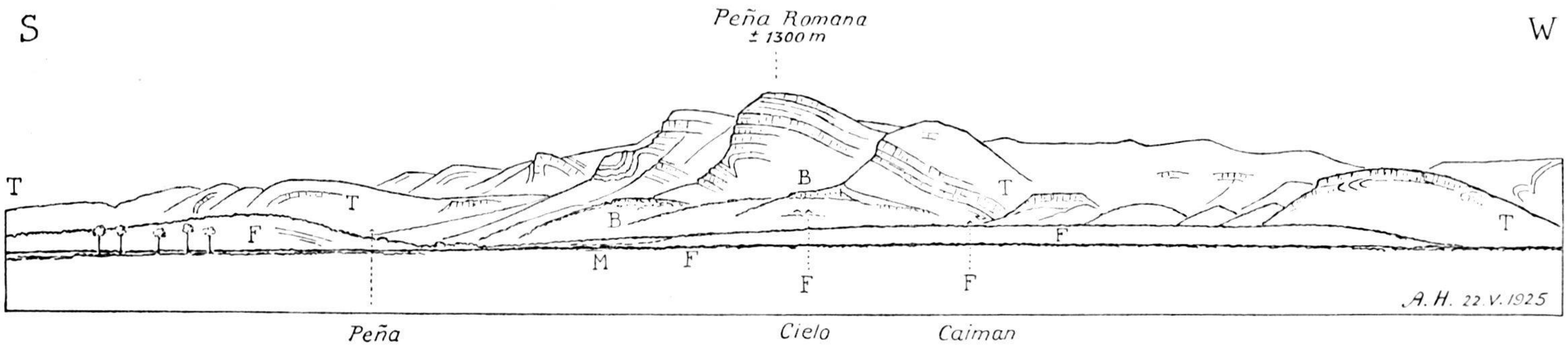

Fig. 8. *The Sierra de Nicolas Perez, pitching south-west, seen from the NE.*

Asymmetric folds in Tamabra and replacement of anticlinal ranges by new structures. Beyond Rancho Peña, the new anticlinal range of the Sierra Morelos commences. The low hills in the great synclinal valley in the foreground are made by secondary anticlines in San Felipe Beds. Above Rancho Caimán is a local thrust of Tamabra over San Felipe.

T: Tamabra Limestone; F: San Felipe Beds; M: Mendez Marls.
B: Mountain-slide.

Agua Vieja, the complete, reversed series is again found, dipping 35—50° W. Below it appears a new secondary anticline in San Felipe Beds, pitching north. Another succeeds farther south. At La Pila both join the large Tamabra outcrop of the range. The front is still overturned.

The whole range is crossed by the Rio Tampaon (Rio Santa Maria on the 1:100000 map), but only the lower end of the tremendous gorge is accessible by canoe from Paliguau. Here the Tamabra is overturned, with dips of 50—70° to W. The same overturned front is seen farther south on the trail between San Francisco and Sabinal. As usual, the western limb is the more regular and gentle. Near Tanchanaco, the Sierra Colmena anticline terminates in the shape of a broad anticlinal arch, pitching 5—10° SSE.

The Sierra de Aquismón.

The border of this fourth range is seen above Pubiche, west of Tanchanaco. The sharp " knee ", with vertically bedded walls of Tamabra, recalls that of the Chamal-Coahuila region. The associated Mendez and San Felipe Beds dip east under this wall, showing that a slight overturn also exists along this mountain-front. Above Aquismón, the Cabeza Aureca shows an anticline. Following it south to Santa Barbarita, the frontal arch is absent and the western limb is thrust over a zone of west dips in scale-like folds of San Felipe (Pl. XVIII, Sect. 14). But at Tocomón, the Tamabra of the Aquismón Mountains pitches south-eastwards under the valley with a normal cover of San Felipe, as if no overthrust were present.

South of Tocomón, vertical Tamabra Limestone again forms the western walls of the valley excavated in Mendez marls. They are part of an internal flexure of the Sierra de Aquismón, which continues farther south-east. At Tampachal, farther inland, Dr. Jenny reported minor overthrusts of the Tamabra over the San Felipe (Pl. XVIII, Sect. 15). The next mountain-trail to the south, from Huichihuayan to Xilitla, again crosses a simple border. The Tamabra dips normally under the Xilitla Beds at 30—45° NE. On the whole, the mountain-structure between Huichihuayan and Xilitla is that of a broad anticline, 5 km across, with local complications (Pl. XVIII, Sect. 16).

At Tlamaya, NW of Xilitla, the stratification of the rudistid-limestone is hard to see and highly confused. Xilitla town stands on the south-western limb of a fine symmetrical syncline (Pl. XVIII, Sect. 16), which can be traced to Cruztitla and farther to the south-east. To the south-west comes another low Tamabra anticline, and then a second syncline (Agua Buena—Tatetla). The latter is scarcely recognisable south-west of Xilitla, but deepens rapidly to the south-east. The axes of these folds strike exactly NW-SE. Finally, at Barranca and Ahuacatlan, we reach a third, broad, gentle Tamabra anticline, with gentle minor structures.

Returning to the eastern border of the limestone-mountains of Xilitla, we find a wall of horizontally bedded Tamabra, ending abruptly above Cristiano. Below it are San Felipe and Mendez Beds which dip towards the wall, so that the Tamabra must be locally thrust over them. This frontal region of Cristiano and Tenexcalco is also characterised by the broadening of the border valley in Mendez Beds and by the appearance of new folds, rising SE, all with steeper or inverted NE limbs.

The Overthrust of the Sierra de Xilitla.

West of Xilitla rises the flat-topped Peña de San Antonio (about 1500 m) with its magnificent needle peak Silleta. It is the abrupt, south-eastern end of the Sierra de Xilitla. The prominence of this Sierra is due to its extraordinary stratigraphic and tectonic position. It is chiefly built of Tamasopo Limestone (Lower Senonian). At the base of this thick series are Lower Xilitla Flags, thrust over Upper San Felipe Beds. The contact west of Xilitla is hidden by boulders, but the absence of a front-fold and the difference in facies can leave no doubt on the presence of an overthrust. To the south-west, the thrust series becomes strongly developed, forming a 200-m wall of white, black, and yellow rocks above Xilitla (Pl. XVIII, Sect. 16).

Tamazunchale.

