Neogene Stratigraphy and Paleontology of Southern Almería Province, Spain: An Overview

GEOLOGICAL SURVEY BULLETIN 1454

Prepared in cooperation with the Empresa Nacional ADARO de Investigaciones Mineras, S.A., sponsored by the National Science Foundation, and conducted under the Agreement of Friendship and Cooperation between the Governments of Spain and the United States

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By WARREN O. ADDICOTT, PARKE D. SNAVELY, JR., DAVID BUKRY, *and* RICHARD Z. POORE

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NEOGENE STRATIGRAPHY AND PALEONTOLOGY OF SOUTHERN ALMERIA PROVINCE, SPAIN: AN OVERVIEW

By WARREN O. ADDICOTT, PARKE D. SNAVELY, JR., DAVID BUKRY, and RICHARD Z. POORE

ABSTRACT

The Neogene sequence of the coastal part of Almería Province, southeastern Spain, consists of carbonate and clastic rocks generally representative of deposition in the neritic zone. Rocks exposed in the Campo de Nijar and Campo de Dalias, broad lowlands bordered on the north by the Betic Cordilleras, are parts of the Almería Basin, a post-orogenic basin of late Neogene age. The late Miocene sequence is characterized by carbonate rocks that commonly contain lithic fragments from middle(?) Miocene volcanic rocks of the Cabo de Gata Volcanic Complex and from pre-Tertiary dolomite and schist of the Nevado-Filabride and Alpujarride Complexes. A late Miocene coral reef and associated forereef facies crop out in a narrow belt along the seaward margin of the Sierra de Gata. A 20-m to 30-m bed of gypsum occurring in the late Miocene Nijar formation associated with foraminifers of the *Globorotalia conomiozea* Zone probably represents the Messinian salinity crisis. Late Miocene (late Tortonian and Messinian) basinal facies are represented by microfossil rich siltstones and turbidite sandstones of the Nijar formation. Basin margin facies of late Miocene age are represented by bioclastic limestone of the Vicar Formation. The base of the Pliocene sequence is marked by a regional unconformity. Generally the lowest part of the Pliocene consists of massive, very fine grained silty sandstone containing abundant *Amusium cristatum* and overlying bioclastic calcarenite, sandstone, or conglomerate nearshore facies. Locally, the megafossil-bearing sandstones and conglomerates directly overlie Miocene and older units. Informal formational names are utilized herein to facilitate discussion of Neogene units in the Campo de Nijar and Campo de Dalias areas.

INTRODUCTION

A late Miocene to late Pliocene carbonate and clastic sequence overlies Paleozoic(?) schistose rock, Triassic dolomite, and middle(?) Miocene volcanic rock in southern Almería Province, southeastern Spain. The Almería Basin, bordered on the north by the Sierra de Gádor and Sierra de Alhamilla, is one of several postorogenic basins of late Neogene age that occur in the northeast-trending Betic Cordilleras of southern Spain. These basins define the Betic Straits (Fernex and others, 1967), a seaway that united the Mediterranean Sea with the Atlantic Ocean during much of the Neogene.

The stratigraphy and paleontology of the Neogene strata of the Almería Basin, briefly described in this report, are based upon reconnaissance studies in the Campo de Dalias and the Campo de Nijar (fig. 1). This work was undertaken to complement concurrent marine geophysical profiling in the adjacent Golfo de Almería and nearby parts of the continental shelf by a team of U.S. Geological Survey and Empresa Nacional ADARO geoscientists (Dillon and others, 1975; Lucena and Greene, 1975), primarily to provide a stratigraphic framework for interpretation and evaluation of offshore acoustical units.

Formations constituting the predominately carbonate sequence of late Neogene age of southern Almería Province were deposited under various depositional environments in areas that now flank the Golfo de Almería in the western part of the Mediterranean Sea. A regional unconformity separates carbonate strata from the older basement rocks; another occurs between the deep-water late Miocene micrites and the shallow-water late Miocene to Pliocene bioclastic limestone, calcarenite, sandstone, and conglomerate. The Mediterranean evaporite sequence (gypsum) of latest Miocene, Messinian age occurs within the deep-water biogenic micrite that contains interbeds of turbidite sandstone. A previously unrecognized late Miocene coral reef complex that overlies volcanic rocks of Miocene age along the southeastern coast in the Sierra de Gata adds a new dimension to the geologic history of the area.

FIELD INVESTIGATION AND ACKNOWLEDGMENT

Geologic data briefly described in this report were collected during March and April 1974 and April 1976 as part of a U.S. Geological Survey-Empresa Nacional ADARO de Investigaciones Mineras, S. A. cooperative study of the coastal zone and continental shelf of Almería Province, southeastern Spain. This program was sponsored by the National Science Foundation and conducted under the Agreement of Friendship and Cooperation between the Governments of Spain and the United States. Field investigations by Snavely and Addicott were of a reconnaissance nature and did not involve detailed geologic mapping or systematic stratigraphic studies. Relatively detailed geologic observations and collections of mollusk and microfossil samples (Addicott and Snavely, 1976) were made in numerous well-exposed areas throughout the region, using the geologic mapping of earlier workers (Aldaya and Garcia Dueñas, 1971; Fúster Casas and others, 1965, 1967; Sánchez Cela, 1968; unpublished ADARO maps). The stratigraphic studies of Snavely and Addicott were greatly enhanced by subsequent field conferences and discussions with Gabriel Martín Zuñiga and Manuel Ruiz Tagle as well as consultation with Enrico Perconig, all of ADARO. We are indebted to Perconig for his critical

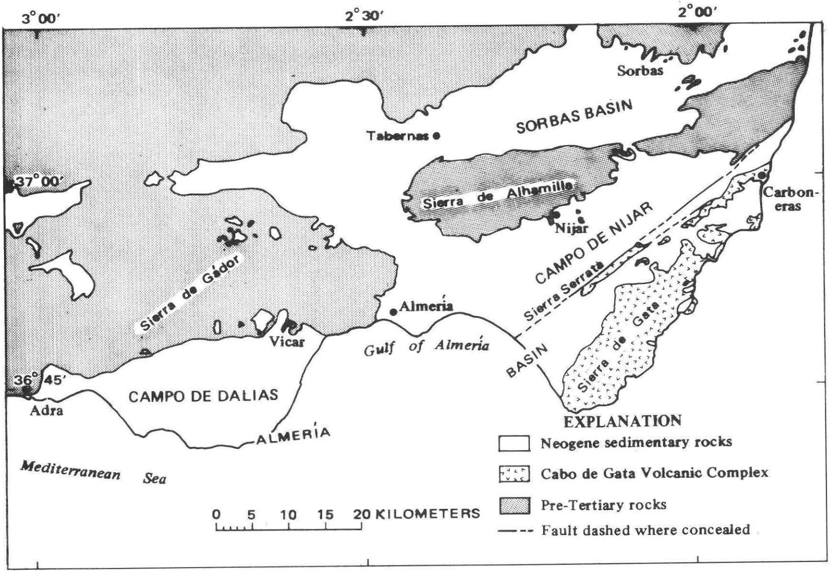

FIGURE 1.—Index map of southern Almería Province, Spain, showing general distribution of Neogene sedimentary rocks and older basement rocks. Geology generalized from Aldaya and Garcia Dueñas (1971).

review of an earlier manuscript. We gratefully acknowledge the petrographic studies of some of the carbonate rocks by Alan Niem, U.S. Geological Survey, and paleontologic determinations by our Survey colleagues, J. A. Barron, J. E. Hazel, and R. C. Margerum, and by J. Wyatt Durham, of the University of California, and J. W. Wells, of Cornell University. A. K. Armstrong and J. M. Robb, also of the U.S. Geological Survey, assisted in measuring stratigraphic sections and collecting samples. Dianne L. Lander helped with the preparation of illustrations. We also wish to acknowledge the friendly assistance and cooperation received from our Spanish friends and associates during this work.

In this report several Neogene lithologic units of formation and member rank are given new informal stratigraphic names. The rank term of these binomial names is not capitalized in accordance with Article 1.7 of the International Guide to Stratigraphic Classification (International Subcommission on Stratigraphic Classification, 1972) to reflect its informal usage as compared with formal stratigraphic names used herein. Comparison of our terminology with that in common use by Spanish geologists is shown in figures 2 and 3. Despite the reconnaissance nature of this study, new and significant data were collected that bear on the depositional history and paleoenvironment of the late Tertiary in southeastern Spain and the western Mediterranean. Detailed geologic mapping and systematic stratigraphic studies are needed before the relation between the tectonic and stratigraphic evolution can be more clearly defined.

STRATIGRAPHY

The late Tertiary sedimentary sequence in southern Almería Province consists of a variety of carbonate and clastic rocks that were deposited in both deep- and shallow-water marine environments. The Miocene sequence is characterized by carbonates, whereas the Pliocene formations consist of both carbonate and terrigenous clastics. The carbonates include marl, biomicrite, bioclastic limestone, and biosparite. They commonly contain minor amounts of lithic fragments derived from the middle(?) Miocene volcanic rocks and from Triassic dolomite and Paleozoic(?) schist of the Nevado-Filabride and Alpujarride Complexes (Garcia Monzón, Kampschuur, and Verburg, 1975). A late Miocene coral-reef limestone and associated forereef facies crops out in a narrow belt along the southeast coast (Snavely and Addicott, 1974). Several regional unconformities occur within this late Neogene sequence; the most significant are at the

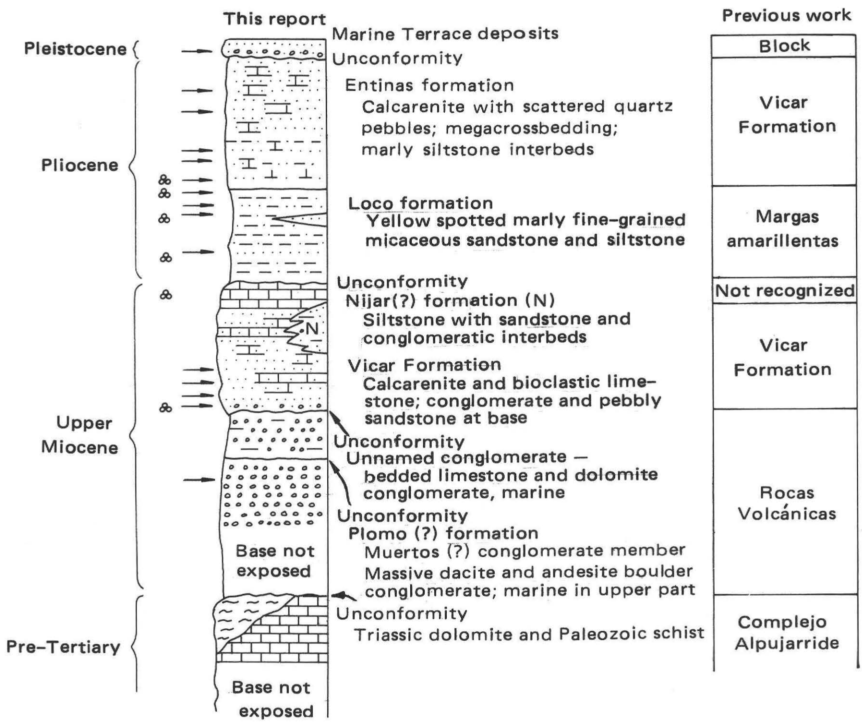

FIGURE 2.—Generalized stratigraphic surface section in the Campo de Dalias and correlation of stratigraphic names used in this report with those of earlier workers. →, macrofossil sample, ஃ planktonic foraminifer sample.

base of the late Miocene Vicar Formation and at the base of the Pliocene sequence. A 20-m to 30-m-thick bed of coarsely crystalline selenite gypsum that occurs locally within the deep-water late Miocene Nijar formation probably represents the so-called Messinian salinity crisis (see Nesteroff and others, 1972; Kidd, 1976). Pliocene clastics include sandstone, conglomerate, siltstone, and calcarenite. The coarser grained units generally overlie very fine grained silty sandstones but locally rest unconformably on Miocene and older units. A sequence of Pleistocene marine terraces is locally developed in Pliocene terrane east of Almería and in the western part of the Campo de Dalias (Ovejero and Zazo, 1971).

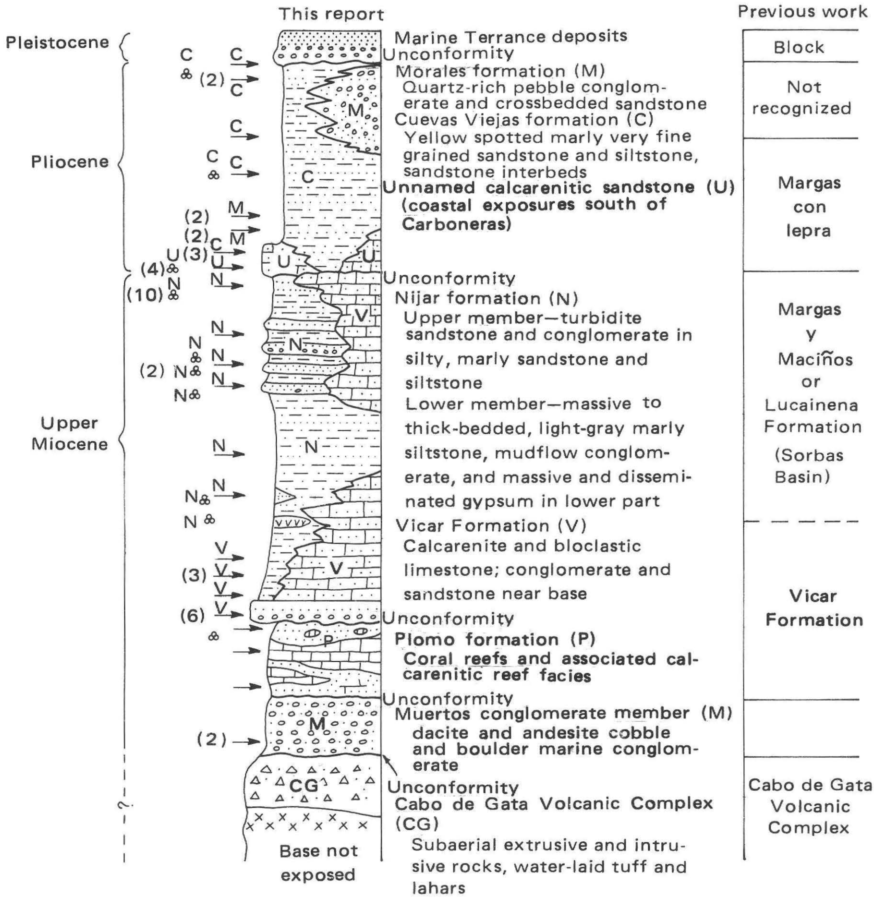

FIGURE 3.—Generalized stratigraphic surface section in the Campo de Nijar and correlation of stratigraphic names used in this report with those of earlier workers. →, macrofossil sample; ꕥ, planktonic foraminifer sample; 10, number of samples from a given stratigraphic level.

PLOMO FORMATION

The oldest Tertiary unit exposed in southern Almería Province is a coral reef and associated forereef facies that crops out in places along the coast from Rambla del Plomo northward to a point 1.4 km north of Punta de los Muertos (fig. 4). This previously unrecognized reef complex (Snavely and Addicott, 1974) overlies the Cabo de Gata Volcanic Complex (Coello and Castañon, 1965; Páez Carrión and Sánchez Soria, 1965; Fúster Casas and others, 1965, 1967; León, 1967; Sánchez Cela, 1968) but is separated from the volcanic breccias, lahars, and water-laid lapilli tuff by a marine conglomerate composed of volcanic boulders here named the Muertos conglomerate member.

