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MUD DIAPIRS OF THE MEDITERRANEAN RIDGE: SEDIMENTOLOGICAL AND MICROPALEONTOLOGICAL STUDY OF THE MUD BRECCIA

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Key-words: Stratigraphy, Accretionary prism, Mud diapirism, Mediterranean Ridge, Mud Breccia.

Riassunto. Due recenti spedizioni oceanografiche hanno dimostrato che il diapirismo di fango è una caratteristica comune delle parti più rilevate del prisma di accrezione della Dorsale Mediterranea. A differenza di altri complessi di accrezione, dove il fenomeno si verifica anche nelle zone antistanti il fronte di deformazione o nelle sue vicinanze, sulla Dorsale Mediterranea il diapirismo di fango si rinviene solo sulla zona di cresta. I tre campi diapirici scoperti sulla Dorsale Mediterranea tra Creta ed il promontorio della Cirenaica sono stati denominati, da ovest verso est, Pan di Zucchero, Prometheus 2 ed Olimpi.

Uno studio comprendente analisi sedimentologiche, micropaleontologiche e mineralogiche è stato condotto sulla breccia di fango di origine diapirica contenuta in 15 carote recuperate durante le crociere oceanografiche BAN88 e BAN89.

Lo studio sedimentologico ha permesso di riconoscere diverse facies tessiturali, interpretate come espressione di differenti meccanismi di messa in posto: 1) tre facies massive interpretate come intrusive; 2) tre facies organizzate interpretate come estruse e probabilmente rimaneggiate.

Lo studio micropaleontologico basato sia sui Foraminiferi planctonici che sui nannofossili calcarei ha permesso di attribuire un'età ai sedimenti coinvolti nel fenomeno diapirico: Oligocene per l'area Pan di Zucchero e Miocene inferiore per le aree Prometheus 2 ed Olimpi. Mancano le evidenze delle tipiche facies e dei microfossili messiniani (dolomite e gesso e faune di lago-mare rispettivamente).

L'analisi ai raggi X ha permesso di individuare i principali componenti mineralogici della breccia ed una diminuzione del contenuto in smectite verso ovest.

Il nostro studio ha inoltre evidenziato che vi sono notevoli differenze tra le aree Pan di Zucchero e Olimpi, mentre le aree Olimpi e Prometheus 2 sono piuttosto simili tra loro.

Infine il Duomo Napoli, ubicato nell'area Olimpi, differisce dagli altri diapiri studiati in numerosi caratteri sedimentologici, micropaleontologici e mineralogici, ed è interpretato come un vulcano di fango.

Abstract. Two recent sea-going expeditions showed that mud diapirism is a common feature in the accretionary wedge of the Mediterranean Ridge, but unlike in other prisms, it is well expressed exclusively in the most elevated areas of the Ridge. Three diapiric fields were discovered on the Mediterranean Ridge and informally called, from west to east, Pan di Zucchero, Prometheus 2 and Olimpi. They are located on the crestal part of the Mediterranean Ridge between Creta and the Cirenaic Promontory.

Sedimentological, micropaleontological, and mineralogic investigations were performed on the mud breccia recovered in 15 cores raised during cruises BAN88 and BAN89.

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The sedimentological analyses allowed to recognize several sedimentary facies which are suggestive of different emplacement processes: 1) three massive facies are indicative of intrusion; 2) three organized facies are indicative of submarine extrusion and probably reworking.

The micropaleontological study based on planktonic foraminifera and calcareous nannofossils provided an Oligocene age for the source sediments and/or for the sediments possibly involved in the diapiric processes of the Pan di Zucchero, and an Early Miocene age for the Olimpi and Prometheus 2 fields. No evidence was found of the typical Messinian lithologies, such as dolomite and gypsum, and microfossils ("lago-mare" biofacies).

X-ray diffraction analyses allow to identify the major mineralogic component of the mud breccia and a westward decrease in the smectite content.

Our investigations reveal that major differences occur between the Pan di Zuccchero and Olimpi areas, whereas minor differences are recorded between the Olimpi and Prometheus 2. Moreover, the Napoli Dome, located in the Olimpi area, differs from the other diapirs in several sedimentological, micropaleontological and mineralogic characters, and is interpreted as a mud volcano.

Introduction.

Mud diapirism, a term including both subaerial and subacqueous manifestations such as mud volcanism and formation of mud domes and ridges, has long been known (Chapman, 1974).

Mud diapirism occurs in two geological environments: a) in submarine deltas, where the phenomenon is accounted by the rapid burial of sediments, exerted by the seaward progradation of the delta forehead sands over the soft clays of the prodelta (Burke, 1972); b) in accretionary prisms, where the quick tectonic burial is due to the typical growth mechanisms of the accretionary complex.

In the last few years mud diapirs were discovered in several accretionary prisms (e.g. Barbados, Makran and Aleutine; Brown & Westbrook, 1988; Langseth et al., 1988; Henry et al., 1990; Brown, 1990; Le Pichon et al., 1990). Because of worldwide occurrence of mud volcanoes and shale diapirs in many modern accretionary settings, a genetic relation between mud diapirs and tectonic mélanges has been proposed by several authors (e.g. Williams et al., 1984).

Within the accretionary prism the mud diapirs appear in two different situations: a) seaward of the deformation front, where they are generated by the load exerted by the prism, associated with the main migration of fluids towards the ocean. This forming mechanism is similar to that generating the mud diapirs in submarine deltas (Westbrook & Smith, 1983); b) alternatively, mud diapirism occurs inside the prism, often near the deformation front, and is produced by the tectonic stress that expells the muddy sediments towards the sea floor (Brown, 1990).

Mud diapirism on the Mediterranean Ridge.

The first domal structure discovered in the Mediterranean Sea and called Prometheus Dome was explored in 1978, on the western Mediterranean Ridge, in the Ares Crater (Cita et al., 1981). Several cores recovered a mud breccia, containing Cretaceous microfossils, in unconformable contact with Pleistocene and Holocene pelagic sediments. This mud breccia was interpreted as a manifestation of extruding deep-seated clay-rich formations in response to the tectonic stress within the ridge (Cita et al., 1981; Ryan et al., 1982; Camerlenghi et al., 1992; Cita & Camerlenghi, 1992).

In 1988 and in 1989, three fields of mud diapirs were discovered by the Italian R/V Bannock on the crest of the Mediterranean Ridge between Crete and the Cirenaic Promontory some 450 km to the SE of Prometheus Dome (Cita, Camerlenghi et al., 1989) (Fig. 1). In this area of the ridge the compressive stress is related to the collision between the African margin and the Aegean margin. The Mediterranean Ridge is thus interpreted as an accretionary prism in a collisional context (Le Pichon & Angelier, 1979; Le Pichon et al., 1979; Le Pichon, Augustithis et al., 1982; Le Pichon, Lyberis et al., 1982; Cita & Camerlenghi, 1992). The three fields were informally called, from west to east, Pan di Zucchero, Prometheus 2 and Olimpi; the distance between the westernmost and the other fields is about 200 km (Fig. 1).

Mud diapirism in this area consists of the upward movement, presumably along fault plains, of strongly tectonized sedimentary material consisting of mud or matrix supported mud breccia, with a plastic behaviour resulting from the high pressure of interstitial water (Cita, Camerlenghi et al., 1989; Camerlenghi, 1991; Camerlenghi et al., 1992; Cita & Camerlenghi, 1992; Cusin et al., 1992).

Purpose of this paper is to provide a sedimentological and micropaleontological characterization of the diapiric sediments.

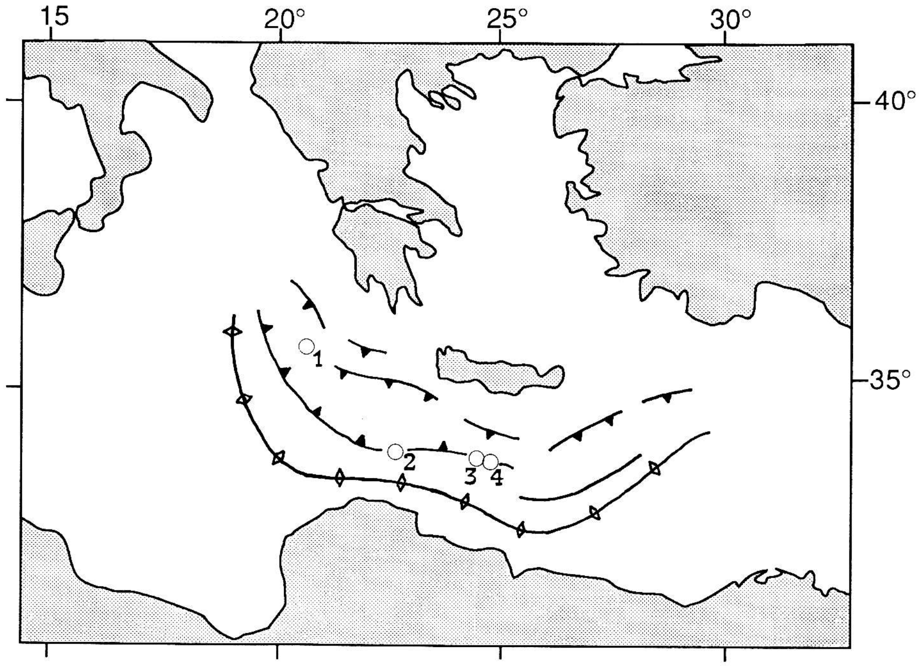


Fig. 1 - Location map of the mud diapiric fields (circles) discovered on the Mediterranean Ridge (Eastern Mediterranean). 1) Cobblestone area 3, Prometheus Dome; 2) Pan di Zucchero area; 3) Prometheus 2 area; 4) Olimpi area. Black triangles indicate major thrust fronts, open triangles indicate the deformation front.

Materials and methods.

The lithological description of the cores was performed on board R/V Bannock (cruises BAN88 and BAN89). Subsequent shorebased investigations on the sedimentary textures provided the support for the interpretation of the sedimentological structures. Samples for analyses on planktonic foraminiferal assemblages were soaked in hydrogen peroxide and then washed through 36 μm sieve under running water. The residues were dried on a hot plate at about 50°C. Calcareous nannofossils were studied on smear slides.

Thin sections were obtained from the larger clasts recovered in the cores and/or core catchers and analyzed with an optical polarizing microscope. The calcium carbonate content was measured with a Dicther-Freeling calcimeter (BAN89 samples). Clay minerals were detected with X-ray diffraction in AGIP S.p.A. Laboratories.

Morphological description.

Pan di Zucchero area.

The westernmost area explored (about 33°47' N and 22°48' E) corresponds to the maximum elevation point of the Mediterranean Ridge (isobath 1200 m). The dome named Pan di Zucchero is a structure with an ellipsoidal shape, trending NW-SE, deeply asymmetric and with a vertical relief ranging from 150 m (NW) to 320 m (SE).

