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CONTENTS

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Preliminary Investigation of the Geology of the Northern San Miguel Allende Area, Northeastern Guanajuato, Mexico

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ABSTRACT

The San Miguel Allende area of Guanajuato, Mexico, is relatively unknown geologically. The study area is located in a graben with border faults whose topographic expression approximates 300 m. Within the graben are Cretaceous and Cenozoic sedimentary deposits and a volcanic sequence consisting mostly of pyroxene andesite. The volcanics are Oligocene to Miocene in age, based upon obtained radiometric dates. The sedimentary units consist of a Late Cretaceous marine turbidite unit, overlain unconformably by latest Miocene to earliest Pleistocene fluvial and alluvial sediments. The late Cenozoic sedimentary beds contain fossil vertebrates that have been the object of earlier studies in this area. The San Miguel Allende area was involved in the early Tertiary Hidalgo Orogeny. Later tectonism, in latest Miocene to earliest Pleistocene, produced widespread tensional faulting accompanied by basalt flows, which have continued intermittently to the present.

INTRODUCTION

The preliminary geological study reported in this article has been done in conjunction with a vertebrate paleontological project in northeastern Guanajuato, Mexico. This paper is unique, being the only example for Mexico where a detailed geologic map accompanies extensive fossil vertebrate field investigations. This project, sponsored by the Instituto de Geología, Universidad Nacional Autónoma de México, is part of an ongoing study begun in 1974. The present study area (fig. 1) includes about 600 square kilometers. To our knowledge, no stratigraphic or other detailed geologic studies have been made of this particular portion of Mexico or its vicinity. Two earlier geologic maps have been made of the region—the Dolores Hidalgo geologic map (Anonymous 1973a), and the San Miguel Allende geologic map (Anonymous 1973b). These maps were based on aerial reconnaissance and some local field investigations by a few workers (Anonymous 1973a and 1973b, Lopez-Ramos 1970). They contain no geologic ages, just rock and soil types. The enclosed geologic map (plate 1) represents the efforts of parts of six field seasons of study related to Cenozoic fossil vertebrate sites found in the area. All three authors, but especially the senior author, have traversed the entire map area by vehicle and on foot. Aerial photos (scale 1:50,000) and the above "geologic" maps, as well as their accompanying topographic maps, were used in compiling the present geologic map. Drill, or other subsurface, data would have been most helpful in our work, especially in

FIGURE 1.—*Location map depicting the area of study in central Mexico.*

determining thicknesses of the sedimentary units; unfortunately, this type of information is not available for the study area.

The investigated area near San Miguel Allende is located nearly in the center of Mexico, between the eastern and western Sierra Madre in the Central Mexico Highlands (fig. 1). Elevations here range from 1,875 to 2,800 m. The eastern border is largely dominated by the volcanic-capped Rancho Viejo Hills (Cerros de Rancho Viejo). The western border is, like that on the east, a volcanic-capped, fault-produced ridge trending north–south. These hills, which form the eastern and western borders of the study area, are displaced by a number of east–west, high-angle cross faults that have controlled canyon development and some sediment distribution (fig. 2). Much of the southern part of the study area is composed of a single large volcanic accumulation, Palo Huérfano, which includes the highest elevations in the region. The relatively flat northern border is poorly defined. Mostly the study area exists as erosionally formed low hills and flatlands situated in a fault-bounded valley, or graben. Despite the relatively high overall elevation of the region, typical desert conditions prevail throughout. Several varieties of cacti and shrubs compose most of the vegetation, supplemented with scattered mesquite trees.

A significant portion of the land is being farmed, with and without irrigation. Average rainfall is about 50 cm per year. Most streams are ephemeral, with the largest drainage system being Río Lajas (essentially a perennial stream), which trends north–south along the western fault boundary of the study area.

The physical borders of the study area are not geologically well defined, rather they relate primarily to localities that have yielded latest Miocene (Hemphillian) through late Pliocene (Blancan) and earliest Pleistocene (Irvingtonian) vertebrate fossils. It is for the purpose of better understanding the geology as it pertains to these fossil localities that the present geological reconnaissance has been undertaken.

Known terrestrial fossil-bearing deposits of the Hemphillian to Irvingtonian interval are rare in Central America (Miller and Carranza 1984, 1989). This span of time is critical regarding the faunal interchange that took place when North and South America joined after more than 50 million years of separation.