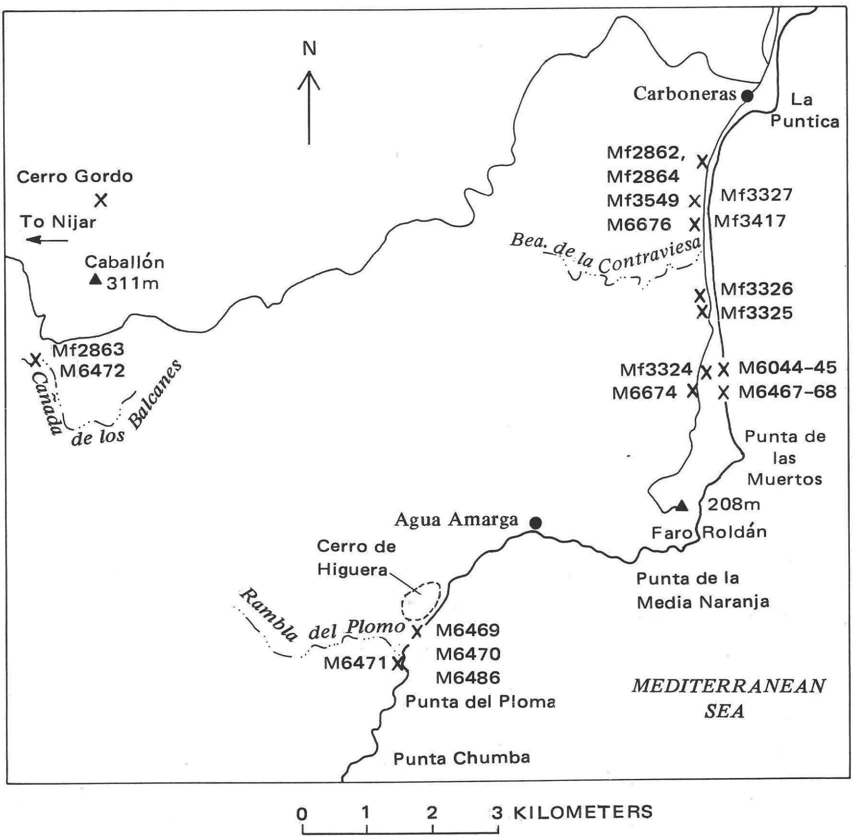

FIGURE 4.—Index map showing Miocene and Pliocene fossil localities along the coast between Carboneras and Rambla del Plomo and along Cañada de los Balcanes, to the west. M, USGS megafossil locaility; Mf, USGS microfossil locaility.

MUERTOS CONGLOMERATE MEMBER

A marine conglomerate composed largely of dacite and andesite boulders, here informally named the Muertos conglomerate member, it typically exposed at the north end of the beach 1.4 km north of Punta de los Muertos (fig. 4). In this area the conglomerate is about 15 m thick. Boulders as much as 2 m in diameter occur in a calcarenitic matrix containing locally abundant pectinids, ostreids, and other bivalve mollusks (loc. M6467). The Muertos overlies a 100-m-thick section of crudely bedded volcanic breccia and conglomerate of the Cabo de Gata Volcanic Complex that Fúster Casas, Ibarrola, and Martín (1967) determined to be of pyroxenitic andesitic composition. The Muertos is overlain by patch reefs and forereef talus characteristic of the Plomo formation. The Muertos probably is equivalent to Sánchez Cela's (1968) Nivel A unit exposed near El Playazo, on the coast about 14 km to the southwest.

In the Campo de Dalias, about 65 km to the west, more than 40 m of marine boulder conglomerate referable to the Muertos conglomerate member is exposed in a gently northward-dipping section at the southwest end of Loma de la Ecarada almost 2 km southwest of Vicar (fig. 1). The indurated and thick-bedded conglomerate is composed of well-rounded dacite and andesite clasts in a calcarenitic matrix that contains local accumulations of mollusk shells and fine shell debris in the uppermost 5 m. These assemblages and barnacle and pectinid fossils, exposed at a sharp bend in the Vicar Road about 40 m below the summit, indicate that the uppermost 40 to 50 m of this unit is of marine origin.

UNNAMED CONGLOMERATE

Unconformably overlying the Muertos on the north side of Loma de la Ecarada near the summit of the Vicar Road is a medium-bedded poorly consolidated conglomerate composed mainly of limestone and dolomite clasts. The imbrication of the flattened pebbles and cobbles of pre-Tertiary carbonates along the Vicar Road suggests northward-flowing currents during deposition. The occurrence of in situ oyster valves on some of the cobbles in this conglomerate indicates a shallow marine origin. This conglomerate is not known to occur elsewhere in the Campo de Dalias or in the Campo de Nijar area to the east.

The Plomo formation is unconformably overlain in most places by the upper Miocene Vicar Formation, which locally overlaps the Plomo and rests on the volcanic rocks. At the north end of Punta de los Muertos, (fig. 4), however, it is overlain by massive calcarenites of Pliocene age. The Plomo is characterized by massive coral reefs composed mainly of an erect, branching species of *Porites* whose "pipe organ" growth form provides a rigid structural framework. According to J. W. Wells (written commun., Nov. 1977), this may be the branching species *P. lobosepta* Chevalier. Within the *Porites* framework are scattered heads of the scleractinian coral *Tarbellastraea* and lenses (as much as 3–4 m thick) of calcareous sandstone and marl that contain abundant shallow-water mollusks, notably *Isognomon*, *Crassostrea*, and *Turritella*. Red coralline algae and *Halimeda* plates are important constituents of the reef. A complex interfingering of calcareous sandstone and marl and reef-derived talus, about 45 m thick, probably represents a forereef facies where active erosion attacked the main reef. The reef cores and reef breccia are composed of calcitic dolomite and are characterized by highly developed moldic and intercrystalline porosity (Armstrong and others, 1977). Approximately 20–30 m of the reef complex is well exposed in the sea cliffs at Cerro de Higuera just north of Rambla del Plomo (fig. 5); a generalized stratigraphic section in this area is shown as figure 6. Locally, bul-

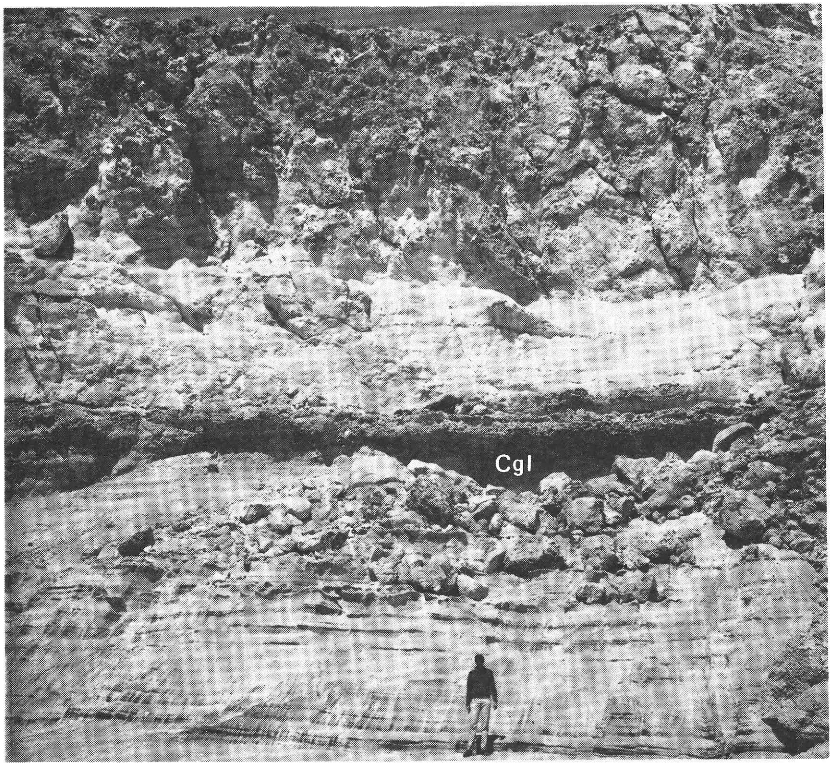

FIGURE 5.—Plomo formation, a reef complex, exposed in sea cliff at Cerro de Higuera about 0.4 km north of Rambla del Plomo. Base of formation is at break in slope and marked by base of a 1-m-thick marine conglomerate (Cgl). Thin-bedded unit below Plomo consists of water-laid tuffaceous sandstone.

bous projections of the reef extend several meters upward into overlying dolomitic limestone of the Vicar Formation.

AGE AND CORRELATION

Mollusks from the Muertos conglomerate member of the Plomo formation seem to be of late Miocene (Tortonian) age and are indicative of a very shallow water, fully marine environment. Collections from the southwest end of Loma de la Ecarada near the village of Vicar (loc. M6032, M6669), Playa del Plomo (M6470), and Playa de los Muertos (M6467) contain pectinids (*Chlamys* cf. *C. macrotis* (Sowerby), *C. fasciculata* Millet, *C. varia* (Linne)), cardiids, venerids, gastropods (*Turritella catedralis* Brogniart var., *T. subangulata* (Brocchi)), and scleractinian corals. Unspecified microfossils from exposures of this conglomerate (Nivel A) in the central part of the Cabo de Gata Range were determined by Saavedra (in Sánchez Cela, 1968) to be of middle or late Miocene, Helvetian-Tortonian, age.

A 30-m-thick section of marine conglomerate south of Vicar that is referable to the "unnamed conglomerate" of this report is overlain by some 60 m of limestone containing planktonic foraminifers referable to the upper part of the Tortonian Stage (Perconig, 1976). Scattered planktonics recorded by Perconig from the conglomerates are compatible with a late Miocene (Tortonian) age.

Mollusks from the localities in the overlying reefal facies of the Plomo shown in figure 4 (USGS M6045 and M6469) are indicative of a late Miocene age and suggest correlation with faunas of the Torto-

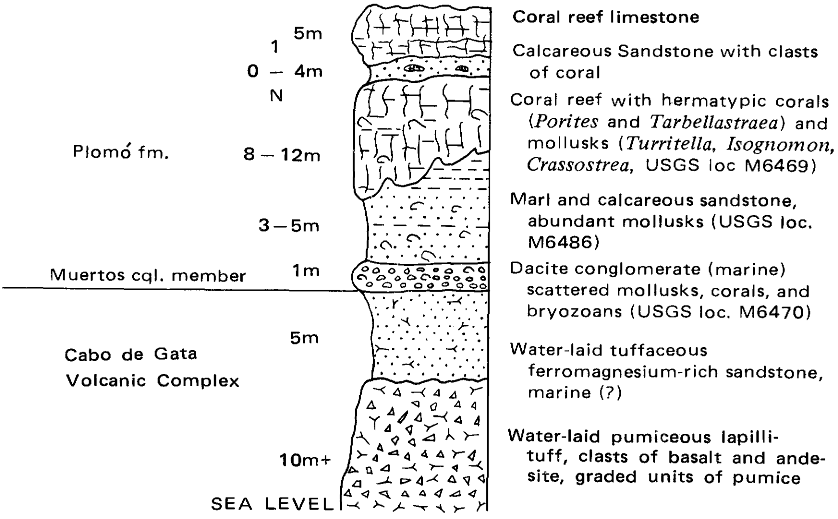

FIGURE 6.—Generalized section of the reef complex in the Plomo formation. Cerro de Higuera, just north of Rambla del Plomo.

nian Stage. Assignment to the Tortonian is indicated by the concurrent range of *Chlamys fasciculata* (Millet), *Clausinella scalaris* (Bronn), and *Turritella vermicularis doublieri* Matheron. Additionally, *Turritella triplicata superneaplicata* Sacco seems to be restricted to the Tortonian Stage.

Specimens of the coral heads that occur within the *Porites* colonies were studied by John W. Wells, of Cornell University, who concluded: "The coral specimens (M6469) from the Plomo formation all pertain to the same species, which I identify as *Tarbellastraea eggenburgensis andalousianensis* Chevalier (1961). According to Chevalier, this variety is characteristic of the late Miocene (Helvetian and Tortonian)." A pre-Pliocene age is further indicated by the fact that reef corals such as *Porites* and *Tarbellastraea* disappeared from the Mediterranean by the close of the Miocene (Vaughan and Wells, 1943). These hermatypic corals point to a tropical or subtropical marine climate during deposition of the Plomo and to an extremely shallow water depositional environment. The molluscan assemblages also suggest a very shallow water, inner sublittoral environment.

Planktonic foraminifers from the Plomo limestones are extremely rare and poorly preserved. Perconig (1976, p. 175) indicates a late Miocene Tortonian and Andalusian age for macroinvertebrate-bearing limestone in the Sierra de Gata that he correlates with rocks that form the type section of the Vicar Formation in the Campo de Dalias. This correlation was based on microfaunal samples collected from strata intercalated in the reefal rocks in the lowest 25 m of the Plomo formation near Rambla del Plomo (Enrico Perconig, written commun., March 1977).

The Plomo formation overlies the Cabo de Gata Volcanic Complex to which earlier workers (Fúster Casas and others, 1965, 1967; Páez Carrión and Sánchez Soria, 1965; Sánchez Cela, 1968) have assigned an early to late Miocene age on the basis of unpublished microfaunal determinations by J. L. Saavedra. A K/Ar isotope age of 11.5 ± 0.4 m.y. (G. B. Dalrymple, written commun., 1975) has been determined on hornblende from a thick flow or sill that crops out along the coast at Cortijo la Isleta about 17 km northeast of Cabo de Gata. According to the work of Fúster Casas, Aguilar, and Garcia (1965), this sample is from an andesitic series in the oldest of the three post-"aglomerados viejos" episodes of volcanism in the Sierra de Gata. The radiometric age is substantially younger than their originally postulated early or middle Miocene age based on Saavedra's microfaunal determinations. If this isotope age is representative of the age of the Cabo de Gata Volcanic Complex, the Plomo can be no older than about 11.5 m.y. or latest middle Miocene (Serravallian) or earliest late Miocene (Tortonian), depending on the age of the middle Miocene–late Miocene boundary. Berggren and Van Couvering (1975) place this boundary at about 11 m.y.; Ryan, Cita, Dreyfus Rawson, Burckle, and Saito (1974) and Vass (1975) put the boundary at about 12 m.y.

Presumably coeval reefal facies have been reported from Neogene basins north of the Sierra de Gata. Late Miocene reefal limestones aggregating as much as 60 m have been recognized along the northern margin of the Sorbas Basin (Garcia Monzón, Kampschuur, Vissers, Verburg, and Wolff 1975). The reefal limestones pass laterally into marls that are locally overlain by gypsum that seems to be of latest Miocene, Andalusian age (Perconig and Martinez in Garcia Monzón, Kampschuur, and Verburg, 1975). In the Vera Basin, about 40 km north of the Plomo reef, Volk and Rondeel (1964) describe local coral and algal reefs in the Cantera Member of their upper Miocene Turre Formation. Perconig (1973) has noted an Andalusian reefal facies trend extending northeastward through these areas toward Murcia. Recently this trend, which extends some 600 km northeastward to the island of Mallorca, has been mapped by Esteban, Calvet, Dabrio, Barón, Giner, Pomar, and Salas (1977).

NIJAR FORMATION

A moderately deep water sequence composed of biomicrites with interbedded turbidite sandstones unconformably overlies the Plomo formation and the Cabo de Gata Volcanic Complex in the eastern coastal region of Almería Province and the Paleozoic schist and Triassic limestone along the south flank of the Sierra de Alhamilla. This sequence is informally named the Nijar formation for excellent exposures on the west side of a north-trending ridge 1.5 km southeast of the village of Nijar (figs. 7 and 8). A 20-m to 30-m-thick bed of coarsely crystalline selenite gypsum occurs locally in the Nijar. It is best exposed along the southern foothills of the Sierra de Alhamilla and locally along the northern flank of the western Sierra Serrata.

The Nijar rests unconformably on pre-Tertiary rocks along the south side of Sierra de Alhamilla; it presumably unconformably overlies Miocene volcanic rocks on the flanks of Sierra Serrata and Sierra de Gata, although the basal contact of the Nijar has not been seen there. The contact between the Nijar and Triassic dolomite is well exposed in a roadcut along old Route 240, about 2 km south of Benahadux. Here a 3-m- to 5-m-thick bed of cobble and boulder conglomerate is present above the contact. Although the basal contact of the Nijar with the Cabo de Gata Volcanic complex was not found, lenses of mudflow volcanic breccia and conglomerate are interbedded in micrites in places along the northwestern side of the Sierra Serrata. These coarse clastic lenses contain shallow-water mollusks that

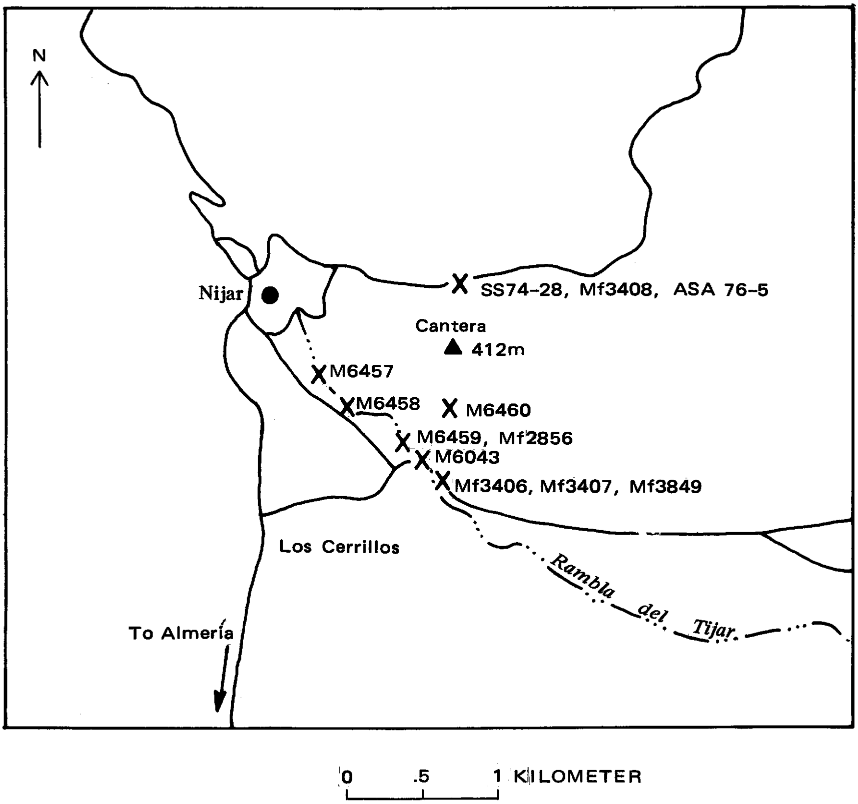

FIGURE 7.—Index map showing mollusk and microfossil localities in the Nijar formation. M, USGS mollusk locality; Mf, USGS microfossil locaility; SS and ASA, field localities.

were probably transported into the deeper water micrites by submarine mudflows.