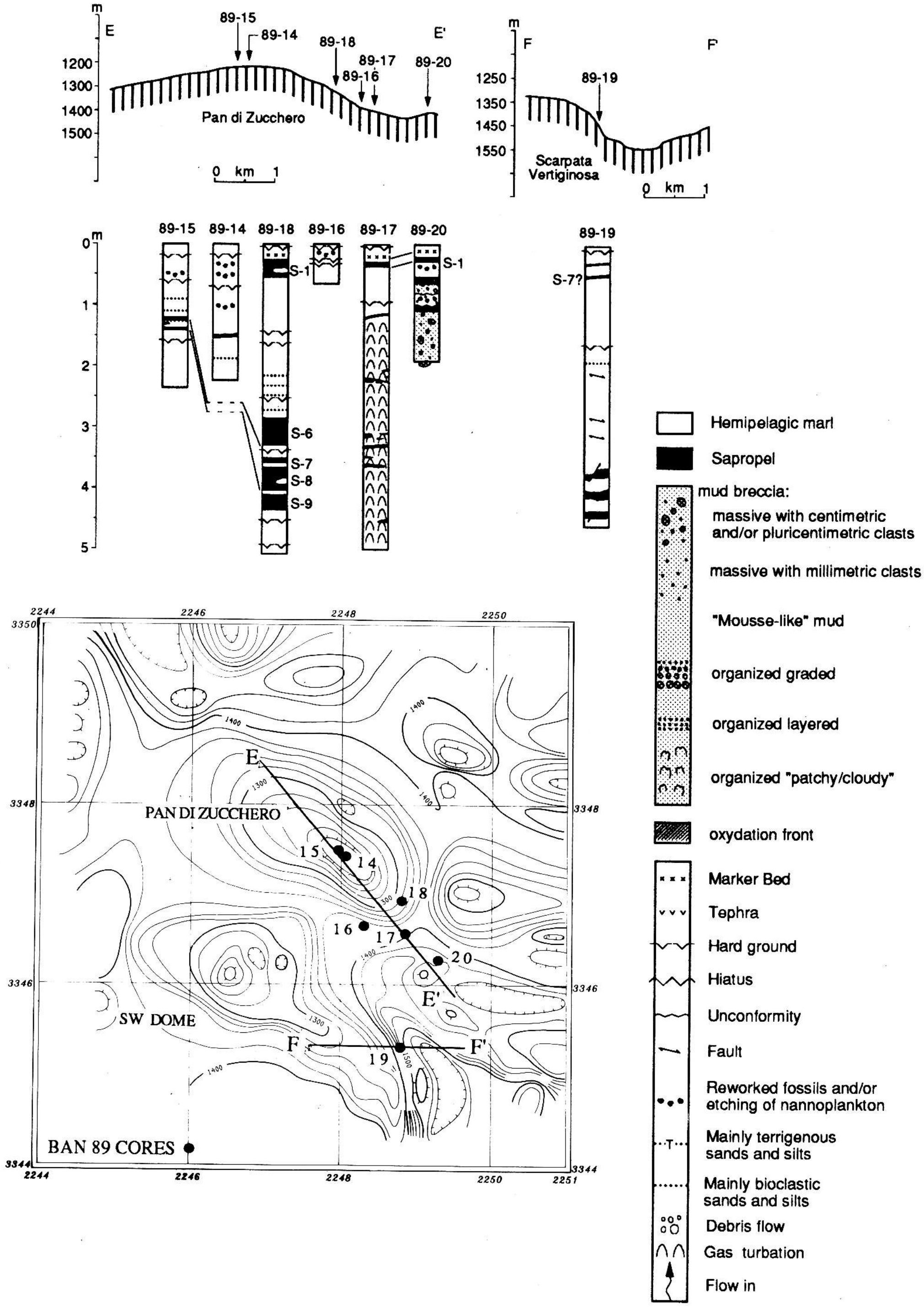
The relief south-west of Pan di Zucchero shows a very asymmetric and step-like profile, also observed in the Napoli Dome (see further on). The eastern side of this dome shows a steep slope (34°) oriented N-S ("scarpata vertiginosa"). Figure 2 shows the mapped bathymetry, two profiles and the core logs. Only one core (BAN89-20GC) from the base of Pan di Zucchero contains the mud breccia.

Prometheus 2 area.

This diapiric field (33°50' N, 24°26' E) contains three domes within about 20 km^2. They are subconical in shape and have a basal diameter of approximately 2 km and an elevation of about 150 m; their flanks are slightly asymmetric and display gentle continuous slopes with angle of 7-8°. The area surrounding this diapiric field is characterized by the typical "cobblestone" topography (Cita, Camerlenghi et al., 1989).

Seven cores were recovered in this area during Cruise BAN88. Four cores contain the mud breccia. Core logs showing the main lithologies of the mud breccia, bathymetric maps and profiles are reported in Fig. 3.

Fig. 2 - Pan di Zucchero area. Core logs showing the main lithologies of the mud breccia, bathymetric map and profiles E-E', F-F' of the diapirs discovered in this field (bathymetric map from Camerlenghi, 1991). The depth is expressed in uncorrected metres (sound velocity=1500 m/s). The Marker Bed is a centimetric and Mn rich black layer occurring in most cores from the diapiric fields (Cita, Aghib et al., 1989).


E
E'
89-15
89-14
89-18
89-17
89-16
89-20
Pan di Zucchero
0 km 1
F
F'
89-19
Scarpata Vertiginosa
S-1
S-6
S-7
S-8
S-9
S-7?
PAN DI ZUCCHERO
SW DOME
BAN 89 CORES
Hemipelagic marl
Sapropel
mud breccia:
massive with centimetric and/or pluricentimetric clasts
massive with millimetric clasts
"Mousse-like" mud
organized graded
organized layered
organized "patchy/cloudy"
oxydation front
Marker Bed
Tephra
Hard ground
Hiatus
Unconformity
Fault
Reworked fossils and/or etching of nannoplankton
Mainly terrigenous sands and silts
Mainly bioclastic sands and silts
Debris flow
Gas turbation
Flow in

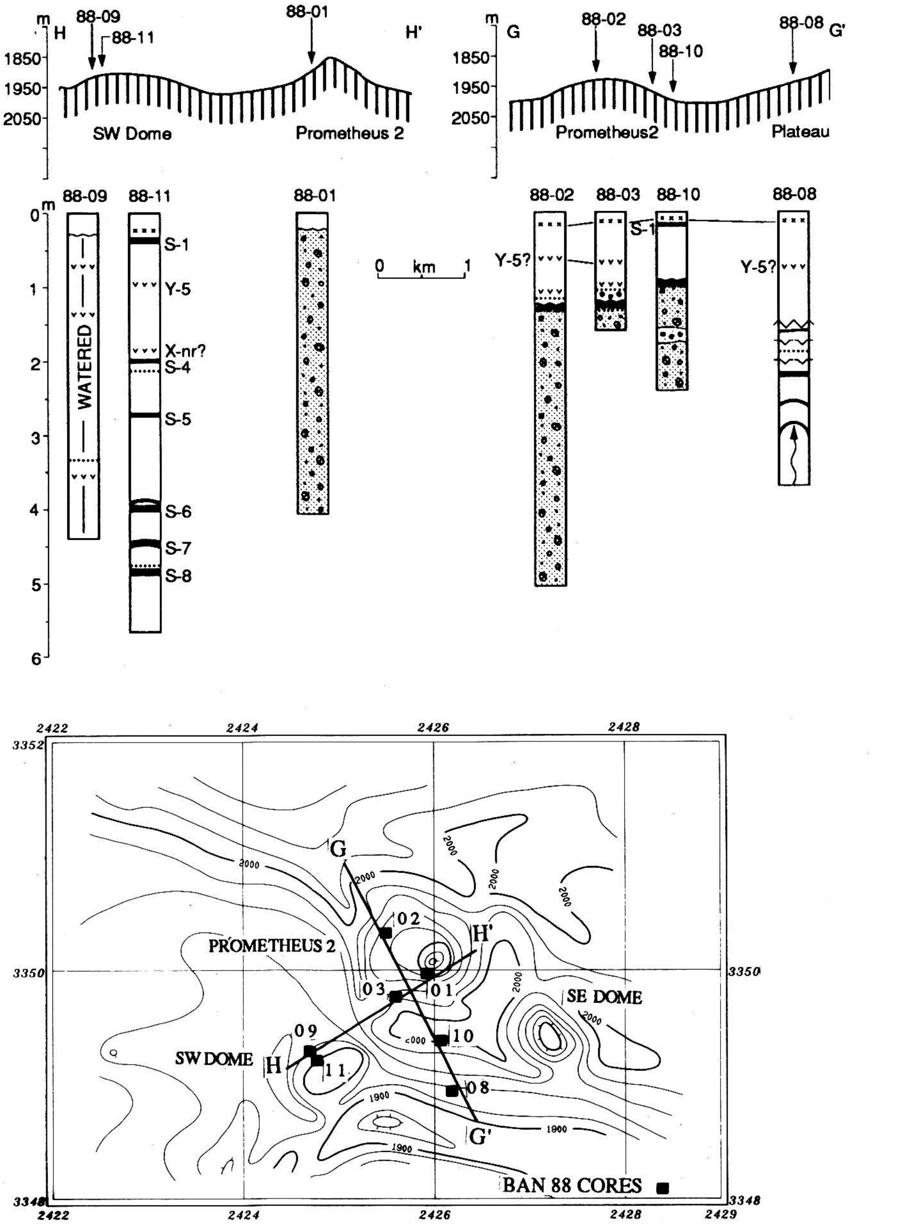


Fig. 3 - Prometheus 2 area. Core logs showing the main lithologies of the mud breccia, bathymetric map and profiles G-G', H-H' of the diapirs discovered in this field (bathymetric map from Camerlenghi, 1991). The depth is expressed in uncorrected metres (sound velocity = 1500 m/s). (See Fig. 2 for legend).

Olimpi area.

This diapiric field is located about 20 km east of the Prometheus 2 area at approximately 33°44' N, and 24°48' E. Six domes are gathered in 30 km^2, three others have been found some 4 miles SW of the main field, but they were not investigated. The largest dome (Napoli Dome) has a subcircular shape and is roughly 4 km in diameter. Its vertical relief is almost twice that of the other domes only because of a narrow anular depression that surrounds the feature, as shown by the map and by the profile A-A' of Fig. 4. The Napoli Dome shows a peculiar step-like profile with slopes varying from 7° to 16°. The top of the dome is flat.

The other 5 diapirs recognized in this area have a depressed tronco-conical shape and diameters ranging from 1.5 to 3 km; the vertical relief is of approximately 100 m. The top of all these structures lies between 1900 and 1920 m water depth. The bathymetric survey carried out in the surrounding areas allowed to identify a general NW-SE alignment of the structures. The area surrounding the diapiric field is characterized by the typical "cobblestone" topography of the Mediterranean Ridge. In this area the mud breccia was recovered in 10 cores out of 16, taken in 4 of the 6 domes investigated (Fig. 4).

Sedimentological characterization.

Diapiric sediments were first recovered in the Prometheus Dome in Cobblestone Area 3 (Cita et al., 1981). They consist of abundant, pluricentimetric, subrounded to angular clasts of semi-indurated sediments embedded in a dark grey clay- and silt-sized matrix. This facies was named "mud breccia" by Cita et al. (1981). Camerlenghi et al. (1992) proposed to use mud breccia as a descriptive term to identify the lithostratigraphic unit associated to the diapiric structures of the Mediterranean Ridge. Mud breccia was been observed in 15 cores (of the total of 31 cores from the 3 studied areas).

