Mesozoic and Cenozoic Rocks from Malta Escarpment (Central Mediterranean)[1]

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ABSTRACT

Sedimentary rocks of Triassic-Neogene age are present on the Malta Escarpment of the eastern Mediterranean.

Upper Triassic dolomitic limestones of shallow-water origin, at depths between 2.5 and 3.5 km, are similar in lithofacies to coeval platform carbonates of the Siracusa (Syracuse) belt of southern Sicily. Jurassic rocks include lower-middle Liassic shallow-water limestones followed by condensed hemipelagic lime deposits indicative of sinking and starving of the former platform. Cretaceous materials are represented by both red marls rich in planktonic faunas and reworked volcaniclastic breccias including shallow-water skeletal material.

Paleogene rocks are both shallow-water limestones with corals, algae, and bivalves, and redeposited calcarenites of lithofacies similar to those from surface and subsurface of the Ragusa zone. Oligocene–?lower Miocene rocks from the escarpment are also similar in lithology to the coeval Ragusa deposits. Tortonian is represented by hemipelagic marls indicating open-marine environment. Pervasive dolomitization on lime crusts and on initial-stage fissure fillings with strongly positive isotopic oxygen ratio is thought to be a product of Messinian evaporitic drawdown. Pliocene sediments belong to the Trubi facies and consist of pelagic foraminiferal chalk.

An impressive vertical relief existed by Miocene times, as attested by Messinian crusts and veins on or in rocks as old as Late Triassic. Our data do not provide evidence that this morphologic feature necessarily coincides with a continent-ocean transition. The present escarpment was produced by faulting, erosion, and defacement.

INTRODUCTION

The Ionian basin (Fig. 1), as well as the entire eastern Mediterranean basin, was an important kinematic factor in Tertiary and Quaternary times in relation to the continental-margin deformation induced by Africa-Europe interaction. However, the Ionian Sea is an enigmatic province, its origin and history poorly known.

Nature and age of the crust and mantle beneath the Messina Abyssal Plain are uncertain. Lack of knowledge of upper-mantle elastic propertes is due to the location of the long-period stations which did not allow the inversion of dispersion profiles crossing the abyssal plain. High positive Bouguer anomalies (+350 mgal) and depths of about 4,000 m, comparable with those of the open oceans, favor the hypothesis of an oceanic-type crust (Makris, 1975). The few deep seismic soundings in the Ionian Sea suggest a crust of intermediate thickness (17 to 19 km, Hinz, 1974; Weigel, 1974) with characteristics different from standard oceanic crust. Heat-flow values measured throughout the Ionian area are low (0.95 HFU as average of 13 data reported by Erickson et al, 1977; 0.80 ±10 HFU and 28°C/km thermal gradient measured at Site 374 by Erickson and von Herzen, 1978). These values were interpreted by Erickson et al (1977) as being coherent with an ancient oceanic crust overlain by an unusually thick sedimentary sequence (maximum 11 km, Hinz, 1974; Giese and Morelli, 1975). Little is known about this sedimentary sequence. Deep-sea drilling in the Messina Abyssal Plain (Site 374) penetrated the Pliocene-Pleistocene column and the underlying Messinian evaporites (Hsu et al, 1978a). Drill sites located in a cleft of the Mediterranean Ridge (Sites 126 and 377) reached Serravallian marlstones underlain by a lower-middle Miocene(?) flyschlike terrigenous sequence consisting of siltstones, sandstones, and dark gray mudstones (Ryan et al 1973; Hsu et al, 1978b).

The Ionian Sea is interpreted by some as a young deep-sea basin originated by foundering of a continental domain (Aubouin, 1965, 1973; Khain and Mailanovskii, 1968; Neprochov, 1968; Caire, 1970; Finetti and Morelli, 1972; Selli and Rossi, 1975; Sonnenfeld, 1975; Fabricius and Hieke, 1977), by others as an old oceanic seaway (Glangeaud, 1957; Smith, 1971; Ryan et al, 1971; Elter and Giglia, 1976; Biju-Duval and Montadert, 1977; Biju-Duval et al, 1977; Hsu, 1978; Hsu and Bernoulli, 1978; Laubscher and Bernoulli, 1978), already existing during Triassic or Jurassic time. Arguments used by some to support the former hypothesis are often weak, as they do not consider the regional geology. This

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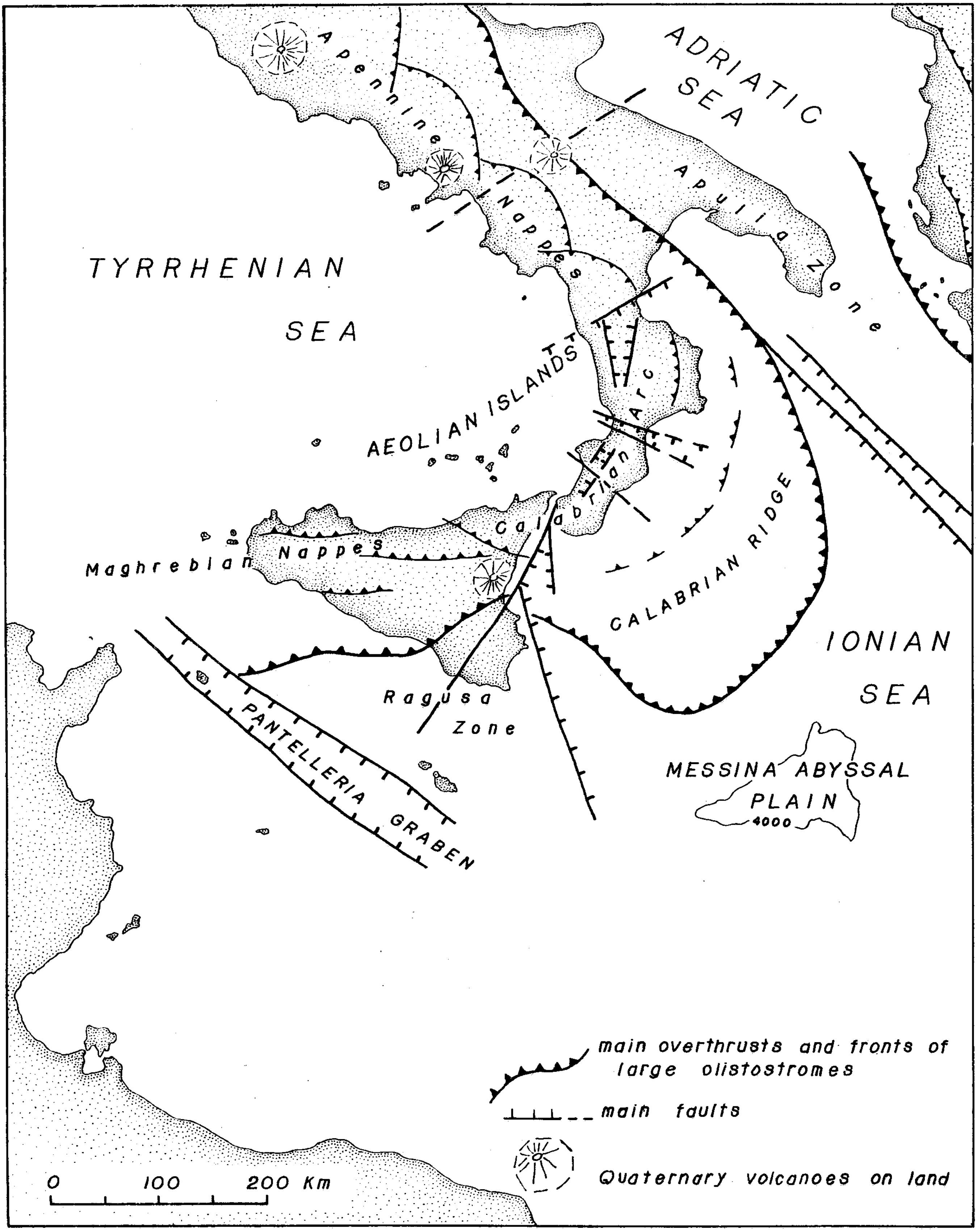


FIG. 1—Schematic structural map of area surrounding Ionian Sea.

also holds true for the latter hypothesis. For example, the lack of direct correlation between evaporite thickness and thickness and facies of the post-Messinian sediments, as well as the difference in deposition rate between the Pliocene and the Quaternary deposits (Fabricius and Hieke, 1977), cannot be proof of post-Messinian foundering, for the northern part of the Ionian Sea has been deeply modified by Messinian and Pliocene-?Quaternary compression along the Calabrian arc. However, the pronounced subsidence and pelagic sedimentation during Early Jurassic time in southeastern Sicily cannot be used as an unquestionable argument to support the oceanic nature of the adjacent Ionian Sea (Hsu, 1978), for Triassic and Jurassic seaways founded on thinned continental crust, far from oceanic realms, are common in Sicily as well as in the whole Mediterranean area (Bernoulli and Jenkyns, 1974; Scandone, 1975; Laubscher and Bernoulli, 1978).

The problem is complex. At least six hypotheses as to the origin of the Ionian basin are possible: (1) the Ionian Sea is a relic of the Triassic Paleotethys; (2) the Ionian Sea is a relict branch of the Jurassic central Tethys; (3) the Ionian Sea is a Triassic seaway founded on thinned continental crust, generated by Middle Triassic incipient rifting; (4) the Ionian Sea is a Jurassic or Cretaceous basin derived from the dissection of a former carbonate platform or shelf; (5) the Ionian Sea is a Tertiary, pre-Messinian, foundered basin coeval with the opening of the Tyrrhenian Sea; (6) the Ionian Sea is a young (Messinian or post-Messinian) foundered basin.

Extensive geologic and geophysical exploration of the Ionian Sea, planned by Progetto Finalizzato Geodinamica (CNR, Italy), has been carried out in recent years and is continuing.

DREDGING PROGRAM

The dredging program was supported financially by the National Science Foundation (USA) and by CNR (Italy). The oceanographic expedition was conducted in two legs (E-3E-78 and E-3F-78) aboard the R/V *Eastward* of Duke University and dredged along the Malta-Siracusa, Apulia, and Cephalonia-Zante escarpments. Numerous submarine cables in the area limited more extensive dredging plans.

Purpose of this paper is to provide the geologic data obtained by dredging on the Malta-Siracusa Escarpment. The exploration was completed by air-gun seismic profiling, bottom-photo stations, and gravity cores. Locations of dredges, camera stations, and gravity cores are given in Table 1 and Figure 2.

Figure 1 is a schematic structural map of the area surrounding the Ionian Sea. The western and southern borders of the Ionian basin are passive margins, whereas the northern and eastern edges are limited by the Calabrian Ridge and the Mediterranean Ridge, both representing young compressional features (Ryan et al, 1971; Finetti, 1976; Kenyon and Belderson, 1977); the structural setting is more complicated than in the southern and western borders. The southwestern margin of the Apulian-Adriatic block in Neogene time was an active margin (Carissimo et al, 1963; Finetti and Morelli, 1972, line MS 25; Scandone, 1972), although it was affected by tensional faulting during Neogene-Pleistocene time.