The Nijar formation can be broadly divided into two members, a lower member consisting of light-gray microfossil-rich thin-bedded to massive micrite with thin fine-grained sandstone interbeds and an upper member characterized by massive very fine grained calcareous sandstone with interbeds of graded conglomeratic sandstone near the base.

The lower member contains abundant coccoliths (fig. 9) and foraminifers, and in places is rich in diatoms. Some molds of foraminifers are infilled with microspar calcite rhombs, celadonite, or dark opaque iron oxide and organic detritus. Small poorly developed nodules found in a few places in the micrite contain scattered silt-size monocrystalline quartz.

In the southwest part of Sierra Serrata, there are scattered expo-

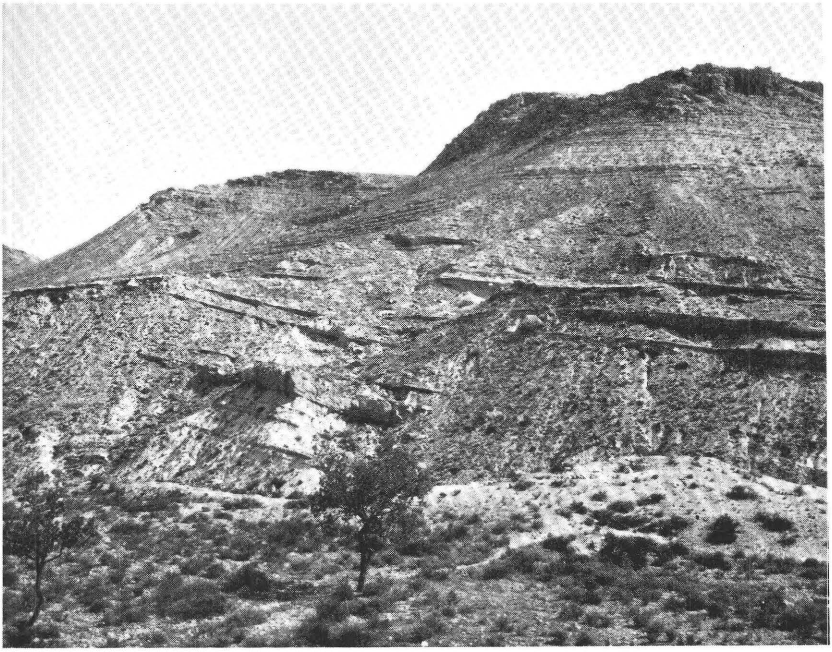

FIGURE 8.—Nijar formation exposed 1.5 km southeast of Nijar on west side of hill 392 m. Prominent ribs are conglomeratic calcarenite turbidite sandstone. Flat-lying bedded bioclastic limestone caps top of ridge.

sures of a massive bed of coarsely crystalline selenite gypsum as much as 20 m thick or mobilized products of this bed that form diapiric domes, sills, or dikes. The thin-bedded micrite and fine-grained calcareous sandstone are commonly intensely folded where intruded by gypsum, as near Cerro Blanco in the southwestern part of Sierra Serrata (fig. 10). No apparent erosional break occurs at either the lower or upper contact of the gypsum bed; this suggests that mobilization of the gypsum occurred after deposition of the overlying beds.

The upper member of the Nijar formation consists of more than 150 m of massive yellowish-brown sandy siltstone and fine-grained sandstone with interbedded conglomeratic medium- to coarse-grained calcarenite beds 1–15 m thick (fig. 11). The sandstone beds are commonly graded and have sharp irregular basal contacts, which in places contain groove casts. Abundant large mollusks, mainly shallow-water pectinids and ostreids, are concentrated in the basal part of some turbidites, as are angular to subangular clasts of pre-Tertiary basement rocks and siltstone clasts (rip-ups). The member is exposed at hill 392 m, about 1.5 km southeast of Nijar (fig. 7), where it in-

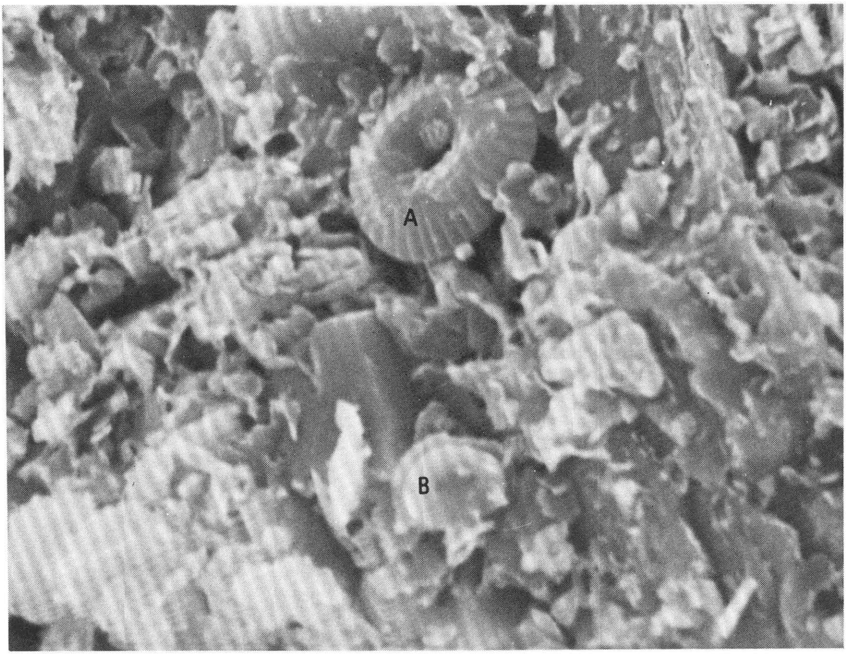

FIGURE 9.—Electron micrograph of micrite in the lower member of the Nijar formation, X4,500; coccolith A, *Coccolithus pelagicus* (Wallich); B, *Reticulofenestra* sp. cf. *R. pseudoumbilica* (Gartner).

cludes about 50 m of interbedded friable micaceous fine-grained gray sandstone and reddish-brown sandy siltstone in strata ranging in thickness from 0.5 to 2 m. The sandstone beds contain scattered rounded elongate clasts of red siltstone. No fossils were observed in this member, which may be of brackish-water or nonmarine origin, suggesting shoaling of the basin in late Nijar time.

A 1.5-m-thick turbidite bed exposed in a cut on the east side of the Nijar-Carboneras Road about 1.5 km southeast of Nijar is composed of subrounded pebbles of quartz, schist, and dolomite in a matrix of fine-grained sand. About 10 percent of the bed is made up of transported pectinid valves and large oysters. The turbidite overlies a light-yellowish-gray very fine grained sandstone. Channels in the underlying sandstone extend downward as much as 0.5 m below the base of the bed. Groove casts along the sides of some of these channels trend N. 30° E. to N. 40° E. Similar turbidites containing abundant broken shells of shallow-water mollusks occur stratigraphically higher in the upper member of the Nijar formation (fig. 11).

An isolated, 3-m- to 4-m-thick exposure of diatomaceous siltstone and claystone interbedded with silty, fine- to very fine grained sandstone in the southwestern part of the Campo de Dalias probably

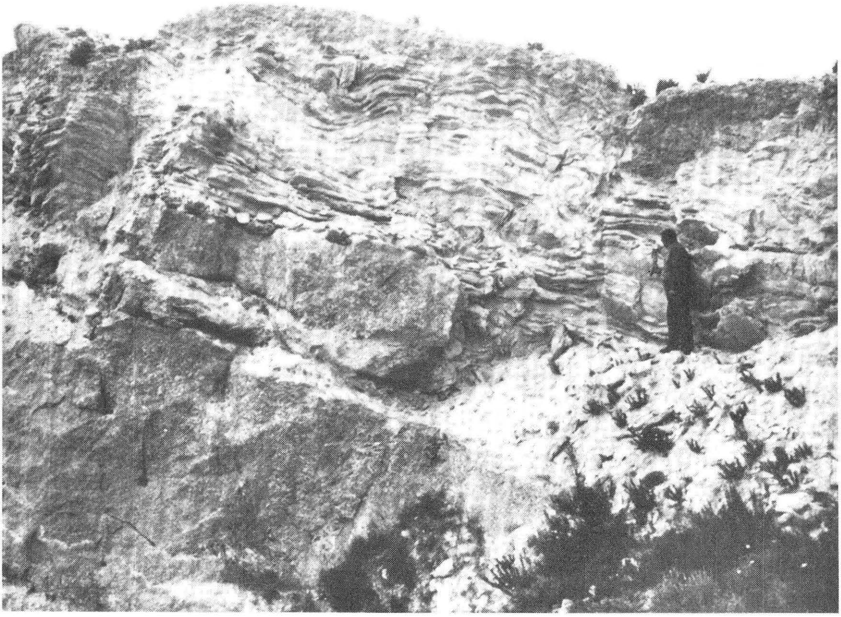

FIGURE 10.—Contact between the gypsum bed and thin-bedded micrite in the lower member of the Nijar formation, Cerró Blanco in southwestern part of Sierra Seratta. Note deformed zone within the bedded sediments produced by intrusion of gypsum sills and dikes from the underlying main bed.

represents the Nijar formation. This faulted, northward-dipping section, exposed in a small quarry about 0.5 km east of Guardias Viejas, includes a penecontemporaneously deformed zone intruded by a sandstone dike (fig. 12). A mixed foraminiferal assemblage from near the top of this section (Mf3405) is suggestive of downslope transport of shallow-water benthic species into deep water. This exposure is the only known occurrence of the Nijar formation in the southern part of the Campo de Dalias; the only Neogene units previously described from coastal exposures were of Pliocene age (Méndez Cecilia, 1971a, 1971b; Fourniguet and LeCalvez, 1975; Perconig, 1976).

AGE AND CORRELATION

A mollusk assemblage from the lower member of the Nijar formation in the Sierra Serrata (fig. 13, USGS loc. M6030) includes fragments of pectinids indicative of a late Miocene age. Specimens of *Chlamys scabrella* forma *sarmenticia* (Goldfuss), a pectinid characteristic of the upper Miocene Sahelian Stage of Morocco (Roger, 1939), are in this small float collection. Mollusks are of common occurrence in the graded conglomeratic sandstones (fig. 11) of the upper member

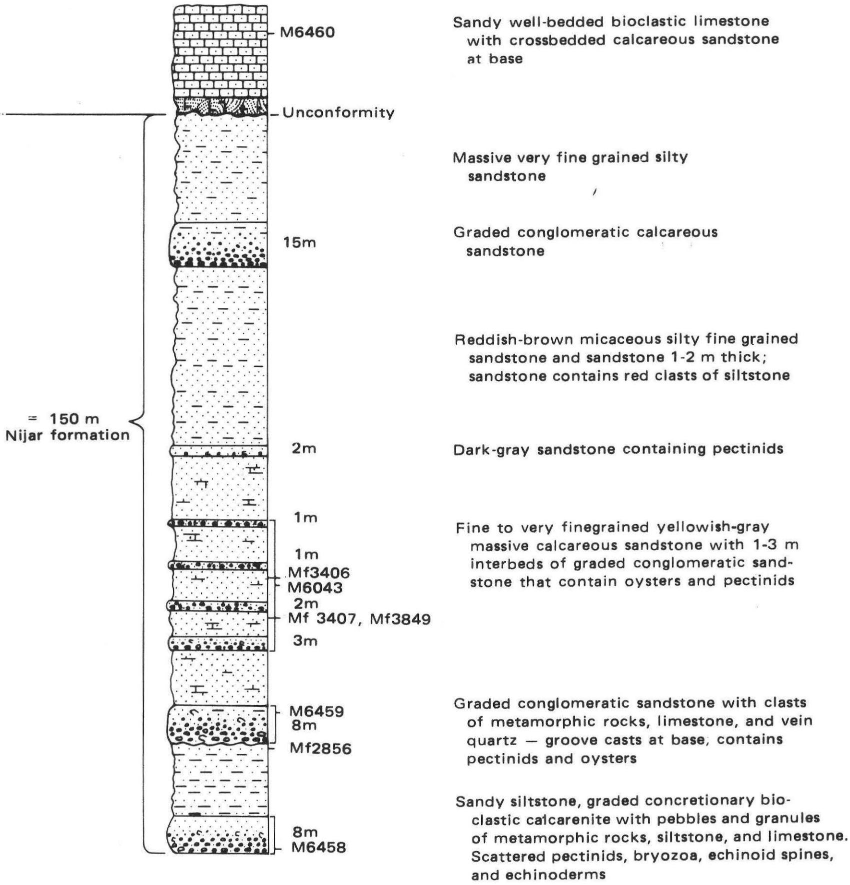

FIGURE 11.—Generalized stratigraphic section of upper Nijar formation on west side of hill 392 m, about 1.5 km southeast of Nijar. USGS fossil collections: megafossils, M prefix; microfossils, MF prefix.

of the Nijar formation in the type area. A late Miocene age is indicated by the cooccurrence of *Pecten revolutus* Michelotti, *Macrochlamis tournali* (de Serres), *Chlamys elegans* (Andrzeowski), *C. scabrella* forma *sarmenticia* (Goldfuss), and *Flabellipecten solarium* (Lamarck). None of these species is known to range into the Pliocene of the Mediterranean region. The disarticulated and abraded or broken pelecypod valves are indicative of considerable post-mortem transport and support the moderately deep-water depositional environment inferred from sedimentological and microfaunal evidence.

Planktonic foraminifers indicative of Zone N17 of Blow (1969) and the *Globorotalia dutertrei-G humerosa* zone of Bizon and Bizon (1972) are found in a number of Nijar outcrops: (1) about 12 km southwest of Carboneras near the head of Cañada de los Balcanes (fig. 4, Mf2863); (2) from strata about 1 km south of Carboneras (fig. 4, Mf2864); (3)

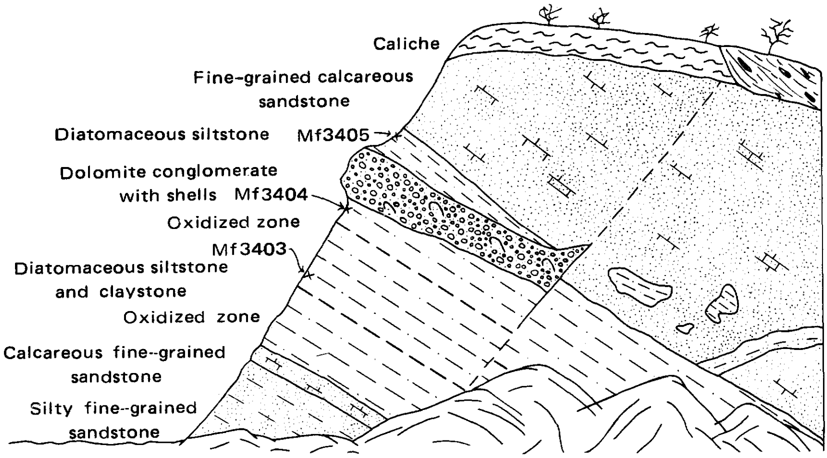

FIGURE 12.—Sketch in small quarry near Guardias Viejas showing penecontemporaneous deformation in fine-grained calcareous sandstone and diatomaceous siltstone assigned to the Nijar(?) formation. Small fault that trends N. 15 W. and dips 65° SW. offsets strata about 0.3 m. Stratigraphic position of microfossil samples indicated by Mf3403–3405. Height of quarry face approximately 3 m.

Rambla del Tejar, about 1.5 km southeast of Nijar (fig. 7, Mf2856, Mf3407, Mf3849); (4) exposures about 6 km north of Almería (fig. 14, Mf2857); (5) near Cerro Blanco and Cerro Colorado in the southwestern part of the Sierra Serrata (fig. 13, Mf2870, Mf3847); (6) about 0.5 km east of Guardias Viejas, Campo de Dalias (fig. 12, Mf3403, Mf3404, Mf3405); (7) along Route 340 about 8 km north of Almería (fig. 14, Mf3848); (8) near Cuevas de los Juanorros about 7 km north-northeast of El Alquián (fig. 22, Mf3850); and (9) on the south side of Cerro Almendral about 15 km northeast of Nijar (Mf3366, Mf3311).