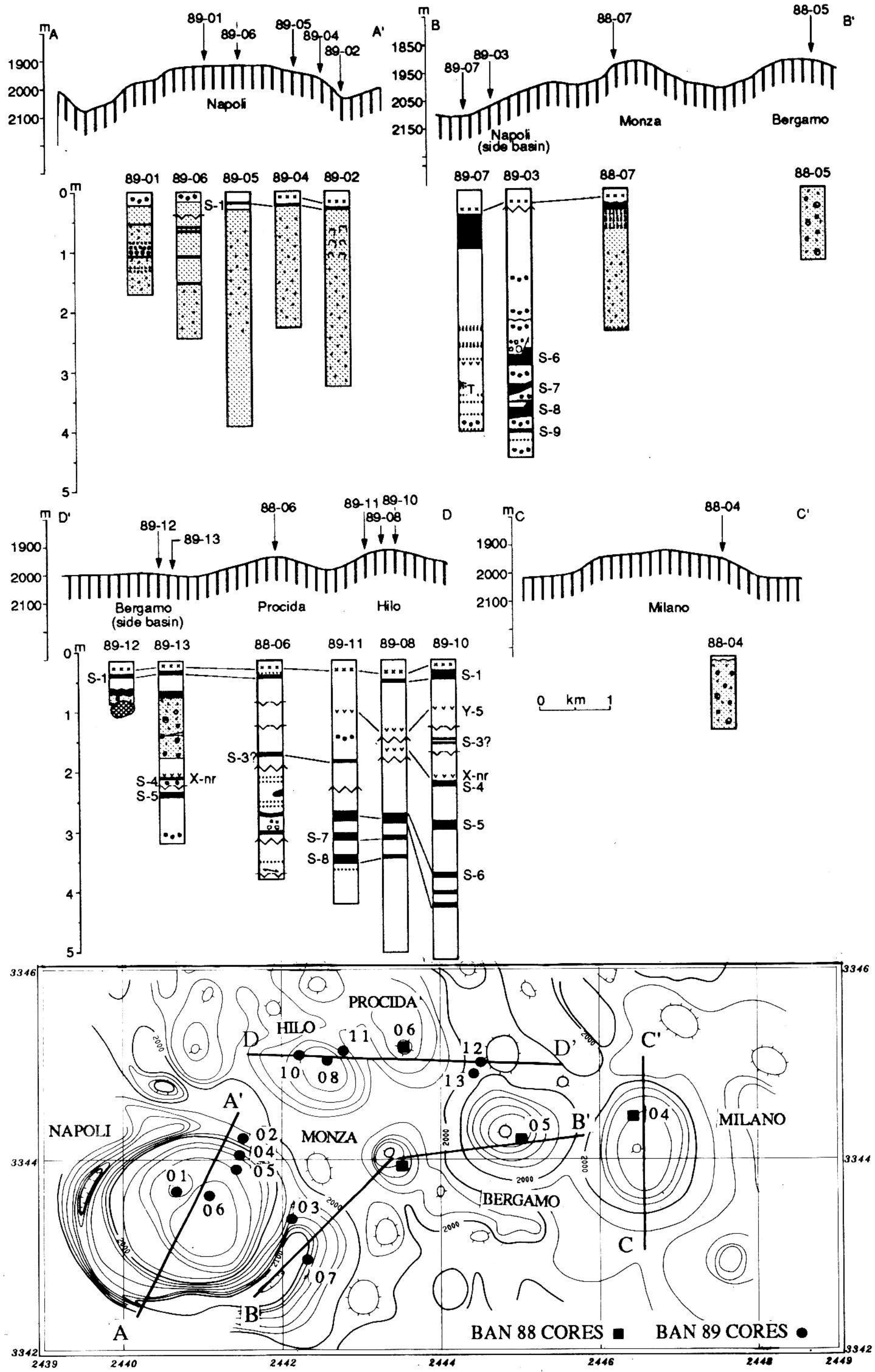
Macroscopic description.

The mud breccia is composed of sticky clay matrix, ranging in colour from grey to dark grey (hue 2.5Y, 2.5YR and 5Y grey and dark grey according to the Munsell Soil Colour Chart) and containing abundant clasts which come in a variety of composition, shape, size and roundness. Following Camerlenghi et al. (1992) and Cusin et al. (1992) we use the terms "massive" and "organized" as follows: massive is structureless, non layered, non graded; organized may be graded or display various textures. Strong smell of hydrogen sulfide and hydrocarbon was often detected.

Six lithological types have been identified representing massive and organized textures (three each, see Pl. 1, 2).

TYPE A1 MASSIVE (centimetric and/or pluricentimetric clasts).

Stiff matrix containing centimetric up to pluricentimetric clasts which consist of soft and slightly indurated marls (ranging in colour from light to very dark grey),


A
A'
B
B'
D'
D
C
C'
89-01
89-06
89-05
89-04
89-02
89-07
89-03
88-07
88-05
89-12
89-13
88-06
89-11
89-10
89-08
88-04
Napoli
Napoli (side basin)
Monza
Bergamo
Bergamo (side basin)
Procida
Hilo
Milano
S-1
S-3?
S-4
S-5
S-6
S-7
S-8
S-9
Y-5
X-nr
0 km 1
NAPOLI
HILO
PROCIDA
MONZA
BERGAMO
MILANO
BAN 88 CORES
BAN 89 CORES

qz-siltstones and reddish subarkose. No size sorting is observed (Pl. 1, fig. 1). The contact with the overlying hemipelagic host sequence is normally sharp; in two cores the contact is transitional. The contact with the underlying host sequence is only observed in core BAN89-13GC (Olimpi area) and is sharp.

Cores BAN88-01PC, BAN88-02PC, BAN88-03PC, BAN88-10PC raised from Prometheus 2 area, core BAN89-20GC from Pan di Zucchero area and cores BAN88-04PC, BAN88-05PC, BAN89-12GC and BAN89-13GC from Olimpi area contain this type.

TYPE A2 MASSIVE (millimetric clasts).

This type differs from A1 only for the clast size, always millimetric (Pl. 1, fig. 2). Cores BAN89-01GC, BAN89-02GC, BAN89-04GC, BAN89-05GC, BAN89-06GC, BAN89-13GC and BAN88-07GC from Olimpi area and core BAN88-03 from Prometheus 2 area contain this type.

TYPE A3 MASSIVE ("mousse-like" mud).

The matrix consists of soft grey mud containing sand-size grains of the same composition as those of the previous types (Pl. 1, fig. 3). Rounded holes of no more than 1 cm, probably due to gas expansion have been observed in the split core sections (cores BAN89-01 and BAN89-05GC). In these cores from Napoli Dome the sediment contains pervasive gas micro-vescicles that give the mud breccia a "mousse-like" texture. This type was only documented in the Napoli Dome, to which it seems restricted.

TYPE B1 ORGANIZED (layered).

The mud breccia shows horizontal bedding and is organized in millimetric layers consisting of millimetric clasts sorted by size, with no detectable imbricate structures. The clasts consist of marl, mudstones, qz-siltstones and sandstones (Pl. 2, fig. 1).

Cores BAN88-07GC and BAN89-01GC from Olimpi area and core BAN88-03PC from Prometheus 2 area contain this type.

TYPE B2 ORGANIZED (graded).

This rare type consists of a grain-supported mud breccia with upward increase of matrix/clast ratio and an upward decrease of grain size (Pl. 2, fig. 2).

Core BAN89-01GC (Napoli Dome) contains a 20 cm thick interval of this type.

Core BAN88-07GC (Monza Dome) contains a 42 cm thick interval composed of 1-4 cm thick quartz sandy layers.

TYPE B3 ORGANIZED (patchy/cloudy).

Fig. 4 - Olimpi area. Core logs showing the main lithologies of the mud breccia, bathymetric map and profiles A-A', B-B', C-C', D-D' of the diapirs discovered in this field (bathymetric map from Camerlenghi, 1991). The depth is expressed in uncorrected metres (sound velocity = 1500 m/s). (See Fig. 2 for legend).

The main feature of this type is that the mud breccia shows patches and clouds of different colours. No visible clasts larger than sand-size are observed. The mud breccia shows typical colour changes from the grey and olive grey clasts to light yellowish brown matrix (Pl. 2, fig. 3).

This type is only represented by a 50 cm thick interval recovered in core BAN89-02GC from the Napoli Dome.

Microscopic description.

The six types show the same composition and variety of grains which consist of fragments of mudstones, qz-siltstones, fine qz-sandstones, qz-grains and planktonic foraminifera; moreover, low amounts of authigenic minerals such as pyrite, glauconite, Fe-oxides and calcite have been recognized (Pl. 3).

The mineral content was also investigated on thin sections obtained from the larger clasts recovered in the core catcher of core BAN89-12GC (base of Bergamo Dome) and BAN89-20GC (base of Pan di Zucchero Dome) (Pl. 4, fig. 1, 2, 4). Part of a thin section (core catcher of core BAN89-12GC) is illustrated in Pl. 4, fig. 3. The rock is a subarkose with grain size ranging from 125 to 250 μm, subangular to subrounded grains not sorted by size. Inorganic components consist of dominant quartz (90-95%) and feldspar predominantly plagioclase (5-10%). Microclyne, muscovite and silt aggregates are very rare. Authigenic minerals consist of Fe-oxide and glauconite.

Another rock fragment recovered within the basal part of a core raised at the base of the Pan di Zucchero Dome (BAN89-20GC) was thin sectioned. The rock consists of bioclastic packstone with planktonic and benthonic foraminifera. Abundant quartz and common opach minerals (probably pyrite) are observed. Matrix consists of micrite, sparite is present only in microfractures.

Mineral composition and carbonate content of the mud breccia.

Table 1 shows the mineralogical composition (major elements) obtained by X-ray diffractometry (courtesy of Geochemistry Laboratory of AGIP-SGEL) of 27 samples of mud breccia from the three diapiric fields. The samples were taken from the matrix and may include small-sized clasts. Anomalous values of individual calcite and dolomite content are attributed to clasts. Samples were taken from the cores, but two (labelled with HF) were from the Heat Flow probe. Clay represents a major component of the mud breccia. Its composition is shown in the right part of Tab. 1, but it is not discussed here in any detail. Reference is made to Camerlenghi et al. (1992) and to Cusin et al. (1992).

Table 2 shows the carbonate content measured on bulk sediments of 19 samples of mud breccia and 5 samples of pelagic host sediments from two diapiric fields (Olimpi and Pan di Zucchero). A Dicther-Freeling calcimeter was used for the purpose. The carbonate content of the pelagic marls always exceeds 50%. That of the mud breccia ranges from 10 to 35% with the higher values recorded in type A3 breccia.

CORE	SECTION	cm from top of sec.	cm from top of core	DOME	TYPE	MAJOR MINERAL COMPONENTS QUARTZ	PLAGIOCLASE	K-FELDSPAR	CALCITE	DOLOMITE	CLAY - MICA	CLAY MINERALS SMECTITE	ILLITE	CHLORITE	KAOLINITE
Prometheus-2 Area															
BAN88-01PC	3	50	223	Prometheus 2	"A1"	12	1	1	17	0	69	43	7	17	33
BAN88-01PC	4	50	343	Prometheus 2	"A1"	9	1	1	11	0	78	46	7	15	32
BAN88-10PC	1	108	108	Prometheus 2	"A1"	34	5	4	16	0	41	52	4	15	29
BAN88-10PC	2	25	134	Prometheus 2	"A1"	19	2	0	9	0	70	55	3	16	26
BAN88-10PC	CC	_	_	Prometheus 2	"A1"	28	0	6	23	0	43	51	6	14	29
Olimpi Area															
BAN88-04GC	1	60	60	Milano	"A1"	30	1	0	14	0	55	33	11	16	40
BAN88-07GC	1	45	45	Monza	"B2"	35	6	3	13	0	43	52	7	14	27
BAN88-07GC	2	40	104	Monza	"A2"	24	1	2	23	0	50	44	7	16	33
BAN88-07GC	2	82	146	Monza	"A2"	21	10	0	14	0	55	41	7	15	37
BAN89-07GC	3	11	195	Monza	"A2"	21	2	0	16	0	61	40	4	17	39
BAN89-01GC	CC	_	_	Napoli	"A3"	21	1	3	13	0	62	37	8	0	55
BAN89-04GC	CC	_	_	Napoli	"A2"	24	3	3	12	2	56	35	11	0	54
BAN89-05GC	1	50	50	Napoli	"A3"	21	1	3	15	6	54	30	7	14	49
BAN89-05GC	1	79	79	Napoli	"A2"	27	4	1	15	12	41	34	4	17	45
BAN89-05GC	CC	_	_	Napoli	"A3"	25	2	2	11	0	60	36	12	0	52
BAN89-06GC	2	35	125	Napoli	"A3"	20	0	3	15	0	62	38	18	0	44
BAN89-06GC	2	98	188	Napoli	"A2"	25	1	5	15	0	54	29	14	0	57
BAN88-05GC	1	60	60	Bergamo	"A1"	24	3	0	10	0	63	38	8	16	36
BAN89-12GC	1	54-56	54-56	Bergamo	"A1"	22	2	2	10	0	64	45	4	14	37
BAN89-12GC	1	64-66	64-66	Bergamo	"A1"	18	3	2	17	0	60	49	2	16	33
BAN89-13GC	2	40	66	Bergamo	"A1"	29	2	1	13	0	55	53	3	13	31
BAN89-13GC	2	47	73	Bergamo	"A1"	17	1	1	20	0	61	53	3	0	44
BAN89-13GC	2	120	146	Bergamo	"A1"	13	0	0	68	1	18	66	8	9	17
HF-3	_	_	_	HF-3	"A1"	11	0	0	68	0	21	52	8	12	28
HF-3	_	_	_	HF-3	"A1"	25	1	2	14	0	58	48	1	16	35
Pan di Zucchero Area															
BAN89-20GC	2	59	99	Pan di Zucch.	"A1"	13	0	1	10	0	76	34	6	0	60
BAN89-20GC	2	70	110	Pan di Zucch.	"A1"	12	1	1	8	0	78	34	6	0	60

Tab. 1 - Main mineralogic components obtained with X-ray diffraction. PC= piston core, GC= gravity core, HF= heat flow probe, CC= core catcher.