This old town stands on Upper San Felipe Beds, dipping generally eastwards and overlain normally by Mendez, Tamesí and Chicontepec Formations. The trail running west along the Rio Moctezuma passes a tremendously crumpled fold on the south side of the first mountain (Pl. XVIII, Sect. 17), where San Felipe limestone and black layers, like Xilitla Beds, striking NNW, are folded on a core of dense, cherty limestone. Near the ferry at Tacial, north of the river, typical San Felipe Beds are exposed in the normal limb of a crumpled, overturned fold. Then follows the zone of Tenestipa, about 2 km wide, with Tenestipa Limestone upon cherty Pimienta Beds. Just west of Tenestipa, in a little side-canyon, this limestone is crushed and marmorized along a minor thrust-fault. A more important thrust occurs some 200 m above the ferry. This apparently indicates thrusting of the Jurassic mountains over the Cretaceous front-fold (Pl. XVIII, Sect. 17).

Beyond the narrow belt of Tenestipa Limestone, just before La Vega, the limestone retreats up to the higher slopes and an extensive mountain-area follows formed entirely of fossiliferous Tamán Beds (Kimeridgian). Pl. XVIII, Sect. 17 shows the details. The Tamán Formation forms an anticlinorium, 8—10 km wide, trending north and north-west, with numerous minor folds. The main axis passes through Tamán village. The Indian huts at Pimienta stand on the chert beds of the western limb, dipping 30—60° W. Then follows the Pimienta Syncline in Tenestipa Limestone, symmetrical like the synclines of Xilitla, but more crumpled. Dr. Fehr followed the creek NW of Tamazunchale and found the Jurassic with some secondary folding, but not thrust over the San Felipe. Hence the Jurassic of Tamazunchale shows only local thrusts and belongs to the normal deeper part of the autochthonous folds.

The Chicontepec Mountains North of the Rio Moctezuma.

South of the Rio Tampaon, in place of the El Abra Range rises a well defined mountain-region, 40 km wide and with a maximum elevation of 600 m, composed entirely of the Chicontepec Formation, mainly Tanlajás Sandstone. Towards the low peneplain to the north, the Chicontepec sandstones are cut off by denudation. To the west and south-west, they are separated from the Cretaceous ranges by the long Aquismón-Matlapa valley, cut in the Mendez and Tamesí Marls. The eastern and north-eastern limits are also determined by erosion.

In the distance the Chicontepec Mountains appear as a plateau with slight tectonic disturbance, but closer study reveals irregular folding and crumpling. Along the western border, south of Tacanhuitz, the Tanlajás sandstones dip 25—75° E and NE, away from the Cretaceous mountains.

The Axtla River exposes an overturned anticline with a gentle western limb. NE of it follows the Axtla Syncline. A second anticline occurs at Choteco, flanked by the Chalma Shale-syncline, of Chenico. The third anticline southwest of Tampamolon is more gentle and symmetrical and would appear favourable for drilling if the Tanlajás Sandstone should contain oil-sands. Between Tancanhuitz and Tanlajás, the Chalma Shale is absent, indicating a general axial rise to the NW. The village of Huehuetlan stands on flaggy sandstone, with a uniform dip of 12° SW. It forms the north-eastern limb of a broad gentle syncline (Pl. XVIII, Sect. 15). Nevertheless, the folding may become more intense locally anywhere, and vertical bedding is common. From Tancanhuitz northward to La Cuesta, the trail crosses a small, sharp anticline in Tamesí Beds, overturned somewhat to the north. A similar steep fold occurs at Tancolol, while the wide region to the south, between San Antonio and Tanlajás, is a flat syncline.

The San Pedro Valley, with its oil-wells, is topographically an inlet of the Tampico Plain. Geologically, it is an anticlinal valley eroded down to the Mendez shales. They are surrounded on three sides by Chicontepec mountains.

It is significant that the gentle anticlinal dips, on both sides of the San Pedro Valley, are suddenly interrupted by steep secondary anticlines. Hence the width of the anticlinal zone of oil-accumulation is not more than about 4 km (Pl. XVIII, Sect. 15). Moreover, the Mendez Beds at the apex of the anticline just south-east of San Pedro village are folded transversely. Farther north-east, the folds seem to flatten out towards the Tampico Plain.

Summary and Conclusions.

South of Victoria the outermost folds of the Sierra Madre Oriental are represented by about ten anticlines over a breadth of 20 km. They are either upright or bent over the to east and diminish gradually, though irregularly, towards the plain. Apart from a general zone of culmination, this group of folds pitches to north (Victoria Plain) and south. Then follows a general depression of the fold-axes along the Rio Guayalejo (near Llera). The largest anticlines are those of the Sierra Boquilla to the north and the Sierra Prieto to the south of that river.

From Xicotencatl southwards, there is no more range corresponding to the Front-Ranges of the Victoria region. But exposures of San Felipe Beds in the great plain prove the continuation of more subdued folding at greater depths.

West of the Front Folds of Victoria comes the great Huizachal Anticline, 15—20 km wide, which seems to pass southwards into the Carabanchel Anticline of equal or greater width, but lesser tectonic height.

North of Chamal, 90 km south of Victoria, this anticline pitches south and changes into the long, shallow Antiguo Morelos Syncline. This is followed on each side by lateral anticlinal ranges developed from the limbs of the Carabanchel Anticline. A remarkable cross-anticline occurs at the point of transformation. From there, the low El Abra Range, east of the Antiguo Morelos Syncline, forms the mountain-front for 120 km, as far as the Rio Tampaon. It is a complex low Tamabra Anticline with the steeper limb facing the plain. Pitching with subdivisions below the Rio Tampaon, it rises again south of this river in the shape of three separate domes (Tantobal, Salsipuedes, Santa Isabel).

The second range begins in the north as the Sierra de Chamal and continues as the Sierra Nicolas Perez for 100 km. The detailed structure is complicated and not that of a single anticline. The chief structural change occurs north of Antiguo Morelos, where the easterly overturned Peña Romana Anticline turns off and pitches SW, while the Morelos Anticline, with a gentle western limb and a steep eastern, continues the general trend of the range, until it pitches under the plain. Thus the two synclines of Morelos merge north-west of Valles.

The third range, followed from Nuevo Morelos for 100 km, shows an inverted series of beds all along its eastern border, except at the southern end where the Sierra Colmena pitches as an upright anticline. As in the Sierra Romana, the structure is complicated. At least two Tamabra anticlines occur at Micos. South of the railway new secondary anticlines rise from the eastern flank and join the main Tamabra outcrop.

The fourth range, the Sierra de Aquismón, is still larger and more complicated. Its front is partly anticlinal, partly thrust. The inner part involves several minor thrusts. At Tocomón, the north-eastern part of the range ends by pitching.