Several samples from both the lower and upper members of the Nijar formation are referable to the *Globorotalia conomiozea* Zone of D'Onofrio and others (1975), which represents the upper part of Zone N17 and approximates the Messinian Stage (D'Onofrio and others, 1975; Ryan and others, 1974). A late Tortonian and Messinian age is thereby indicated for the Nijar formation.

A locality in the lower member of the Nijar formation along the Nijar-Lucainena road about 1 km east of Nijar (see fig. 7, Mf3408, SS 74-28 [=Mf4723, not plotted on fig. 7]) yielded nannofossils that could be as old as the middle Miocene *Discoaster exilis* Zone. The associated planktonic foraminifer assemblage includes *Neogloboquadrina acostaensis* (Blow) and *Globorotalia* aff. *G. mayeri* Cushman and Ellisor, which suggest correlation with the lower part of Zone N16. We assign this locality to the upper Miocene Tortonian Stage.

Siliceous microfossils from the lower member of the Nijar include abundant diatoms, some silicoflagellates, and scattered radiolarians.

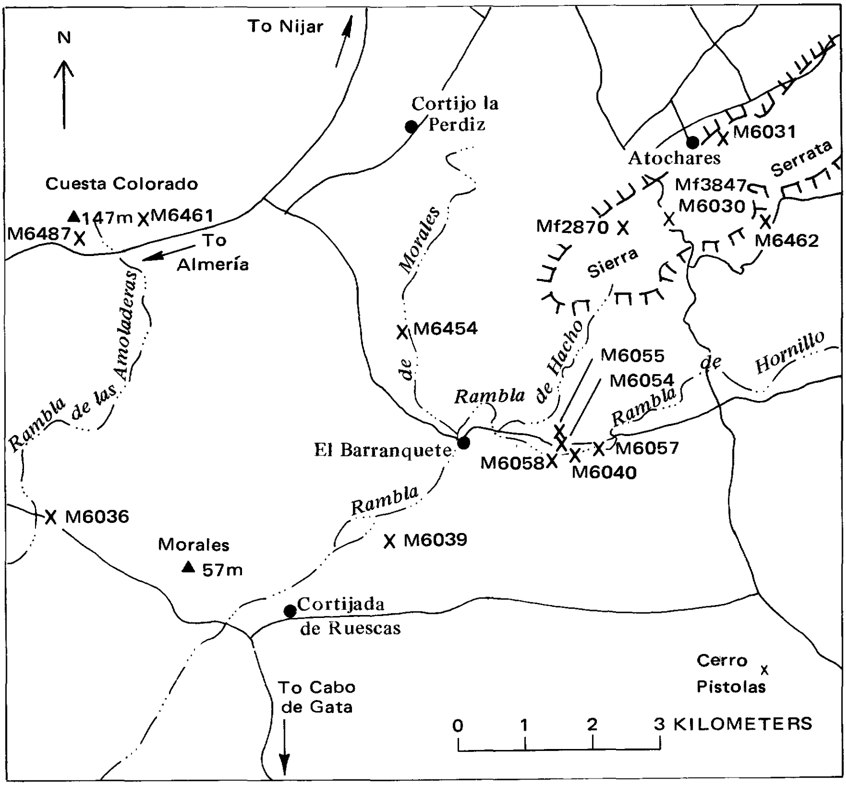

FIGURE 13.—Index map showing Neogene mollusk and microfossil localities along the southwestern flanks of the Sierra Serrata and in the vicinity of El Barranquete. M, USGS Megafossil locality; Mf, USGS microfossil locality.

Diatoms from strata exposed about 1 km south of Carboneras (fig. 4, Mf2862) that may be coeval with exposures of the upper member of the Nijar farther west are referable to North Pacific Diatom zone 11 or 12 of Schrader (1973) according to John A. Barron, U.S. Geological Survey, who suggests that they are of late Miocene age. Schrader (1975) correlates these zones with Blow's Zones N17 and N18 and believes that the boundary between them is approximately equivalent to the Miocene-Pliocene boundary. A latest Miocene age assignment for this sample is corroborated by a foraminiferal assemblage referable to the *Globorotalia conomiozea* Zone obtained from a nearby locality (Mf2864). Mollusks from this locality (M6676) are of late Miocene or early Pliocene age; they are most similar to Pliocene assemblages from the Cuevas Viejas formation. Localities in sea cliffs between here and a point 4 km south of Carboneras contain planktonic foraminifers of Pliocene age (loc. Mf3417, Mf3325, Mf3326, Mf3327). The occurrence of *Globorotalia puncticulata* (Deshayes) in two of these assemblages suggests reference to Zone N19.

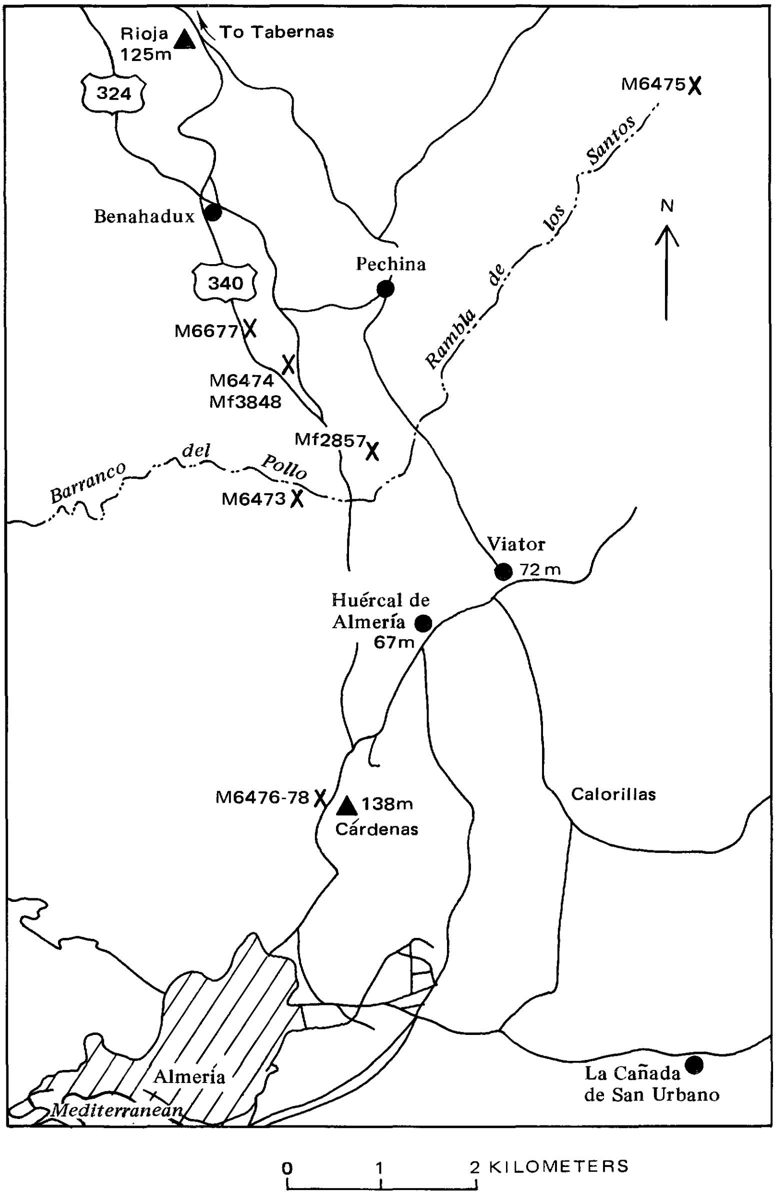

FIGURE 14.—Index map showing mollusk and microfossil localities north of Almería. M, USGS megafossil locality; Mf, USGS microfossil locality.

Nannofossil assemblages from the Nijar formation are characterized by redeposition; most of the samples contain rare to fairly common Cretaceous to Eocene coccoliths that have been recycled from older formations. Autochthonous calcareous nannofossil assemblages from the Nijar formation are poorly preserved and have low species diversity. Most of them lack zonal marker species and can be recognized only as of generalized middle or late Miocene to middle Pliocene age. Four of the nannofossil samples from the Nijar are of late Miocene age. Five samples have assemblages that range in age from middle to late Miocene or late Miocene to early Pliocene; this temporal overlap provides further support for a late Miocene age. The occurrence of the short-ranged species *Amaurolithus primus* (Bukry and Percival) in a sample from near the base of the Nijar formation on the south side of Sierra de Alhamilla (fig. 15, loc. G76–3 +20 m) is indicative of the *Discoaster quinqueramus* or *Amaurolithus tricorniculatus* Zone. Apparently correlative assemblages occur in the Nijar formation about 7 km north of Almería (field loc. SS74–62) and in the upper part of the correlative Lucainena Formation about 75 m stratigraphically below the base of the prominent gypsum bed near el Rio de Aguas (field loc. SS76–12) in the nearby Sorbas Basin.

A sequence of massive foraminiferal siltstone of the Nijar formation that underlies the gypsum bed and is in fault contact with pre-Tertiary carbonates and schist (Garcia Monzón, Kampschuur, and Verburg, 1975) is exposed along the northeastern margin of Almería Basin about 16 km northeast of Nijar. A 15-m-thick conglomerate and sandstone at the base of the Nijar in this area (fig. 15) contains macroinvertebrates of middle or late Miocene age (*Macrochlamis solarium* (Lamarck), *Crassostrea* sp., and *Clypeaster* cf. *C. alticostatus* Michelin). Planktonic foraminifers from 20 and 24 m above the base of this unit (loc. Mf3366) are of latest Miocene, Messinian, age and are referable to the *Globorotalia conomiozea* zone. Nannofossils from this locality (+ 20 m level) are referable to the *Discoaster quinqueramus* or *Amaurolithus tricorniculatus* Zones, which are compatible with the foraminifer determination. Planktonic foraminifers (loc. Mf3331) from a 90-m-thick section of the Nijar formation on the south side of Cerro del Almendral that is overlain by a 20-m-thick gypsum bed (fig. 15) are also of latest Miocene, Messinian, age. In this area the gypsum is conformably overlain by sandy siltstone that contains planktonic foraminifers (loc. Mf3367) of probable early Pliocene, Zanclian, age (that is, Zone N18 or N19). Poorly preserved mollusks from massive very fine grained sandstone that occurs about 40 m above the gypsum in this area (loc. M6673) are of probable Pliocene age (fig. 15). Thirty meters of barren siltstone that conformably overlies the gypsum bed along Rambla de los Feos west of the Nijar-Sorbas road is tentatively referred to the Nijar formation on the basis of lithologic similarity to the Nijar.

According to de Porta, Martinell, and Civis (1977), the basal conglomeratic sandstone and overlying massive foraminiferal siltstone

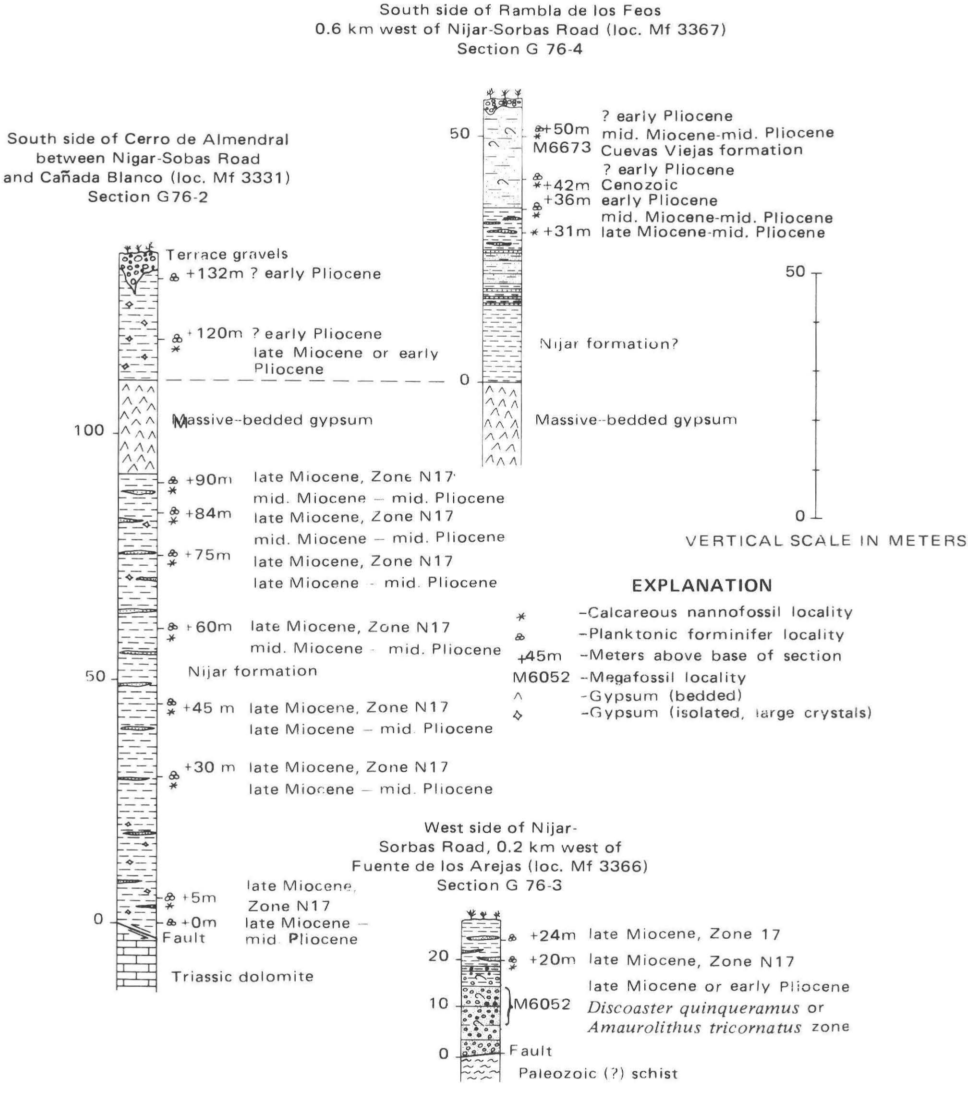

FIGURE 15.—Stratigraphic sections of the Nijar formation near Cerro del Almendral, 16 km northeast of the village of Nijar (measured by A.K. Armstrong, April 1976).

correspond, respectively, to the Azagador and Abad Members of the Turre Formation of Volk and Rondeel (1964) described from the Vera Basin, a coastal embayment lying northeast of the Sierra de Alhamilla-Sierra Cabrera chain. These members have been mapped by Dronkert (1977) along the eastern margin of the nearby Sorbas Basin, an interior basin lying directly north of the Almería Basin and separated from it by the Sierra de Alhamilla.

A previously unreported occurrence of siltstone and sandstone of latest Miocene Messinian age in the western part of the Campo de Dalias near Guardias Viejas (fig. 23, locs. Mf3403–3405) seems to represent a unique occurrence of the Nijar formation. The presence of *Globoquadrina dehiscens* (Chapman, Parr, and Collins), *Globorotalia plesiotumida* Blow and Banner, and *G. conoidea* Walters (s.l.) is indicative of Zone N17. Earlier micropaleontologic studies of this area (Fourniguet and LeCalvez, 1975; Perconig, 1976) found only Pliocene foraminifers.

A pregypsum sequence of deep-water thin-bedded fissile siltstone with interbedded fine-grained sandstone is well exposed in the Sorbas Basin along the north flank of the Sierra de Alhamilla. Recently this unit was named the Lucainena Formation by Iaccarino, Morlotti, Papani, Pelosio, and Raffi (1975) for exposures of fine-grained turbidites exposed near Lucainena along the southeastern edge of the Tabernas quadrangle (Garcia Monzón, Kampschuur, Vissers, Verburg, and Wolff, 1975), about 30 km northeast of Almería. These strata, commonly referred to as Margas, contain a few thin units of fossiliferous sandstone and limestone called Maciños. The upper part of the Lucainena, or Margas, sequence probably correlates with that part of the Nijar formation exposed below the gypsum bed along the northwestern part of the Sierra Serrata and in a small area along the western flank of the Sierra de Alhamilla, about 13 km north of Almería. The planktonic foraminifer *Globorotalia conomiozea* occurs in the upper part of the Lucainena Formation (Iaccarino and others, 1975, p. 269). The first occurrence of this species approximates the lower boundary of the Messinian Stage (Van Couvering and others, 1976).