Foraminiferal micropaleontology.

Micropaleontological analyses on diapiric sediments allow to tentatively identify the age of the source sediments involved in the diapiric extrusion, as it has been done for some land mud diapiric fields in Trinidad and Irian Java (Higgins & Saunders, 1967; Williams et al., 1984) and for the Prometheus Dome, the first dome-like structure discovered on the Mediterranean Ridge (Cita et al., 1981). In this latter case, the planktonic foraminiferal content of the clasts (the matrix was carbonate free) provided a Late Aptian age.

In the present paper the zonal scheme of Iaccarino (1985) has been used for Middle-Late Neogene species and that of Spezzaferri (1992) for Oligocene and Early

CORE	SECTION	cm from top sec.	cm from top core	DOME	LITHOLOGY	TYPE	CARBONATE %
Olimpi Area							
BAN89-01GC	CC	_	_	Napoli	MUD BRECCIA	"A2"	26,9
BAN89-02GC	CC	_	_	Napoli	MUD BRECCIA	"A2"	22,7
BAN89-04TW	CC	_	_	Napoli	PELAGIC MARL		55,6
BAN89-04GC	CC	_	_	Napoli	MUD BRECCIA	"A2"	22,3
BAN89-05GC	1	1	1	Napoli	PELAGIC MARL		52,7
BAN89-05GC	1	32	32	Napoli	MUD BRECCIA	"A3"	33,9
BAN89-05GC	1	60	60	Napoli	MUD BRECCIA	"A3"	35,1
BAN89-05GC	2	32	152	Napoli	MUD BRECCIA	"A2"	29,6
BAN89-05GC	2	60	180	Napoli	MUD BRECCIA	"A2"	30
BAN89-05GC	3	60	229	Napoli	MUD BRECCIA	"A3"	29
BAN89-06GC	2	30	120	Napoli	MUD BRECCIA	"A3"	27
BAN89-06GC	2	70	160	Napoli	MUD BRECCIA	"A2"	28,8
BAN89-06GC	2	100	190	Napoli	MUD BRECCIA	"A2"	21,5
BAN89-06GC	CC	_	_	Napoli	MUD BRECCIA	"A2"	18,9
BAN89-12GC	1	42	42	Bergamo	PELAGIC MARL		58,4
BAN89-12GC	1	63	63	Bergamo	MUD BRECCIA	"A1"	16,6
BAN89-13GC	2	29	55	Bergamo	MUD BRECCIA	"A2"	30,3
BAN89-13GC	2	33	59	Bergamo	MUD BRECCIA	"A2"	18,5
BAN89-13GC	2	41	67	Bergamo	MUD BRECCIA	"A1"	10,2
BAN89-13GC	2	43	69	Bergamo	MUD BRECCIA	"A1"	20,2
Pan di Zucchero Area							
BAN89-20GC	2	4	44	Pan di Zucch.	PELAGIC MARL		51,9
BAN89-20GC	2	20	60	Pan di Zucch.	MUD BRECCIA	"A1"	13,6
BAN89-20GC	2	52	92	Pan di Zucch.	PELAGIC MARL		58
BAN89-20GC	2	60	100	Pan di Zucch.	MUD BRECCIA	"A1"	13,9

Tab. 2 - Calcium carbonate content of selected samples of mud breccia. GC= gravity core, TW= trigger core, CC=core catcher.

Miocene species. The stratigraphic distribution of Eocene and Cretaceous species is reported according to Nocchi et al. (1988) and Premoli Silva (1990, pers. comm.). The generic and specific concepts used by Premoli Silva & Boersma (1988, 1989) and Spezzaferri (1992) are retained herein. The results are reported in Tab. 3, 4, 5 and 6 and summarized herebelow. Selected planktonic foraminifera are represented in Pl. 5, 6.

Pan di Zucchero area.

Six samples from Pan di Zucchero have been analyzed for their planktonic foraminiferal content. The well preserved Quaternary species are associated with older and poorly preserved specimens belonging to species ranging from Early-Middle Eocene to Early Pliocene (Tab. 3). Only one specimen of *Acarinina bulbrooki* group (Eocene) is identified. The more abundant faunas range from Early to Late Oligocene and are represented by *Pseudohastigerina naguewichiensis* (Early Oligocene), *Paragloborotalia opima opima* (Early-Late Oligocene), "*Globigerinoides*" *primordius* and *Paragloborotalia pseudokugleri* (Late Oligocene). The Early-Middle Miocene species are here

20GC-CC	20GC-2-93	20GC-2-61	20GC-2-54	20GC-2-40	20GC-2-13	samples Pan di Zucchero
C/A	R	R	-	A	C	pyrite
-	VR	C	-	C	C/A	quartz
-	-	R	R	C/R	-	glauconite
C	R	VR	VA	R	VR	Quaternary species
						EOCENE SPECIES
	X					*Acarinina bulbrooki* group
						OLIGOCENE SPECIES
	X					*"Globigerina" ampliapertura*
		X		X		*Pseudohastigerina naguewichiensis*
				X		*Chiloguembelina cubensis*
		X				*Paragloborotalia opima opima*
	X	X			X	*Globigerina officinalis*
		X				*Tenuitella munda*
X	X	X	X			*"Globigerina" ciperoensis*
		X		X		*"Globigerina" angulisuturalis*
				X		*"Globigerinoides" primordius*
					X	*Paragloborotalia pseudokugleri*
						MIOCENE SPECIES
		X	X			*Zeaglobigerina druryi*
		X	X	X		*Globoquadrina dehiscens*
		X		X	X	*Globigerinoides bisphericus*
				X		*Praeorbulina transitoria*
						PLIOCENE SPECIES
	X					Globorotalia puncticulata
						LONG RANGE SPECIES
	X	X		X	X	*Cassigerinella chipolensis*
				X	X	*Globorotaloides* spp.
				X		*Dentoglobigerina globularis*
				X		*Dentoglobigerina altispira globosa*
		X		X		*"Globigerina" venezuelana*
		X				*Guembelitria* sp.
X	X					*Globigerinita juvenilis*
	X	X	X			*Tenuitellinata angustiumbilicata*
			X			*Globigerina praebulloides*
X		X		X		*Paragloborotalia semivera*
				X		*Zeaglobigerina brazieri*
	X		X			*Zeaglobigerina woodi*
		X		X	X	*Globigerinita uvula*
	X					*Dentoglobigerina baroemoenensis*
	X					*Paragloborotalia siakensis*
X	X					*Globigerinoides trilobus*

Tab. 3 - Planktonic foraminiferal content of the mud breccia of cores BAN89-20GC of the Pan di Zucchero. In the table are also reported the semiquantitative data of pyrite, quartz, glauconite, Quaternary species (VR=very rare; R=rare; C=common; A=abundant; VA=very abundant). GC=gravity core, CC=core catcher.

less abundant with respect to the other diapiric fields and consist of few specimens of *Praeorbulina transitoria* and *Globigerinoides bisphericus.*

Prometheus 2 area.

Twenty-one selected samples from matrix and clasts (the latter marked with * in Tab. 4) have been analyzed for their planktonic foraminiferal content. Several clasts are barren. Quaternary species are generally well preserved, but they are very scarce; older species (Oligocene to Pliocene) are mostly recrystallized, poorly preserved and sometimes deformed.

Only one specimen of *"Globigerina" ciperoensis* (Oligocene) and one of *Globorotalia margaritae* (Early Pliocene) are identified. The remaining assemblages consist of Burdigalian-Langhian (Early-Middle Miocene) species, including *Praeorbulina transitoria*, *Praeorbulina sicana*, *Praeorbulina glomerosa*, *Globigerinoides bisphericus*, and of some long range Neogene species.

01PC-4-56	*01PC-4-25	01PC-3-65	01PC-3-53	01PC-2-45	01PC-2-40	01PC-1-40	02PC-CC	*02PC-5-50	*02PC-4-85	*02PC-4-47	02PC-3-73	*02PC-3-7	02PC-2-110	02PC-2-98	03PC-3-10	03PC-2-102	10PC-3-40	10PC-2-47	10PC-2-29	10PC-1-104	Prometheus 2 samples
R	-	R	-	R	C	VA	-	F/C	-	-	-	-	-	-	C/R	-	R	R	R	R	pyrite
R/C	-	C	VR	R	R/C	R/C	C/A	C/A	R	R/C	C	R	R	F	A	VA	A	VR	R	C/A	quartz
-	VR	-	-	-	-	R	R	-	-	-	VR	-	-	-	R	-	-	-	-	R	glauconite
R/C	-	R	A	R/C	R	R	VR	R/C	-	C	C	-	R/C	C	A	R	R	C	VR	VR	Quaternary species
																					OLIGOCENE SPECIES
							X									X					*"Globigerina" ciperoensis*
																					MIOCENE SPECIES
X		X	X		X	X	X						X		X		cf			X	*Globoquadrina dehiscens*
X				X		X				X			X			X	X				*Praeorbulina transitoria*
		X		X			X	X		X										X	*Zeaglobigerina druryi*
		X																			*Praeorbulina sicana*
		X					X						X			cf					*"Globigerinoides" altiaperturus*
				X	X			X							X		X			X	*Praeorbulina glomerosa*
						X	X	X					X								*Globigerinoides bisphericus*
							X														*Paragloborotalia acrostoma*
		X		X				X		X				X							*Globorotalia praescitula*
																X					*Globigerinella praesiphonifera*
																					PLIOCENE SPECIES
										cf											*Globorotalia margaritae*
		X																			LONG RANGE SPECIES
X					X	X	X			X	X				X				X		*Zeaglobigerina woodi*
X				X			X									X					*Globigerinita juvenilis*
X		X			X								X			X	X			X	*Paragloborotalia semivera*
X														X							*Globigerina praebulloides*
X				X				X					X								*Globoquadrina praedehiscens*
		X		X		X	X	X		X				X	X	X		X			*Zeaglobigerina nepenthes*
		X				X		X					X			X	X				*Globigerinita incrusta*
				X	X		X						X			X					*"Globigerina" venezuelana*
					X	X	X						X								*Dentoglobigerina altispira altispira*
														X							*Globigerinoides obliquus*
																				X	*Zeaglobigerina decoraperta*
X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	*Globigerinoides trilobus*

Tab. 4 - Planktonic foraminiferal content of the mud breccia of cores BAN88-01PC, BAN88-02PC, BAN88-03PC, BAN88-10PC of the Prometheus 2. PC= piston core, CC=core catcher.