At Xilitla, more regular folding with exactly NW-SE strike, produces two synclines in the San Felipe-Mendez strata, subdividing the broad mountain-area of Tamabra. At the outer margin the Tamabra is slightly thrust over the San Felipe. Four or more new anticlines rise in the broadened valley of Mendez Beds.

Finally, at the Rio Moctezuma, appears in the southeastern continuation of the Xilitla region the Tamán Anticlinorium of 10 km width, with many minor complications and an overthrust eastern border.

Over the autochthonous mountains of Xilitla, the Tamasopo Limestone of the Peña de San Antonio is overthrust, forming the Sierra de Xilitla. The nearly horizontal overthrust from the west explains the sudden change in facies.

Here, in the south, east of the Cretaceous ranges extends the great mass of the Chicontepec Mountains above the buried Cretaceous Front folds. Although no unconformity was observed at the contact with the Cretaceous along the western border, the folding in the Chicontepec Mountains is unlike that in the Cretaceous ranges. The difference in structure may be partly due to the difference in sediments. The most important anticline of the Chicontepec region is in the San Pedro Valley, where Mendez Beds reach the surface.

The strike of the Chicontepec Formation is NW-SE, corresponding as a whole to that of the Cretaceous ranges to the west, but not in harmony with the termination of the El Abra Range nor of the Cretaceous domes north of Tacanhuitz. The structure in the narrow valley from Aquismón to Tocomón makes the impression that the folding of the Front Ranges found some obstacle in the Chicontepec region, and that the former continued to be pushed against the latter even after the erosion of the Tocomón Valley.

The general t y p e of f o l d i n g in the Sierra Madre Oriental is that of the Jura Mountains of Switzerland or of the Lebanon-Antilebanon. The anticlines are upright or overturned to the east. No case to the contrary was found. While the frontal El Abra Range shows regular, smooth, anticlinal forms, the structure becomes more complicated towards the inner ranges. The southern part of the latter is also the region of small overthrusts. This is in contrast to the Jura Mountains, where the outer folds are the more intensely thrust. The folding and thrusting of the region has taken place as a horizontal movement towards the Gulf of Mexico.

Special attention was paid to faulting. Several minor faults have been described and others may have been overlooked. But in comparison with other similar ranges, the absence of longitudinal and transverse faulting of any importance is striking.

The Chicontepec Mountains partly excepted, all the mountain-ranges correspond to anticlines or anticlinal thrusts, the valleys being synclines in Mendez Marls. Thus the anticlinal structure is visible in the distance, as is the case with the young Iranian Ranges along the Persian Gulf.

V. Summary of Geological History.

We recognise the following phases in the history of the Sierra Madre Oriental:

1. Pre-Mississipian orogeny.
2. Denudation and submergence.
3. Deposition of the marine Peregrina Formation (Carboniferous). Filling of the basin with continental sandstones and conglomerates of the Red Beds (Permian).
4. Pre-Jurassic uplift and denudation. Removal of part of the Red Beds. So far as known, no intense folding took place, the contact with the Mesozoic strata showing only local unconformities.
5. The Mesozoic submergence seems to have occurred earlier in the south (Tamazunchale), where the fully marine Jurassic sediments accumulated in great thickness. In the north (Victoria) they are differently and poorly developed. The gypsiferous lagoon-beds of Nuevo Leon are regarded as Jurassic by Baker, and this may be the case with the Olvido Formation of Victoria. Marine Jurassic is known farther north in Nuevo Leon, and the Victoria region may have been an island or peninsula during part of Triassic and Jurassic times. W. Staub (1939, p. 348) calls it the Peregrina Horst.
6. In Lower and Middle Cretaceous times the sea spread all over the area, with striking facies-variations. By itself, the Tamaulipas Limestone with its rare ammonites would be taken for a deep-water deposit, as by Muir (1936, p. 94), while the rudistid-facies is certainly a warm, shallow-water deposit. But in the region of mixed facies, the two types alternate so much that it would be hard to explain the difference on the basis of varying depth alone. Here we meet the same problem as in the Upper Jurassic of the Swiss Alps *(Quintnerkalk-Troskalk)* (Arn. Heim in Alb. Heim 1916—1919, II, p. 287).
7. Above the Middle Cretaceous, a break of sedimentation separates the Tamabra from the overlying beds over a large part of the area. In the north, the inner and southern ranges, where the San Felipe is fully developed, the break is not uniform and might be explained by interruption of sedimentation without emergence. But on the eastern border of the Front Ranges, for 125 km between Gomez Farias and the Rio Tampaon, there is a gap, corresponding to Turonian and Coniacian, with the Mendez Marls resting on a roughly weathered or solution-eroded surface of rudistid-limestone (Textfig. 4). If the Tamabra here showed the Tamaulipas facies, we might suppose the gap to be due to submarine solution. But the coincidence of the break with the neritic, sub-reef facies of the Tamabra, and with overlying conglomerates and breccias, clearly points to shallow-water and emergence during part of Turonian-Coniacian times. The same phenomena are presented by the well-records of the great Dos Bocas-Alamo oil-fields (Southern Fields).

In the Panuco (Northern) oil-fields the San Felipe, though always present, is thinner on the anticlines than in the synclines. These results, deduced from a few well-records in 1925, are amply confirmed by MUIR (1934, 1936). The simplest explanation is that slight submarine folding commenced in Middle Cretaceous times. This folding was very gentle in the Northern Fields where no angular unconformity has been observed. If this explanation is correct, the earliest fold in the Front Ranges between Victoria and Tamazunchale corresponds to the long, gentle El Abra Range from Gomez Farias to Taninul. Possibly similar gentle folding occurred at La Pila along the inner Colmena Range.

In Turonian times, the region of the Front Ranges partly emerged (break and conglomerates on east side of El Abra Range and at Jaumave). But the sea prevailed where the Xilitla Formation with its bituminous, siliceous limestone-flags and fish-scales was deposited. In contrast to the warm-water conditions of the rudistid-limestone, the Xilitla Formation is regarded as being deposited in a cold current, at moderate depths.

8. In Coniacian times a general subsidence occurred, during and after which the marly limestones with foraminifera of the San Felipe were deposited. The typical San Felipe beds are regarded as deep-sea deposits.

9. Throughout the Front Ranges and their foreland, the Senonian is characterised by quiet, uniform, geosynclinal deposition. The Mendez Marls, of the type of recent calcareous and blue muds, were deposited along the continental slopes. This facies, with its abundant small foraminifera, strikingly resembles the synchronous, deep-water deposits of the Helvetic Alps *(Amdener Mergel)*.