Where the Lucainena, or Margas, is exposed on the north side of the Sierra de Alhamilla, between Peñas Negras and El Rio de Aguas, about 7 km southeast of Sorbas (Garcia Monzón, Kampschuur, Vissers, Verburg, and Wolff, 1975) map units TBc–BC 11–12, TBc c 12, and TBc m 12), strata approximately 50–60 m below the 30-m gypsum bed (TBc y 12) contains a coccolith assemblage indicative of the *Discoaster quinqueramus* Zone, *Amaurolithus primus* Subzone of late Miocene age. As in the Nijar formation, samples in the upper 50–60 m of the Lucainena, or Margas, commonly contain reworked Cretaceous and Eocene coccoliths. Marker species of nannofossils are lacking throughout most of the section sampled in this area; a sample collected approximately 100 m above the base of the Lucainena, or Margas (where it unconformably overlies Triassic(?) dolomite along the Nijar-Sorbas road), contains a nannofossil assemblage indicative of a late middle Miocene age. Yet the base of the 900-m-thick Lucainena Formation where exposed about 12–15 km west of Peñas

Negras apparently is no older than late Miocene in that area on the basis of the occurrence of planktonic foraminifers referable to the *Globorotalia acostaensis* Zone of the Tortonian Stage (Iaccarino and others, 1975). Middle Miocene strata may be present in the subsurface in the Campo de Nijar and the Campo de Dalias, but are overlapped by the Nijar against the pre-Tertiary basement high of Sierra de Alhamilla and against a Miocene volcanic high along the Sierra Serrata.

VICAR FORMATION

Bioclastic limestones and calcarenites that make up the Vicar Formation probably have a wider areal distribution than any other unit in southern Almería Province. These strata are well exposed in places along the southern flank of the Sierra de Gádor, particularly along the ridges that bound the Rambla de Vicar that drains into the northeastern part of the Campo de Dalias (fig. 16), here taken to be the type area. These strata are largely covered by Pliocene and Pleistocene deposits in the broad areas of the Campo de Nijar and the Campo de Dalias. A regional unconformity separates the Vicar Formation from older rocks in the area, indicating that a major orogenic

FIGURE 16.—Thick-bedded bioclastic limestone (l) of the Vicar Formation overlying massive reddish-brown-weathering schist (s) along the south flank of the Sierra de Gádor, 1 km south of the village of Vicar.

event preceded deposition of this transgressive shallow-water marine carbonate unit. The unconformity between the Vicar and Paleozoic(?) sheared phyllite and schist is well exposed in roadcuts about 1.3 km northeast of the village of Vicar, where a basal 2-m-thick laterite bed containing scattered cobbles and pebbles of quartz, schist, and dolomite overlies the older rocks (figs. 17 and 18). In areas where Vicar limestone unconformably overlies the Cabo de Gata Volcanic Complex, the contact is one of irregular relief. In outcrops along the west side of Cerro del Marchal, about 2.6 km northeast of the coastal village of San José, fossiliferous bioclastic limestone of the Vicar is deposited against a near-vertical Miocene seacliff of flows and breccias, and the Vicar contains numerous talus blocks derived from the volcanic rocks. Ancient sea caves and fissures cut in the Cabo de Gata Volcanic Complex are filled with Vicar limestone.

Although detailed geologic mapping needed to document the pre-Vicar tectonic history is not available, reconnaissance studies indicate that in places the Vicar Formation overlaps earlier faults. For example, along the south side of the Sierra de Gádor, a major fault that juxtaposes pre-Tertiary rocks on the north against steeply north-dipping Miocene conglomerates on the south is overlapped by undisturbed Vicar limestone.

In outcrops, the Vicar Formation commonly has a light-yellowish-gray and massive- to thick-bedded appearance imparted by a veneer of caliche or calcareous cemented slope wash. In less weathered outcrops and in some quarries, the Vicar is thick to medium bedded and in places exhibits sweeping megacrossbedding. The bedding is emphasized by thin beds of coarser grained calcareous sandstone intercalated in the massive fine-grained calcarenites. In places, these coarser sandstone beds exhibit microcrossbedding.

Near its basal contact with pre-Tertiary dolomites and schists, the Vicar contains beds of pebble and cobble conglomerate and crossbedded to massive gritty and pebbly sandstone. In places, lag boulders to 0.5 m in diameter occur at or near the contact. The gritty and pebbly sandstone contains borings of mollusks; some borings extend below the contact into the ancient soil zone developed on the schist (fig. 17). Where the Vicar overlies the Triassic dolomite, subangular boulders of dolomite to 0.3 m in size and scattered clasts of volcanic rocks occur near the contact.

The Vicar Formation is predominately a coarse-grained bioclastic limestone composed largely of fragments of red calcareous algae, bryozoans, and less abundant echinoid spines and plates, foraminifers, and broken mollusk shells. A few fine sand-size quartz and schist grains are scattered through the limestone, which is loosely cemented by fine sparry calcite and has high porosity resulting both from a high intraparticle porosity when deposited and from post-depositional vug or solution telogenetic porosity. In places, Vicar limestone contains rip-up clasts of carbonate mud (micrite), and micrite rims recrystallized pelecypod fragments and infills bored algal fragments. Veins of sparry or banded calcite fill fractures in the limestone.

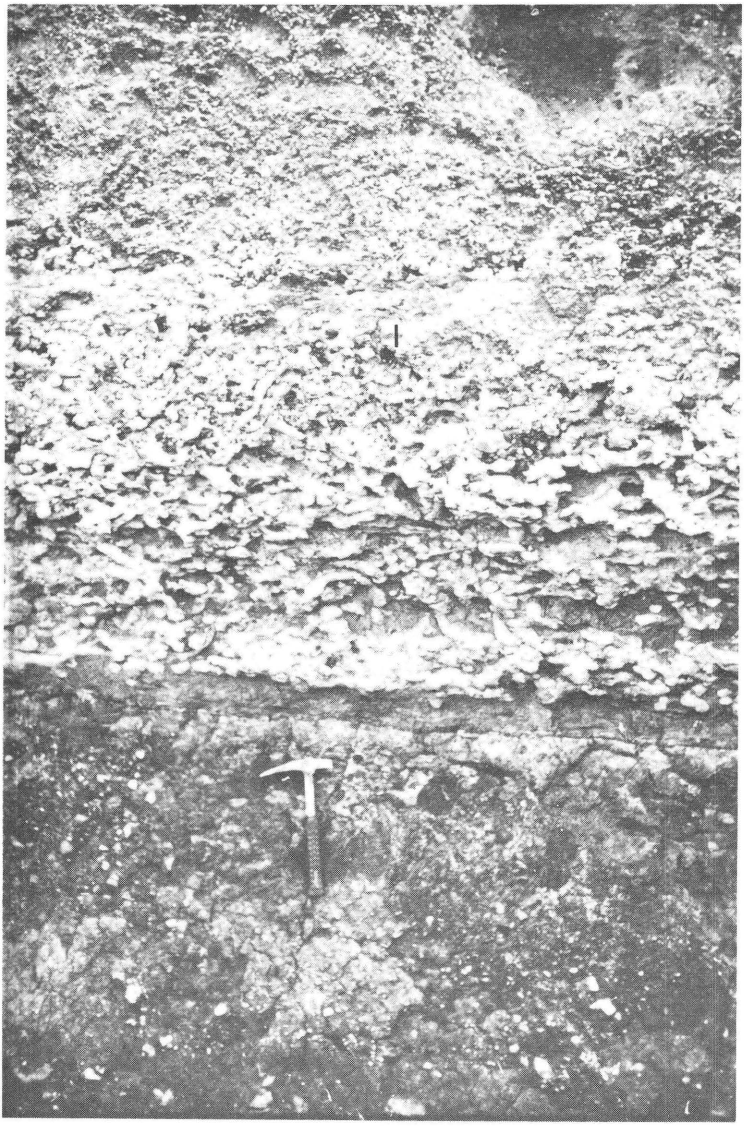

FIGURE 17.—Basal contact of the Vicar Formation and Paleozoic(?) schist about 2 km northeast of village of Vicar. Large borings in red laterite (l) near contact.

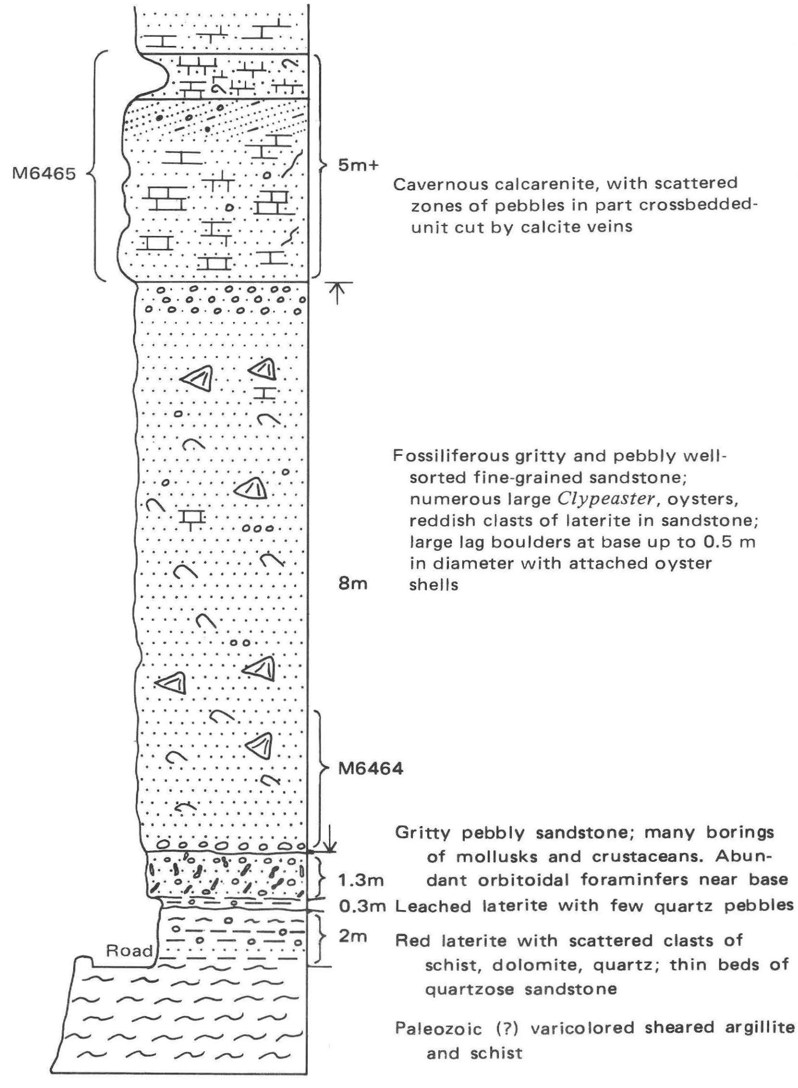

FIGURE 18.—Section of the basal part of Vicar Formation overlying pre-Tertiary phyllite in roadcut 1.3 km northeast of Vicar. M prefix, USGS megafossil collection.

AGE AND CORRELATION

Extensive collections of larger marine invertebrates from the Vicar Formation contain species indicative of a late Miocene age and, presumably, of correlation with the Tortonian and Messinian Stages. The Neogene sequence of southwestern Spain is better suited than the type Messinian Stage of Italy for stage/age correlation of the latest Miocene of the Mediterranean according to de Aguirre and

Perconig (1975), but the Andalusian seems to extend from about 9 to 5 m.y. and is correlated with the middle part of the Tortonian Stage through the Messinian Stage (Berggren and Haq, 1976; Van Couvering and others, 1976). On the other hand, the boundaries of the Messinian Stage are well documented by micropaleontologic data and appear to correspond to a much shorter interval of time, 6.5 to about 5 m.y., according to these authors. There are biostratigraphic data on shallow-water mollusks of the Andalusian Stage, unlike the Messinian Stage, but the information (Raffi, 1973) is as yet very limited. Mollusks from the Vicar Formation in the Campo de Nijar area that are restricted to the late Miocene of the Mediterranean region include *Mesalia cochleata* (Brocchi), *Macrochlamis latissima* forma *nodosiformis* (de Serres), and *Chlamys malvinae* (Dubois). *Chlamys malvinae* also occurs in southwestern Spain (Raffi, 1973) in strata assigned to the Andalusian Stage of Perconig (1966).

The giant echinoid *Clypeaster* is abundant in the basal part of the Vicar Formation in the southern foothills of the Sierra de Gádor (fig. 19) and along the southeast margin of the Sierra de Gata; one broken specimen appears to have been about 200 mm in greatest diameter. These spectacular highly domed echinoids are characteristic of the late Miocene of Alicante and Murcia Provinces of southeastern Spain (Montenat and Roman, 1970). The occurrence of *Clypeaster* in the Cabo de Gata Range has been noted by Melendez, de Aguirre, and Bautisto (1964, 1966). Giant specimens of *Spondylus crassicosta* Lamarck, *Macrochlamis latissima* (Brocchi), *Ostrea* sp., and *Isognomon* are characteristic of exposures of the Vicar in the Campo de Nijar. These organisms are indicative of a very shallow, fully marine environment.

Foraminifers from exposures of the Vicar Formation in the vicinity of its type area in the Campo de Dalias are referable to the Tortonian and Andalusian Stages (Perconig, 1976). The lowest 60 m of a 100-m-thick measured section on the south side of Loma de la Ecarada, about 1.5 km south of Vicar, is referred by Perconig (1976, fig. 18) to the Tortonian. At the base of the upper 40 m of section, the very shallow water Tortonian assemblages are replaced by neritic assemblages containing planktonic foraminifers referable to the Andalusian Stage (Perconig, 1976, p. 175). The occurrence of similar shallow-water assemblages of late Tortonian and Andalusian age in limestone of the Cabo de Gata Range near Rodaquilar, presumably referable to the Vicar Formation, is noted by Perconig (1976, p. 175). The lowermost few meters of the Vicar Formation in the type area (fig. 18) contains abundant specimens of the orbitoidal foraminifer *Heterostegina complanata spiralis* Papp and Keuper, according to Richard Margerum (written commun., Dec. 1975). This species has

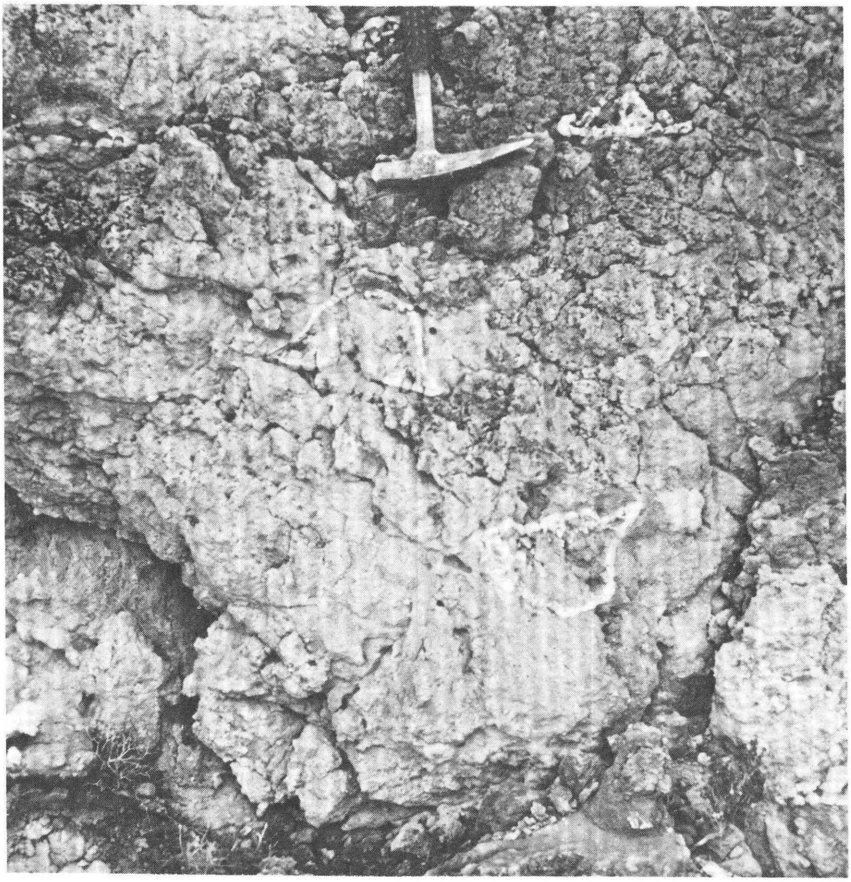

FIGURE 19.—*Clypeaster* in bioclastic calcarenite exposed in roadcut about 5 m above the base of the Vicar Formation 1.5 km northeast of Vicar.

been found in the Miocene of northern Morocco (Choubert and others, 1964). It is also reported from the Guadalquivir basin, southwestern Spain, together with oysters, pectinids, large *Clypeaster*, and planktonic foraminifers that are indicative of a late Tortonian age (Perconig, 1971).