Olimpi area.

Nineteen samples from the Napoli Dome have been analyzed for their foraminiferal content. The identified "old" species, which are generally poorly preserved, range from Late Eocene to Pliocene. Quaternary species are rather well preserved. The results are reported in Tab. 5.

The Eocene faunas are very rare and consist of very few specimens of *A. bulbrooki*, *Pseudohastigerina micra* and *Subbotina linaperta*. The Oligocene faunas are common and well diversified. They range from Early to Late Oligocene and consist of small specimens of *Pseudohastigerina naguewichiensis* (Early Oligocene), *Paragloborotalia opima opima*, *"Globigerina" angulisuturalis* (Early to Late Oligocene) and *Paragloborotalia kugleri* (Late Oligocene-Early Miocene). The Miocene species are the most abundant among the "old faunas" and are represented by *Globigerinoides diminutus*, *P. transitoria* and *P. glomerosa* (Burdigalian-Langhian; Early-Middle Miocene) and only one specimen of *Globorotalia merotumida* (Late Miocene). The remaining assemblage comprises some long range Paleogene and Neogene species.

Twelve selected samples from the Bergamo Dome have been analyzed for their planktonic foraminiferal content (Tab. 6a). Preservation of the "older" faunas is generally poor relative to that of Quaternary species. Few specimens of *Globotruncana rosetta* group indicate a Campanian-Maastrichtian age. A single small specimen (150 μm) of *Pseudohastigerina barbadoensis*, very few specimens of *"G." angulisuturalis* and

"*Globigerina*" *ciperoensis* provide an Oligocene age, whereas the Early-Middle Miocene species, represented by *P. transitoria*, *P. glomerosa*, *P. sicana*, *Globigerinoides diminutus*, and *Globorotalia peripheroacuta*, are more abundant.

Two samples of the Monza Dome (Tab. 6b), and only one, out of the three analyzed, of the Milano Dome (Tab. 6c) contain planktonic foraminifera. They are

Olimpi Napoli Dome samples	01GC-CC	01GC-2-110	01GC-2-25	01TW-CC	02GC-3-42	02GC-1-110	04GC-CC	04GC-2-60	04GC-1-70	05GC-CC	05GC-3-60	05GC-2-60	05GC-1-32	05GC-1-32	06GC-CC	06GC-2-100	06GC-2-30	06GC-1-90	06GC-1-30
pyrite	C	A	R/C	R	A	A	C/A	VA	C/A	C/A	C/A	A	R	C	R	A	R/C	R/C	A
quartz	C	VA	A/C	C	C/A	VA	C/A	VA	C	A	A/C	A	C/A	C	C/R	VA	A	VA	A
glauconite	-	-	C	-	-	-	R	R	-	R/C	-	R	-	-	R	R/C	R	R	R
Quaternary species	C/A	R	C/A	VR	C	R	C	C	R	C	R	C	C	C/A	R	R	R	R	R
EOCENE SPECIES																			
Acarinina bulbrooki group															X	X		X	
Subbotina linaperta																	X		
Pseudohastigerina micra (>150 um)																	X		
OLIGOCENE SPECIES																			
Pseudohastigerina naguewichiensis	X												X	X				X	
Chiloguembelina cubensis			X			X													
Paragloborotalia opima opima						X													
Globigerina ouachitaensis													X						
"Globigerina" ciperoensis	X	X				X		X	X		X	X	X	X			X		
"Globigerina" angulisuturalis	X		X				X	X	X									X	
Paragloborotalia pseudokugleri																X			
Paragloborotalia kugleri					X														
MIOCENE SPECIES																			
Globoquadrina dehiscens	X	X	X	X	X		X	X	X		X		X				X		
"Sphaeroidinellopsis" disjuncta	X					X			X										
Zeaglobigerina druryi	X	X	X			X						X	X	X			X		X
Globigerinoides subsacculifer							X	X								X			
Paragloborotalia acrostoma															X				
Globorotalia praescitula	X	X	X	X	X	X	X	X	X	X		X	X					X	X
Globigerinoides bisphericus				X						X					X				
Globigerinoides diminutus			X	X						X			X						
Praeorbulina glomerosa							X						X				X		
Praeorbulina transitoria										X			X						
Globorotalia merotumida						X													
PLIOCENE SPECIES																			
Globorotalia puncticulata															X				
Globorotalia margaritae													X	X					
LONG RANGE SPECIES																			
"Globigerina" ampliapertura	X																		
Cassigerinella chipolensis					X		X							X					X
"Globoquadrina" rohri							X										X		
Globigerinita incrusta	X	X				X		X	X	X	X			X	X		X		
"Globigerina " venezuelana							X	X											
Globorotaloides variabilis						X													
Tenuitellinata angustiumbilicata														X					
Zeaglobigerina decoraperta		X																	
Dentoglobigerina baroemoenensis															X	X			
Globigerinita juvenilis					X	X	X	X			X							X	X
Tenuitellinata clemenciae							X												
Paragloborotalia siakensis					X					X			X		X				
Paragloborotalia semivera		X	X				X				X	X					X		
Paragloborotalia opima nana								X											
Zeaglobigerina brazieri																	X		
Zeaglobigerina woodi			X	X		X	X				X	X		X				X	
Dentoglobigerina altispira globosa									X										
Dentoglobigerina altispira altispira	X												X		X				
Globigerinoides obliquus					X	X	X	X		X	X		X						
Sphaeroidinellopsis spp.		X	X				X				X	X		X				X	
Zeaglobigerina nepenthes							X	X		X					X				
Globigerinoides trilobus	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	

Tab. 5 - Planktonic foraminiferal content of the mud breccia of cores BAN89-01GC, BAN89-01TW-CC, BAN89-02GC, BAN89-04GC, BAN89-05GC, BAN89-06GC of the Napoli Dome, Olimpi area. GC= gravity core, TW= trigger core, CC=core catcher.

represented by mixed Quaternary and Early-Middle Miocene species (*P. sicana*, *G. bisphericus*, *Globoquadrina dehiscens* and *Zeaglobigerina druryi*). A single specimen of *Globorotalia merotumida* is identified in the Monza Dome.

05PC-1-75	05PC-1-24	12GC-1-60	12GC-1-50.5	12TW-CC	13GC-3-67	13GC-3-9	13GC-3-3.5	13GC-2-99.5	13GC-2-97	13GC-2-36	13GC-2-30	Olimpi Bergamo Dome samples (a)
R	R	-	-	-	R	R	R	R	R	R	R	Pyrite
A	VA	A	A	C/A	C/A	C	C/A	VA	C/A	VA	A	Quartz
R	-	R	R	R	R	VR	R	R	R	R	C/R	glauconite
R	R	R	R	A	R	C	VR	R	A	R/C	C/A	Quaternary species
												CRETACEOUS SPECIES
										X	X	*Globotruncana rosetta* group
												OLIGOCENE SPECIES
X												*Pseudohastigerina barbadoensis*
			X		X		X		X			*"Globigerina" ciperoensis*
				X	X							*"Globigerina" angulisuturalis*
												MIOCENE SPECIES
	X											*Globorotalia praescitula*
X	X	X	X		X		X					*Zeaglobigerina druryi*
			X									*Globorotaloides stainforthi*
		X										*Paragloborotalia acrostoma*
										X		*Globorotalia peripheroacuta*
X		X	X	X			X	X	X		X	*Globoquadrina dehiscens*
								X	X		X	*Globigerinoides bisphericus*
					X	X		X	X			*Globigerinoides diminutus*
			X		X							*Praeorbulina sicana*
		X	X			X	X	X				*Praeorbulina glomerosa*
			X						X		X	*Praeorbulina transitoria*
												LONG RANGE SPECIES
X												*Globorotaloides suteri*
		X		X			X	X			X	*"Globigerina " venezuelana*
										X		*Cassigerinella chipolensis*
				X								*Dentoglobigerina baroemoenensis*
		X	X		X	X			X			*Globigerinita incrusta*
					X							*Globigerinoides bollii*
							X					*Zeaglobigerina decoraperta*
					X							*Tenuitellinata angustiumbilicata*
		X						X		X	X	*Globoquadrina praedehiscens*
X									X			*Paragloborotalia siakensis*
X	X	X	X									*Paragloborotalia semivera*
X												*Paragloborotalia opima nana*
	X											*Globigerinita juvenilis*
X		X	X	X	X	X	X					*Zeaglobigerina woodi*
					X				X			*Globigerinoides obliquus*
		X										*Zeaglobigerina nepenthes*
				X								*Globigerinoides extremus*
X				X			X					*Dentoglobigerina altispira altispira*
X	X	X	X	X			X	X	X	X	X	*Globigerinoides trilobus*

07PC-3-15	07PC-2-72	Olimpi Monza Dome samples (b)
R	VR	pyrite
VA	VA	quartz
F/C	F/C	glauconite
VA	C/A	Quaternary species
		MIOCENE SPECIES
X	X	*Globoquadrina dehiscens*
	X	*Praeorbulina sicana*
	X	*Globorotalia merotumida*
	X	*Globorotalia peripheroronda*
		LONG RANGE SPECIES
	X	*Paragloborotalia siakensis*
X		*Globigerinita incrusta*
	X	*Zeaglobigerina decoraperta*
	X	*Globigerinoides trilobus*

04PC-CC	*04PC-1-100	04PC-1-5	Olimpi Milano Dome samples (c)
R	-	C	pyrite
A	R	VA	quartz
-	-	F/C	glauconite
C	-	VR	Quaternary faunas
			MIOCENE SPECIES
X			*Globoquadrina dehiscens*
X			*Zeaglobigerina druryi*
X			*Globigerinoides bisphericus*
			LONG RANGE SPECIES
X			*Zeaglobigerina decoraperta*
X			*Globigerinoides trilobus*

Tab. 6 - Planktonic foraminiferal content of the mud breccia of cores a) BAN88-05PC, BAN89-12GC, BAN89-12TW-CC, BAN89-13GC of the Bergamo Dome, Olimpi area; b) BAN88-07PC of the Monza Dome, Olimpi area; c) BAN88-04PC of the Milano Dome, Olimpi area. PC= piston core, GC= gravity core, TW= trigger core, CC=core catcher.

Comparison with calcareous nannoplankton data.

The calcareous nannofossil content confirms the age derived from planktonic foraminifera. Both matrix and clasts of diapiric sediments recovered in the Prometheus 2 and Olimpi areas generally contain rare Oligocene species (*Dictyococcites bisectus*) and more common Miocene to Pliocene nannofossils such as *Cyclicargolithus floridanus*, *Coccolithus miopelagicus*, *Reticulofenestra pseudoumbilica*, *R. minuta*, *Sphenolithus abies*, *S. belemnos*, *S. heteromorphus*, *Discoaster druggii*, *D. exilis*, *D. challengeri*, *D. pentaradiatus*, along with very rare Cretaceous taxa such as *Lithraphidites carniolensis*, *Lithastrinus floralis*, *Eiffellithus turriseiffelii*, *Parhabdolithus angustus* and *Watznaueria barnesae* (Cita, Camerlenghi et al., 1989; Erba & Castradori, 1992, pers. comm.). Samples from the Pan di Zucchero contain Quaternary floras and mixed Miocene, Pliocene and rarer Cretaceous taxa (as listed above) with some Oligocene species such as *Dictyococcites bisectus* and *Cyclicargolithus abisectus* (Erba & Castradori, 1992, pers. comm.).

Discussion.

Intrusion and extrusion versus sedimentary textures.