GEOLOGIC RESULTS

The Siracusa-Malta Escarpment (Fig. 2) divides the foreland of the Maghrebian and Calabrian nappes (Fig. 1) in two parts: the Ragusa zone and the Sicily Channel on the west and the Ionian area on the east. We shall call the Siracusa Escarpment the segment between 37°40′ and 36°30′N, and the Malta Escarpment the segment between 30°30′ and 35°40′N. The overall length of the slope is about 257 km and the general trend is NNW-SSE. Southward, the escarpment trends east-west and grades into the Medina slope. The upper boundary of the Siracusa Escarpment coincides with the shelf break at a depth of about 140 m; the lower boundary reaches about −2,000 m and faces the edge of the Calabrian Ridge. The upper boundary of the Malta Escarpment coincides with a sharp transition from the upper to the lower continental slope, at a depth of about 600 m; the lower boundary, facing the Messina Abyssal Plain, reaches a depth of 3,000 to 3,500 m. The average dip is about 9° along the Siracusa Escarpment, about 7°30′ along the Malta Escarpment. Dips exceeding 15° are reached locally. The entire escarpment is dissected by several canyons, the most prominent ones being east of Malta and east of Capo Passero (Figs. 2-4).

Previous knowledge of the submarine geology of this area is limited. The Gesite 1 cruise dredged Pliocene marls ("Trubi" facies) at 2,800 m depth on the slope southeast of Malta (Bobier, 1974). Interesting results on Mesozoic rocks came from dredging of Alfeo Seamount (Rossi and Borsetti, 1977), where Jurassic condensed deposits have been recognized.

Rocks recovered in the *Eastward* cruise range in age from Late Triassic to early Pliocene and can be referred to lithostratigraphic units of southeastern Sicily where prevailing Tertiary sediments and mafic volcanic rocks are exposed, and the Mesozoic succession is well known from commercial boreholes (Patacca et al, 1979). Most of the collected samples can be dated directly from their fossil content. Following are descriptions of the dredged rocks (Table 1) from the oldest to the youngest.

Triassic

Upper Triassic rocks have been recovered in dredging stations 9, 11, 12, and 16 from the Malta NE transect and in dredge 18 seaward of Augusta (Siracusa Escarpment). All samples were broken from outcrops, except those coming from dredge 18, which are talus pebbles and blocks. The lithologies include:

a. Limestones, white and cream banded, loferitic, dolomitic (dredge 11), consisting of thin algal layers alternating with irregular laminae of fine-grained peloidal-bioclastic packstones with micritic matrix commonly recrystallized into sparite (Fig. 5a). The allochems are represented by small rounded micritic grains, arenaceous forams,

Table 1. Dredges, Camera Stations and Cores

Station Depth (m)	Lat./Long. Location	Lithology	Age	Facies
35,450 Dredge 1 3,494-2,690	36°05.1′N-15°43.2′E to 36°10.8′N-15°42.4′E	1 rounded block of olive-gray, silty, dolomitic marlstone 1 fragment of carbonate breccia with 1 fresh fracture surface (broken off from outcrop) and other surface bored and encrusted by serpulids and coated by Mn. Breccia consists of	Late Tortonian	Hemipelagic
		clast: pinkish crinoidal limestone	Jurassic?	Condensed (hemipelagic)
		matrix: green dolomite	Tertiary	
35,451 Dredge 2 3,027-2,840	36°07.7′N-15°44.9E Malta E Escarpment, lower steep slope (north promontory of canyon)	1 chip of whitish, porous, limestone breccia	Messinian?	
		2 chips of green dolomite recovered in dredge bag and small chips imbedded in lead pig	Tertiary	
35,452 Dredge 3 3,255	36°07.3′N-15°44.2′E to 36°06.0′N-15°45.3′E Malta E Escarpment, lower steep slope (north promontory of canyon)	Lost dredge		
35,453 Gravity Core 1 2,885	36°08.8′N-15°35.7′E Malta E Escarpment, lower slope (north side of canyon)	Yellowish and olive-gray silty marl (40cm)	Quaternary N22	
		Olive-gray dolomite embedded as small chips in marl	Messinian?	
35,454 Gravity Core 2 2,534	36°08.6′N-15°35.0′E Malta E Escarpment, middle slope (north side of canyon)	Light gray to yellow, semilithified dolomitic marl (core catcher only)	Early Messinian NN11	
35,455 Gravity Core 3 2,457	36°09.2′N-15°34.9′E Malta E Escarpment, middle slope (north side of canyon)	Light-gray to yellow limestone rubble with Mn crust on top and dark marl with chips of semilithified marl (14 cm); in core catcher, olive, semilithified dolomitic marl	Early Messinian NN11	
35,456 Gravity Core 4 2,476	36°08.8′N-15°34.3′E Malta E Escarpment, middle slope (north side of canyon)	Olive marl with rare dark silty laminae (20cm)	Quaternary N22	
35,457 Camera 1 2,381	36°08.2′N-15°35.0′E to 36°07.5′N-15°34.7′E Malta E Escarpment			
35,458 Gravity Core 5 2,480	36°10.0′N-15°35.2′E Malta E Escarpment, middle slope (north side of canyon)	Olive to gray-greenish marl (20 cm); in core catcher, tephra	Quaternary N22	
35,459 Gravity Core 6 3,590	36°05.3′N-15°45.4′E Malta E Escarpment, near base of canyon	Gray to yellow marl with silty-sandy laminae (45cm)	Quaternary N22	

(Continued on next page)

Table 1. Continued

Station Depth (m)	Lat./Long. Location	Lithology	Age	Facies
35,460 Gravity Core 7 2,900	36°06.8′N-15°44.5′E Malta E Escarpment, near base of canyon	Pale yellow calcareous ooze with lumps of indurated chalk (core catcher only)	Early Zanclean MP1 (?) NN12	
35,461 Camera 2	36°05.4′N-15°45.6′E Malta E Escarpment			
35,462 Piston Core 1 3,431	36°05.7′N-15°44.2′E Malta E Escarpment, near base of canyon	Light olive-gray marl with some silty layers (44cm)	Quaternary N22	
35,481 Dredge 4 2,112-1,885	35°57.7′N-15°43.9′E Malta E Escarpment (south promontory of canyon	1 small fragment of Mn-coated, indurated marl with one fresh surface	Quaternary N22	Hemipelagic
		Gray mud		
35,482 Dredge 5 2,786-1,958	35°57.3′N-15°40.9′E Malta E Escarpment (south promontory of canyon)	Talus elements:		
		2 blocks and 5 pieces of vesicular basalts	Late Cretaceous	
		12 pieces of hyaloclastites	Late Cretaceous	
		2 boulders and some tens of pieces of volcaniclastic breccia associated with red marls	Late Cretaceous	Basinal proximal resediments (debris flows) with neritic, pelagic, and volcanic elements
		1 boulder and 20 cobbles-pebbles of red marl and silty marlstone locally color mottled by bioturbation or faintly laminated	Late Cretaceous	Basinal resediments with pelagic materials and terrigenous - volcanic aggregate
		2 fragments of white calcarenite	Eocene	Coarse-grained resediments with shallow-water and subordinate pelagic material
		1 fragment of white limestone	Eocene	Shallow water
		fragments of light-cream porous calcarenite	Eocene-Oligocene?	Basinal resediments with neritic and pelagic material
		2 fragments of green-to-pink banded dolomitized limestones with burrows and borings filled with several generations of sediment. Fragments show 1 fresh surface (broken from outcrop) and other surfaces encrusted by serpulids and coated by Mn film	Tertiary?	Hardground
		Yellowish marl	Late Pliocene MPL 6	Hemipelagic
		Gray marl		Hemipelagic
		25 pieces of solitary corals; pieces of large bivalves, gastropods, and bone materials		
35,483 Dredge 6 2,653-1,885	35°58.8′N-15°44.1′E Malta E Escarpment (south promontory of canyon)	2 fragments of light-cream porous calcarenite with 1 surface coated by Mn film	Late Oligocene	Basinal proximal resediments with pelagic and shallow-water material
		2 small fragments of manganese crust		
		1 fragment of marlstone		

(Continued on next page)

Table 1. Continued

Station Depth (m)	Lat./Long. Location	Lithology	Age	Facies
35,484 Dredge 7 3,200-2,200	36°01.4′N-15°45.5′E Malta E Escarpment (south promontory of canyon	Lost dredge		
35,485 Dredge 8 2,534-2,404	36°24.9′N-15°36.1′E Malta NE Escarpment, lower steep slope	1 fragment of irregularly (pink and green) banded dolomite with borings filled by several generations of sediment. Fragment shows 1 broken-off surface; other surface encrusted by serpulids	Tertiary?	Hardground
		1 piece of green dolomite bored and encrusted by serpulids	Tertiary	
		2 small pieces of green and broken marls coated by thin manganese film	Early Pliocene MPL 3	Hemipelagic
35,486 Dredge 9 2,476-2,400	36°26.1′N-15°36.4′E Malta NE Escarpment, lower steep slope	1 piece of light-cream calcarenite	Late Triassic	Shallow water
		Chips imbedded in lead pig, consisting of green dolomite	Tertiary	
		white limestone	Early-middle Liassic	Shallow-water
			Liassic	Basinal resediment with neritic material
		whitish limestone		
35,487 Dredge 10 3,255-2,482	36°26.3′N-15°36.3′E Malta NE Escarpment, lower steep slope	Dredge empty		
35,488 Dredge 11 3,255	36°25.5′N-15°37.0′E to 36°25.0′N-15°38.2′E Malta NE Escarpment, base of lower steep slope	1 fragment of white-and-cream banded loferitic limestone with borings and small fissures filled by several generations of sediment	Late Triassic	Shallow-water
		3 small pieces of white algal limestone	Late Triassic	Shallow-water
35,489 Camera 4 3,450	36°27.6′N-15°36.1′E to 36°27.2′N-15°37.1′E Malta NE Escarpment			
35,490 Dredge 12 3,450-2,807	36°27.5′N-15°35.4′E to 36°26.5′N-15°35.2′E Malta NE Escarpment, lower steep slope	6 small fragments of white loferitic limestone broken from outcrop	Late Triassic	Shallow-water
		1 chip of light-cream limestone broken off from outcrop	Early-middle Liassic	Shallow-water
35,491 Dredge 13 2,180-1,804	36°26.0′N-15°34.2′E to 36°26.7′N-15°32.8′E Malta NE Escarpment, lower-middle part of slope	2 chips of Mn crust	Early Pleistocene	Hemipelagic
		Pale brown mud from outer part of dredge		
		Light-olive mud on pig	Quaternary N22	Hemipelagic

(Continued on next page)