The Tamasopo Limestone-facies of the Sierra de Xilitla has not been sufficiently studied to comprehend its conditions of deposition.

10. The close of the Cretaceous Period has been regarded as marked by a break. But in our area, no distinct break has been observed below the Tertiary Chicontepec Series, the Tamesí with a wealth of foraminifera forming a transition-series.

11. In Eocene time, an enormous amount of calcarous mud and sand was washed down from the interior into the subsiding fore-deep. They formed the marine Chicontepec and the following Tertiary deposits of the Tampico region.

12. The main folding of the Front Ranges is post-Chicontepec or post-Paleocene. It terminated before the lava-flows of the unfolded mesas, whose present elevation is due to recent uplift.

VI. Petroleum-Relations.

Surface Indications.

From Victoria to the San Luis Potosi railway, rare indications of petroleum are known in the Front Ranges. We may mention the odour of the Tamabra Limestone, which is sometimes more like that of petroleum than of sulphuretted hydrogen. The Xilitla Beds, with their fish-scales, have a distinctly bituminous smell, though in the northern region not exactly that of petroleum. Oil could certainly be produced in minor quantities by distillation. But chloroform-tests give only a slight brown colour, if any. At Ojo de Agua, south of Quintero, the hollow chambers of rudistids in the Tamabra are covered with black calcite-crystals. Their black crust was first taken for asphaltite, but it is insoluble in chloroform and is carbon derived from the rudistids. At El Abra quarries, the same rudistidcavities occur in the miliolinid-limestone. Some contain not only calcite and carbon, but also volatile yellow oil of an aromatic smell. At Guerrero, small cracks, filled with asphaltite, have long been known in the grey Mendez Marls.

In the Chicontepec Mountains, a slight smell of oil was noted locally in the Tanlajás Sandstone. At Santa Cruz, north of Tanchanaco, two seepages were reported. Both were found dry but are located on Xilitla Beds with a slight smell of oil. The Xilitla region is rich in natural indications of oil *(chapapote)*. So far as seen, they all occur in the Xilitla Formation or the dense limestones of San Felipe facies which alternate with black, bituminous beds. In a small quarry on a ranch, SE of Tlamaya, semiliquid, darkbrown oil fills cracks in dense San Felipe Limestone. Liquid oil is reported from a hole about 1 km farther west. The same type of seepage occurs on the trail between Cristiano and Tenexcalco, again in cracks of dense limestone, interbedded with black, bituminous Xilitla Beds.

Thus the petroleum-occurrences are of four types:

(a) Liquid oil in the Abra Limestone in fossils (El Abra).

(b) Oil exuding from shaly, black, bituminous Xilitla Flags, in place of its origin (Buena Vista and Santa Cruz).

(c) Dark brown oil in cracks in dense, grey limestone of San Felipe type with *Globigerina*, in the passage-zone between Xilitla and San Felipe Beds (Tiamaya, Cristiano).

(d) Asphaltite in cracks in Mendez Shale, in secondary position (Guerrero).

Thus along the Sierra Madre Oriental, there are two primary oil-formations, the Tamabra and the Xilitla.

Sulphur-Water.

Like oil-seepages, sulphur-waters are only found in the southern part of the Front Ranges, at: (a) Palmas, on the eastern border of the Sierra del Abra; (b) Taninul, in a spring rising at the contact between rudistid-limestone and overlying Mendez; (c) Los Bañitos, 10 km SE of Valles, from boulders of San Felipe limestone; (d) Agua Hedionda, NW of Tancolol, rising from black soil above San Felipe Limestone.

Drilling.

Among borings of tectonic interest, we may note:

Santa Isabel No. 1, drilled in 1914 to 1400 ft (Pl. XVIII, Sect. 14), on a San Felipe dome, a little south of its apex. The nearest outcrops of highest San Felipe or basal Mendez show dips of 20° to SW. Coarse, black, crystalline, miliolinid-limestone was encountered between 440 and 740 ft. It is unknown whether this represents the Xilitla. Below 740 ft, typical Abra Limestone was found with a strong flow of sulphur-water.

Huitzalté. This boring, at the mouth of the San Pedro Valley encountered San Felipe with a show of oil at 3328 ft, and black platy crystalline limestone with black chert (Xilitla ?) at 3706—3910 ft. The true Abra Limestone was reached at 3960 ft and drilled to 4028 ft. Until 1925, this was the only drilling in the San Pedro district to reach Tamabra (Pl. XVIII, Sect. 14). The oil, found under high gas pressure in the well is of light yellow colour, rich in benzine, and of density 0,78.

San Pedro Valley. The best well was La Labor No. 1, though located some 100 m NE of the anticlinal apex. Oil was struck at 3870 ft in San Felipe

Beds (passage to Xilitla?). It is light brown, rich in benzine, and of density 0,796. The well flowed 30—40 barrels per day.

San Pedro No. 1 was the second best. High-grade oil was found in the San Felipe from 3650 to 4000 ft. In July 1925, drilling was continued at 4155 ft. Samples of San Felipe type-beds with green shale were collected by the writer.

Guerrero No. 1, on the Rio Tamuin, started in Mendez Beds. According to MUIR (1936, pp. 64—65) the base of the underlying San Felipe occurs at about 2421—2450 ft and the top of the grey cherty Tamaulipas Limestone at 2813 ft.

Rodriguez. In this well, 10 km NNW of Guerrero, MUIR (1936, p. 43) records a mixed facies of Tamabra, at 1906 ft below sea-level, at a distance of 8 km east of the Sierra del Abra.

Origin of Oil.

Practically all the oil in the Tampico Fields comes from the Tamabra, Xilitla and San Felipe Formations. The last, however, is non-porous and only a horizon of secondary impregnation, the oil from below filling cracks. As stated above, the Xilitla is regarded as a typical source-rock. But no locality is known where important production comes definitely from the Xilitla. Possibly the light oil in the San Felipe of San Pedro originates in the Xilitla Flags.

It has long been known that the major production in the Tampico region comes from the Tamabra Limestone. But the primary source of the oil is not definitely decided on by oil-geologists. The writer's view of 1925, at the time much contested, that the primary source is the Tamabra itself seems to be adopted by MUIR (1934). Under specially favourable conditions of non-oxidation, its organisms were transformed into oil. Along the border of the Front Ranges (Sierra del Abra), however, the greater part of the organic substances has been oxidised and evaporated, or has been transformed into carbon.