The deposits representing this chronologic interval in the study area are herein informally named the Rancho Viejo beds. They contain the most extensive late Cenozoic continental fossiliferous exposures in all Central America. As such, they offer an outstanding possibility to better understand the detailed dispersal patterns of South American faunal immigrants as they moved northward, and North American faunal emigrants as they traversed southward. The major faunal movements almost certainly would have occurred between the Sierra Madre Oriental and Sierra Madre Occidental ranges. Thus the Rancho Viejo beds, being located in what amounts to the central portion of a geographic funnel, are ideal for having the potential of containing the earliest immigrants and emigrants in this very important faunal interchange. The effects of this faunal interchange are still apparent in the modern biotas of both continents. Thus far, South American immigrants such as a marsupial, several edentates, and at least one giant rodent (a capybara), and North American emigrants including horses, camels, and a variety of carnivores and rodents have been identified in the Rancho Viejo beds.

Four major stratigraphic units are present in the study area. These include Cretaceous marine beds, an Oligocene to Miocene volcanic sequence consisting primarily of pyroxene andesite with some basalt, fossiliferous latest Miocene to early Pleistocene fluvial sediments, and unconsolidated to poorly consolidated Quaternary fluvial-alluvial and spring deposits (fig. 3).

Within the Pliocene deposits lies the contact between the Hemphillian and Blancan mammal stages. The representation of terrestrial fossil-bearing deposits for these ages is probably better represented here than anywhere in North America. Datable ashes in these beds have the potential to provide, along with recovered mammals and paleomagnetics, the most accurate dating possible for this boundary.

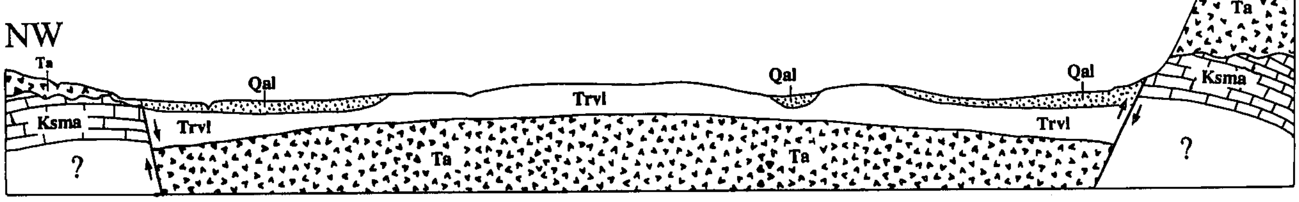


FIGURE 2.—*Generalized cross section in study area showing inferred structural and stratigraphic relationships.*

STRATIGRAPHY AND SEDIMENTARY ENVIRONMENTS

SAN MIGUEL ALLENDE BEDS

The selection of the San Miguel Allende beds as an informal, rather than a formal, name for the Cretaceous strata in the study area stems from a lack of definitive stratigraphic knowledge, as well as poorly known regional relations of the sedimentary units of this age. Lopez-Ramos (1982, p. 418) suggests the use of Mezcala (?) Formation for the region east of the study area for beds that might be equivalent in age. Until further study justifies formal nomenclature, the informal terminology seems warranted. The name is taken from the largest town in the area, San Miguel Allende, Guanajuato.

The marine San Miguel beds outcrop in several areas near the city of San Miguel Allende. They are exposed immediately southeast of the city, along the foot of the uplifted fault block that traverses the eastern side of the study area, and also in another small outcrop 10 km south of San Miguel. This unit is composed of a series of turbidite couplets consisting of clay laminae interbedded with moderately well cemented siltstones. Cement is dominated by calcite, occasionally silica. Most couplets range in thickness from 2–20 cm, the average being 4–6 cm. The fine-grained clayey laminae are generally only a fraction of the thickness of the underlying coarser silty laminae. The thickest coarse units measure 0.6 m.