In summary, available micropaleontologic data indicate that the lower part of the Vicar Formation, as in its type area and along the seaward margin of the Cabo de Gata Range, is of early late Miocene (Tortonian) age. Many of our planktonic foraminiferal determinations from the deeper water Nijar formation, from both the lower and upper members, are referable to the *Globorotalia conomiozea* Zone of late Miocene (latest Tortonian and Messinian) age. Although we have no definite lower Tortonian (i.e., Zone N16) in the Nijar, microfossils from an exposure about 1 km east of Nijar (fig. 7; locs. Mf3408, SS74–28, ASA 76–5) are of possible middle Miocene age on the basis of both low-diversity assemblages of planktonic foraminifers and nannofossils. On this evidence, the Nijar formation may span all of late Miocene time and extend into the middle Miocene.

It seems likely that the Vicar Formation represents, in large part, a post-orogenic basin-margin and shallow-water predominately carbonate facies of late Miocene (Tortonian and Messinian) age and that the Nijar represents the deep-water basin facies, also of late Miocene (at least latest Tortonian and Messinian) age. The relation between these two formations is very difficult to determine as they are in contact at very few places. The Vicar seems to be best developed on, or in close association with, late Miocene structural highs that correspond to the present-day Sierra de Gádor and Cabo de Gata Ranges. In contrast, the deep-water Nijar formation and the correlative Lucainena Formation of the Sorbas Basin are closely associated with the modern Sierra de Alhamilla, suggesting that that range probably was not as prominent a topographic feature as the Sierra de Gádor during the late Miocene. In a few areas, shallow-water calcarenite and bioclastic limestone of Vicar-like lithology overlie either the lower or upper member of the Nijar formation, as in the middle part of the Sierra Serrata (Mf2863, fig. 4) and at the type section of the Nijar formation southeast of Nijar (Mf2856, fig. 11). Planktonic foraminiferal assemblages from these localities are of latest Miocene (late Tortonian and Messinian) age. The age of the overlying shallow-water calcarenites and carbonates is not well known, but in the Nijar area, at least, mollusks from thick-bedded calcarenites (loc. M6460, fig. 11) are suggestive of late Miocene age. The age and stratigraphic position of shallow-water beds invite comparison with the Cantera Member of the Lucainena Formation of Iaccarino, Morlotti, Papani, Pelosio, and Raffi (1975) in the Sorbas Basin on the north flank of Sierra de Alhamilla.

PLIOCENE FORMATIONS

Pliocene marine strata were deposited in a shallow northeastward-trending coastal basin that was bordered on the north by the Sierra de Gádor and Sierra de Alhamilla. The southern part of the Pliocene Almería Basin may have been silled by the seaward extension of the southwest-trending Sierra de Gata volcanic ridge. The deepest part of the Pliocene basin is probably under the present inner continental shelf. The continuity of Pliocene strata between outcrops in the western part of the Campo de Nijar and the western part of the Campo de Dalias is interrupted by the Golfo de Almería.

Four informal formation names, the Cuevas Viejas, Loco, Entinas, and Morales, are applied to shallow-water Pliocene lithologic units that unconformably overlie Miocene and older strata in southern Almería Province. These marine clastic sediments were deposited in different depositional environments within a single basin. They are therefore in part equivalent in age but of varied lithofacies. The most widespread Pliocene strata are massive yellowish-gray, very fine grained friable silty sandstone and siltstone, which in the western part of the Campo de Nijar are called the Cuevas Viejas formation and in the western part of the Campo de Dalias are named the Loco formation. Sandstone and conglomerate beds that intertongue with, but generally overlie, the Cuevas Viejas formation in the southwestern part of the Campo de Nijar are referred to as the Morales formation. A calcareous sandstone unit that overlies the Loco formation in the southeastern part of the Campo de Dalias is named the Entinas formation. The inferred facies relation between these four Pliocene units is shown in figure 20.

Some 600 m of yellow silty sandstone and conglomerate with quartzitic clasts exposed along the west end of the Sierra de Alhamilla has been described as the Barranco de Granaderos Formation by Iaccarino, Morlotti, Papani, Pelosio, and Raffi (1975). In lithology these rocks correspond to our Cuevas Viejas and Morales formations.

The paleogeology of the Pliocene units described in this report is inferred to represent a shallow shelf basin in which fine-grained marly sandstones (Cuevas Viejas and Loco formations) were depos-

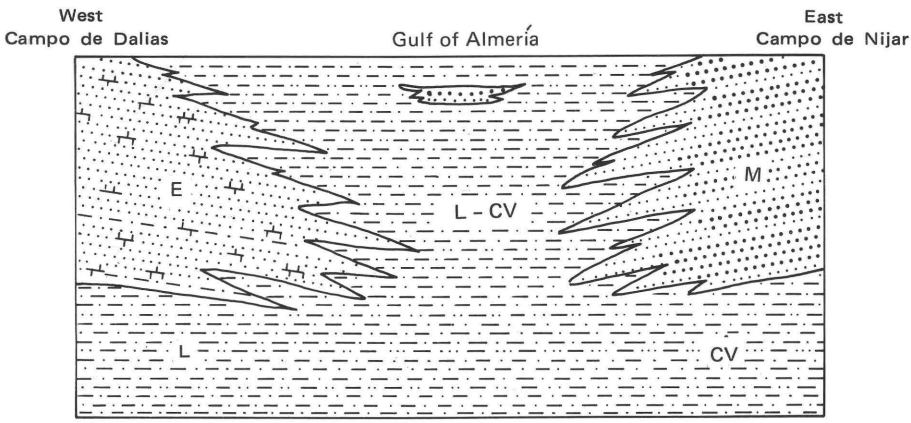

FIGURE 20.—Diagrammatic section showing the inferred relations between the Pliocene sedimentary units in the Campo de Dalias and the Campo de Nijar. E, Entinas formation; L, Loco formation; C, Cuevas Viejas formation; M, Morales formation.

ited and into which wedges of coarse bioclastic calcarenite (Entinas formation and an unnamed sandstone exposed near Carboneras) and conglomerate and sand (Morales formation) were transported. Rapid lateral facies changes in the coarse clastic units probably occur toward the deeper parts of the basin, which presumably lay offshore. On the continental shelf, marly fine-grained sands representing a deeper water environment probably are the dominant Pliocene lithology.

CUEVAS VIEJAS FORMATION

Pliocene strata that have the widest areal distribution in southern Almería Province are a sequence of yellowish-gray very fine grained micaceous, calcareous sandstone and siltstone with a few interbeds of coarse-grained or gritty sandstone. The soft friable sandstone characteristically contains large articulated valves of the smooth pectinid *Amusium cristatum* (Bronn). Many of the coarser sandstone interbeds contain rich assemblages of mollusks and scattered echinoids. These strata form steep bluffs along major drainages east and northeast of Almería (fig. 21). Numerous caves (cuevas) have been eroded into these massive sands, and dwellings, now abandoned, have been carved into these beds. These rocks are frequently described as marls (Ovejero and Zazo, 1971; Méndez Cecilia, 1971a, 1971b; Fourniguet and LeCalvez, 1975). Because of their general yellow and gray mottling, they have been informally referred to as "Margas con Lepra."

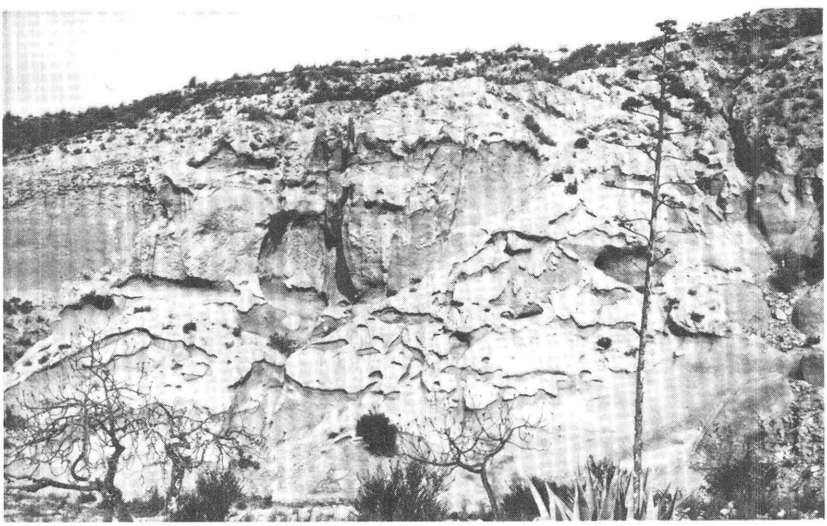

FIGURE 21.—Massive very fine grained calcareous sandstone of the Cuevas Viejas formation about 3.5 km northeast of El Alquián near Cortijo de Andújar. Height of bluff is about 50 m.

The Cuevas Viejas formation is best exposed in numerous small drainages in an area about midway between Almería and the village of Nijar, in particular, in Rambla de la Sepultura about 4 km north-northeast of El Alquián (fig. 22). Many of the mollusks described here were collected from outcrops along the secondary road leading up this rambla from El Alquián to Cuevas de los Juanorros and from along the road to Las Cuevas de las Medinas about 4 km to the east (fig. 22). Very fossiliferous strata are well exposed just north of the highway between Almería and Nijar (about 20 km east of Almería) in the vicinity of Cuesta Colorada and Las Mazorgas (fig. 22). The southernmost exposure of the Cuevas Viejas is at Cortijos de la Moladera 2 km from the coast in the northeastern part of the Golfo de Almería.

The contact of the Cuevas Viejas with older rocks is exposed at only a few places. It is well exposed about 7 km northeast of El Alquián near the head of Rambla de la Jaca (fig. 22), where *Amusium*-bearing

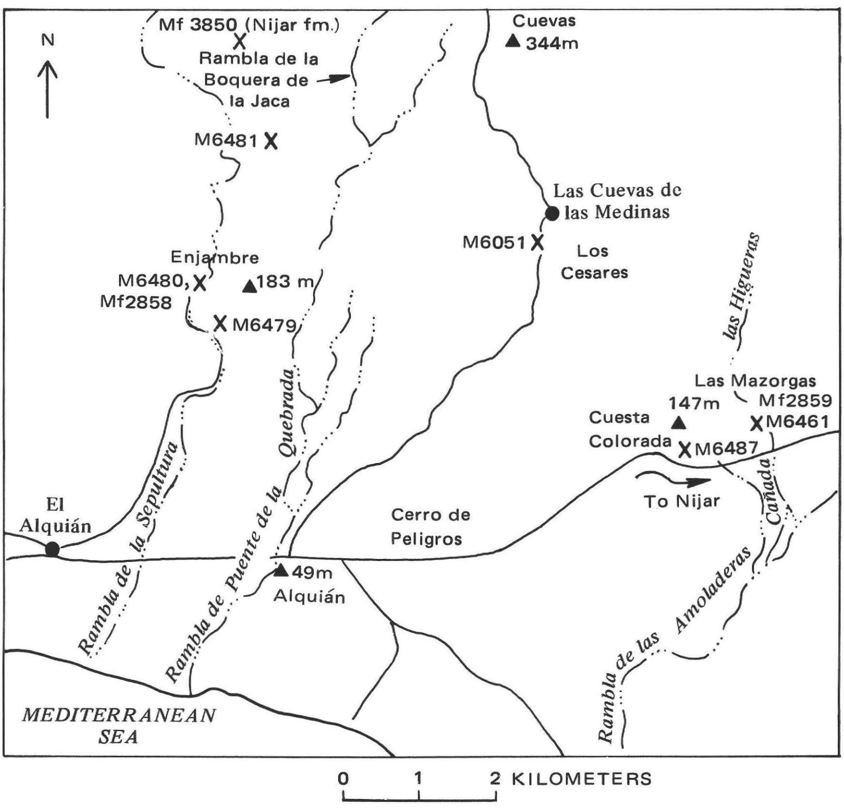

FIGURE 22.—Index map showing mollusk and microfossil localities in the Cuevas Viejas formation. M, USGS megafossil locality; Mf, USGS microfossil locality.

sands onlap what appears to be a broad structural high formed by the lower part of the Nijar formation. The Cuevas Viejas overlaps the marly siltstone of the Nijar and rests on a thick (10-m) gypsum bed that forms the domelike structure. Large blocks of gypsum to several meters in diameter near the basal contact of the Cuevas Viejas may represent blocks eroded from this structural high prior to, or during, the deposition of the Cuevas Viejas. Vertical veins of gypsum 5 to 10 cm wide occur in the Cuevas Viejas at its contact with the gypsum bed. Correlative yellowish silty sandstone exposed at the west edge of Sierra de Alhamilla, some 10 km to the northwest, locally overlies late Miocene gypsum with apparent conformity but generally is in fault contact with Miocene strata (Iaccarino and others, 1975).

The Cuevas Viejas formation appears to be coeval with the Cuevas [de Almanzora] Formation of Volk and Rondeel (1964, p. 314), a homologous sandy mudstone of presumed early or middle Pliocene age in the Vera Basin about 75 km northeast of Almería. The Cuevas Formation of the Vera Basin is a fine-grained massive basal Pliocene unit that unconformably overlies older units along the basin margin and has a rich, but undescribed, megafauna. Their Cuevas Formation where exposed near Aguilas, about 25 km northeast of Vera, contains a rich macrofauna (Fernex and others, 1967, p. 243) very similar to that of the Cuevas Viejas formation of the Almería basin.

In the narrow synclinal area of Neogene strata that crop out between the Sierra de Gádor and the Sierra de Alhamilla north of Almería, the Pliocene is represented by a mollusk-bearing basal conglomerate that varies in thickness from 1.5 to about 50 m. The unconformable contact between this unit and the underlying gray fissile siltstone of the Nijar formation is well exposed on the east side of Route 340 near km 240 about 7 km north of Almería (loc. M6677, fig. 14). Here a 1.5-m-thick basal conglomerate containing very abundant fragments of pectinids and scattered giant oysters is overlain by massive yellowish-brown spotted silty sandstone of the Cuevas Viejas formation. The conglomerate consists of subrounded to rounded pebbles and cobbles of dolomite, schist, and quartzite; clasts of selenite gypsum, 2–10 cm long, derived from the gypsum bed in the underlying Nijar formation are a principal constituent of the conglomerate. At Barranco del Pollo, about 1.5 km to the south, a much thicker conglomerate unconformably overlaps 0.3-m- to 1-m-thick turbidite sandstone beds of the Nijar formation to rest on Triassic carbonates. The conglomerate is composed of cobbles and scattered boulders in a matrix of limey arkosic sand containing finely ground shell debris, commonly occurring barnacles, and broken *Chlamys* valves.

LOCO FORMATION

Massive yellowish- and greenish-silty sandstone and sandy siltstone that crop out in the southwest part of the Campo de Dalias near the village of Balerma seem to be homologous with the Cuevas Viejas formation. These strata are informally referred to as the Loco formation, as they are best exposed in quarries along Rambla del Loco about 1.5 km east of Balerma (fig. 23). This massive unit is increasingly sandy toward its top, a trend that is paralleled by an increase in both the abundance and diversity of the invertebrate megafauna. In the stratigraphically lower exposures (loc. M6048), there are only widely scattered bivalve mollusks (mostly the distinctive *Pseudamussium clavatum* (Poli) and *Neopycnodonte navicularis* (Brocchi)). Near the top of the formation, there is a very diverse megafauna of pectinids, ostreids, and echinoids (locs. M6670, M6671). The green marls and overlying yellow sandy marls of Fourniguet and

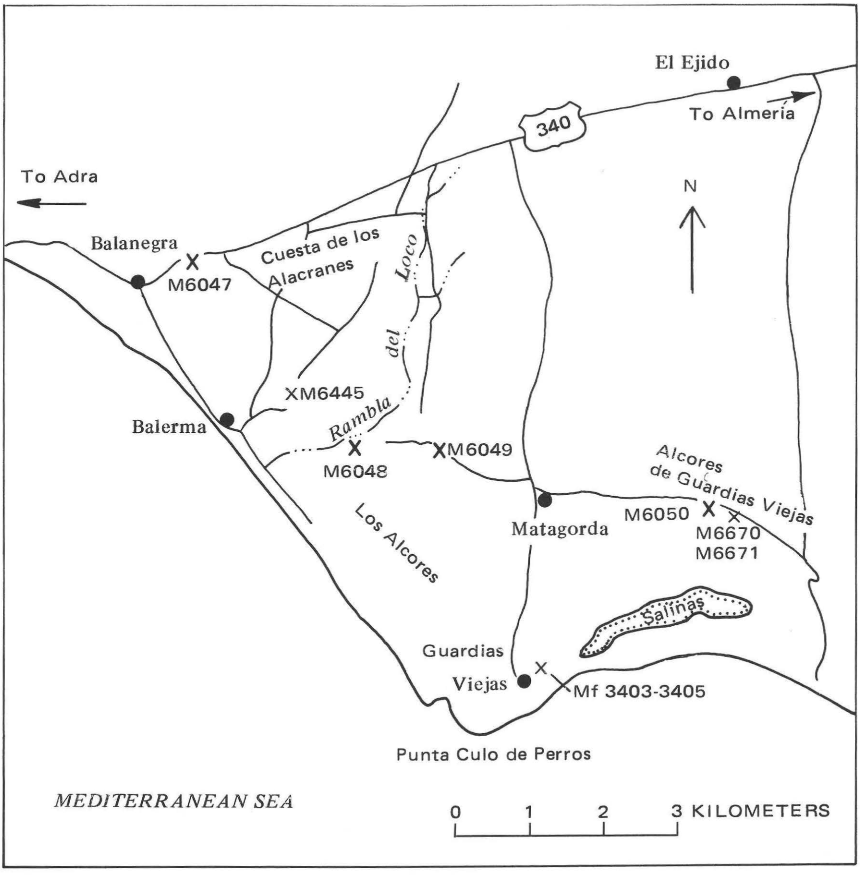

FIGURE 23.—Index map showing mollusk and foraminifer localities in the Loco formation in the southwest part of the Campo de Dalias. M, USGS megafossil locality; Mf, USGS microfossil locality.