Accumulation is generally anticlinal, but is also connected with faults or igneous intrusions. The initial production of one well on the anticline of the Southern Fields is only rivalled in the Caucasus. (Total production of Potrero del Llano No. 4, 1910—1928, over 100000000 barrels.) This enormous accumulation is due to primary porosity and cavities in the rudistid-limestone. In the Northern Fields, however, the Tamaulipas-facies prevails and practically the only space within this dense limestone is related to fissures and fracturing (induced porosity of MUIR). What organisms have been transformed into oil in the Pánuco Fields and from what horizon remains an open question.

VII. Appendix.

Notes on the Inner Ranges west of Victoria.

The road from Jaumave, on the Rio Guayalejo SW of Huizachal, to Palmillas crosses a double anticline of the Sierra de los Ebanos, with its eastern limb overturned (Textfig. 9—10). At Paradita, on the western limb, we find beds, 1—2 m thick, of more or less oolitic Tamabra limestone, formed largely of fragments of algae resembling *Lithothamnium*. A second anticline is crossed east of Palmillas, the great westerly dipping walls of Tamabra forming a mountain-range. They are joined, according to W. S. ADKINS, by vertical San Felipe Beds at the western foot. The next Tamabra Anticline rises 7 km NNW of Palmillas. It is replaced southwards by a brachy-anticline which crosses the road to Tula 6 km west of Palmillas, where oolitic, algal rock, rich in rudistids is seen. This fold is 10 km long and plunges to north and south. Farther west the road passes a long (Tamabra?) range and there are two more such folds between Tula and Bustamente. All these anticlines strike N-S.

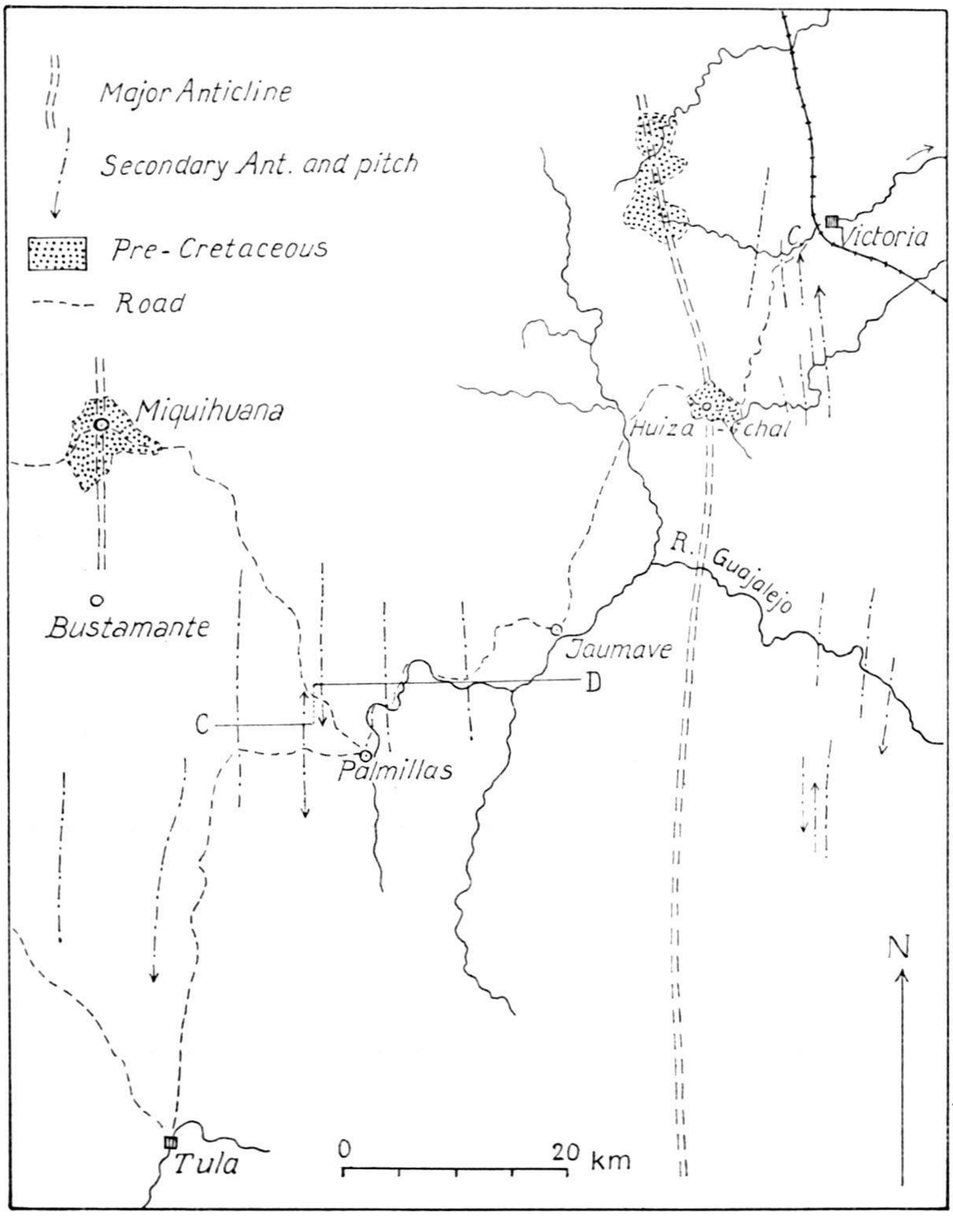

Fig. 9. *Sketch-Map of the Region between Victoria, Tula and Miquihuana.*

At Miquihuana, 55 km west of Huizachal, pre-Cretaceous rocks appear in the core of a great N-S anticline, 15—20 km broad and 3—4 km high. Here the following section was found:

4. Tamaulipas Limestone. ADKINS reported Albian fossils in the middle of the series, west of Miquihuana . . . . about 1500 m.

3. Valanginian. Reddish, sandy marls with many *Exogyra couloni* DEFR. in the lower part. In the middle, large ammonites identified by Dr. C. BURCKHARDT as *Acanthodiscus* of *michaels*-group . . . . 150 m.