Very little is known from the literature about the sediment texture comparable to the mud breccia of the Mediterranean Ridge. Probably, the mud diapirism maintains the same general distinctive characteristics in different settings (Brown, 1990). Therefore, a comparison between the mud diapirs of the Mediterranean Ridge and those of the other accretionary complexes studied only with sidescan survey and submersible dives (Henry et al., 1990; Le Pichon et al., 1990) could contribute in the understanding of this process. The surface manifestation of mud extrusion often consists of creep and slumping (Cita et al., 1981; Ryan et al., 1982) that may produce reworked sediments, mud flows (Langseth et al., 1988; Henry et al., 1990) and slope landslide which results in debris fans (Prior et al., 1989). The sedimentation of reworked materials is facilitated by the extrusion of fluid mud associated with the growth of a mud volcano.

A massive and compact breccia with no graded bedding or clast orientation in sharp contact or unconformity with the overlying host sediments (type A1, Pl. 1) is suggestive of intrusive mechanisms with no evidence of further reworking. The mud breccia recovered from the Prometheus 2, from the Milano Dome, and from the top of the Bergamo Dome is characteristic of type A1 facies. Type A1 facies is also observed in cores from the lateral basin of the Bergamo Dome and from the Pan di Zucchero Dome. In this case the hemipelagic sediments recorded under the mud breccia suggest debris flow as emplacement mechanism (Camerlenghi et al., 1992).

Organized (type B) and massive (types A2 and A3) textures are typical of the cores recovered from the Napoli Dome. This dome shows a step-like profile which is characteristic of the mud volcanoes and/or mud pies (Brown & Westbrook, 1988; Henry et al., 1990; Camerlenghi, 1991). A mud lake may be located on top of the mud volcano (Henry et al., 1990; Le Pichon et al., 1990). Although there is no bathymetric evidence of large depressions located at the top of the Napoli Dome, the massive and "mousse-like" sediments (type A3) recovered from the top of the cores raised from the Napoli Dome could be interpreted as a mud lake deposit where the extruded clasts, heavier than the diluted mud, sink.

The organized texture (type B) is indicative of reworking processes, which are probably due to debris flows or local turbiditic flows (types B1, B2) producing grain size sorting, graded bedding and laminated textures. These textures suggest that the diapir erupted fluid mud at least in its early stage. The high fluidity of the extruded mud is demonstrated by the "mousse-like" textures, gas bubbles and transitional boundaries between diapiric and host hemipelagic sediments.

Similarities and differences among the diapiric fields.

The mud breccia usually consists of grey and dark-grey to olive matrix sometimes containing clasts of different nature, size and shape (see Pl. 1, 2). In all three diapiric fields the uppermost few centimetres of the mud breccia are characterized by a yellowish oxydation layer just below the contact with the overlying host sediments.

The microscopic analyses of residues reveal that the Olimpi and Prometheus 2 fields are very similar and are characterized by large amount of quartz, which is missing in the Pan di Zucchero. The difference between fields is supported by a decrease in abundance of smectite and an increase of kaolinite from east (Prometheus 2) to west (Pan di Zucchero) as discussed by Camerlenghi et al. (1992).

The calcium carbonate content of the the bulk breccia varies according to the different facies. It ranges from 10 to 20% in the type A1. The higher values recorded in type A3 sediments are probably due to the mixing of mud breccia and host hemipelagic sediments (always higher than 50%).

Analogies between Prometheus 2 and Olimpi are supported by the planktonic foraminiferal and calcareous nannofossil assemblages which mostly consist of Burdigalian-Langhian species, whereas the assemblages recorded from the Pan di Zucchero contain predominantly Oligocene species. No evidence of typical Messinian lithologies (such as gypsum or dolomite) or microfossils (such as brackish water ostracods) was found in the mud breccia.

Oligocene species which are present also in Prometheus 2 and Olimpi areas suggest a possible double source and/or two different phases in the extrusion processes. The presence of rare Cretaceous and Eocene microfossils in the mud breccia could be due to reworking within the Oligocene-Miocene sediments, whereas the occurrence of Late Miocene and Early Pliocene species could be related to contamination during the diapiric extrusion/intrusion.

Age of the extrusions and intrusions.

The age of extrusive and intrusive events is inferred on the basis of stratigraphic position and microfossil content of the host sediments in contact with the mud breccia. It may also be inferred indirectly by the occurrence of older microfossils reworked from the mud breccia in the hemipelagic sediments of the surrounding areas, as discussed by Camerlenghi et al. (1992, p. 502).

In summary,

1) The absence of the Holocene sediments above the mud breccia on the Prometheus 2 Dome suggests that the diapiric extrusion is presently active, or alternatively that Holocene sediments are continuously removed by bottom currents.

2) The occurrence of a few centimetres of hemipelagic sediments including sapropel S-1 overlying the intruded mud breccia (consisting of types A2 and A3) in the Olimpi (Napoli and Bergamo Domes) and Pan di Zucchero areas (cores BAN89-02GC, BAN89-05GC, BAN89-12GC, BAN89-13GC, BAN89-20GC) are probably indicative of diapiric activity just older than sapropel S-1 (about 10,000 years).

3) The diapiric activity is documented as persistent from sapropel S9 (about 250,000 years) till at least Sapropel S-6 (about 180,000 years) (core BAN89-03GC) on the basis of reworked microfossils from the mud breccia exposed on nearby sea floor.

4) The marker bed recorded in most cores (Cita, Aghib et al., 1989) is possibly suggestive of a recent pulse of diapiric activity about 3000-4000 years BP.

Source sediments.

The Mediterranean pre-Messinian sedimentary record is poorly known; therefore, the source sediments of the mud breccia are only tentatively identified. They should be pre-Messinian sediments, underlying the evaporite layer, and as old as early Miocene for the Prometheus 2 and Olimpi areas and as old as Oligocene for the Pan di Zucchero. The composition of the matrix, consisting of silt and clay, and of the clasts, consisting of silt, pyrite and quartz rich arenites (see Tab. 1), suggests a terrigenous origin for the source sediments.

The mud diapirism is usually induced by the subduction of high porosity and low permeability clay sediments (Brown & Westbrook, 1988; Barber & Brown, 1988; Speed, 1990).

Conclusions.

The study performed on the cores raised from three diapiric fields discovered on the Mediterranean Ridge (Eastern Mediterranean) leads to the following conclusions:

1) Mud diapirism is recorded on the Mediterranean Ridge. The diapiric activity may be intrusive as on Prometheus 2 and Milano Dome or extrusive and originating mud volcanoes (Napoli Dome) similar to that observed in the Barbados Ridge (Henry et al., 1990). Sedimentary textures of the mud breccia are strictly related to implacement and/or reworking processes. The massive texture type A1 facies is suggestive of intrusive events in Milano, Bergamo and Pan di Zucchero domes. The massive texture type A2 and A3 are indicative of intrusive mechanism and/or successive undisturbed sedimentation of the mud breccia (mud lake deposit on the top of Napoli Dome). The

organized type B is probably indicative of reworking processes following the extrusion of fluid mud from mud volcanoes such as debris flows and local turbiditic events (types B1 and B2).

2) The mud breccia is substantially similar in all the three diapiric fields investigated, but compositional differences occur between the Pan di Zucchero area SW of Crete, in the shallowest point of the Mediterranean Ridge, and the other two diapiric fields about 200 km to the east. The age of the former seems older (Oligocene instead of Miocene).

3) The composition of clasts and matrix suggests a terrigenous origin for the source sediments. The age of these sediments is probably Oligocene to Middle Miocene. The sparse pre-Oligocene microfossils are interpreted as reworked within the source sediments.

4) Although the mud breccia should have penetrated the Messinian evaporitic formations, we did not recover lithological or micropaleontological evidence of typical Messinian facies.

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PLATE 1

Type A massive texture of the mud breccia.

Fig. 1 - Type A1 (core BAN88-02PC-4, 78-110 cm, Prometheus 2 area) is characterized by stiff matrix containing centimetric up to pluricentimetric clasts. No size sorting is observed.

Fig. 2 - Type A2 (core BAN89-01GC-2, 100-120 cm, Napoli Dome, Olimpi area) represented below the white line, is characterized by a stiff matrix containing millimetric clasts.

Fig. 3 - Type A3 (core BAN89-04GC-1, 25-60 cm, Napoli Dome, Olimpi area) is characterized by soft grey "mousse-like" mud containing sand-size clasts.

PLATE 2

Type B organized texture of the mud breccia.

Fig. 1 - Type B1 (core BAN89-01GC-2, 30-60 cm, Napoli Dome, Olimpi area) is characterized by millimetric horizontal bedding with clasts sorted by size.

Fig. 2 - Type B2 (core BAN89-01GC-2, 60-90 cm, Napoli Dome, Olimpi area) is characterized by a grain-supported mud breccia with upward increasing of matrix/clast ratio and decreasing of grain size.

Fig. 3 - Type B3 (core BAN89-02GC-2, 50-73 cm, Napoli Dome, Olimpi area) is characterized by the absence of clasts exceeding sand size and by patches and clouds of different colours.

PLATE 3

Fig. 1 - SEM photographs of the mud breccia type B2 showing millimetric aggregates of silt and clay (BAN88-03-2, 45 cm).
Fig. 2 - SEM photographs of the mud breccia type B3 showing millimetric aggregates of silt and clay and planktonic foraminifera (BAN89-02GC-2, 65 cm).
Fig. 3 - SEM photographs of the mud breccia type A1 showing millimetric aggregates of silt and clay and small fragments of pyrite (BAN89-13GC-2, 43 cm).
Fig. 4 - SEM photographs of the mud breccia type A2 showing millimetric aggregates of silt and clay and planktonic foraminifera (BAN89-013GC-2, 95 cm).
Fig. 5 - SEM photograph showing a fine sand with crystals of pyrite (BAN89-06GC-1, 30 cm).
Fig. 6 - SEM photograph showing silt with angular quartz (BAN 89-02GC-1, 110 cm).

PLATE 4

Fig. 1 - Core catcher with a large arenitic clast (BAN89-12CC).
Fig. 2 - Detail of the clast recovered in BAN89-12CC.
Fig. 3 - Thin section of the subarkose recovered in the core catcher of core BAN89-12GC (base of Bergamo Dome).
Fig. 4 - Large clasts of bioclastic packstone recovered in cores BAN89-20GC (base of the Pan di Zucchero Dome).

