7. STRUCTURE AND STRATIGRAPHY OF THE MAZAGAN ESCARPMENT: PRELIMINARY RESULTS OF THE CYAMAZ DIVING EXPEDITION—A POST-SITE SURVEY FOR LEG 79[1]

CYAMAZ Group[2]

INTRODUCTION

The Mazagan Escarpment is located about 200 km southwest of Casablanca in the Central Atlantic (Fig. 1). It constitutes an almost 3000-m-high cliff between the Mazagan Plateau and the Seine Abyssal Plain. This escarpment is one of the best studied examples of starved passive continental margins, where it is possible to collect direct geological information on the history of that margin. Reconstructions of the Central Atlantic at the end of the Liassic show the location of the Mazagan Escarpment between the African continent and its thinned, stretched margin, where evaporitic series were deposited opposite the Nova Scotian margin (Bhat et al., 1975; Hinz et al., 1982; Jansa and Wiedmann, 1982). Because of its steepness, the Mazagan Escarpment provides an exceptional opportunity to study the Mesozoic to Paleogene stratigraphy, paleoenvironment, and subsidence history of a nearly sediment-free external carbonate platform, exposing the Late Jurassic and Cretaceous continental margin sediments of the Atlantic Ocean.

With these objectives in mind, a French-German project was developed in this area, using the French submersible CYANA SP 3000 (CYAMAZ cruise). This cooperative project was executed by the Centre National pour l'Exploitation des Océans (CNEXO) and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), and well prepared by a large amount of preexisting geological and geophysical information.

Different seismic surveys were conducted for several years in this area: single-channel seismic surveys by *Vema, Atlantis-II*, and *Meteor* expeditions (*Vema* Cruises 23, 27, 29, 30, 32 by Lamont-Doherty Geological Observatory; and *Meteor* Cruises 25 and 46 by BGR) are enhanced by multichannel seismic surveys carried out by the BGR (*Meteor* 39 and 53, *Valdivia* 79) as site surveys for IPOD Legs 50 and 79 (see Uchupi et al., 1976; Wissmann and von Rad, 1979; Hinz, Dostmann, et al., 1982).

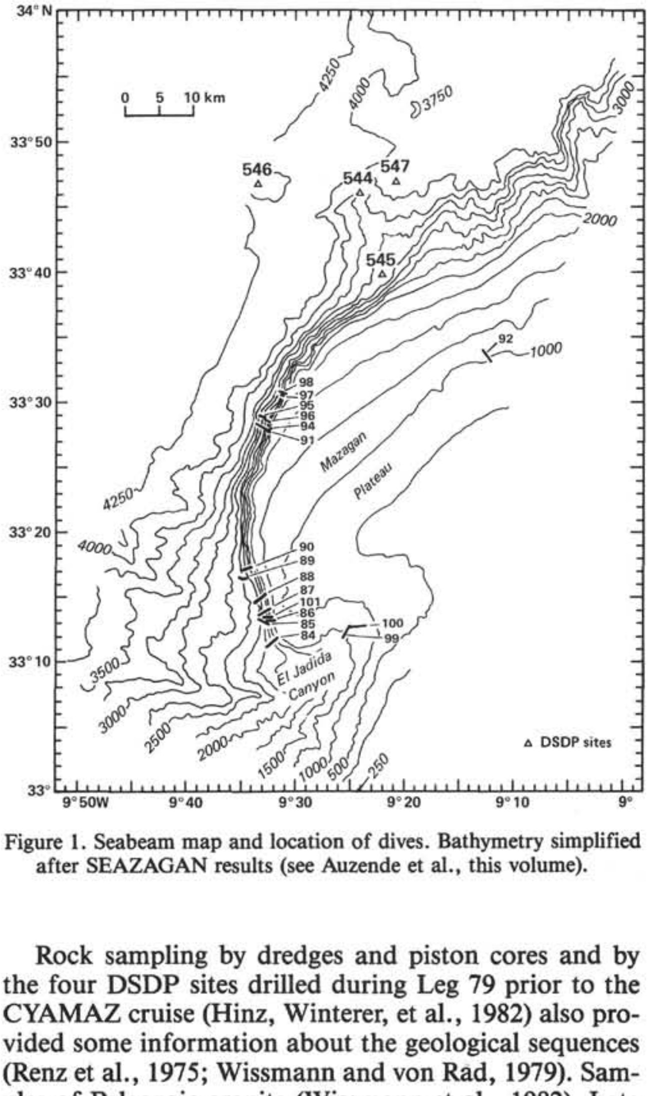

Figure 1. Seabeam map and location of dives. Bathymetry simplified after SEAZAGAN results (see Auzende et al., this volume).