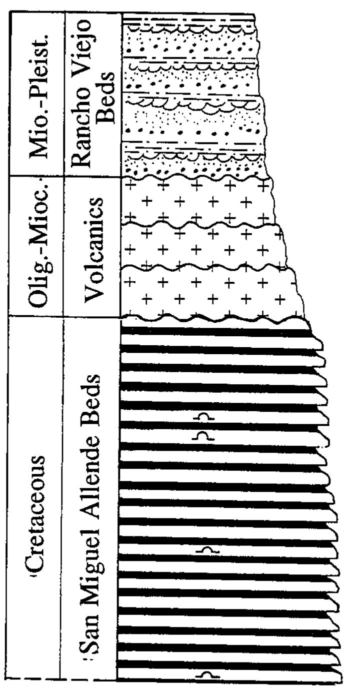


FIGURE 3.—*Erosional profile showing stratigraphic relationships of all beds exposed in the study area.*

Microscopic examination of the disaggregated particles in these beds reveals a diversity of mineral types. Grains of feldspar, quartz, mica, and pyroxene have been mixed with an abundance of glass shards, all apparently derived from a nearby volcanic source area.

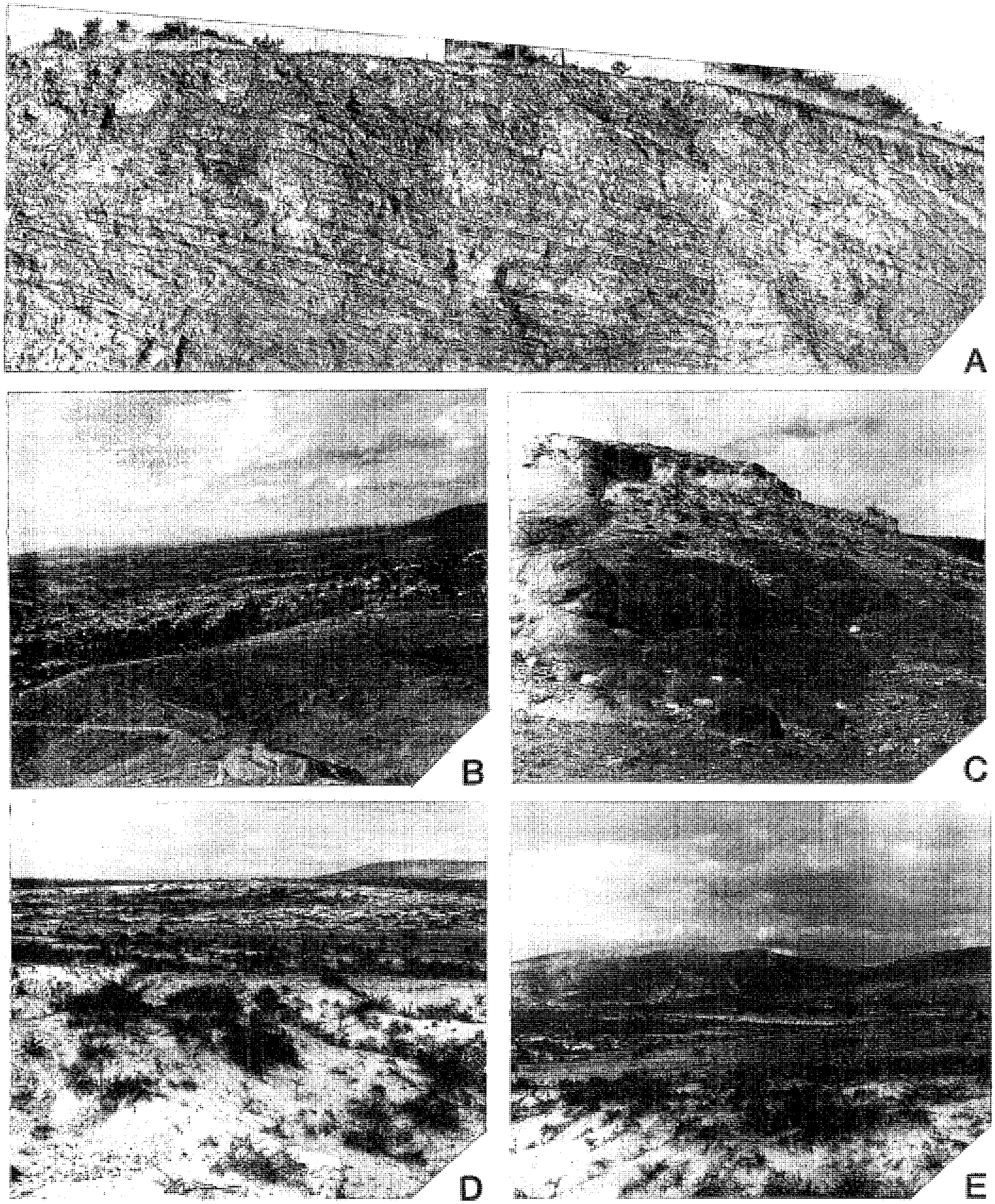
The rock was examined in the field and laboratory for both megascopic and microscopic fossils. Screens as small as 150 mesh were used in the search for microscopic fossils. The material was also processed for pollen; however, no fossils were found in spite of an exhaustive laboratory search of the rock samples. The thinly alternating, yet horizontally persistent, bedding, frequently preserving the effects of truncation and slumping, coupled with a complete lack of fossils, combine to suggest a deep marine origin for the San Miguel Allende beds. Truncation surfaces and slump structures are also common in these strata (fig. 4A). Within the San Miguel Allende beds are weakly to moderately oxidized zones of a reddish color. Small veinlets of secondary gypsum are common throughout the unit, usually following joint patterns. The beds of the San Miguel sequence are generally light brown to dark gray in color. The base of these beds is not exposed, and the frequent slump features combine to preclude reliable thickness determination. We estimate the thickness to be on the order of a few hundred meters.