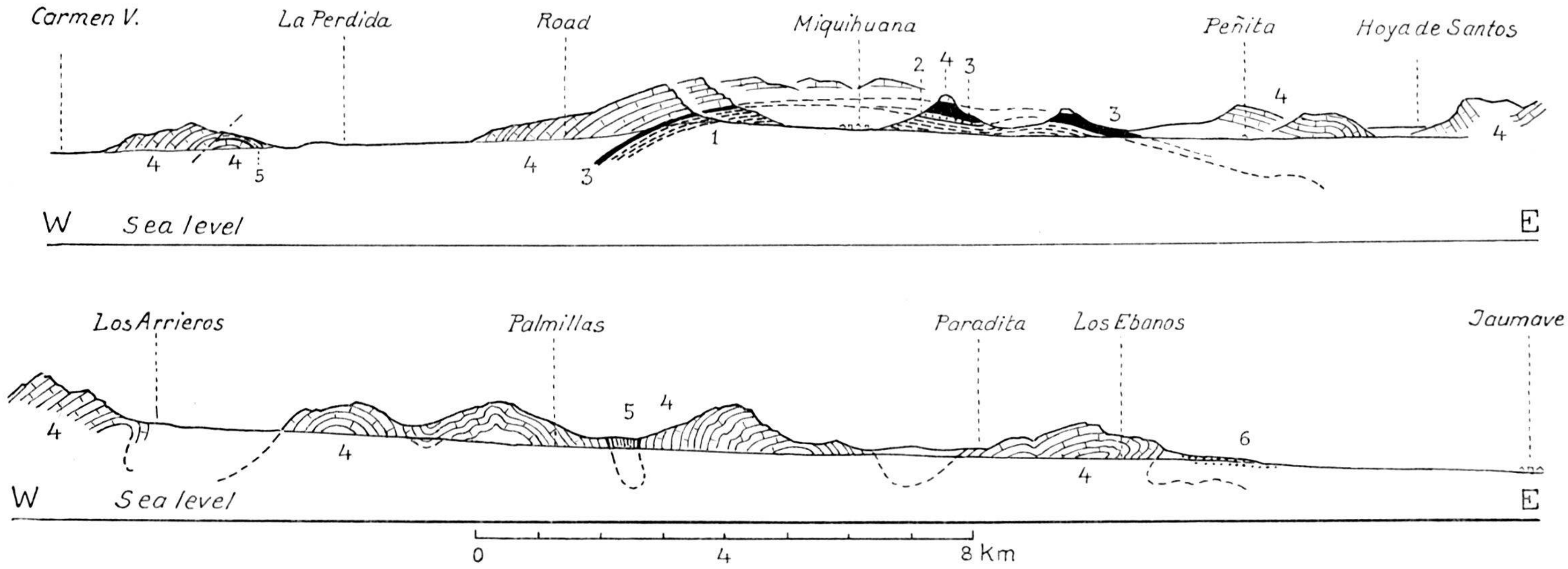

Fig. 10. *Sections of Interior Ranges.*

(Compare Sketch-Map Fig. 9).

1: Redbeds; 2: Portlandian; 3: Valanginian; 4: Tamabra Limestone; 5: San Felipe beds; 6: Terrace gravel.

2. Portlandian. Grey limestone with brachiopods and small oysters. Absent from the west flank . . . . 0—12 m.
1. Red Beds. Base not seen, identical with those of Huizachal . . . . 200—300 m.

The western limb of the Miquihuana Anticline steepens up to 45—50°. According to BAKER the Tamaulipas Limestone is underlain farther west by nearly 1000 m of Lower Cretaceous limestone, under which come Gypsum Beds which he considers Upper Jurassic.

Farther north, towards Aramberri in Nuevo Leon, the structure is completely different from that of the Sierra Madre Front Ranges. Great hills, dipping uniformly NW, are followed by Lower Cretaceous limestones dipping NE. Under these are Gypsum Beds and Red Beds with Gabbro-intrusions. The Red Beds are found a long way north and west of Aramberrí.

VIII. References.

BLUMER, E. 1922. Die Erdöllagerstätten. Stuttgart.
BÖSE, E. 1906A. La Fauna de Moluscos del Senoniano de Cárdenas, San Luis Potosí. *Inst. Geol. de Mexico*, Bol. 24.
— 1906B. De San Luis Potosí à Tampico. *Guide des excurs. Xe Congrès géol. internat.*, No. XXX, Mexico.
— 1913. Algunas faunas del cretacico superior de Coahuila. *Inst. Geol. de Mexico*, Bol. 30.
— and O. A. CAVINS. 1927. The Cretaceous and Tertiary of Southern Texas and Northern Mexico. *Univ. Texas. Bull.* 2748.
BURCKHARDT, C. 1930. Étude synthétique sur le Mésozoïque mexicain. *Mém. Soc. pal. Suisse*, XLIX—L.
HAACK, W. 1914. Über eine marine Permfauna aus Nordmexiko nebst Bemerkungen über Devon daselbst. *Zeit. deutsch. geol. Ges.*, LXVI, 482—504.
HAARMANN, E. 1913. Geologische Streifzüge in Coahuila. *Zeit. deutsch. geol. Ges.*, LXV, Monatsb., 18—47.
HEIM, ALB. 1919—22. Geologie der Schweiz. Leipzig, 3 vols.
HEIM, ARN. 1924. Über submarine Denudation und chemische Sedimente. *Geol. Rund.*, XV, 1—47.
— 1926. Notes on the Jurassic of Tamazunchale (Sierra Madre Oriental, Mexico). *Eclogae geol. Helv.*, XX, 84—87.
— 1934. El Bernal de Horcasitas, a volcanic Plug in the Tampico Plain, Mexico. *Zeit. Vulkan.*, XV, 254—260.
MUIR, J. M. 1934. Limestone Reservoir Rocks in the Mexican Oil Fields. In: Problems of Petroleum Geology, 377—398, Tulsa.
— 1936. Geology of the Tampico Region, Mexico. Tulsa.
STAUB, W. 1937. Geologische Querprofile durch das Erdölgebiet von Nordost-Mexico. *IIe Congrès Mondial du Pétrole*, Paris, Sect. I, Géologie, p. 619—622, 2 pl.
— 1939. Ost-Mexico, das Nordwest-Ende der mediterranen, orogenen Zone. *Geologische Rundschau*, XXX, p. 346—351, Taf. IV u. V.