Table 1. Continued

Station Depth (m)	Lat./Long. Location	Lithology	Age	Facies
35,492 Dredge 14 1,881	36°24.01′N-15°35.2′E Malta NE Escarpment, middle slope	Lost dredge		
35,493 Dredge 15 2,038-1,958	36°24.3′N-15°35.5′E to 36°24.8′N-15°35.0′E Malta NE Escarpment, upper part of lower steep slope	5 boulders and 50 small pieces of deeply weathered vesicular basalts and volcanic breccia with white and pink calcilutite matrix. Lithotypes show borings and several generations of fractures filled with different kinds of sediment		
		18 fragments of greenish, marly limestone encrusted by serpulids and corals		
		Pale broken mud	Quaternary N22	Hemipelagic
		3 bags of solitary corals		
35,494 Dredge 16 3,275-2,904	36°26.0′N-15°36.4′E to 36°25.8′N-15°35.3′E Malta NE Escarpment, lower steep slope	12 small fragments with fresh surfaces of white loferitic limestone displaying small sedimentary dikes filled by Tertiary green dolomite	Late Triassic	Shallow-water
		1 small chip of dark-gray dolomite		
		2 small fragments of pumice		
35,495 Dredge 17 1,939-1,500	37°14.9′N-15°24.4′E to 37°14.7′N-15°20.8′E Siracusa Escarpment, lower slope	Gray-green marl	Quaternary	Hemipelagic
35,496 Dredge 18 1,440-1,364	37°12.4′N-15°21.9′E to 37°12.0′N-15°22.4′E Siracusa Escarpment, "Cesare Augusto" Canyon	Talus elements: Several pieces of gray limestone	Late Triassic	Shallow-water
		Several pieces of light-cream and whitish limestone	Early-middle Liassic	Shallow-water
		2 chips of white limestone with small fractures filled by red sediment	Jurassic	?
		Pieces of yellowish, poorly lithified calcarenite and 1 chip of white limestone	Latest Oligocene — Early Miocene	Basinal proximal resediments with shallow-water and pelagic material
		Pieces and blocks of basalt		
		1 piece of volcanic breccia		
		1 piece of limestone breccia broken from outcrop	Tertiary?	
		3 small fragments of "pauelina"		
		Solitary corals and pelecypods		
		Yellowish marl	Middle Miocene	Hemipelagic
		Gray mud	Quaternary N22	Hemipelagic
35,497 Dredge 19 1,987-1,045	37°12.4′N-15°21.9′E to 37°15′N-15°26.3′E Siracusa Escarpment, "Cesare Augusto" Canyon	Marl and silty marl		

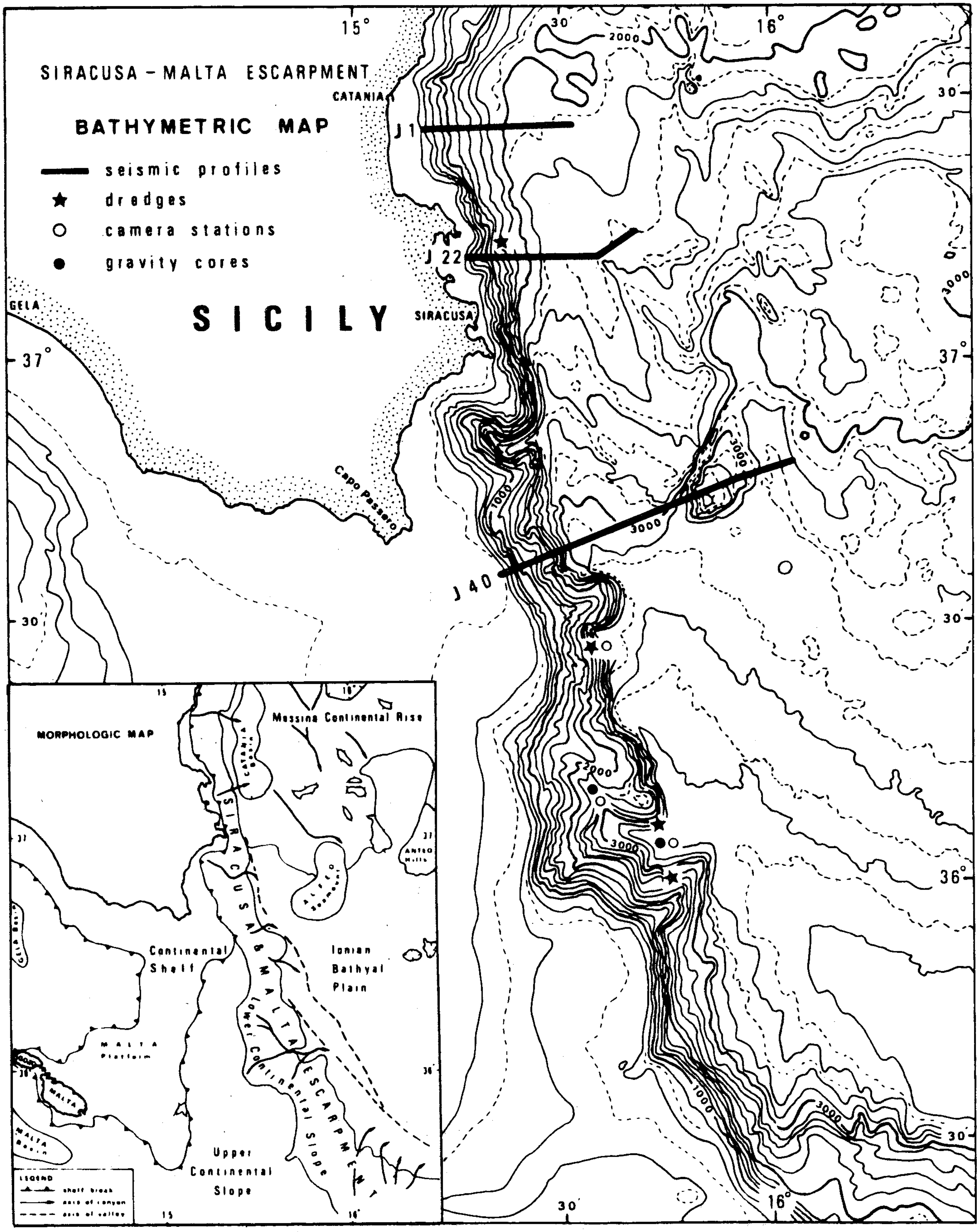


FIG. 2—Bathymetric map of Siracusa-Malta Escarpment area (after Morelli et al, 1975). Mercator projection (38°N lat.). Contour interval 200 m (solid lines) and 100 m (dashed lines).

small ostacods, and micritized and unidentified bioclasts. Laminoid fenestrae are filled with blocky calcite as well as with carbonate-silt internal sediment. Age: Norian (by microfacies correlation with Gela Formation on land, see Siracusa 1 well, Fig. 13). Environment: shallow-water carbonate platform, intertidal zone.

b. Limestones, white, algal (dredge 11), with recrystallized *Thaumatoporella* remains and rare scattered arenaceous forams associated with thin-shelled

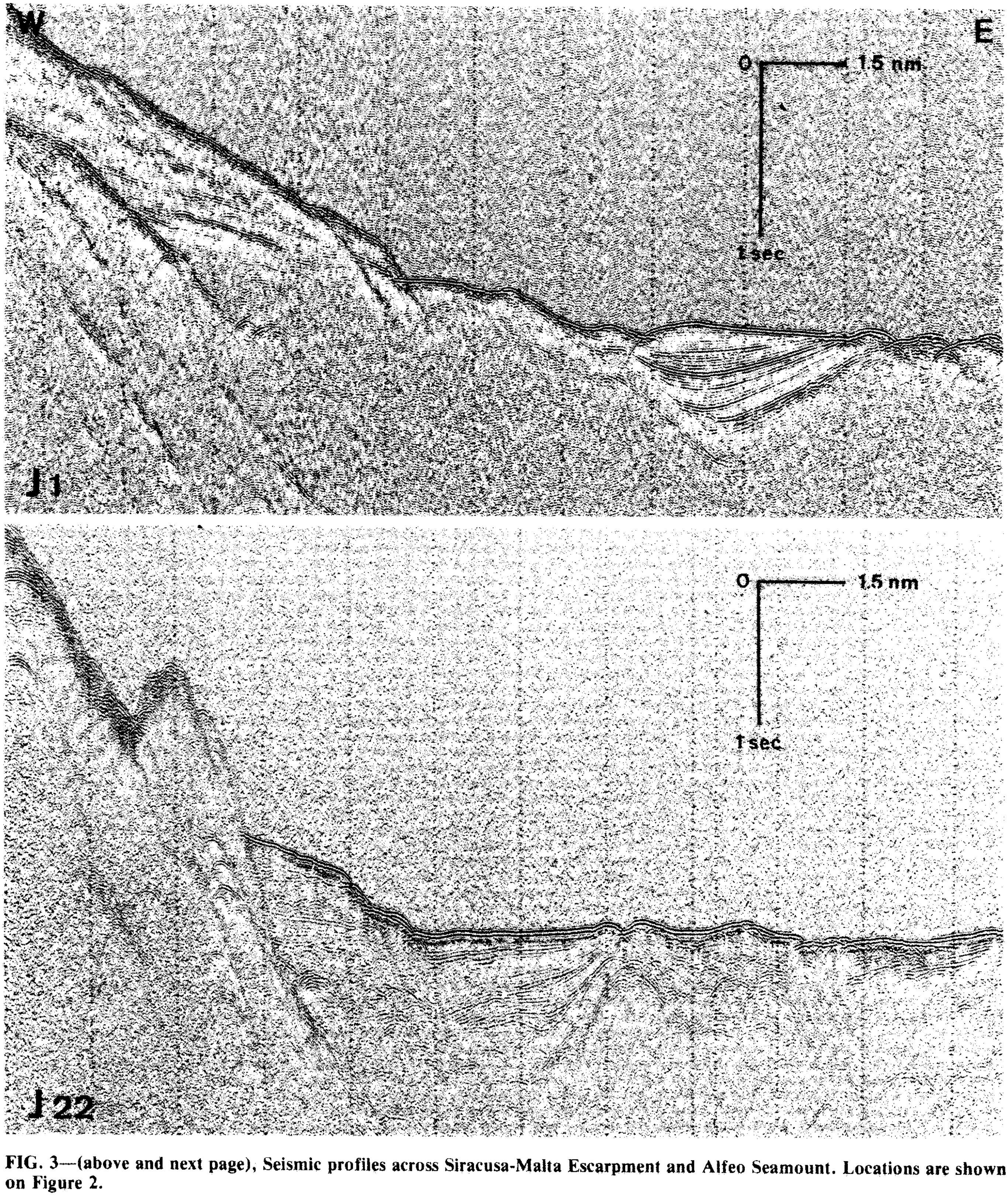


FIG. 3—(above and next page), Seismic profiles across Siracusa-Malta Escarpment and Alfeo Seamount. Locations are shown on Figure 2.