An angular unconformity of up to 30° separates San Miguel Allende beds from the overlying volcanic rocks. It is presumed that the folding was the result of compression associated with the early Tertiary Hidalgo Orogeny, which formed the Sierra Madre Oriental fold and thrust belt (Ortega-Gutierrez and Guerrero-Garcia 1982, p. 103). Extensive erosion of these folded marine beds preceded the eruption of the lava flow that produced the angular unconformity.

The age of the San Miguel Allende beds is somewhat speculative. The lithologic similarity of these beds to rocks near Zacatecas, Zacatecas, that have yielded Cretaceous ammonoids (Burckhardt 1930) seems to warrant a Cretaceous age determination. At an outcrop of the San Miguel beds, 10 km south of the city of San Miguel Allende, is an exposure of deeply weathered intrusive rock that appears to be intruded into this sedimentary unit (fig. 4C). Intrusive bodies, which are probably feeder dikes for the overlying volcanics, have been noted by other authors such as Wandke and Martinez (1928, p. 11) at other localities in the general area; presumably this particular outcrop is related to them.

RANCHO VIEJO BEDS

The Late Cenozoic sedimentary and volcaniclastic deposits in the study area represent a chronologic interval from latest Miocene to earliest Pleistocene (Hemphillian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to Blancan) based on numerous mammalian fossils (Arellano 1951; Carranza 1987, 1989, 1991; Carranza and Ferrusquia 1978; Carranza and Miller 1988, 1989; Dalquest and Mooser 1980; Miller and Carranza 1982, 1984, 1989; Mooser 1957). Undoubtedly later Pleistocene and Holocene sediments are also present, but they have limited exposures, minor thicknesses, and have yielded but few fossils.

In an article by Ledezma (1951), Arellano was purported to have used the name "Nopalera" for a lower Pliocene formation of supposed lacustrine deposits in the area between and west of San Miguel Allende and Comonfort, Guanajuato. However, this formation was never formally named and described. The deposits described by Arellano (1951) may correlate with some of the Pliocene sediments described in this paper, but the latter are clearly fluvial, not lacustrine in origin. We informally name these deposits the Rancho Viejo beds for the good exposures near the village of Rancho Viejo, Guanajuato.