LeCalvez (1975, fig. 4) are both referable to the Loco.

The contact of the Loco formation with underlying units is not exposed in the Campo de Dalias proper, but it seems to be represented by the base of an extremely attenuated, basin-margin section exposed at the westernmost edge of the Campo de Dalias about 3 km northeast of Adra. This thin sequence includes an *Ostrea*-bearing basal conglomerate that unconformably overlies Paleozoic rock and an overlying yellow-colored sandy marl that contains an abundance of benthic foraminifers of middle Pliocene age (Fourniguet and LeCalvez, 1975). In the western part of the Campo de Dalias, the Loco formation may be locally underlain by a northward-dipping upper Miocene unit of diatomaceous siltstone and silty sandstone with thin conglomeratic interbeds exposed about half a kilometer east of Guardias Viejas. Although the contact is not exposed, a depositional hiatus is suggested by the fact that the earliest part of the Pliocene is not known to be present in the western part of the Campo de Dalias.

The contact between the Loco and the overlying Entinas formation is well exposed in small quarries carved into the late Pleistocene seacliff formed during the third, or Balerma, transgression described by Ovejero and Zazo (1971). These quarries, about 3 km northeast of Guardias Viejas, expose a 5-m-thick section of mottled gray and yellow massive very fine grained sandstone of the Loco formation, here conformably and gradationally overlain by about 14 m of fine-to medium-grained sandstone of the Entinas formation (fig. 24).

The calcareous very fine grained sands of the Loco and Cuevas Viejas formations commonly contain finely disseminated muscovite and scattered heavy minerals. Petrographic study of a sample collected from the Loco indicates that quartz and feldspar are the most common clastic grains; muscovite and biotite are minor constituents. Heavy minerals recognized include green and brown hornblende and pyroxene; tourmaline is sparse. Fragments of microfossils and bryozoans are common, and the sand is partly cemented with calcite. A sample of the Cuevas Viejas formation collected near Las Mazorgas (fig. 22) has almost the same composition as samples from the Loco formation. In addition to abundant quartz and feldspar and common biotite and muscovite, the Cuevas Viejas contains a small percentage of iron minerals.

ENTINAS FORMATION

A coarse-grained bioclastic sandstone that conformably overlies the Loco formation in the Campo de Dalias is here informally named the Entinas formation. The Entinas is very well exposed along a Pleistocene seacliff in an area about 2 km north-northwest of Punta Entinas (figs. 25, 26), which is taken to be the type area. Here about 14

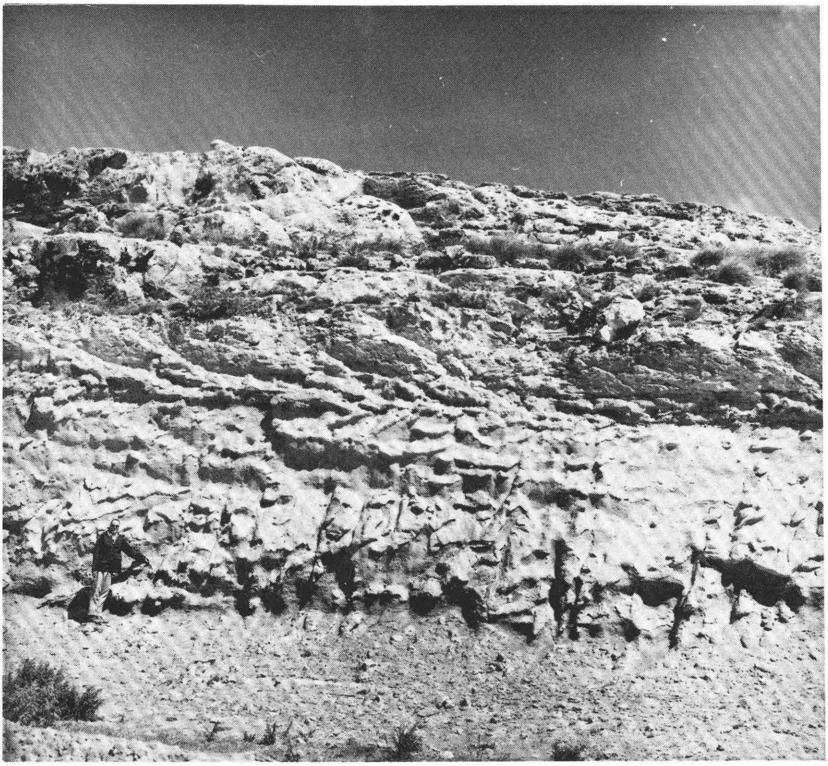

FIGURE 24.—Conformable contact between fine-grained marly sandstone of the Loco formation and the overlying crossbedded calcarenite of the Entinas formation, near Alcores de Guardias Viejas, Campo de Dalias.

m of yellow calcarenitic sandstone is unconformably overlain by Pleistocene terrace deposits consisting of carbonate-cemented pebble conglomerate and gritty sandstone. Exposures of the Entinas formation continue eastward some 4 km to the vicinity of Cortijo de Villalobos.

The Entinas formation is a light-yellowish-gray, porous, medium- to coarse-grained calcarenite that locally exhibits megacrossbedding. The formation is thick bedded but contains 0.3-m- to 1-m-thick interbeds of fine-grained silty bioclastic sandstone. The coarse-grained to gritty calcarenite contains scattered grains of schist, gneiss, and quartz in a matrix of finely comminuted shell debris. Molluscan fossils are common in the Entinas; the most abundant in the type area are the bivalves *Mytilus* and *Ostrea*. The contact with the underlying Loco formation is conformable and gradational; it is well exposed in quarries cut into the face of the Pleistocene seacliff about 5 km northwest of Punta Entinas.

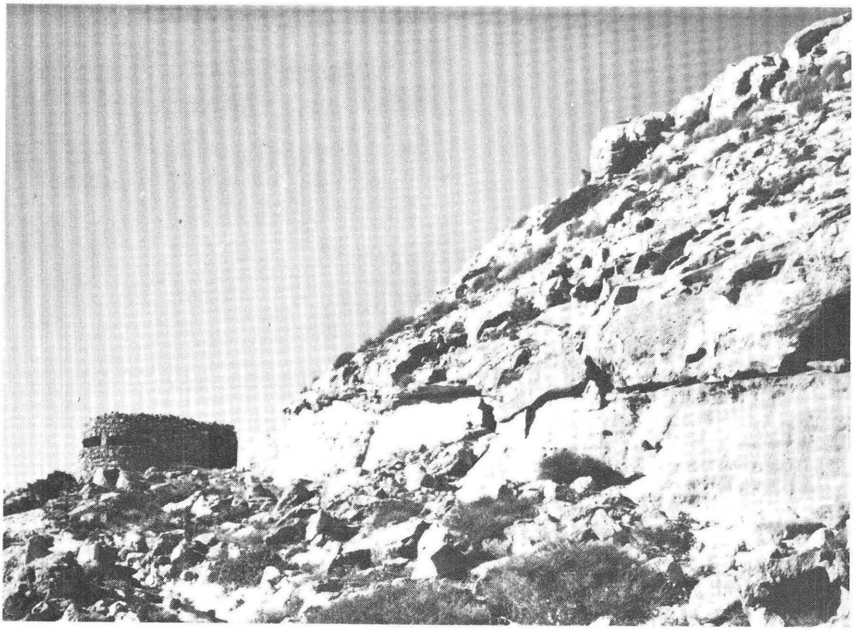

FIGURE 25.—Medium-bedded to large-scale crossbedded calcarenite at the type area of the Entinas formation, about 2 km north-northeast of Punta Entinas.

Excellent easily accessible exposures of Entinas sandstone occur in cuts along the south side of Route 340 at the west end of Cuesta de los Alcaranes about 1 km east of Balanegra (fig. 23)). Here yellow pebbly arkosic bioclastic sandstone contains abundant *Ostrea* and scattered broken pectinids occurring in 0.1-m- to 0.2-m-thick beds. The yellow calcarenitic sandstones of this area apparently were first noted by Méndez Cecilia (1971a, 1971b), who considered them a unique occurrence of Astian facies in the Pliocene Almería Basin.

In thin section the dominant organic debris in the Entinas calcarenite consists of fragments of mollusk shells, echinoids, and red calcareous algae; benthic foraminifers are common. The bioclasts are rounded and broken fragments, and the absence of micrite suggests a high-energy, wave-agitated environment of deposition. The presence of large-scale sweeping crossbedding in these strata suggests that the Entinas was a shallow-water bank or deltaic deposit. The orientation of *Mytilus* in two beds exposed in the Pleistocene seacliffs north-northwest of Punta Entinas suggests that the major current direction was to the south. The presence of grains and granules of metamorphic rock types, quartz, and muscovite indicate that terrigenous material derived from the Sierra de Gádor also was transported southward into the Pliocene depositional basin.

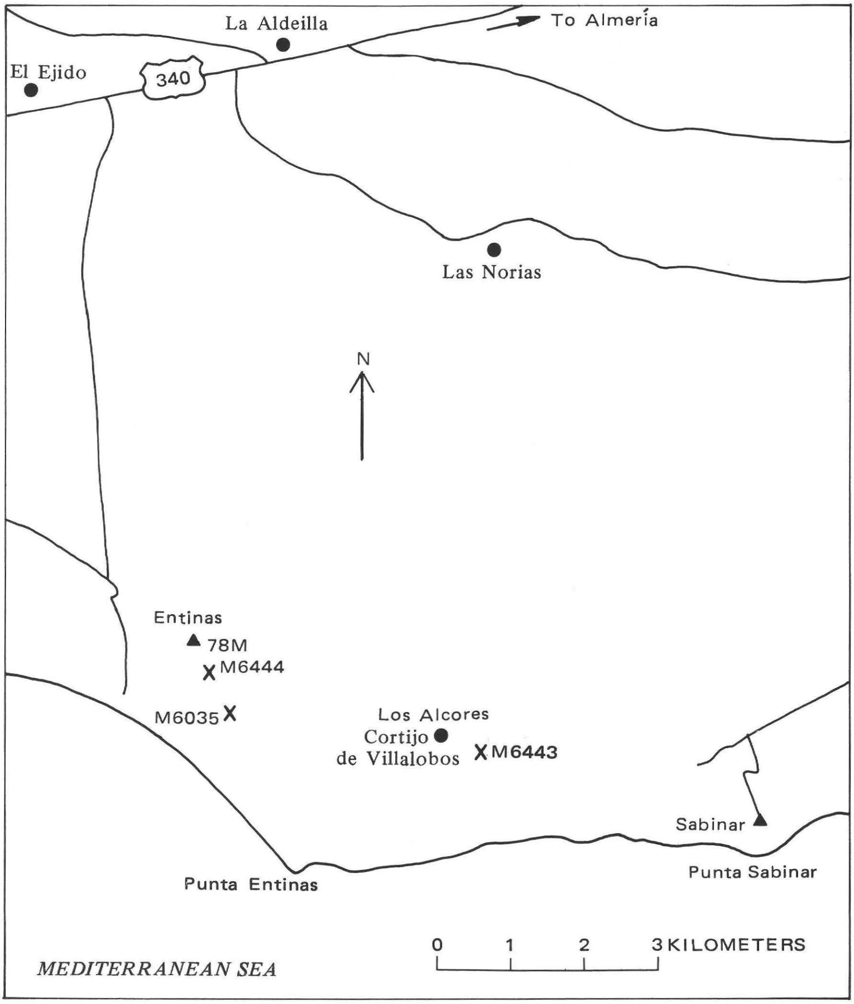

FIGURE 26.—Index map showing mollusk localities from the Pliocene Entinas formation in the southwestern part of the Campo de Dalias. M, USMS megafossil locality.

MORALES FORMATION

In the western part of the Campo de Nijar, adjacent to the southwestern part of the Sierra Serrata, an interbedded sequence of coarse-grained sandstone and conglomerate unconformably overlies Miocene sedimentary and volcanic rocks. These very fossiliferous strata, well exposed in bluffs along Rambla de Morales from the village of El Barranquete to a point 2 km northwest (fig. 13), are here named the Morales formation. The Morales is well exposed along the banks of Rambla del Hornillo and its small tributaries east of El

Barranquete for a distance of about 2 km to Cortijo los Cazadores. The easternmost outcrop of these strata recognized by Snavely and Addicott is along the northwest flank of the Sierra Serrata in a small ravine 0.5 km east of the village of Atochares. Here the Morales overlies the upper Miocene Vicar Formation with marked angular unconformity (fig. 27).

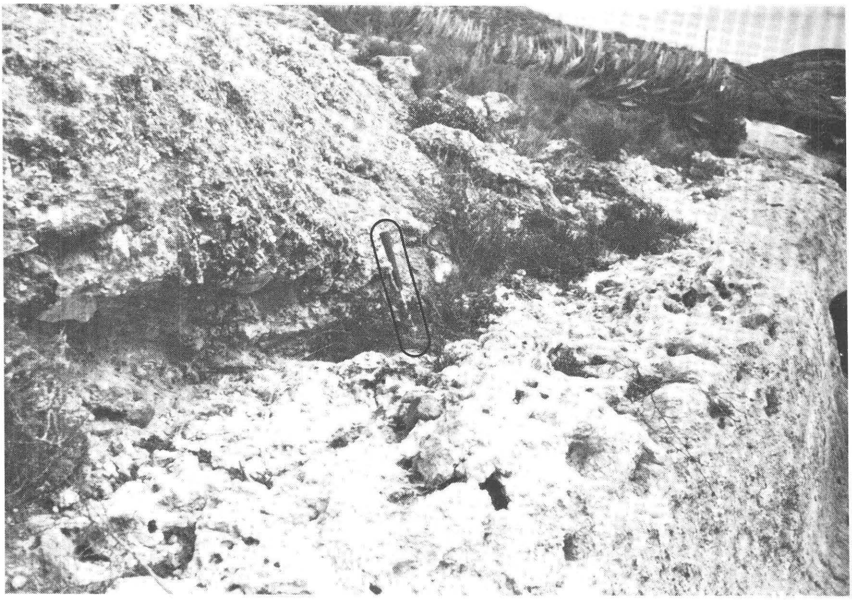

FIGURE 27.—Morales formation overlying Vicar limestone with approximately a 90° unconformity, northwest side of Sierra Serrata, about 0.5 km east of the village of Atochares. Hammer (circled) is resting on contact.

The Morales formation is a wedge of coarse-grained sandstone and pebble to cobble conglomerate that probably represents a high-energy, shallow-water inner shelf (infralittoral) and prograding deltaic environment. Morales strata generally overlie and interfinger with the fine-grained rocks of the Cuevas Viejas formation. The relation between the basin-margin conglomerate and sandstone of the Morales with the massive basinal siltstone and very fine sandstone of the Cuevas Viejas is generally homologous with that of the Pliocene Entinas. In an apparently correlative sequence exposed at the west edge of the Sierra de Alhamilla, yellowish silty sandstone at the base of a 600-m-thick Pliocene sequence is overlain by conglomerate containing abundant quartz clasts. These two units, included by Iaccarino, Morlotti, Papani, Pelosio, and Raffi (1975) in their Barranco de Granaderos Formation, can be correlated, respectively, with the

Cuevas Viejas and Morales formations of the southwestern part of the Campo de Nijar.

In the type area, 2 km northwest of El Barranquete, the Morales consists of cobble and pebble conglomerate composed of well-rounded quartz and less common volcanic rocks and interbedded well-sorted coarse-grained quartzose sandstone with thick (to 2 m) beds of giant oysters (fig. 28). The unit commonly exhibits sweeping megacross-beds, and in places horizontal beds pass laterally into low-dipping foreset beds (fig. 29). Although the large mollusks (mostly ostreids with much less commonly occurring pectinids) have been concentrated into beds by bottom currents, there are many paired valves, and commonly large ostreids at the upper surface of these beds have attached barnacles that are in an upright, living position (fig. 30).