Rock sampling by dredges and piston cores and by the four DSDP sites drilled during Leg 79 prior to the CYAMAZ cruise (Hinz, Winterer, et al., 1982) also provided some information about the geological sequences (Renz et al., 1975; Wissmann and von Rad, 1979). Samples of Paleozoic granite (Wissmann et al., 1982), Late Jurassic peri-reefal and Oxfordian ammonite-rich limestones, and Early Cretaceous and Eocene marls were collected during the *Vema* 30, *Meteor* 46, and *Valdivia* 79 cruises. But this information is very incomplete because of the discontinuous sampling and its poor localization.

The CYAMAZ diving cruise was based on a bathymetric survey using the multibeam echo-sounder Seabeam (Auzende et al., 1983 and this volume). Single-channel seismics were recorded along the multibeam tracks, and their geological interpretation will be used to extend the diving data to the whole Mazagan Plateau (Fig. 2).

During the CYAMAZ cruise, 18 dives enabled us to take 130 rock samples and more than 6000 color photo-

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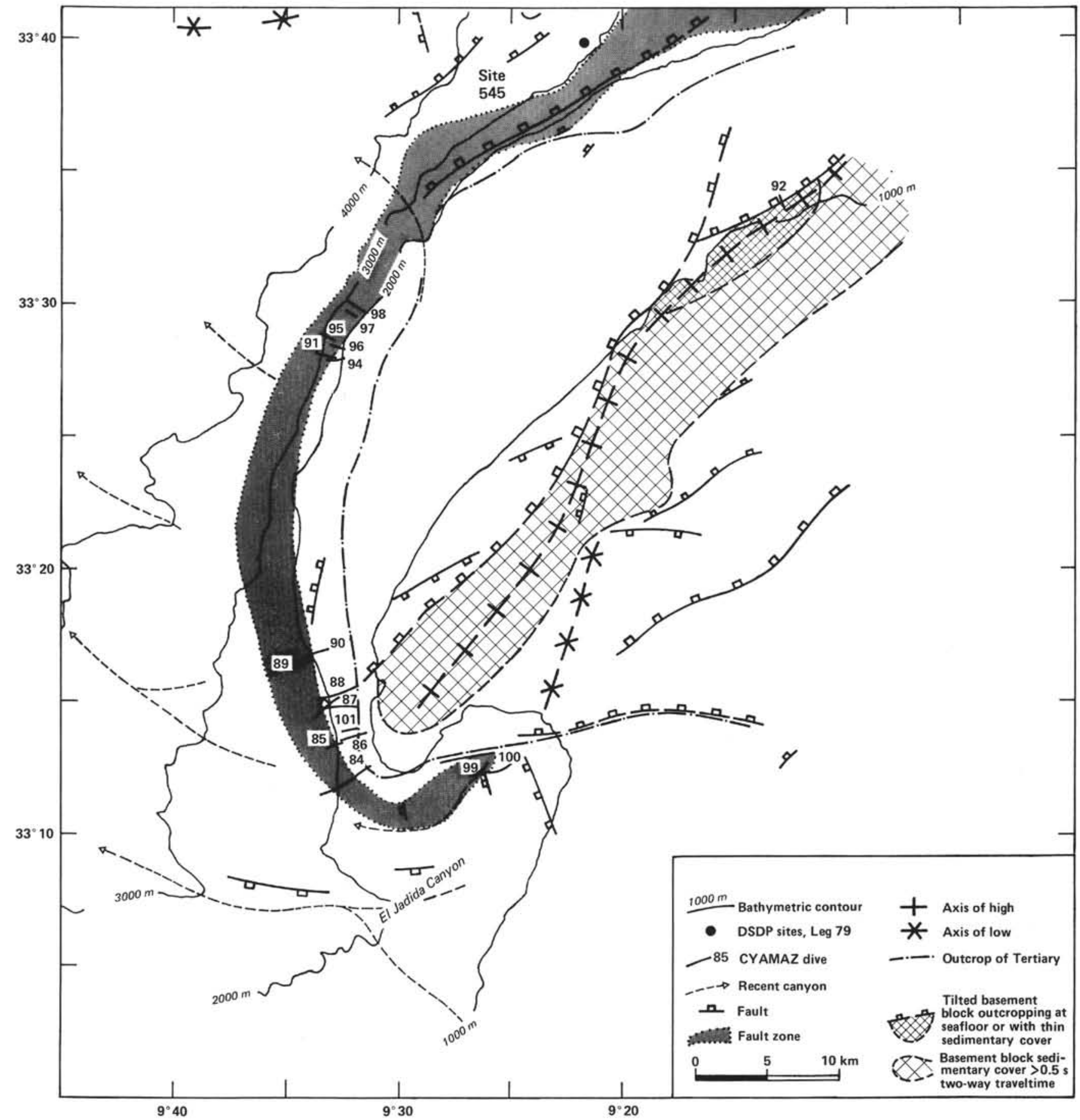