LOWER RANCHO VIEJO BEDS

Early Pliocene (Hemphillian) sediments have been identified at five localities, all of which are very limited in their exposures. One site is situated immediately southwest of the small village of El Ocote, Guanajuato, mentioned as fossil bearing in a report by Arellano (1951, pp. 612–13), in a ravine called Arroyo La Carreta; the second, Coecillo, occurs along an unnamed wash nearly four kilometers south of Rancho Viejo; the third, Rinconada, lies immediately east of Highway 51, about seven kilometers northwest of Rancho Viejo; the fourth, Rancho San Martin, is located 0.5 km east of the village of Rancho Viejo; and the fifth, La Presa, lies 1.5 km southeast of Rancho Viejo. Based upon mammalian fossils at all five sites, earliest Pliocene (and latest Miocene) sediments may only occur at the La Presa locality. Exposed lower Pliocene sediments show a total thickness of no more than 8 m. Lithologically, they consist of clays, sandy to silty clays with lenses of volcanic ash, as well as minor amounts of sand and gravel. These beds are weakly indurated to nonindurated and represent mostly alluvial and fluvial sediments. Commonly they are greenish to grayish in color, representing episodes of reducing conditions; however, some reddish brown sediments, usually unfossiliferous, also occur. The beds apparently were deposited as point-bar sequences consisting of cross-bedded and laminar sands and gravels within a meandering river channel, and as silts and muds deposited on adjacent floodplains. The antecedent to the Río Lajas (presently flowing south along the western border of the study area) must have been a much more voluminous river during the late Tertiary, one which shifted its meandering patterns across the graben as it deposited the sediments that constitute the Rancho Viejo beds. While much of the introduced ash shows at least some reworking, a lens of uniform white tuff at the El Ocote site, which exceeds 1 m in thickness, is interpreted as an air-fall deposit that accumulated in an oxbow lake. Fission track analysis on 30 zircon crystals from this deposit produced dates ranging from 2.0 to 45.0 Ma (Kowallis and others 1986). Either there is reworked volcanic material in the presumed air-fall accumulation, or errors have been made in the dating process. Vertebrate fossils from the deposit and equivalent adjacent beds indicate an age on the order of 4.0 to 5.5 Ma. Of the dates derived from the 30 zircon grains, several fall within this range.

UPPER RANCHO VIEJO BEDS

Middle Pliocene to earliest Pleistocene (Blancan) beds are those which are most widespread throughout the study area. Commonly their bases are not exposed; however, at the El Ocote, Coecillo, Rinconada, and Rancho San Martin sites, lowermost beds rest disconformably upon earlier Pliocene to latest Miocene (Hemphillian) deposits. The upper Rancho Viejo beds approach 100 m in total thickness. The thickest single exposure in the study area is 30 to 40 m at Arroyo El Tanque (fig. 5A–F). These deposits, like those of the earlier Pliocene, consist of sandy and silty clays, some lenses of reworked volcanic ash, sands, and some thin gravel layers. Slight differences

FIGURE 4.—*Photographs depicting geological features in the report area: (A) composite photo showing turbidite couplets of the Cretaceous San Miguel Allende beds located immediately southeast of San Miguel de Allende; (B) view looking north across the city of San Miguel Allende showing graben in which much of the present study has been made; (C) deeply weathered intrusive rock cutting into the San Miguel Allende beds—located about 10 km south of the city of San Miguel Allende; (D) view looking northeast across graben floor showing typical late Cenozoic sediments—hill in distance just south of El Ocote; and (E) graben floor in foreground and upthrown Cerros de Rancho Viejo (Rancho Viejo Hills) to the east showing the Cretaceous San Miguel Allende beds in their lower half and mid- to late Cenozoic volcanic rocks above.*

between these and the lower Pliocene deposits consist of more tan, yellow brown, and gray colors with a higher calcium carbonate content. Also, the upper beds show relatively more sand and less volcanic ash than the lower beds. Like the older Pliocene sediments beneath, these beds mostly typify fluvial deposition. Abundant point-bar deposits display both horizontal and vertical sequences in cyclic thicknesses of from less than a meter to 10 m. Basal gravels, cross-bedded sands, and laminar sands are overlain by silt and clay-mud accumulations containing abundant calcareous concretions and root traces. Sand and clay material, representing abandoned channel deposits, and volcanic ash from air falls are present throughout. Vertebrate fossils are much more common in the finer floodplain deposits of the ancient river system. This is also true for earlier Pliocene deposits. Fossil bones contained in the floodplain sediments are rarely found in articulation, but do not typically exhibit significant erosion. This implies some, but not extensive, postmortem transportation.