ostracods. This lithotype is characterized by the presence of large irregular fenestrae commonly filled with drusy calcite (Fig. 5d). Age: Rhaetian (by microfacies correlation with upper part of Gela Formation, see Siracusa 1 and Melilli 1 wells, Fig. 11). Environment: shallow-water carbonate platform, intertidal zone.

c. Limestones, white, loferitic (dredges 12 and 16), consisting of bioclastic packstones with *Thaumatoporella, Involutina* spp., and *Glomospira,* associated with rare pelecypods. Age: Rhaetian. Environment: shallow-water carbonate platform, intertidal zone.

d. Calcarenite, light-cream (dredge 9), consisting of bioclastic packstone (Fig. 5b) with *Triasina hantkeni, Triasina* sp., *Involutina* Gr. *sinuosa, Frondicularia* cf. *woodwardi, Trochammina,* remains of *Thaumatoporella,* gastropods, and pelecypods, associated with rare ostracods, *Aeolisaccus*-like forms, and coprolites. Most of the *Triasina* and *Involutina* specimens are characteristically recrystallized into microsparite. Age: Rhaetian. Environment: shallow-water carbonate platform.

e. Limestones, gray (dredge 18), consisting of recrystallized bioclastic packstones (Fig. 5c) and wackestones with large fragments of calcareous algae (Cyanophyceae, Solenoporaceae, *Thaumatoporella, (?)Lowcenipora),* rounded intraclasts, lumps and small oncoids, arenaceous forams (Trochamminidae, Ataxophragmiidae, Ammodiscidae, small Textulariidae, and Lituolidae), fragments of large pelecypods and gastropods, rare ostracods, small *Frondicularia,* and scattered *Involutina* and *Triasina. Involutina* and *Triasina* tests are almost completely recrystallized into microsparite. Sporadic irregular fenestrae may be only partly filled with drusy calcite mosaic. Age: Rhaetian. Environment: shallow-water carbonate platform.

Jurassic

Jurassic rocks were recovered in dredging stations 1 (Malta E transect), 9, 12 (Malta NE transect), and in dredge 18 from Siracusa Escarpment. As in the Triassic rocks, samples were collected from fresh outcrops only along the Malta Escarpment. The following basic lithologies were recognized:

a. Limestones, white and light cream (dredges 9, 12, 18), texturally referable to:

1. Peloidal wackestones with bored and micritized large intraclasts, algal-coated bioclasts, rare and small Lagenidae, arenaceous forams, and ostracods.
2. Oncoidal packstones/grainstones with lumps and micritized bioclasts; some algae and arenaceous forams are still recognizable; large irregular fenestrae are present locally.
3. Bioclastic packstones/grainstones with large fragments of algae (Solenoporaceae, Cyanophyceae, and *Thaumatoporella),* gastropods and bivalves, associated with arenaceous forams (Textulariidae, Ataxophragmiidae, Ammodiscidae, Lituolidae), rare Lagenidae, and *Aeolisaccus* (Fig. 5e); bioclasts are intensively micritized and in some places coated by thin algal rinds.
4. Fine-grained ooidal packstones/grainstones with small and badly preserved arenaceous forams (Textulariidae and Ataxophragmiidae), *Aeolisaccus.* Micrite matrix is commonly recrystallized into sparite or microsparite. Most bioclasts appear entirely micritized.
5. Peloidal wackestones with rare arenaceous forams (Textulariidae and Ataxophragmiidae), Lagenidae, small ostracods, and scattered fragments of *Thaumatoporella.* Thin parallel fenestrae.

Age, early-middle Liassic (by microfacies correlation with Siracusa Formation on land, see Melilli 1 and Siracusa 1 wells, Fig. 13). Environment, shallow-water carbonate platform.

b. Limestone, white, with small fractures filled by red calcareous sediment (dredge 18). White limestone is fragment of Liassic

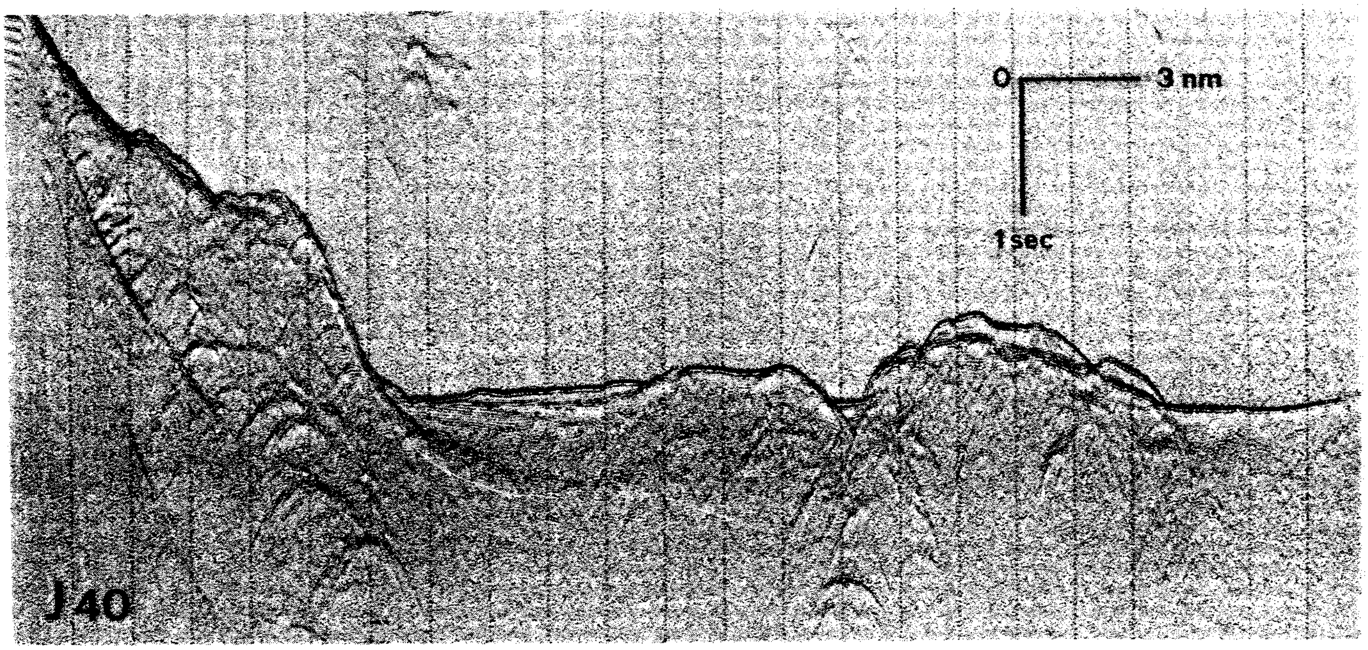


FIG. 3 (Continued).

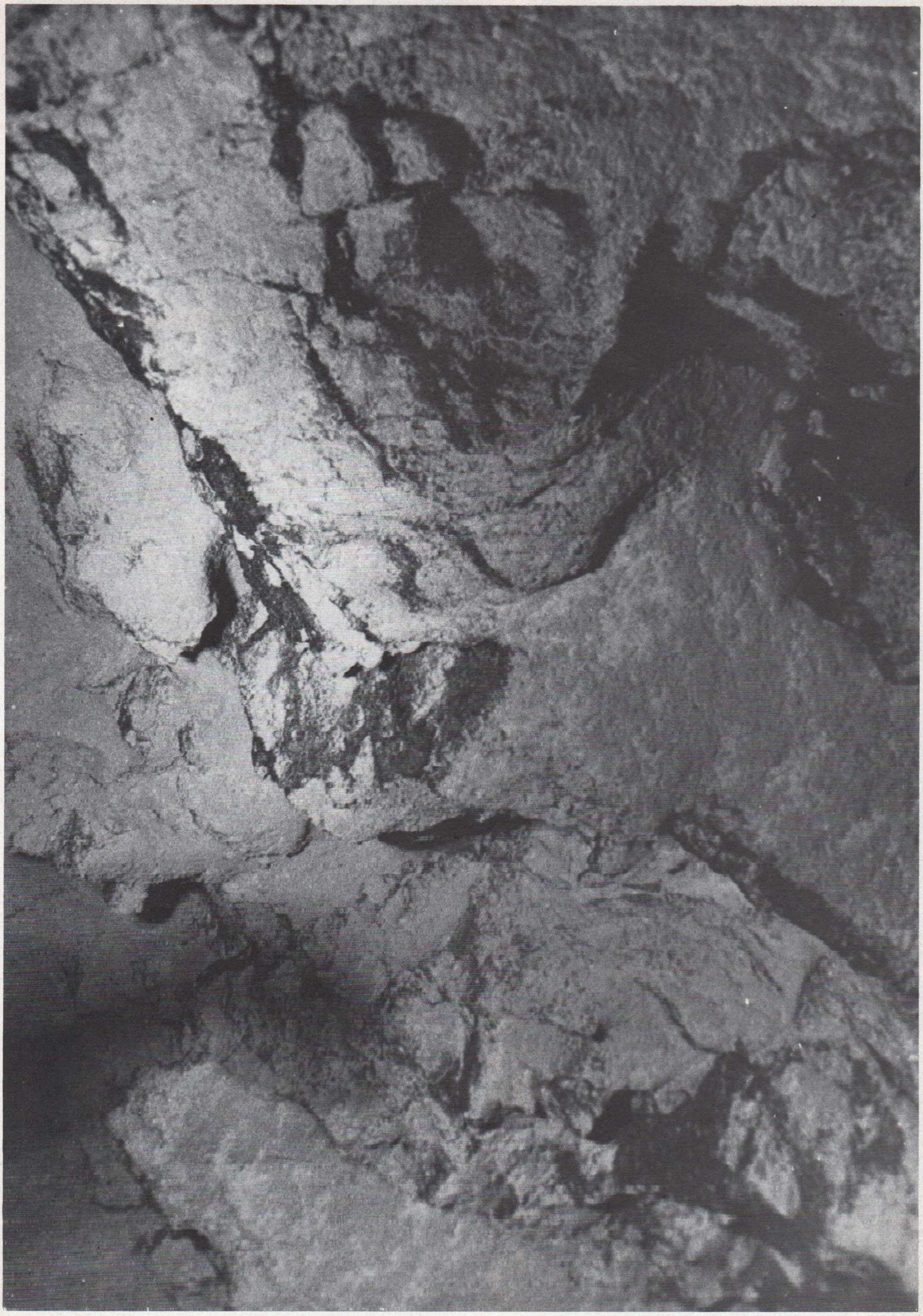
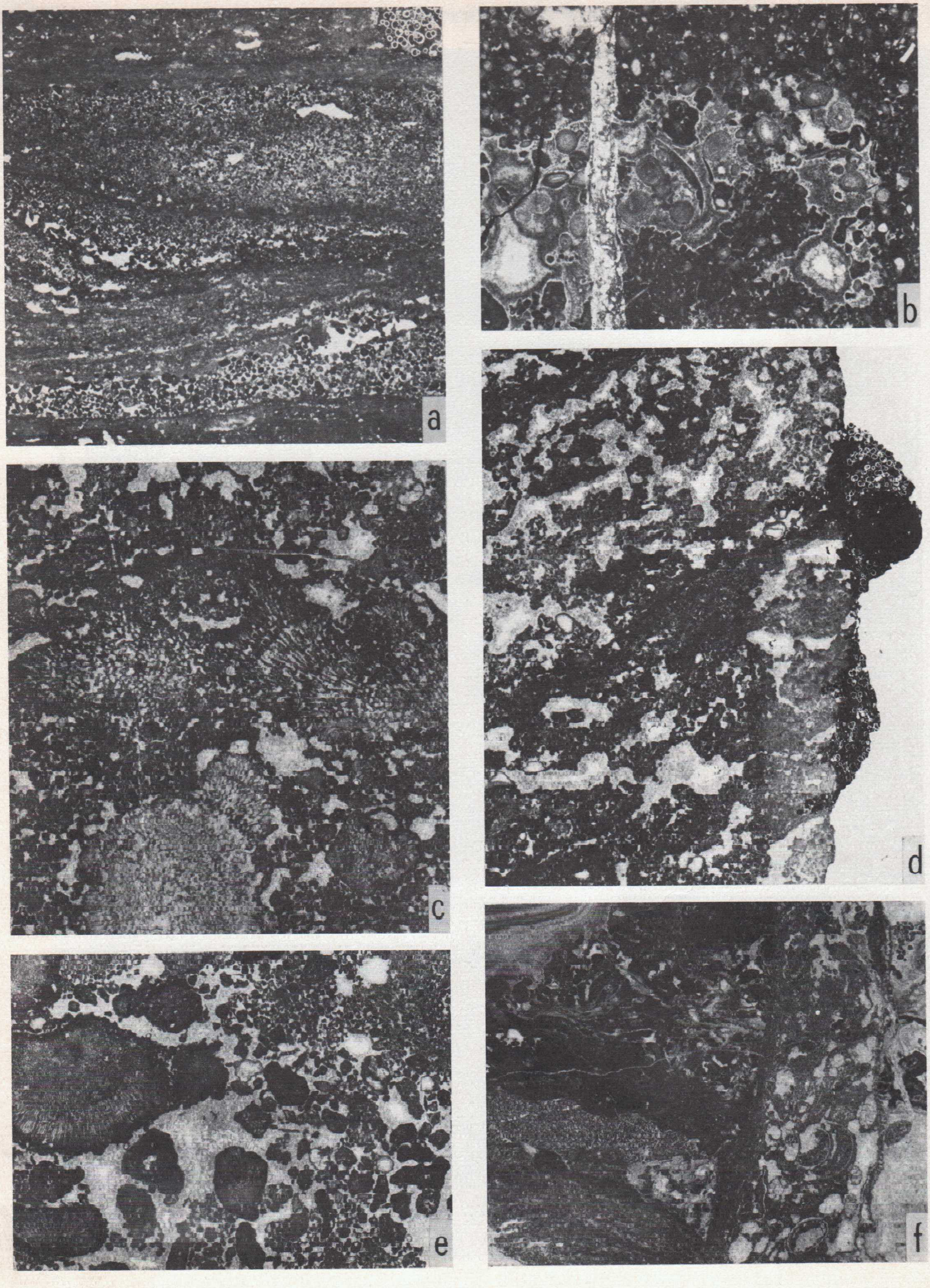