The Morales formation, where exposed in Rambla del Hornillo and its tributaries, about 1.5 km east of El Barranquete (fig. 13), is characterized by sandy quartz-pebble conglomerate beds 0.2 m to 0.5 m thick that locally contain abundant large ostreids. In this section are several yellowish, soft fine- to medium-grained sand interbeds ranging in thickness from 1 to 2 m. The sands contain an abundant

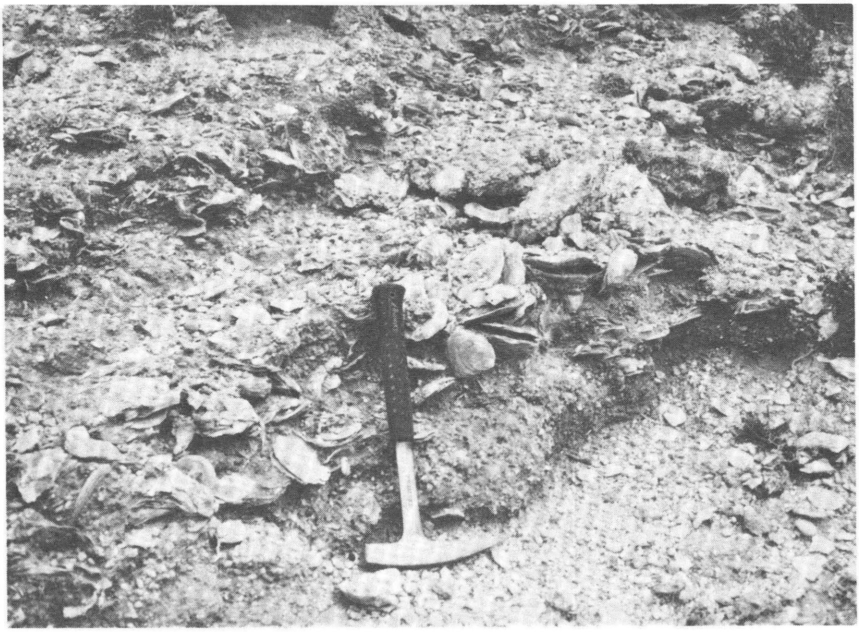

FIGURE 28.—Oyster bed interstratified in sandstone and conglomerate of the Morales formation in Rambla del Morales 2 km northwest of El Barranquete. Note numerous paired oyster valves.

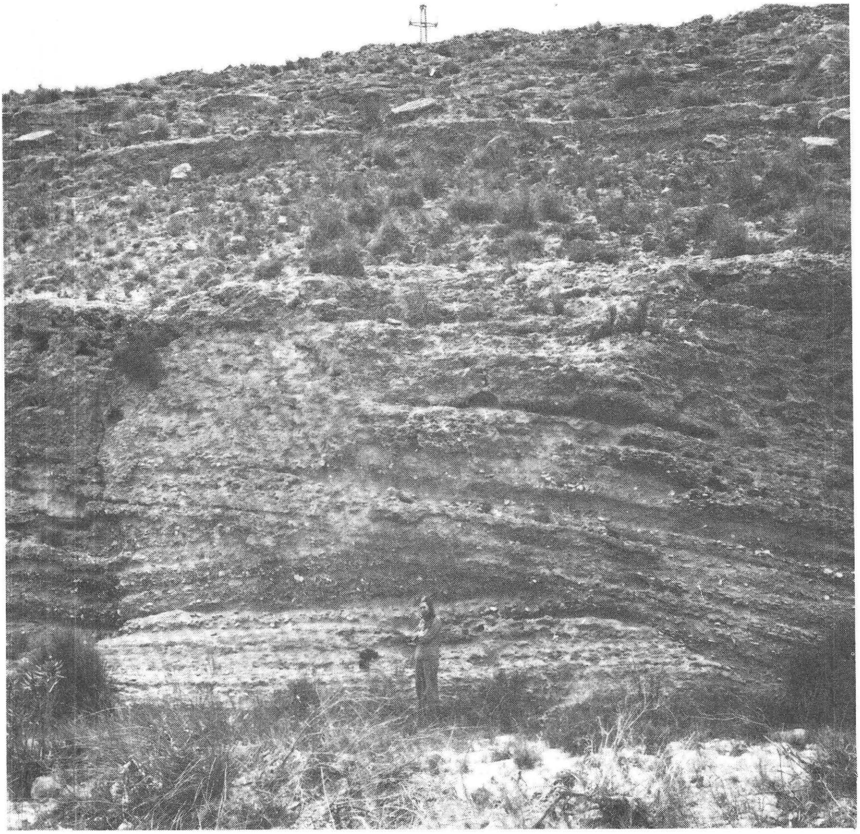

FIGURE 29.—Prograded richly fossiliferous pebbly sandstone in the Morales formation; Rambla del Morales about 1.5 km northwest of El Barranquete. Height of bluff about 10 m.

and more varied macrofauna than the conglomerates; included are pectinids, ostreids, barnacles, bryozoans, echinoids, and calcareous algae and locally a 0.5-m bed of *Flabellipecten*. Locally beds of pebbly, silty very fine grained sandstone contain molds and casts of aragonitic-shelled mollusks including *Turritella* (loc. M6057).

Thin-section studies of sandstones from the Morales formation show them to be quartz-lithic pebble biomicrites or quartz-bearing biosparite. Well-rounded clasts are composed of quartzite, gneiss, polycrystalline and monocrystalline quartz, strained quartz, quartz mica schist, less common andesite, and rare muscovite flakes. This material is set in a carbonate matrix composed of micrite and broken shell material. Bioclasts consist of foraminifers, echinoid plates and spines, mollusk fragments, bryozoans, and red calcareous algae. The sandstone is cemented with sparry calcite or lithified carbonate mud or micrite and has a low porosity.

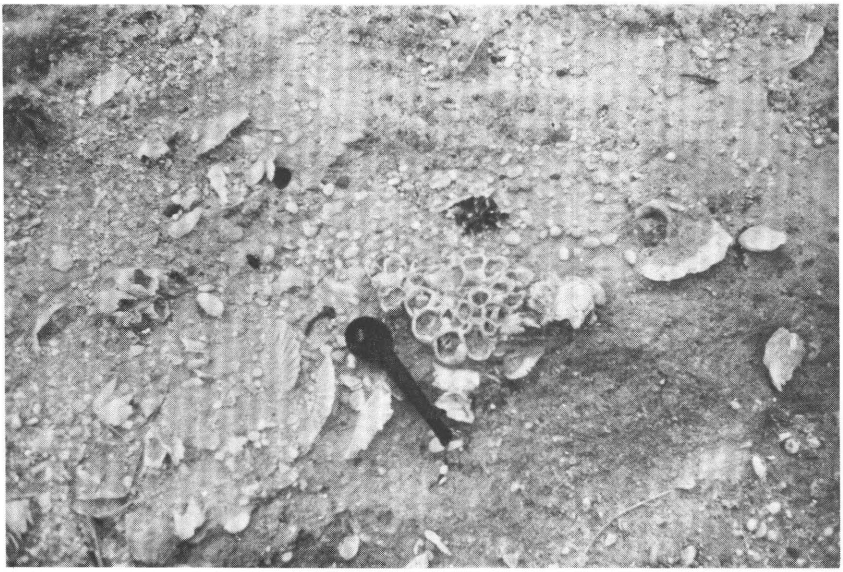

FIGURE 30.—Barnacles in upright (living) position on upper surface of 2-m giant oyster and pectinid bed. Morales formation 2 km northwest of El Barranquete on the south side of Rambla del Morales.

AGE AND CORRELATION

Planktonic foraminifers from exposures of the Cuevas Viejas formation in the western part of the Campo de Nijar near El Alquián (fig. 22, locs. Mf2858 and Mf2859) include *Globigerinoides ruber* (d'Orbigny), *G. obliquus* Bolli, *G. trilobus* (Reuss) s.l., *Sphaeroidinellopsis subdehiscens* (Blow), *Globorotalia puncticulata* (Deshayes), *Globigerina apertura* Cushman, and *G. woodi* Jenkins. These assemblages are referable to Blow's (1969) N19 Zone and to the Zanclian Stage of the Mediterranean Pliocene. In the western part of the Campo de Dalias, planktonic foraminifers indicative of Zanclian age have been reported by Fourniguet and LeCalvez (1975) from exposures of the Loco formation just north of the abandoned salt works (salinas) at Guardias Viejas. Species listed by them indicate placement in the upper part of Zone N19. Other samples from this area are referred to the biozone of *Globorotalia puncticulata* by Perconig (1976, p. 176) and therefore are referable to Zone N19.

Planktonic foraminifers identified by Iaccarino, Morlotti, Papani, Pelosio, and Raffi (1975) from yellow silty sandstones in the lower part of their Barranco de Granaderos Formation several kilometers northeast of Almería are of Tabianian age and are referred to the *Globorotalia margaritae* Zone. As *Globorotalia puncticulata* is reported from many of the samples from the Barranco de Granaderos Formation, the *G. margaritae* Zone of these workers is correlative to Zone N19 (lower part). These strata are equivalent to the Cuevas Viejas formation of this report. They are locally overlain by poorly consolidated, very fossiliferous Pliocene sandstone and conglomerate that has been correlated by Iaccarino, Morlotti, Papani, Pelosio, and Raffi (1975) with the Pliocene II unit (Brebion and others, 1971) of the Elche region of the east coast of Spain. This shallow-water unit is exposed in cuts along Route 340 at the northern outskirts of Almería near the Cárdenas radio tower (fig. 14, locs. M6477, M6478).

Scattered planktonic foraminifers in samples from flat-lying massive bryozoan-rich calcarenites that crop out in seacliffs along the beach road south of Carboneras are of Pliocene age. Samples Mf3325 and Mf3326 contain *Globorotalia puncticulata* and are referable to Zone N19, whereas sample Mf3417 contains *Globorotalia margaritae* Bolli and Bermudez and probably represents Zone N19 (fig. 4). Benthic foraminifers, ostracodes, bryozoans, echinoid spines, and mollusk fragments are very abundant constituents of these samples. Planktonic foraminifers suggesting a Zone N19 assignment occur near the top of a 75-m-thick Neogene section measured at the headland bounding Playa de los Muertos on the north (loc. Mf3324). Mollusks from exposures along the nearby Carboneras-Agua Amarga Road (loc. M6674) also are of Pliocene age. Pliocene sediments have not previously been reported from this coastal area. These Pliocene strata represent a calcarenitic facies that is lithologically very similar to that of the Entinas formation of the western part of the Campo de Dalias.

Ostracodes from brown siltstone in the Cuevas Viejas formation on the east side of Rambla Morales southwest of El Barranquete (loc. M6039, fig. 13) include exceptionally abundant specimens of *Cyprideis pannonica* Mehes according to J. E. Hazel (written commun., Dec., 1976), who compares this assemblage with the chronozone of the "brackish" Zone 2 of Sissingh (1976) of the central and eastern Mediterranean. According to Hazel, the dominance of *Cyprideis* signifies either low salinity, brackish-water conditions or hypersaline conditions. A low-diversity, possibly brackish-water molluscan assemblage occurs in strata immediately underlying this ostracode assemblage (loc. M6039). Included in the molluscan assemblage are abundant *Cerithium vulgatum* Bruguiere, *Cerastoderma* sp., *Ruditapes* sp., and tellinid.

The pectinid fauna from the Cuevas Viejas, Loco, Entinas, and Morales formations contains 25 identified species. A Pliocene age is indicated by *Amusium oblongum* (Philippi), *Flabellipecten alessi* (Sacco), *F. bosniasckii* (deStefani and Panatelli), *Chlamys pes-felis*

(Linne), and *Flexopecten inaequicostalis* (Lamarck). This fauna is very similar to the Pliocene pectinid fauna of the Elche region (Demarcq, in Brebion and others, 1971), which also has a lower marly or pelitic facies that is overlain by a coarser sandstone (Astian) facies.

Pectinids from these Pliocene formations in the Almería Basin clearly represent the classic Astian and Plaisancian facies of northern Italy as noted earlier by Gignoux and Fallot (1927) and, especially by Méndez Cecilia (1971a, 1971b). Seven of the twenty-five pectinids identified in this study are restricted to the fine-grained, marly rocks included in the Cuevas Viejas and Loco formations. These formations are referable to the Plaisancian facies and seem to represent offshore deposition in a low-energy, middle to outer neritic environment. The nearshore, coarse-grained to conglomeratic molassic rocks herein named Morales and Entinas formations are of an Astian facies. Eight species of pectinids are restricted to these two formations, which contain sedimentological and biological evidence of deposition in a very shallow water, basin-margin environment. Dense accumulations of giant *Crassostrea* in conglomeratic beds of the Morales formation in Rambla del Hornillo, about 1.5 km east of El Barranquete, and in Rambla del Morales, about 2 km northwest of El Barranquete (fig. 13), are suggestive of deposition in the intertidal zone or the uppermost reaches of the sublittoral zones. Mollusks from the bioclastic calcarenites of the Entinas formation of the Campo de Dalias are suggestive of very shallow water deposition but of a lower energy environment than the Morales.

SUMMARY

The Almería Basin contains a sequence of mildly deformed marine sediments of Miocene and Pliocene age that were deposited mainly in the upper reaches of the neritic zone. The basin is one of several late Neogene marine basins along the Mediterranean Coast of southeastern Spain (Montenat and others, 1976) that follow the trend of the Betic Cordilleras and mark the seaway that connected this part of the western Mediterranean Sea with the Atlantic during the late Neogene. The sequence of marine units has been pieced together from scattered exposures of generally flat-lying strata in the Campo de Nijar and the Campo de Dalias, broad coastal plains separated by the Golfo de Almería.

The marine Neogene sequence unconformably overlies pre-Tertiary schistose and carbonate rocks of the Alpujarride and Nevado Filabride Complexes along the northern margin of the basin. Along the southeastern margin of the basin, the Neogene sequence overlies volcanic units constituting the Cabo de Gata Volcanic Complex. A radiometric age of about 11.5 m.y. on samples from near the top of the volcanic sequence suggests that the overlying basinal sequence is no older than latest middle Miocene or early late Miocene age. This age is supported by paleontologic age determinations from the lowest parts of the marine section that are of late Miocene age as well as by the occurrence of late Miocene reefal facies in Neogene basins to the northeast. The oldest marine units in associated basins of the so-called Betic Straits also are of late Miocene age.

Upper Miocene strata are dominantly carbonate in composition. The basal unit, however, is a marine conglomerate composed of dacite and andesite boulders in a calcarenite matrix containing scattered shallow-water mollusks. Local coral reefs formed principally of *Porites* overlie this conglomerate along the eastern seaward margin of the Cabo de Gata Range near Carboneras. The most widespread upper Miocene unit is the Vicar Formation, a basin margin facies of Tortonian and Messinian age. The basal part of this limestone unit consists of coarse-grained calcarenitic sandstone with mollusks, the giant echinoid *Clypeaster*, and orbitoidal foraminifers, all indicators of extremely shallow water deposition. Basinward the Vicar carbonates pass laterally into coeval marly fine-grained clastics of the Nijar formation. These basinal sediments consist of turbidite sandstones and foraminiferal and diatom-rich siltstones and silty very fine grained sandstone, all representing markedly deeper water environments. Gypsum locally exposed in the Nijar formation represents the salinity crisis of the Mediterranean of the latest part of the Miocene Epoch. Planktonic foraminiferal determinations of Messinian age (*Globorotalia conomiozea* Zone) are associated with the gypsum bed. The best exposure of the gypsum bed occurs along the southern foothills of the Sierra de Alhamilla.

The base of the Pliocene Series is marked by a distinct unconformity in most areas. The Pliocene sequence consists of coarse-grained marginal facies and much finer grained basinal facies; carbonate rocks are much less common than during the late Miocene. Generally, the basal Pliocene consists of marly very fine-grained sandstones characterized by commonly occurring specimens of *Amusium cristatum*. This widespread basinal facies grades upward into very shallow water *Mytilus*-bearing calcarenites of the Entinas formation in the Campo de Dalias area. The silty very fine grained sandstones of the Cuevas Viejas formation form the dominant Pliocene lithology in the Campo de Nijar. Locally pebble conglomerate and coarse-grained sandstone occur at the base of the Pliocene at the western edge of the Sierra Serrata, and unnamed bryozoan-rich calcarenites unconformably overlie upper Miocene limestone at the eastern edge of the Cabo de Gata Range near Carboneras. Rich molluscan faunas that occur throughout the Pliocene sequence bear striking resemblances to the coarse-grained Astian facies and the fine-grained Plaisancian facies of northern Italy. Planktonic foraminifers from the Pliocene siltstones are early Pliocene (Zone N19).

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