As shown by 18 years of collecting, early to late Pliocene deposits are much more fossiliferous than those of the Pleistocene and Holocene. Late Pleistocene deposits, if properly identified, show a distinct color difference. Where observed, they mostly appear brown to dark brown, even brownish black. Also, included rock clasts are commonly composed of olivine basalt and tend to be subangular. This differs from the earlier-named Plio-Pleistocene Rancho Viejo beds, which are always lighter in color and have well-rounded clasts, usually andesitic in composition. Northwest- and northeast-oriented fracture patterns cut all exposed Hemphillian and Blancan sediments to some degree but are especially numerous in the El Ocote area. They were not, however, seen to intersect any younger deposits. These fractures vary in width from about 0.5 cm to 5.0 cm and are sediment filled.

QUATERNARY DEPOSITS

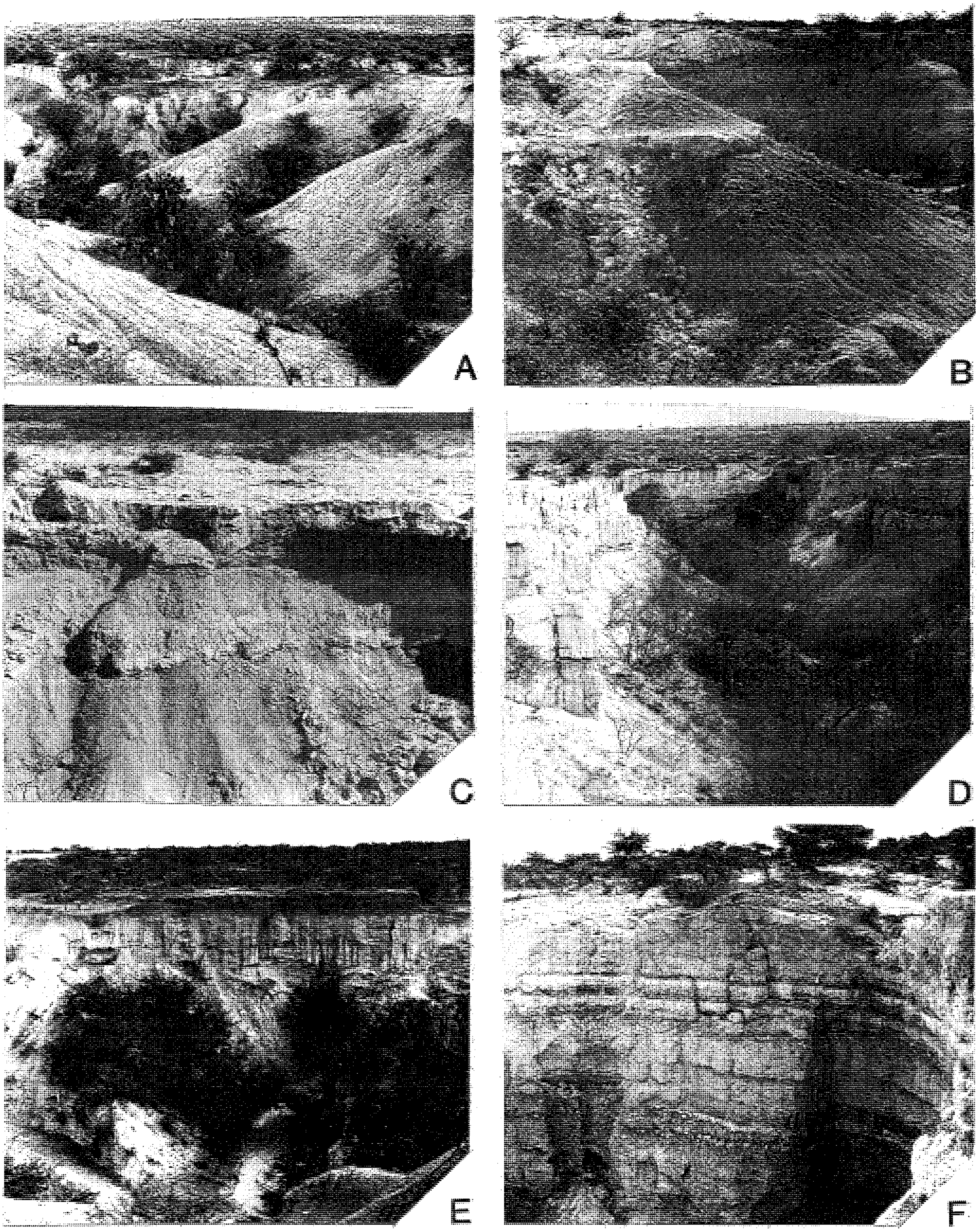
A substantial amount of the study area is covered by unconsolidated and poorly consolidated Quaternary deposits. For purposes of mapping, these have been divided into older undifferentiated deposits and younger Quaternary alluvium. The former consist mostly of reworked volcanic clasts (cobble to clay size), but include tufa and sinter deposits. Reworked volcanics can be found as angular, nonsorted aggregates containing a high percentage of large clasts (e.g., the area around the village of Presa de Allende) to fine-grained, well-sorted, even beds (e.g., roadcuts in the hills immediately west of the city of San Miguel Allende). Stream channel deposits can occasionally be seen cutting these poorly to sometimes moderately indurated beds. Commonly rounded volcanic clasts are included in these. Active spring systems have produced both calcareous deposits (e.g., the area immediately south of San Miguel Allende) and siliceous deposits, sometimes as opal (e.g., the area in the vicinity of the village of Santuario). It is assumed that the calcareous spring deposits resulted from percolating groundwaters dissolving calcium carbonate from the Cretaceous San Miguel Allende beds, precipitating this compound when solutions became saturated. Similarly, groundwaters dissolved silica from volcanic rocks and sediments in the areas of hot springs where deposits of opal can now be found. Quaternary alluvium is mostly confined to present stream channels, but may occur elsewhere.