FIG. 4—Rocks (probably Upper Triassic–Lower Jurassic shallow-water limestones) exposed on Malta Escarpment at 3,450 m depth. Station 35,489, camera station 4. Area pictured is about 2 m across.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d
e
f

shallow-water limestone with "microkarst" structures (Fig. 5f). Complex cavity system is filled with micrite sediment, chemically precipitated calcite, and/or secondarily introduced material. Latter consists of fine-grained bioclastic packstone/grainstone with arenaceous forams, *Aeolisaccus,* and small rounded micritic grains, as well as of bioclastic wackestone with floating large intraclasts. Red sediment filling fractures is "clotted" micrite with fragments of ammonite skeletons and of bioclastic packstone with *Thaumatoporella* and arenaceous forams. Red hemipelagic sediments of Middle-Late Jurassic age filling fractures in Liassic shallow-water limestones are common in southeastern Sicily and are related to early phase of synsedimentary tectonics responsible for foundering and sinking of shallow-water platforms.

c. Limestone, whitish (dredge 9), consisting of partly recrystallized bioclastic wackestone/packstone with arenaceous forams (Ammodiscidae, Ataxophragmiidae, Textulariidae), algal fragments (Dasycladaceae), crinoidal plates, bivalves, Lagenidae, and ostracods. Micrite matrix in some places is recrystallized into sparite. Age: Liassic (by microfacies correlation with Siracusa Formation on land, see Siracusa well 1, Fig. 13). By the sedimentary texture and by comparison with previously mentioned land record, this deposit is interpreted as coarse-grained, basinal, resedimented rock.

d. Limestone, pinkish, crinoidal (dredge 1), consisting of recrystallized crinoidal packstone or grainstone with shadowed arenaceous forams and molds of small gastropods. Echinoderm particles (crinoidal columnals and plates, echinoid spines) are enclosed in syntaxial cement rim. This lithotype forms clasts in monogenic breccia in which matrix is composed of green dolomitized calcilutite of Tertiary age. Age of these clasts is probably Jurassic, by analogy with Jurassic condensed deposits characterizing submarine highs in Sicily and in all peri-Adriatic domains (Bernoulli et al, 1979).

Cretaceous

Upper Cretaceous sediments were recovered from dredging station 5 on the Malta E transect. They include boulders and pebbles of red mottled marls and silty marlstones strictly associated with volcaniclastic breccias.

The red marls are bioclastic wackestones with abundant volcanogenic silt and sand (volcanic glass, feldspar, pyroxene, biotite); minor amounts of terrigenous silt (quartz, white mica) are also present. The samples studied yield a rich assemblage of planktonic and subordinate benthic forams, *Pithonella,* sponge spicules, and ostracods, belonging to the middle Campanian (*Globotruncana elevata* Zone). Species recorded include *Globotruncana arca, G. elevata, G. fornicata, G. bulloides, G. linneiana, G. lapparenti, G. tricarinata, G. calciformis, Globigerinelloides involutus, G. bollii, G. alvarezi, Pseudotextularia elegans, Heterohelix reussi,* etc (Fig. 6). The breccias are composed of fragments of vesicular basalts, volcanic glass, altered phenocrysts of plagioclase and pyroxene, as well as shallow-water skeletal material (*Omphalocyclus,* rudistid fragments, *Siderolites, Orbiotoides,* Dasycladaceae, Corallinaceae, Squamariaceae, large bivalves and gastropods, bored echinoderm particles, and Bryozoa) and soft clasts of the previously described red marls (Fig. 7). The matrix of the breccia is a pale-red micrite locally recrystallized into a blocky calcite mosaic. Late diagenetic zeolites (phillipsite) commonly form rosettes of crystals around larger volcanic clasts. A large dredged block shows that the breccia is interlayered in the red marls. The breccia, which displays massive poor sorting with the largest elements set at random, is interpreted as deposited by debris flow.

Eocene

Rounded fragments of Eocene rocks were recovered in dredging station 5. Lithologies include:

a. Limestone, white, consisting of coarse-grained bioclastic packstone/grainstone with corals, algae (Corallinaceae and *Ethelia alba),* large bivalves, echinoid spines, gastropods, byrozoans, rotalids, miliolids, textularids, and skeletal debris (Fig. 8). The rock displays depositional vugs and moldic cavities geopetally filled with peloidal micrite or with fine-grained bioclastic wackestone; sheltering effects are also common. This lithology is comparable with some Eocene shallow-water limestones of southeastern Sicily, deposited on top of volcanic seamounts which reached the photic zone.

b. Calcarenites, white, consisting

FIG. 5—Microfacies of Upper Triassic–Lower Jurassic carbonates of Siracusa-Malta Escarpment.

a. Upper Triassic loferitic, dolomitic limestone from Malta NE Escarpment, dredge 11 (3,255 m). Thin algal layers alternate with irregular laminae of fine-grained peloidal-bioclastic packstones. Sample is encrusted (right upper corner) by Quaternary bioclastic packstone with *Globigerina* and *Globorotalia.* Thin section, ×5.

b. Rhaetian shallow-water calcarenite from Malta NE Escarpment, dredge 9 (2,476 to 2,400 m). Bioclastic packstone with well-preserved *Triasina* and recrystallized smaller *Involutina.* Thin section, ×5.

c. Rhaetian shallow-water limestone from Siracusa Escarpment, dredge 18 (1,440 to 1,364 m). Bioclastic packstone with large fragments of calcareous algae (*Lowcenipora(?)* and *Thaumatoporella*) and badly preserved arenaceous forams. Thin section, ×4.

d. Upper Triassic limestone from Malta NE Escarpment, dredge 11 (3,255 m). Algal loferite with *Thaumatoporella.* Sample is encrusted by bored Quaternary bioclastic packstone with *Globigerina* and *Globorotalia.* Thin section, ×1.

e. Lower-middle Liassic shallow-water limestone from Siracusa Escarpment, dredge 18 (1,440 to 1,364 m). Bioclastic packstone/grainstone with fragments of calcareous algae and arenaceous forams. Thin section, ×3.

f. Liassic shallow-water limestone with fracture (right side of photo) filled by hemipelagic peloidal calcareous sediment with ammonite remains. Thin section, ×3. Siracusa Escarpment, dredge 18 (1,440 to 1,364 m).