PLATE 5

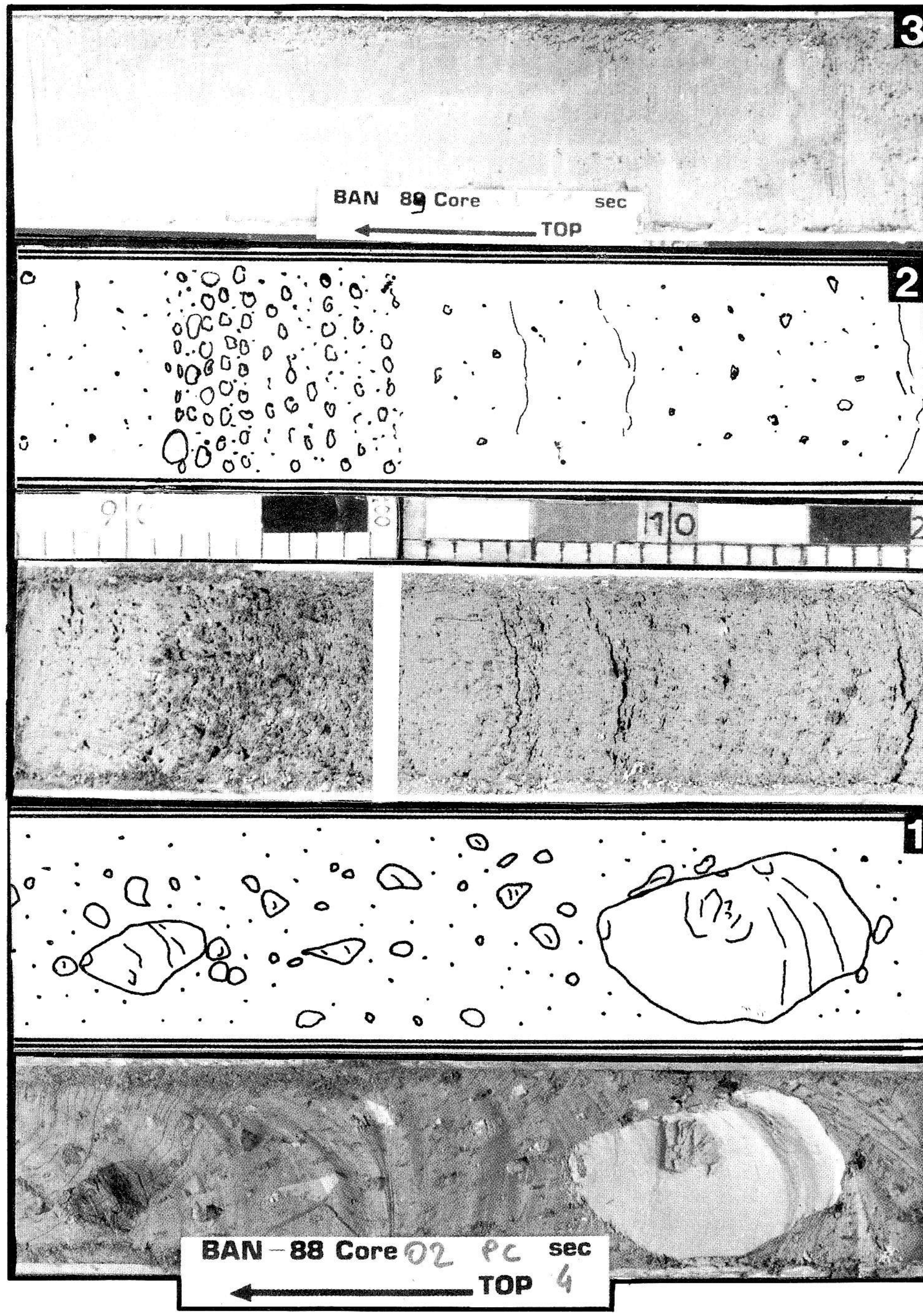
Fig. 1 a, b - *Globotruncana rosetta* (Carsey) group. a) Spiral view; b) umbilical view. Sample BAN89-13GC-2, 30 cm.
Fig. 2 - *Zeaglobigerina nepenthes* Todd. Umbilical view. Sample BAN89-04-CC.
Fig. 3 - *Sphaeroidinellopsis paenedehiscens* Blow. Umbilical view. Sample BAN89-04-CC.
Fig. 4a, b - *Acarinina bulbrooki* (Bolli) group. a) Umbilical view; b) spiral view. Sample BAN89-06GC-2, 30 cm.
Fig. 5 - *Globoquadrina dehiscens* (Chapman, Parr & Collins). Umbilical view. Sample BAN89-20GC-2, 61 cm.
Fig. 6 - *Praeorbulina sicana* (De Stefani). Umbilical view. Sample BAN89-20GC-2, 40 cm.
Fig. 7 - *Praeorbulina transitoria* (Blow). Spiral view. Sample BAN89-20GC-2, 40 cm.

All figures same magnification.

PLATE 6

Fig. 1 - "*Globigerina*" *angulisuturalis* Bolli. Umbilical view. Sample BAN89-04GC-2, 60 cm.
Fig. 2 - *Cassigerinella chipolensis* (Cushman & Ponton). Umbilical view. Sample BAN89-20GC-2, 61 cm.
Fig. 3 - *Cassigerinella chipolensis* (Cushman & Ponton). Spiral view. Sample BAN89-20GC-2, 61 cm.
Fig. 4 - *Zeaglobigerina druryi* Akers. Umbilical view. Sample BAN89-01-CC.
Fig. 5 - "*Globigerina*" *angulisuturalis* Bolli. Spiral view. Sample BAN89-04GC-2, 60 cm.
Fig. 6 - "*Globigerina*" *ampliapertura* Bolli. Umbilical view. Sample BAN89-01-CC.
Fig. 7 - *Pseudohastigerina micra* (Cole). Spiral view. Sample BAN89-20GC-2, 61 cm.
Fig. 8 - *Globoquadrina dehiscens* (Chapman, Parr & Collins). Umbilical view. Sample BAN89-20GC-2, 61 cm.
Fig. 9 - *Globigerinella obesa* (Bolli). Umbilical view. Sample BAN89-20GC-2, 40 cm.
Fig. 10 - *Globorotalia* sp. Blow & Banner. Spiral view. Sample BAN89-01-CC.