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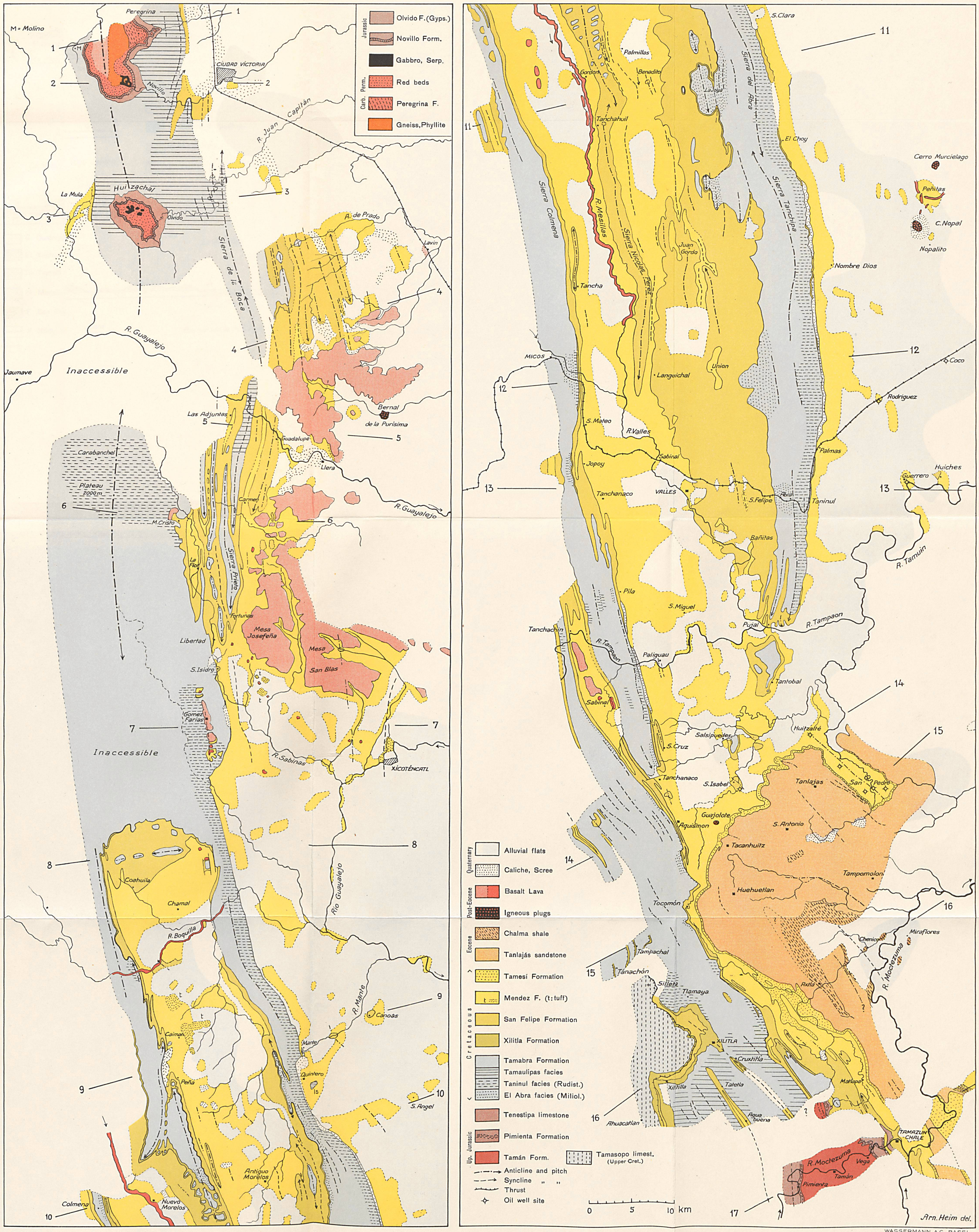

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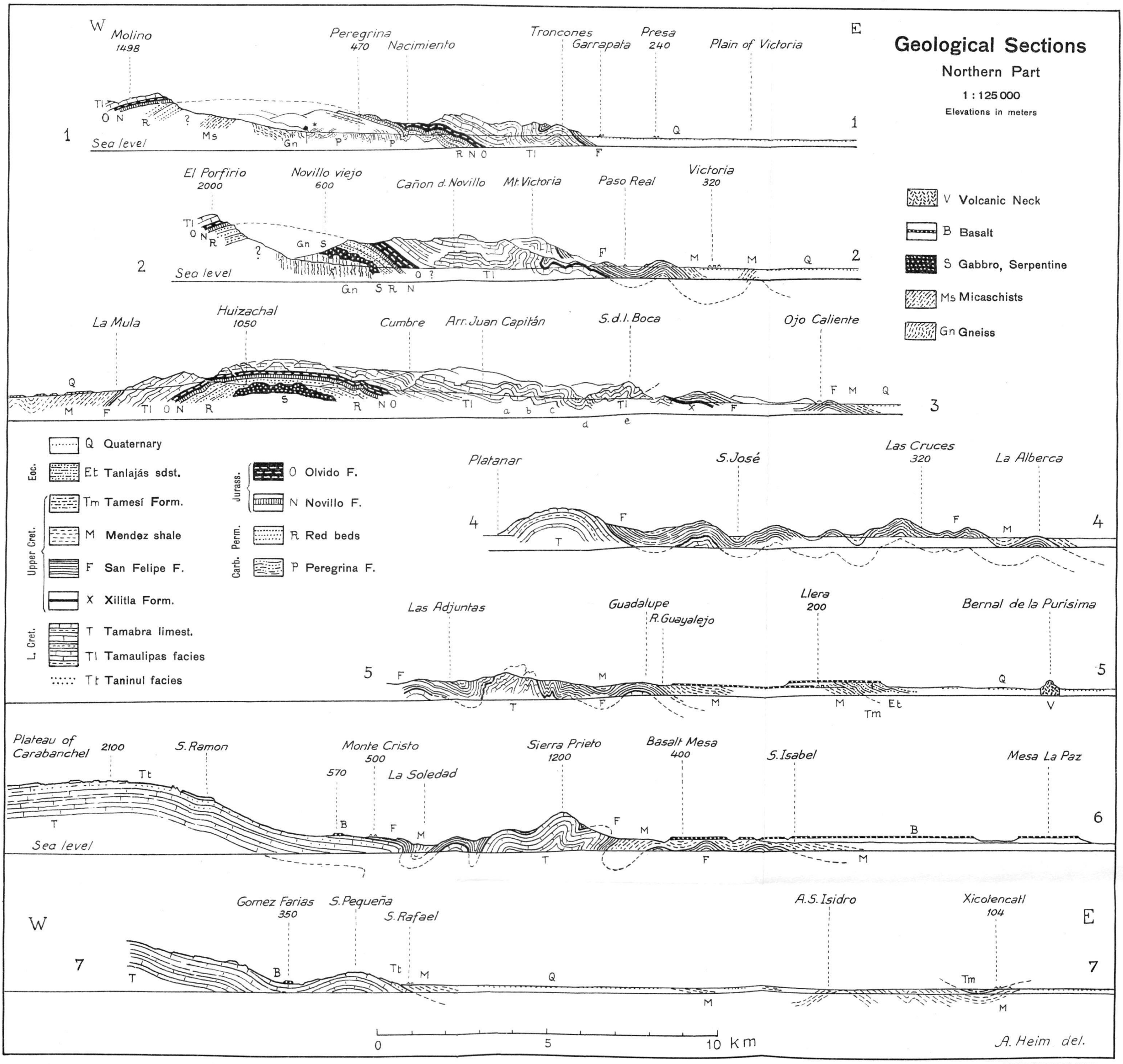
Geological Map of Sierra Madre Oriental, Mexico, from Victoria to Tamazunchale