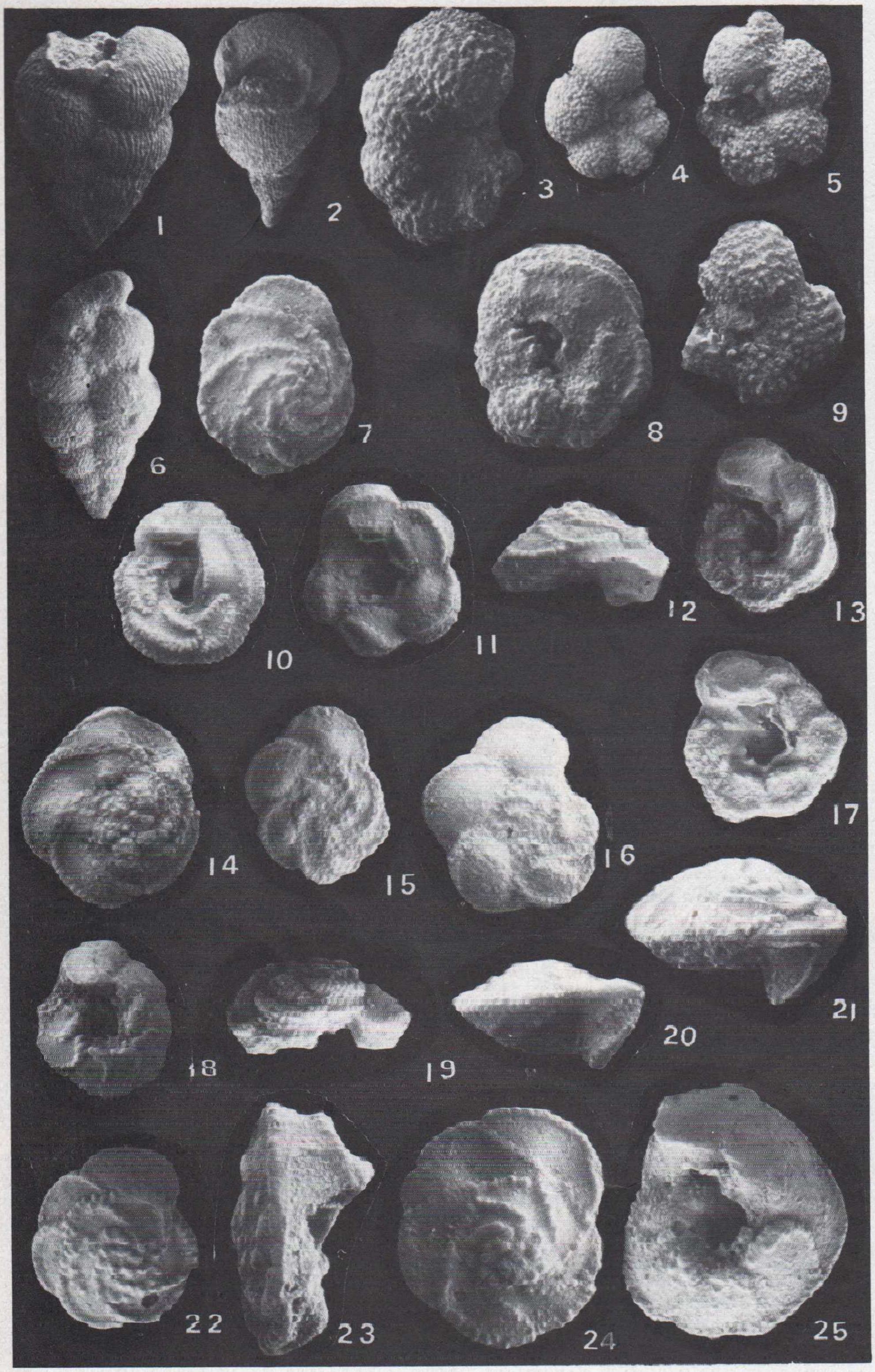

FIG. 6—Late Cretaceous, Campanian Stage, *Globotruncana elevata* Zone, planktonic Foraminifera from red marls, dredging station 5 (2,786 to 1,958 m), lithology B, Malta Escarpment, E transect. SEM photographs.

1, 2, *Pseudotextularia elegans* (Rzehak), × 50.

3, *Globigerinelloides alvarezi* (Eternod Olvera), × 75.

4, *Globigerinelloides* cf. *bollii* Pessagno, × 75.

5, *Globigerinelloides involutus* (White), × 75.

6, *Heterohelix* sp., × 50.

7, 18, 21, *Globotruncana stuartiformis* Dalbiez, × 25.

8, 14, 19, *Globotruncana fornicata* Plummer, × 25.

9, *Globigerinelloides* sp., × 75.

10, 12, *Globotruncana arca* (Cushman), × 25.

11, 13, 15, *Globotruncana linneiana* (d'Orbigny), × 25.

16, *Globotruncana bulloides* Vogler, × 25.

17, *Globotruncana lapparenti* (Brotzen), × 25.

20, 24, 25, *Globotruncana elevata* (Brotzen), × 25.

22, *Globotruncana rosetta* (Carsey), × 25.

23, *Globotruncana tricarinata* Quereau, × 25.

of bioclastic packstones/wackestones with algae (mainly Corallinaceae), bryozoans, corals, shell fragments, echinoid spines, miliolids, rotalids, *Discocyclina,* and subordinate planktonic forams (globigerinids, *Globorotalia).* This lithology, known also from drilling on land (e.g., Melilli well 1, Fig. 13), is interpreted as a proximal basinal resediment rich in shallow-water materials.

Eocene-?Oligocene

Light-cream calcarenites of Eocene-?Oligocene age were dredged in station 5. They consist of bioclastic wackestone/packstones with micrite matrix patchily recrystallized into microsparite (Fig. 9). Bioclasts are represented by globigerinids, heterohelicids, *Catapsidrax, Globorotalia opima nana, Globorotaliodes, Pseudohastigerina micra,* rotalids, arenaceous forams, rare *Discocyclina,* echinoderms, and pelecypods. These calcarenites are comparable with the lithologies of the lower part of the Ragusa Formation widely exposed in southern Sicily, and are interpreted as basinal resediments.

Oligocene-?Lower Miocene

Uppermost Oligocene rocks were broken off from fresh outcrop in dredging station 6. They are represented by light-cream porous calcarenites consisting of bioclastic wackestones/packstones with *Lepidocyclina, Amphistegina, Heterostegina, Operculina,* smaller benthic forams, rotalids, nodosarids, bryozoans, serpulids, echinodermal particles, algal fragments (Corallinaceae), and subordinate planktonic forams (Fig. 10). The porous texture is due to the presence of unfilled foram tests and to late diagenetic processes involving both matrix and allochems. Scattered dolomite rhombs are also developed. These calcarenites are comparable to the most common lithotypes of the Ragusa Formation, and are interpreted as basinal resediments.

Uppermost Oligocene-?lower Miocene rocks were recovered in dredge 18 from a talus slope. They include yellowish, poorly lithified calcarenites and white limestones consisting of bioclastic packstones with large fragments of bryozoans, Corallinaceae (Melobesioideae and Corallinaceae), corals, echinodermal particles, probable *Miogypsina,* nummulites, *Amphistegina, Heterostegina, Operculina,* and rare scattered globigerinids and *Globorotalia.* These lithologies are strictly comparable to some lithotypes characterizing the upper part of the Ragusa Formation, and are interpreted as basinal proximal resediments.

Neogene

Neogene sediments, well dated by microfossil contents, include:

a. Marls, olive-gray, silty, recovered at the base of Malta E lower slope in dredge 1. These marls could be part of a sediment drape on top of the previously described Mesozoic-Tertiary rocks, or a talus block. The marls are hemipelagic, and indicative of open-marine environment with bathyal depth. Age: late Tortonian, foram Zone 16 and nannofossil Zone NN 11 (Cita et al, 1979).

b. Marls, yellowish, hemipelagic (dredge 18), with planktonic and subordinate benthic forams of middle Miocene age.

c. Marls, green and brown hemipelagic (dredge 8), with planktonic and subordinate benthic forams of early Pliocene age (MPL 3 Zone). The marls also yield reworked *Globotruncana (G. linneiana* and *G. elevata).* Lower Pliocene whitish marls ("Trubi" facies) have been recovered from gravity core 7 on top of the lower slope in the Malta E transect (Cita et al, 1979).

d. Marls, yellowish, hemipelagic (dredge 5), with planktonic and subordinate benthic forams of late Pliocene age (MPL 6 Zone), also containing some reworked *Globotruncana.*

Fine-grained green dolomites have been recovered in several dredgings. They constitute the oldest filling of fractures in Triassic limestones (dredges 11 and 16, Fig. 11, and the matrix of carbonate breccias, dredge 1, Fig. 12). Green dolomites have also been recovered as single fragments broken from outcrops (dredges 2, 8, 9). The rock appears texturally homogeneous and consists of a mosaic of euhedral/subeuhedral dolomite rhombs ranging in size from 26 to 52 μ. Only a single ghost of a large planktonic foram (Fig. 10) and several spherical vugs probably representing molds of microfossils are preserved. The latter appear as voids less than 100 μ across, coated internally by a thin drusy dolomite rim. A few grains of glauconite and irregularly shaped aggregations of fine-grained iron oxides are scattered throughout the dolomite rhombs. The homogenous, fine-grained texture and the relic of the planktonic foram suggest that this rock results from dolomitization of an original hemipelagic calcilutite. The planktonic foram indicates undefined Tertiary age. The Messinian salinity crisis might be responsible for these dolomitization processes.

Irregularly green-to-pinkish, banded dolomites were recovered in dredges 5 and 8. The dolomites are discontinuous millimetric laminae of alternating dololutite and "clotted" dolomicrosparite/dolosparite. Rare ghosts of small arenaceous forams, ostracods, thin sponge spicules, globigerinids, and biogenic silt, as well as molds of microfossils, are preserved in the dololutite and dolomicrosparite layers. Subparallel laminoid fenestrae are developed in the dolosparite layers. They appear geopetally filled with dolomicrosparite, glauconite, and silty micrite containing biogenic ash and small feldspars. Irregularly interconnected small voids filled with dolosparite, iron oxides, and glauconite are also present in the dolomicrosparite layers. Both voids and fenestrae are lined by a rim of dolomite crystals. Sedimentary and diagenetic structures and fossil content suggest pervasive dolomitization phenomena superimposed on early lithified hemipelagic lime deposits probably forming hardgrounds. We think that in these deposits also the dolomitization occurred during the Messinian salinity crisis.

A chip of calcareous breccia was recovered from dredge 2. The elements have dimensions ranging from a few millimeters to 1 cm; shapes vary from angular to rounded. They consist of limestones with algal remains (originally algal tufa?) and of wholly recrystallized limestones commonly displaying solution porosity. The matrix is a mixture of silty/sandy-sized dolomite crystals, angular grains of quartz and feldspars, and small aggregates of iron minerals. A similar lithology was recorded in gravity cores 2 and 3. Here the breccia forms a crust which overlies dolomitic marls yielding forams of Messinian age (*Globorotalia conomiozea* Zone, Cita et al, 1979).

Several boulders and pebbles of weathered vesicular lavas and volcanic breccias of probable Tertiary age were recovered from dredges 15 and 18. The breccias display at least four generations of filling and show close analogies with upper Miocene-lower Pliocene volcanic breccias recovered from the Tyrrhenian Sea at Site 373A (Bernoulli et al, 1978). This volcanism may be related to the Monti Iblei activity in southeastern Sicily, but geochemistry of the collected samples has not yet been studied.

DISCUSSION

The Mesozoic and Paleogene-?lower Miocene rocks dredged along the Malta-Siracusa Escarpment may be directly correlated with coeval deposits exposed on land or penetrated by commercial boreholes in southeastern Sicily (Fig. 13; Patacca et al, 1979). In this region, the sedimentary sequences distinguish, from Rhaetian to earliest Cretaceous time, two paleogeographic domains: the Ragusa belt and the Siracusa belt (Fig. 11). From the Hauterivian, this differentiation disappeared and the whole area displays the same sedimentary characteristics.

In the Ragusa belt, the Upper Triassic-Lower Cretaceous sequence consists mainly of:

Limestones, white, loferitic (Norian, Gela Formation).