Figure 2. Structural sketch map of the Mazagan Plateau (H. Dostmann).

graphs during 73 hours of observation. The purpose of the CYANA dives was mainly to observe and sample the steepest part of the escarpment, where the seismic results suggested that old sedimentary rocks were exposed. The diving limit was the 3000-m isobath. A series of diving traverses was made (Figs. 1 and 2): eight dives in the southern part of the escarpment between 30°10'N and 33°N, and five dives around 30°30'N. Moreover, three dives were devoted to the younger geological section, one on the top of the Mazagan Plateau, and two in the vicinity of El Jadida Canyon, which strongly erodes the southern scarp (see Table 1).

MAIN STRATIGRAPHIC RESULTS

Late Jurassic–Neocomian Carbonate Platform

The Mazagan Plateau is underlain by Late Jurassic to early Neocomian shallow-water carbonates. During the CYANA dives outcropping platform limestones and their Cretaceous/Tertiary cover (Fig. 3) were observed over a

Table 1. Overview of important data of CYAMAZ dives.

No.	CYANA dive No.	Scientific observer	Date (1982)	Total time	Working time on seafloor (hour)	Seafloor depth (m) (max.-min.)	Distance (km)	No. of samples	No. seafloor photos	No. of tapes	Area	Stratigraphy
CYAMAZ—A												
1	84	von Rad	Sept. 20	09:16–16:30	5:10	2236–1190	3.8	6	290	2	Southernmost Mazagan Escarpment	? Ju, Kl, Ku/Tl, Tu
2	85	Auzende	Sept. 21	11:11–16:08	2:44	2146–1586	1.5	8	~200	1		Ju, Kl,
3	86	Dostmann	Sept. 22	09:15–14:58	4:00	1817–1000	1.4	6	178	2		Ju, ?Ku/Tl, Tu
4	87	Lancelot	Sept. 23	08:53–16:25	5:31	2335–1230	2.1	9	~420	2		Ju, ?Kl, ?Tl, Tu
5	88	Çousin	Sept. 24	10:40–18:16	5:27	2403–1378	2.5	9	~270	2	Southern Mazagan Escarpment	Ju, Kl, Tl, Tu
6	89[a]	Čepek	Sept. 25	09:00–15:04	3:24	2440–1953	1.8	4	246	1		Ju, ?Kl
7	90	El Asri	Sept. 27	09:06–15:37	4:40	2260–1400	1.8	3	525	2		Ku
8	91	von Rad	Sept. 28	09:06–17:32	5:33	3003–2035	2.0	8	520	2	Central Mazagan Escarpment	Ju, Kl, ?Ku/Tl
CYAMAZ—B												
9	92	Auzende	Oct. 2	16:30–19:55	2:14	1090–976	2.0	6	162	1	Central Mazagan Plateau	Tl
10	93[b]	Steiger	Oct. 3	09:16–13:04	1:01	2412–2400	0.1	—	36	1	Central Mazagan Escarpment	Ju
11	94	Steiger	Oct. 6	09:43–16:08	4:01	2492–1809	1.2	8	245	2		Ju, Kl
12	95	Biju-Duval	Oct. 7	11:36–18:33	3:37	2978–2300	1.5	7	364	2		Ju/Kl, Tu
13	96	Jaffrezo	Oct. 8	11:00–18:25	5:04	2380–1766	1.5	11	~340	2		Ju, Kl, Ku
14	97	Ŗuellan	Oct. 9	14:48–19:53	2:26	2420–1960	0.6	4	~670	1	Central Mazagan Escarpment	Ju, Kl,
15	98	Čepek	Oct. 10	08:50–17:21	5:40	2943–1956	2.3	12	~630	2		Ju, Kl, Ku
16	99[a]	von Rad	Oct. 11	14:00–18:32	3:04	1357–1142	1.2	8	369	1	North slope of El Jadida Canyon (south Mazagan Plateau)	Kl, ?Ku
17	100	Auzende	Oct. 12	09:22–14:47	4:01	1331–1061	2.9	12	473	2		Kl, Tl
18	101	Biju-Duval	Oct. 13	09:49–16:59	5:17	1985–1195	1.5	9	490	2	South Mazagan Escarpment	Ju/Kl, Tl
				Σ	~73		• 31.7	130	~6430	30		