1: 300 000



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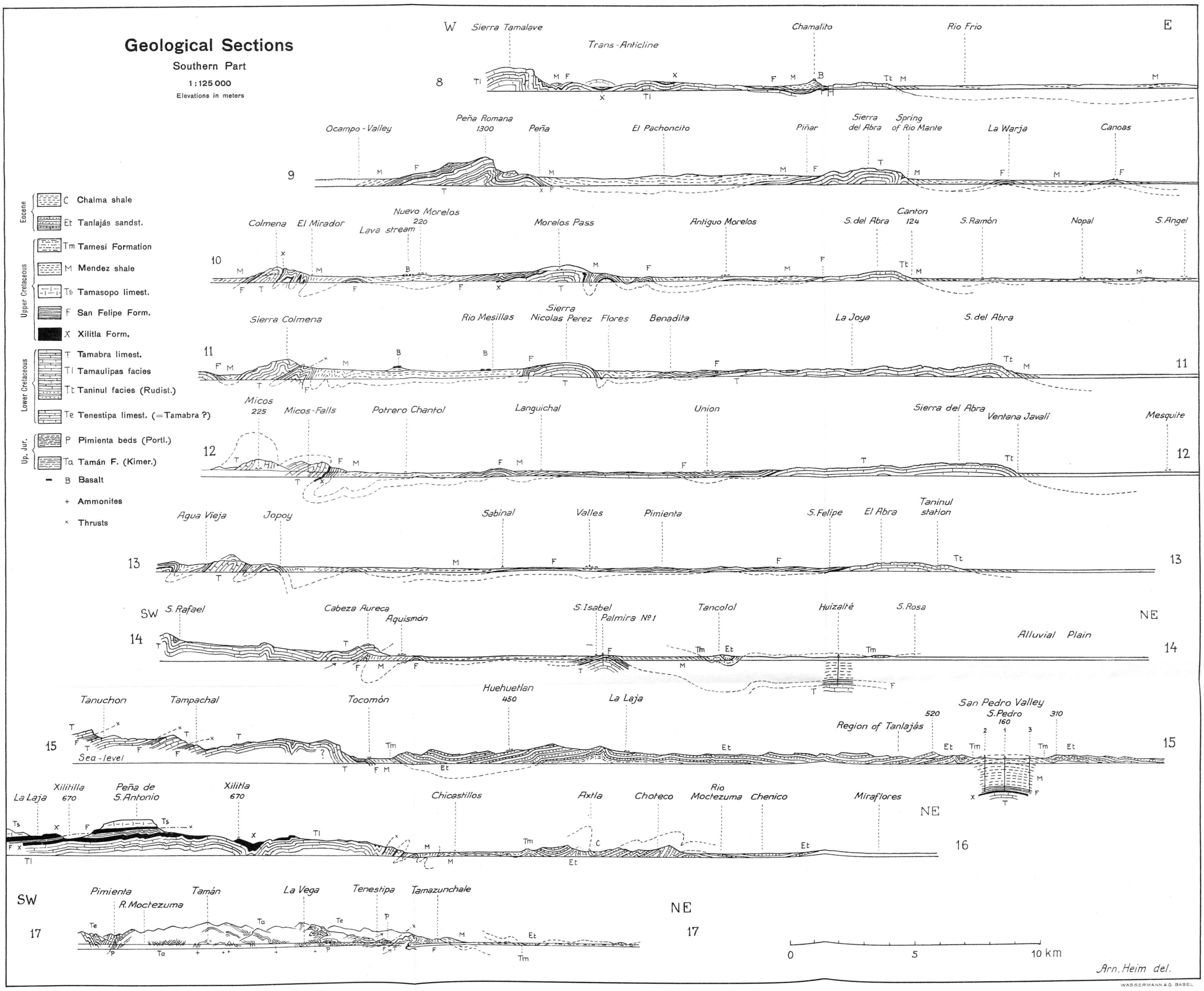

Geological Sections
Southern Part
1:125 000
Elevations in meters
Eocene
C Chalma shale
Et Tanlajás sandst.
Upper Cretaceous
Tm Tamesi Formation
M Mendez shale
Ts Tamasopo limest.
F San Felipe Form.
X Xilitla Form.
Lower Cretaceous
T Tamabra limest.
Tl Tamaulipas facies
Tt Taninul facies (Rudist.)
Te Tenestipa limest. (=Tamabra ?)
Up. Jur.
P Pimienta beds (Portl.)
Ta Tamán F. (Kimer.)
B Basalt
+ Ammonites
× Thrusts
W
E
8
Sierra Tamalave
Trans-Anticline
Chamalito
Rio Frio
9
Ocampo-Valley
Peña Romana 1300
Peña
El Pachoncito
Piñar
Sierra del Abra
Spring of Rio Mante
La Warja
Canoas
10
Colmena
El Mirador
Nuevo Morelos 220
Lava stream
Morelos Pass
Antiguo Morelos
S. del Abra
Canton 124
S. Ramón
Nopal
S. Angel
11
Sierra Colmena
Rio Mesillas
Sierra Nicolas Perez
Flores
Benadita
La Joya
S. del Abra
12
Micos 225
Micos-Falls
Potrero Chantol
Languichal
Union
Sierra del Abra
Ventana Javalí
Mesquite
13
Agua Vieja
Jopoy
Sabinal
Valles
Pimienta
S. Felipe
El Abra
Taninul station
SW
NE
14
S. Rafael
Cabeza Aureca
Aquismón
S. Isabel
Palmira Nº 1
Tancolol
Huizalté
S. Rosa
Alluvial Plain
15
Tanuchon
Tampachal
Tocomón
Huehuetlan 450
La Laja
Region of Tanlajás
520
San Pedro Valley
S. Pedro 160
310
Sea-level
16
La Laja
Xilitilla 670
Peña de S. Antonio
Xilitla 670
Chicastillos
Axtla
Choteco
Rio Moctezuma
Chenico
Miraflores
17
Pimienta
R. Moctezuma
Tamán
La Vega
Tenestipa
Tamazunchale
0
5
10 km
Arn. Heim del.
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