Because much of the mapped area has a vegetative cover, both natural and cultivated, it was not always possible to determine exact mapped contacts between the two above-mentioned units. Many are approximated. Also, without careful examination the undifferentiated Quaternary deposits are very difficult to distinguish from some of the underlying Rancho Viejo beds.

VOLCANIC ROCKS

Volcanic rocks form extensive cappings on the upthrown fault blocks (horsts) adjacent to major valleys throughout the entire region. In addition, some volcanic masses occur beneath valley fill as evidenced by their presence where erosion has exposed them and in railroad cuts. Almost all large clasts contained in the late Cenozoic sedimentary deposits discussed above are volcanic in nature. Although there appears from field inspection to be wide variation in the types of volcanic rocks in the area, petrographic analysis indicates a pervasive abundance of pyroxene andesite with much lesser amounts of rhyolite and basalt (usually olivine basalt), along with previously mentioned volcanic ash in the sedimentary deposits. In every instance where field relations bear on this matter, the basalt lies on top of the andesite and rhyolite. Where observable, all volcanic rock surfaces show angles of inclination of less than 6°; probably no more than the original erosional slope upon which they were deposited. As seen

FIGURE 5.—*Photographs of fossil-bearing late Cenozoic strata (Rancho Viejo beds) exposed within the study area, A-F.*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in the hills to the northeast of the study area (Cerros de Rancho Viejo), this inclination is to the east.

One sample of pyroxene andesite was collected near the base of the oldest observable flow in the area immediately north of the village of Palo Colorado, Guanajuato. The results of a potassium-argon analysis yielded an age of 30.5 ± 1.2 Ma. This places the onset of volcanism sometime in the early Oligocene since a K/Ar date on the volcanic flow should be considered a minimum age for the flow. Two additional samples of andesite were dated by potassium-argon methods from a volcanic outcrop of moderate size exposed within the graben, nearly two kilometers due west of the village of Palo Colorado. The samples were collected approximately 100 m west of the north–south-trending railroad track. Results indicated ages of 12.5 ± 0.9 and 10.7 ± 0.7 Ma, suggesting a history of volcanism in this vicinity lasting at least 20 million years.

Immediately north of the study area is the Trans-Mexico volcanic province, which has been the site of intense volcanism from Oligocene through Holocene time. It represents the probable source area for the pervasive extrusive rocks (Luhr and others 1985). This chronologic span is reflected in part by fission track dating of zircon crystals contained in ashes intercalated within valley fill sediments. Results obtained from 65 crystals collected at three stratigraphic intervals indicate a range in dates of 2 to 45 Ma (Kowallis and others 1986). Although no observed field relationships show basalt flows on top of Late Cenozoic sediments, clasts of this rock type are common in presumed Late Pleistocene deposits but rarely occur in older ones. This helps indicate that more recent volcanic events involve mostly basic flow activity.