Figures 1, 2, 3, 7 same magnification; figures 4, 5, 6, 8, 9, 10 same magnification.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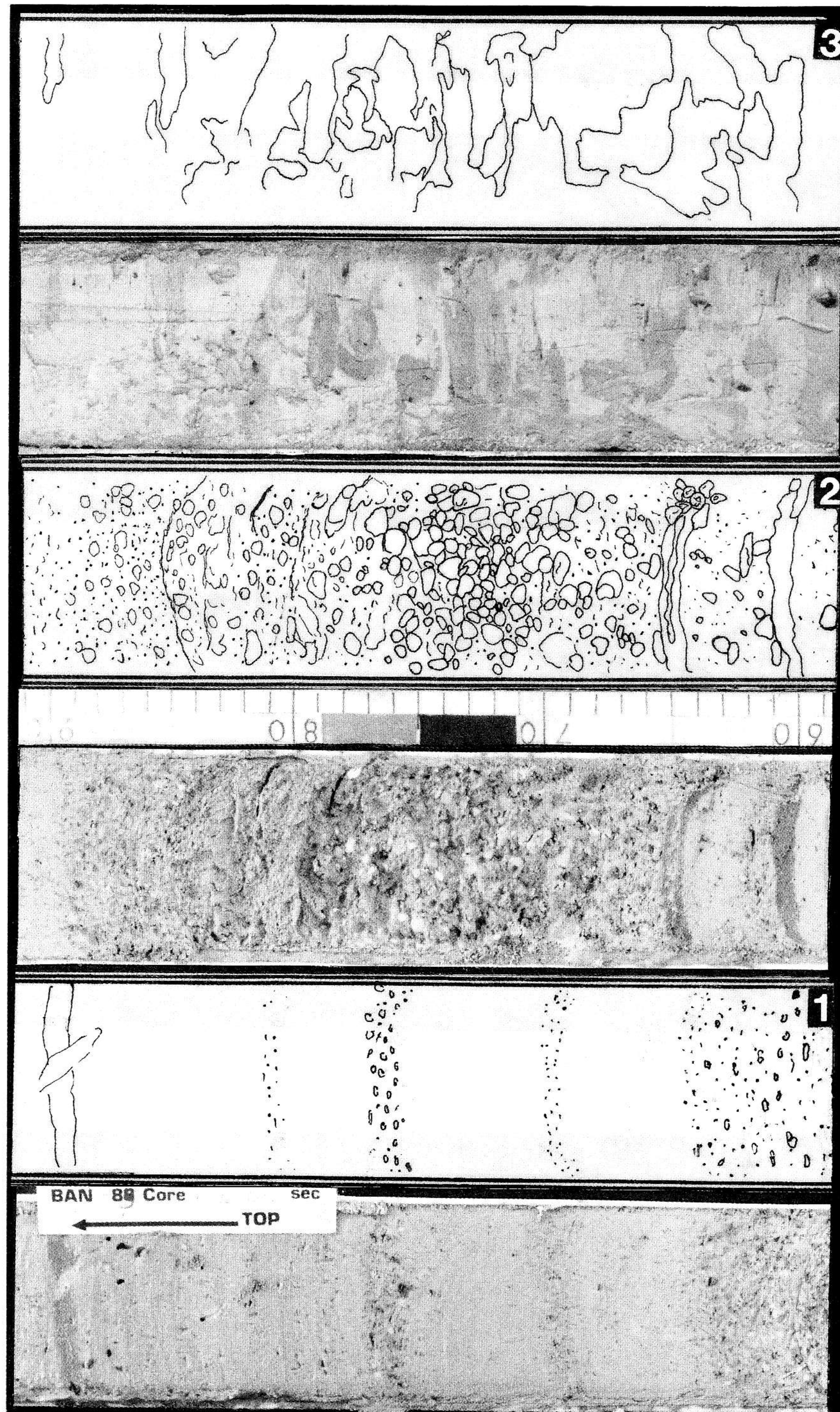
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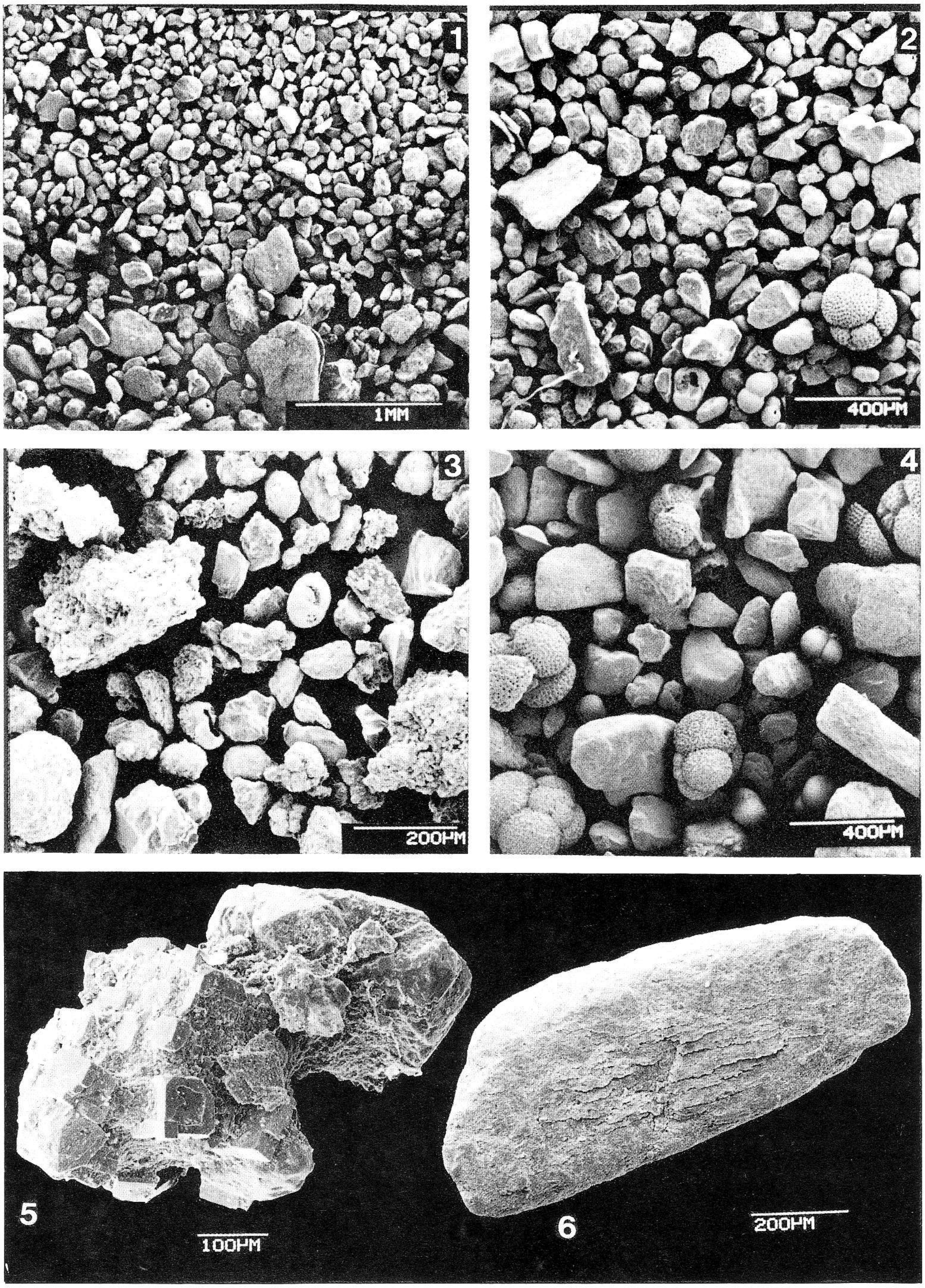
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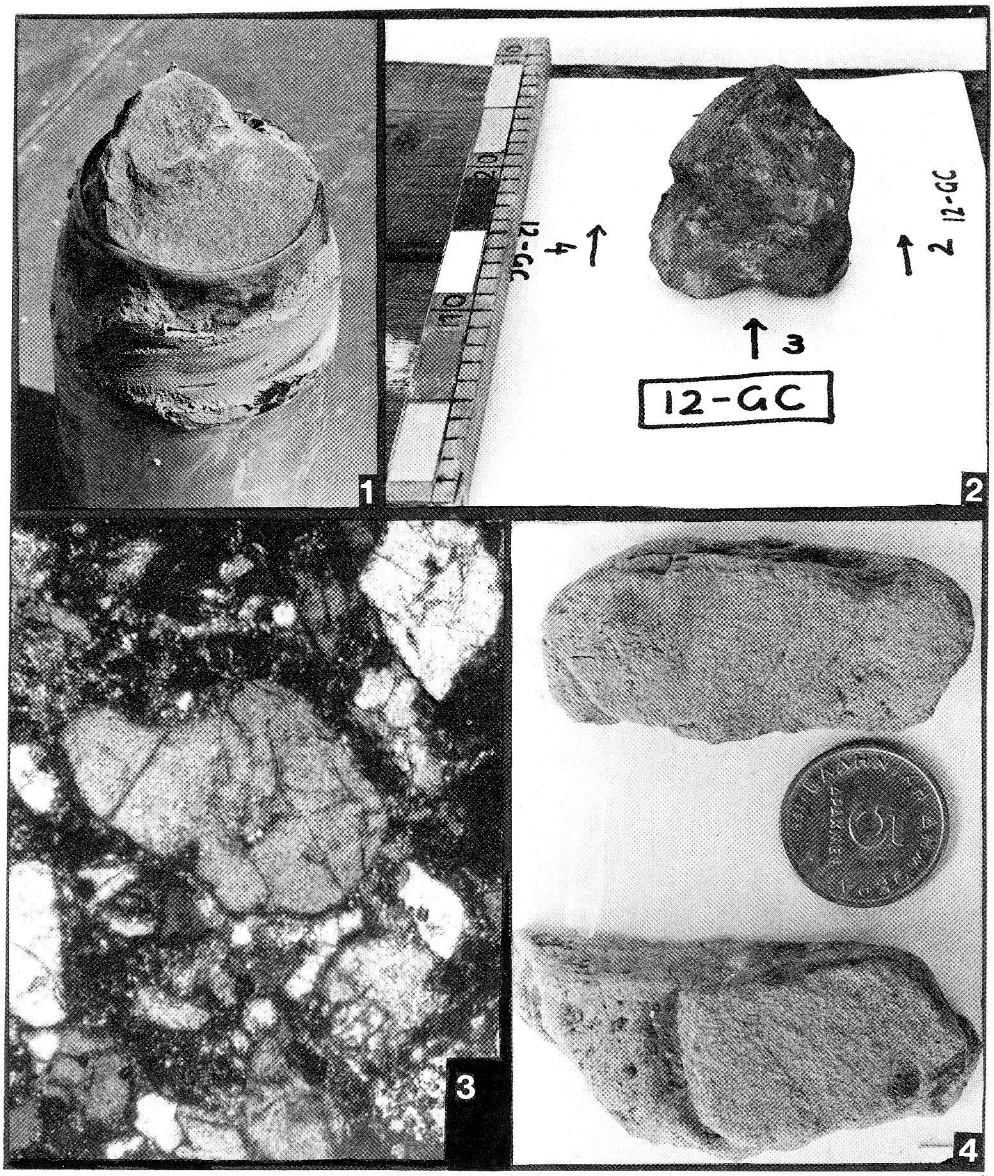
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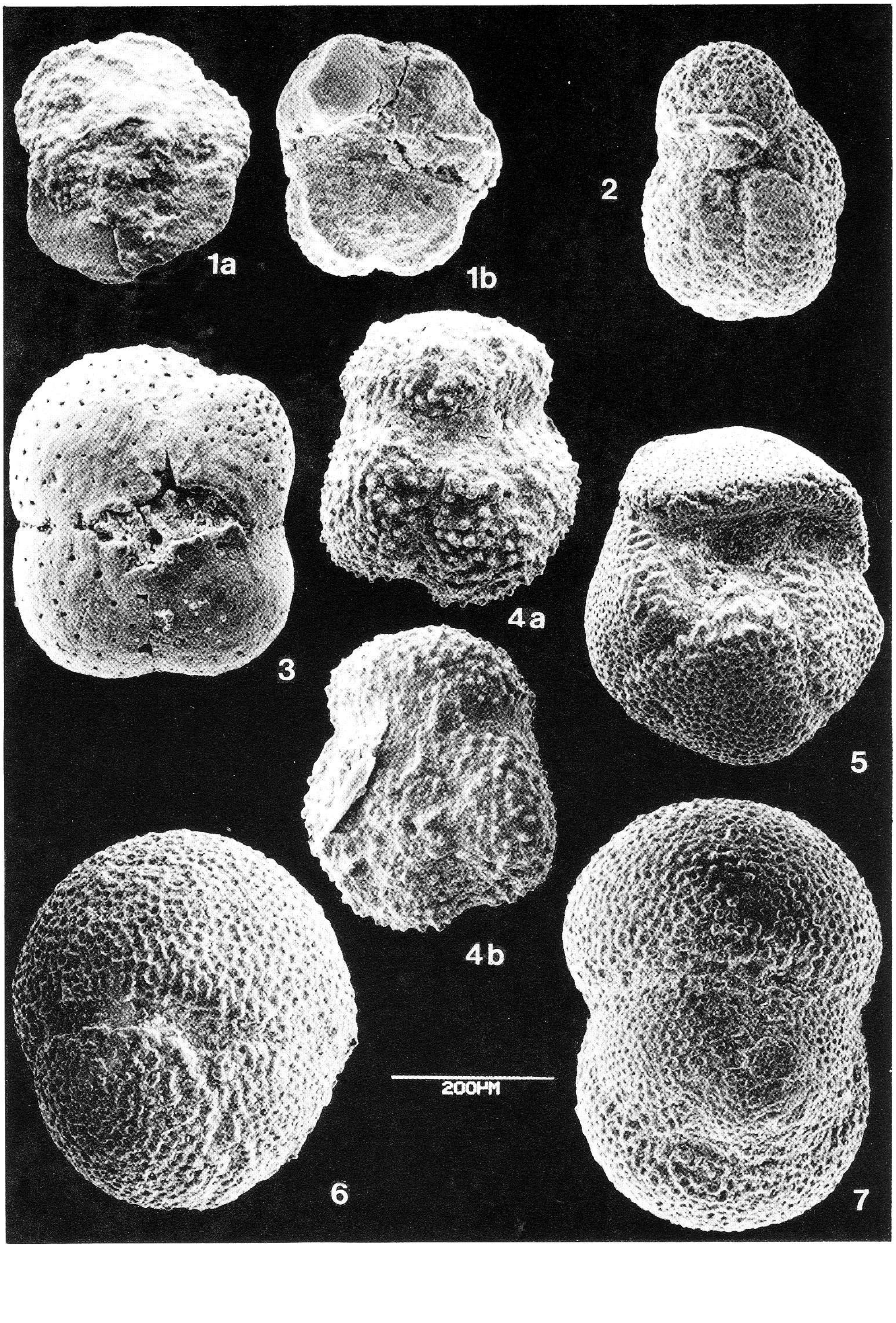
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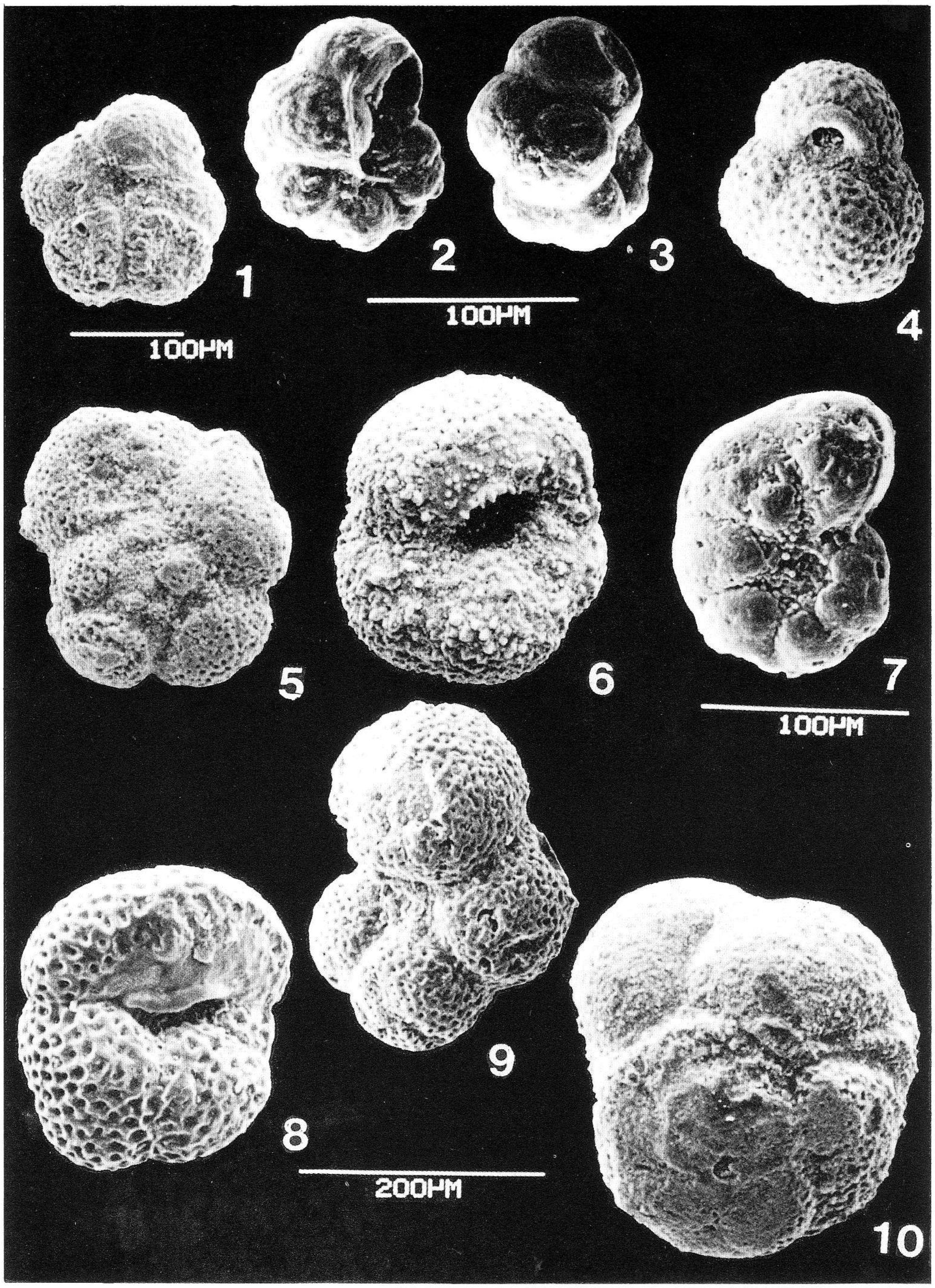
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