Dolomites and evaporites, brownish (Norian-Rhaetian, Naftia Formation).

Limestones, gray and brownish thinly laminated, dolomitic, and dolomites with black shale intercalations (Rhaetian, Noto Formation); they are interpreted as channelized deposits of tidal flats.

Limestones, gray-greenish, dolomitic, and marly, with black shale interbeds (Hettangian-Sinemurian, Streppenosa Formation), mostly deposited by turbidity currents. Intercalations of mafic volcanites are widely developed.

Limestones, light-gray, marly, with sporadic cherty nodules, interbedded with gray-greenish marls (Lotharingian-Pliensbachian, Modica Formation), interpreted as fine resediments mainly consisting of pelagic materials.

Marls with marly limestone intercalations followed by bedded cherty limestones and siliceous limestones (Toarcian-lower Tithonian, Buccheri Formation); they result from lower flow regime turbidity currents. Isolated volcanic edifices have also been recognized.

Limestones, white, cherty, with subordinate marly interlayers (upper Tithonian-Neocomian, Chiaramonte Formation), interpreted as fine basinal resediments.

In the Siracusa belt, the Upper Triassic-Lower Cretaceous sequence mainly consists of:

Dolomites, white, loferitic, identical with the coeval deposits of the Ragusa belt (Norian, Gela Formation).

Dolomitic limestones, shallow-water, white (Rhaetian, Gela Formation).

Limestones, shallow-water, white (lower-middle Liassic, Siracusa Formation).

Marls, red, nodular, and marly limestones (Callovian-lower Tithonian, Buccheri Formation), representing (hemi)pelagic condensed sediments with common sedimentary gaps, deposited on submarine hills.

Limestones, red, nodular, followed by hemipelagic white cherty limestones (upper Tithonian-Neocomian, Chiaramonte Formation).

After the Neocomian, the Mesozoic sequence in southern Sicily is represented everywhere by basinal deposits consisting of:

Marls, gray-greenish mottled, with thin intercalations of marly limestones (Barremian-Albian, Hybla Formation).

Limestones, bedded, white, cherty, with volcanic intercalations (Albian-Maestrichtian, Amerillo Formation). Volcanic seamounts overlain by shallow-water rudistid limestones are locally developed.

The Tertiary deposits are poorly known. From the literature, the sequence consists of:

Calcarenites, cream, with sporadic cherty nodules and subordinate marly interlayers (Paleogene-middle Miocene, Ragusa Formation). Locally, on top and flanks of volcanic seamounts, shallow-water limestones and coarse-grained resediments with organic shallow-water components are developed (Eocene, Cozzo Cugni Formation; Oligocene-?lowermost Miocene, Grotta Calafarina Formation).

Marls, gray, and subordinate calcarenites (middle-upper Miocene, Tellaro Formation) followed by yellowish calcarenites and subordinate marls (upper Miocene, Palazzolo Formation).

Neogene volcanic activity is widespread in the Monti Iblei region.

The samples recovered from the Malta Escarpment (Fig. 14) correlate well with the land records. The dredged Mesozoic rocks display close analogies with the deposits of the Siracusa belt, with few exceptions.

The Upper Triassic and lower-middle Liassic shallow-water limestones dredged in the Malta and Siracusa belts are identical with the coeval carbonates of the Gela and Siracusa Formations drilled on land in the Siracusa belt.

The Liassic calcarenites recovered in dredging station 9 have their counterpart in calcarenites drilled along the margins of the Siracusa platform (e.g., Siracusa well 1, Fig. 13). They represent the eastward pinchout of the Modica Formation, and are interpreted as coarse-grained resediments accumulated at the base of fault scarps during the Early Jurassic tensional tectonics. This phase, which was responsible for the dissection and sinking of the Siracusa platform, is recorded also by the sedimentary dikes of ammonite-bearing limestones recovered in dredge station 18.

During the Middle and Late Jurassic and the Early Cretaceous, the Siracusa belt was characterized by condensed pelagic deposits, whereas basinal conditions with fairly high sedimentation rates persisted in the Ragusa belt. Rocks recovered from the Malta Escarpment during our 1978 exploration which possibly belong to this time

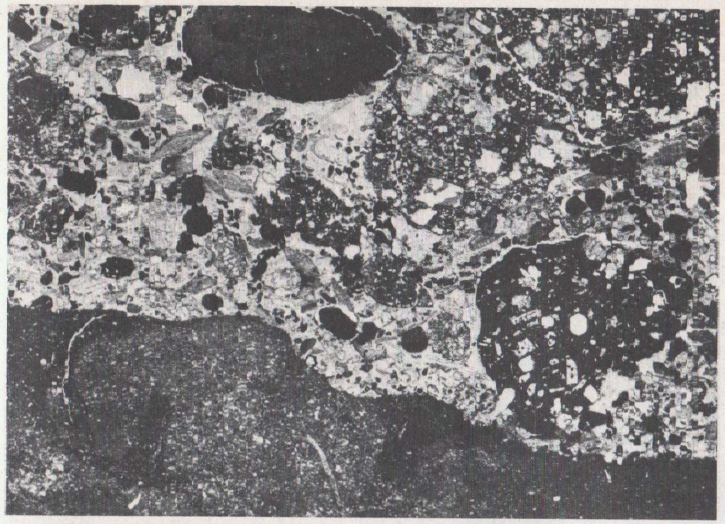

FIG. 7—Upper Cretaceous volcaniclastic breccia with *Siderolites* and other benthic bioclasts overlying, with sharp, erosional contact, layer of silty marl. Thin section, × 2. Malta E Escarpment, dredge 5 (2,786 to 1,958 m).

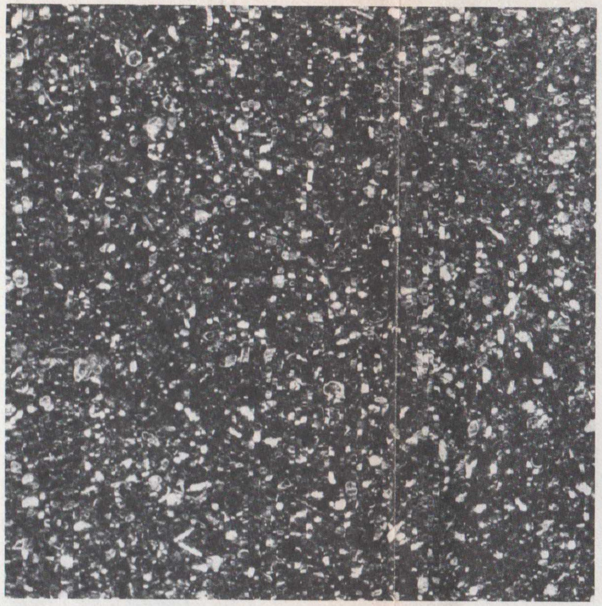

FIG. 9—Eocene calcarenite from Malta E Escarpment, dredge 5 (2,786 to 1,958 m). Bioclastic wackestone with *Globorotalia* and globigerinids. Thin section, × 9.

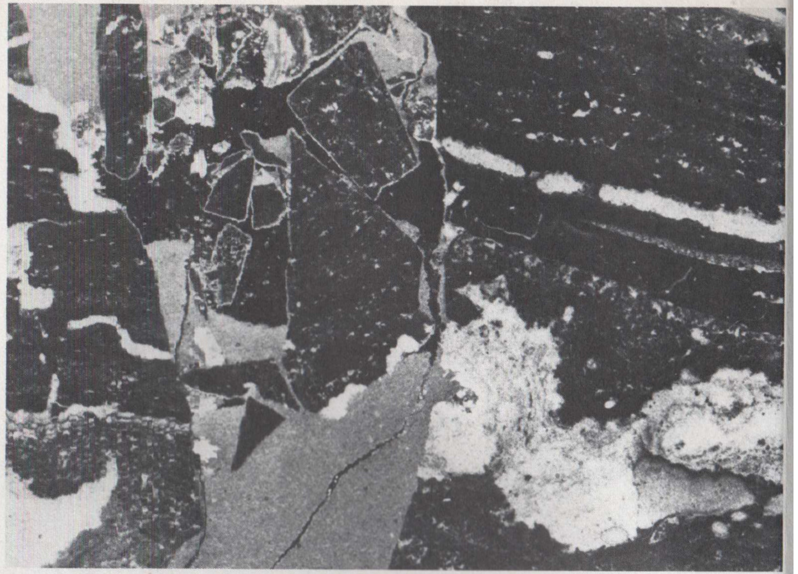

FIG. 11—Fracturing in Triassic limestone from Malta NE Escarpment, dredge 11 (3,255 m). Fissure is filled with at least two generations of sediments. Oldest filling is fine-grained dolosparite supporting collapsed angular fragments of Triassic limestone. Second is very fine-grained bioclastic wackestone with planktonic forams. Thin section, × 4.

FIG. 8—Eocene shallow-water limestone from Malta E Escarpment, dredge 5 (2,786 to 1,958 m). Bioclastic grainstone/packstone with corals, bryozoans, brachiopods, and shell debris. Thin section, × 4.

FIG. 10—Uppermost Oligocene calcarenite from Malta E Escarpment, dredge 6 (2,653 to 1,858 m). Bioclastic wackestone with *Lepidocyclina*, *Amphistegina*, and planktonic forams. Thin section, X 5.

FIG. 12–Monogenic breccia from Malta E Escarpment, dredge 1 (3,494 to 2,690 m). Clast on right is crinoidal packstone; matrix is dolomicrosparite with single ghost of planktonic foram. Thin section, × 15.