The thickness of andesite, capping fault blocks in the area of this study, reaches a maximum in excess of 100 m. The overlying basalts are not as extensive. Erosion has significantly reduced original thicknesses of volcanics as seen by much thicker basalts in surrounding areas. Local outcrops of acidic volcanic rocks as well as basalts are found within the valley wherein they are surrounded by Pliocene and Pleistocene sediments. We interpret this to indicate the presence of a volcanic surface of moderate relief subsequently buried by deposits of younger alluvial material, leaving occasional volcanic outcrops protruding to the present-day surface. Very few sites in the study area allow examination of the nonconformable contact between the Rancho Viejo beds and the underlying volcanics. Surfaces of the latter show surprisingly little weathering. Whether very little time elapsed between cooling of the lava and subsequent alluvial deposition, or whether much of the rhyolitic surface was eroded clean prior to this deposition has not been determined.

STRUCTURE

Broad folds resulting from the compressive Hidalgo Orogeny have deformed all Mesozoic strata. Slump features further complicate the structure on a local scale within the marine Mesozoic units. Cenozoic units are characteristically near horizontal.

An essentially north–south-trending normal fault system bounds the valley (fig. 2). Displacements, which decrease southward, are minimally 200 m. A cross fault system, consisting of east–west normal faults, transects the graben system at fairly regular intervals of a few kilometers. Smaller, more closely spaced faults can be observed in recent roadcuts through hills immediately west and northwest of the city of San Miguel Allende, where minor displacements along them of 0.5 m to more than 2.0 m attest to continuing tensional forces existing in the general region probably to the present. The local topographic relief, due mainly to the primary faulting, approximates 300 m. The major border fault systems are recognizable by their prominent fault line scarps, brecciation, and shearing of the resistant rocks in the area. The cross faults are best observed in the near-vertical displacement of blocks along the uplifted borderlands. Several minor tension faults have produced small grabens within the main valley. These fractures are apparently a part of the cross faulting mentioned above. The small grabens have been filled by Pleistocene sediment in most cases. The minor structures have displacements of a few meters and generally trend parallel to the main faults. Since basaltic clasts have only been observed in Pleistocene deposits, and yet their dated ages exceed 10 Ma, it appears probable that the basalt-capped fault blocks that border the study area were rejuvenated during the Pleistocene, providing a local source for basaltic sediments.

Small to modest-size slump blocks occur at several localities. South of Arroyo La Carreta slump blocks tilt to the north from 8°–10°. Slump blocks have also been observed within the Los Galvanes and El Ocote areas and in Arroyo El Tanque. In each case the slump angles are about 8°. These slumps appear to have occurred before the sediments were lithified.

Tufa deposits, sometimes containing opaline siliceous material, are abundant along the border faults on either side of the valley. The village of Palo Colorado, for example, is situated upon a large such tufa deposit. Calcareous- and siliceous-bearing thermal springs are present within the valley, presumably localized by the cross faults.

SUMMARY

The deposition of a turbidite sequence (San Miguel beds) during the Cretaceous period records the final marine inundation of this area. Slumping within this sequence occurred contemporaneous with deposition, reflecting gravity deformation on a sloping depositional surface. Uplift and folding of the San Miguel and earlier beds was a consequence of the early Tertiary Hidalgo Orogeny. Erosional beveling of the folded San Miguel beds are a consequence of this orogenic activity. Volcanic eruptions during the Oligocene and Miocene produced mostly pyroxene andesites with accompanying basalts, rhyolites, and ash flow tuffs. Tensional, pre-Pliocene faulting produced the main north–south-trending graben. During late Miocene to early Pleistocene, Rancho Viejo fluvial and alluvial sediments were deposited. Vertebrate remains of an important mammalian fauna were preserved by flood deposits along the meandering rivers and by occasional volcanic ash falls.

Rejuvenation of stress forces in the region produced small grabens within the major-fault–bounded valley. Rejuvenated faulting of volcanic-capped borderlands provided local volcanic sediment to the sediment-filled graben. Fracture patterns in earliest Pleistocene and older Rancho Viejo sediments occurred as a result of renewed tectonic activity. Resultant uplifted borderlands most recently shed olivine basalt clasts into accumulating late Pleistocene and Holocene sediments.

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