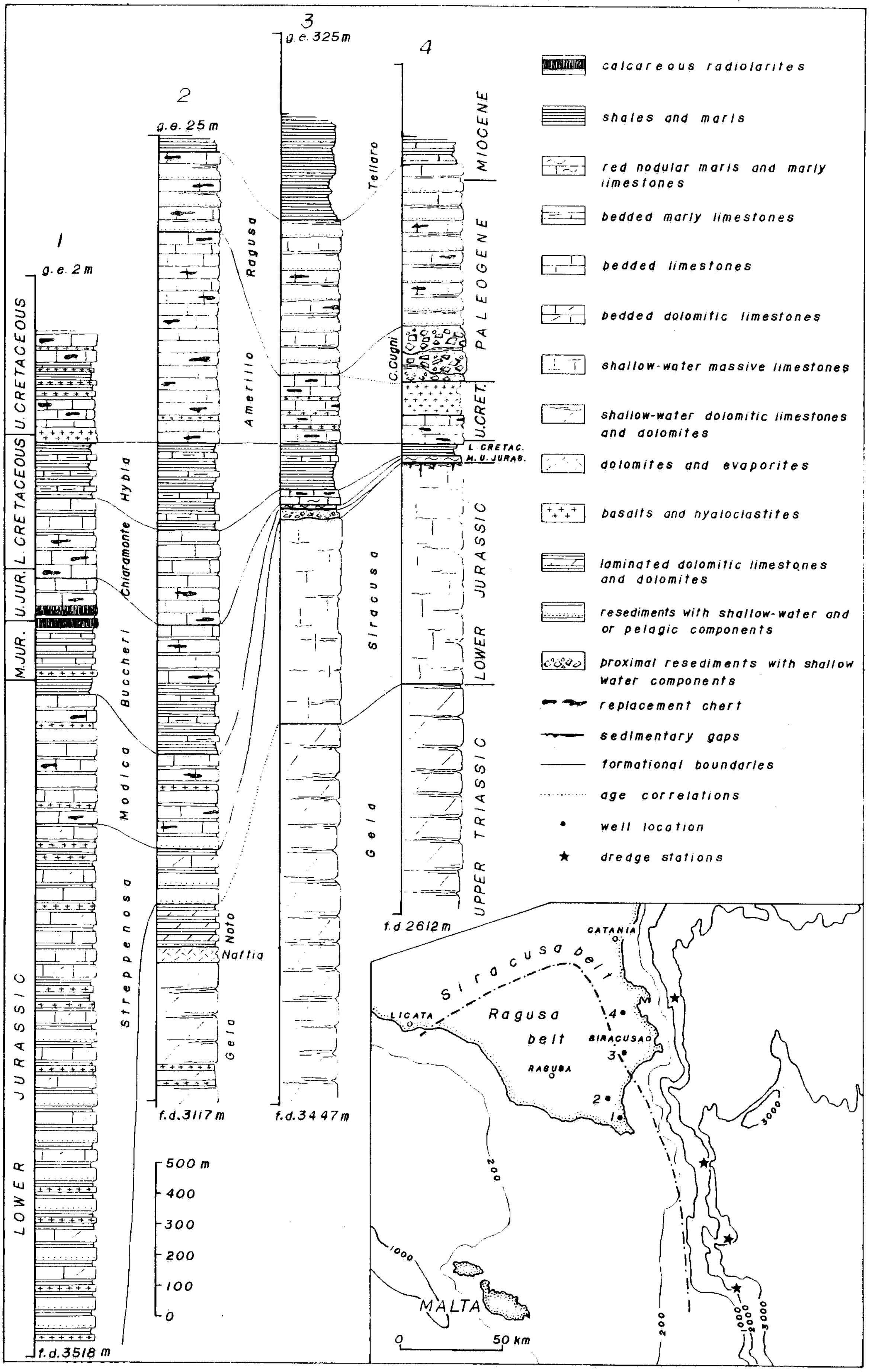

FIG. 13—Columnar sections from selected commercial boreholes in southern Sicily, representative of Mesozoic-Tertiary sedimentary sequences in Ragusa and Siracusa belts. (1) Marzamemi 1; (2) Noto 1; (3) Siracusa 1; (4) Melilli 1.

interval are represented only by crinoidal limestones present as elements of the breccia recovered in dredge station 1. The lack of any other recovery may suggest the presence of a sedimentary sequence with a condensed Middle-Upper Jurassic interval. Stronger evidence supporting this interpretation is provided by findings in the nearby Alfeo Seamount (Rossi and Borsetti, 1977). Two fragments of Mesozoic rocks were dredged along the southern slope of this faulted block (Fig. 3).

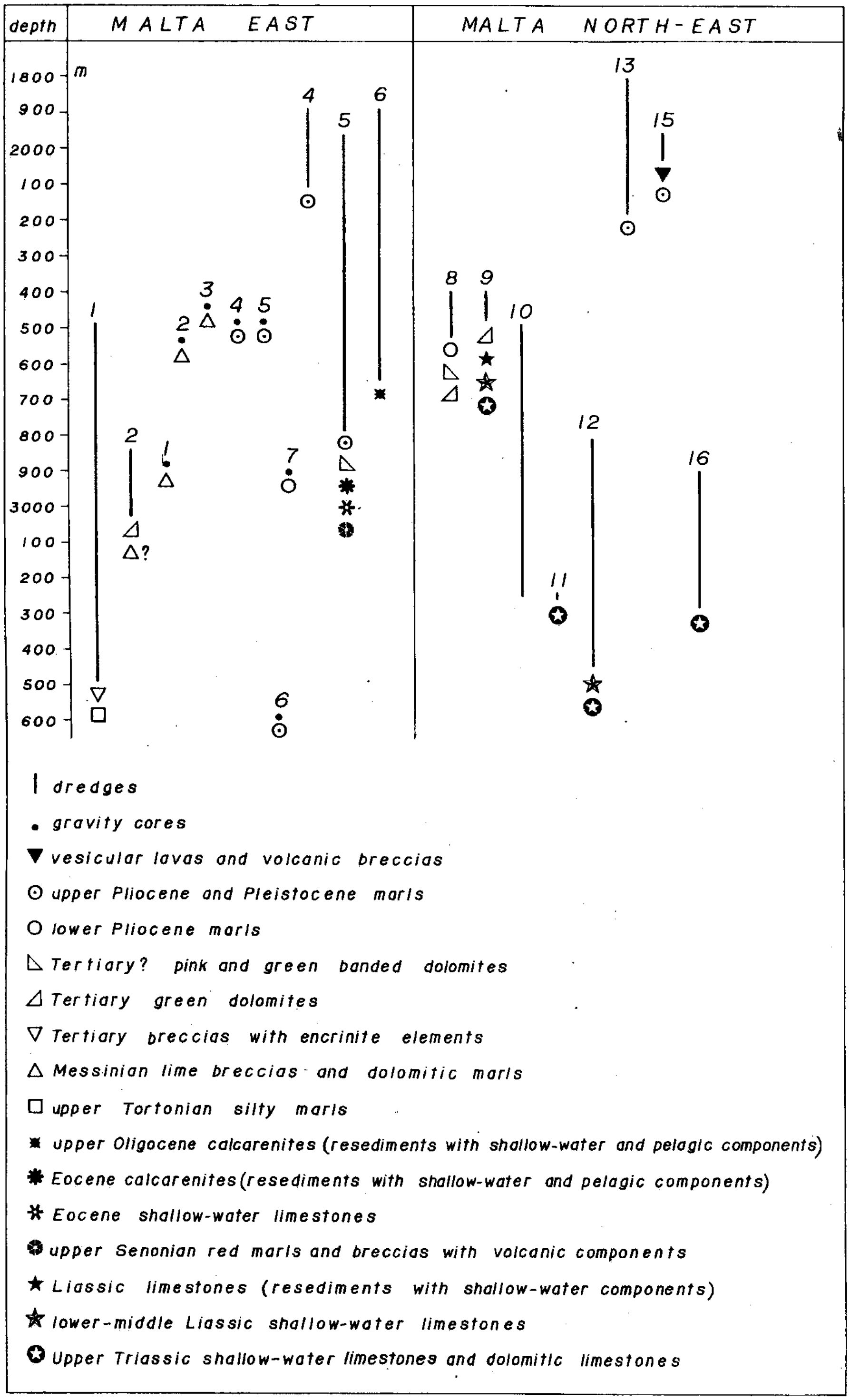

FIG. 14—Synoptic table summarizing dredging and coring results on Malta Escarpment.

The first consists of a shallow-water white limestone of undefined age, yielding ostracods, badly preserved arenaceous forams, and probable algal remains. The second is an Upper Jurassic pinkish crinoidal limestone appearing as a bioclastic packstone with echinodermal ossicles and *Globigerina helvetojurassica* associated with *Saccocoma, Lenticulina, Ammobaculites,* Ammodiscidae, attached forams, rare small *Spirillina,* fragments of gastropods and pelecypods. The globigerinid tests are filled with a micrite rich in iron oxides, and in places are coated with oolitic films. More commonly they are included with other skeletal material within small intraclasts. The echinodermal plates, micritized and bored, generally display syntaxial calcite overgrowth. The matrix consists of a dark micrite patchily recrystallized into sparite. This kind of sediment, which represents a typical condensed deposit related to submarine hills, has been widely recorded in the Upper Jurassic sequences (Buccheri Formation) of the Siracusa belt.

Unconsolidated pelagic oozes yielding a foram assemblage of middle Albian age was recovered in April 1979, from the lower slope of the Malta Escarpment (M. B. Cita, personal commun.).

The upper Senonian red marls recovered in dredge station 5 are different from the coeval white cherty limestones of the Amerillo Formation drilled on land. The benthic organic components associated with planktonic forams and volcaniclastic material in the breccias interlayered with the red marls may be derived from shallow-water sediments overlying volcanic seamounts (e.g., Porto Palo Limestone, Colacicchi, 1963). We think that the Eocene shallow-water limestones recovered in the same dredge station were also derived from deposits overlying volcanic seamounts. Counterparts on land are represented by the so-called Cozzo Cugni calcarenites (Colacicchi, 1963).

The Eocene–?lower Miocene calcarenites dredged from the Malta E transect and from the Siracusa Escarpment may be strictly correlated with the coeval deposits of the Ragusa Formation.

The Tortonian marls recovered as a boulder in dredge station 1 are comparable with the marls of the Tellaro Formation.

The green dolomites of probable Messinian age forming fillings of fissures in Triassic rocks and the matrix of breccias exposed along the slope of the Malta Escarpment have no counterpart in land records. Messinian dolomitic marls have also been cored from the middle part of the Malta Escarpment (Cita et al, 1979); these deposits cover, as a sedimentary drape, the less steep parts of the escarpment, which existed before the Messinian salinity crisis. The Messinian sediments recovered in gravity core 2, and the lower Pliocene hemipelagic marls dredged in station 8 yield well-preserved specimens of reworked *Globotruncana*. These stations are close to dredging station 5, where Upper Cretaceous marls rich in planktonic forams have been recovered (Fig. 6).

In conclusion, present knowledge of the Malta Escarpment indicates that:

1. The Siracusa-Malta Escarpment lies within the Siracusa belt.
2. The Siracusa belt extended eastward from the present escarpment at least as far as the Alfeo Seamount.
3. The close analogies between Upper Triassic through upper Oligocene-lower Miocene deposits of southeastern Sicily and those exposed along the Malta Escarpment (the Upper Cretaceous red marls being the only exception) testify that the present steep slope does not necessarily coincide with the original foreslope of a continental-margin edge facing an oceanic realm; it corresponds, on the contrary, with a scarp created by tectonic processes and modeled by mechanical erosion.
4. The escarpment was already in existence during the late Miocene, if the Messinian age attribution for the green dolomites is correct.

It is unlikely that the Malta Escarpment strictly coincides with the original margin of the Ionian basin; many data suggest that the latter is more ancient than the early Miocene. Our data, consequently, do not offer evidence of the history or even the existence of a deep-ocean realm since formation of the basin. We think that the original margin of the Ionian basin was located somewhere east of the present Malta Escarpment and has been reactivated by faulting including important displacements after late Oligocene-early Miocene times, with consequent retreat of the escarpment face to its present position. The final physiography was therefore reached by late Miocene, that is, in a close time relation with formation of the Tyrrhenian Sea.

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