Note: Ju = Upper Jurassic, Kl = Lower Cretaceous, Ku = Upper Cretaceous, Tl = lower Tertiary (Paleogene), Tu = upper Tertiary (Neogene).
[a] Premature termination of dive, because of worsening weather conditions.
[b] Premature termination because of technical problems.

lateral distance of about 40 km from 3000 to 1400 m water depth. The profiles showed approximately 600–800 m of Upper Jurassic carbonates. Such a thickness is perfectly compatible with a carbonate platform subsiding at 50 m/m.y. for 15 m.y. Seven facies types of shallow to deeper water environments were distinguished along the profiles.

1. *Massive pelsparite*. The major rock type shows irregularly distributed pelmicritic layers, which indicate occasional algal (stromatolitic) binding of the sediment. Calcium carbonate supersaturation gave rise to the development of ooids and an early cementation of the normal peloidal sediment. Calcified hexactinellid and lithistid siliceous sponges grew on the peloidal substratum, but did not construct true sponge reefs, as known from European epicontinental seas.

2. *Pelsparites with shallow-water benthic foraminifers* are less frequent and distributed within the algal pelsparitc facies. The components are often bound to grapestones similar to those of the recent shallow-water, high-energy carbonate environments.

3. The pelsparites alternate with *algal-encrusted reef debris*.

4. Above the pelsparites the shallow environment grades into *high-energy oncolitic sediments*.

5. Younger sediments are represented by *foraminiferal algal grainstones*.

6. *Bioclastic wackestones* contain *calpionellids* and siliceous sponge debris. The sediment was deposited on the deeper foreslope of the carbonate platform with accumulations of pelagic organisms.

7. The shallow-water platform finally was covered by shallow-water *oolites*.

CRETACEOUS TO TERTIARY SEDIMENTS

From mid-Early Cretaceous times on, thin hemipelagic nannofossil marls were deposited, especially on fault blocks along the lower part of the escarpment. However, south of the Mazagan Plateau, along the northern branch of El Jadida Canyon (around 1200 m depth), we observed a sequence, several hundred m thick, of well-bedded, Berriasian to Barremian, sandy bioclastic (quartz-echinoderm-rich) limestones. Cross lamination, slump structures, and intraformational breccias suggest deposition in a slope environment.

Mid-Early Cretaceous sedimentation is characterized by conspicuous condensation horizons that are well bedded and only a few tens of meters thick. They occur only along the central Mazagan Escarpment (around a water depth of 1800–2000 m: Dives 91, 93–98). In the area of the southern Mazagan Escarpment (Dives 84–90, 101), the platform limestones are overlain at a water depth of approximately 1400–1700 m by a condensed series of micritic limestones, dolomites, phosphatized carbonates, cherts, and breccias of Late Cretaceous to Paleogene age. The breccias contain numerous reworked clasts and fossils of Late Jurassic to Cretaceous age.

ish gray, hemipelagic nannofossil marks were deposited only on the deeper parts of the block-faulted paleoslope, which are correlated with the Aptian to Cenomanian greenish nannofossil claystone facies of Site 545.

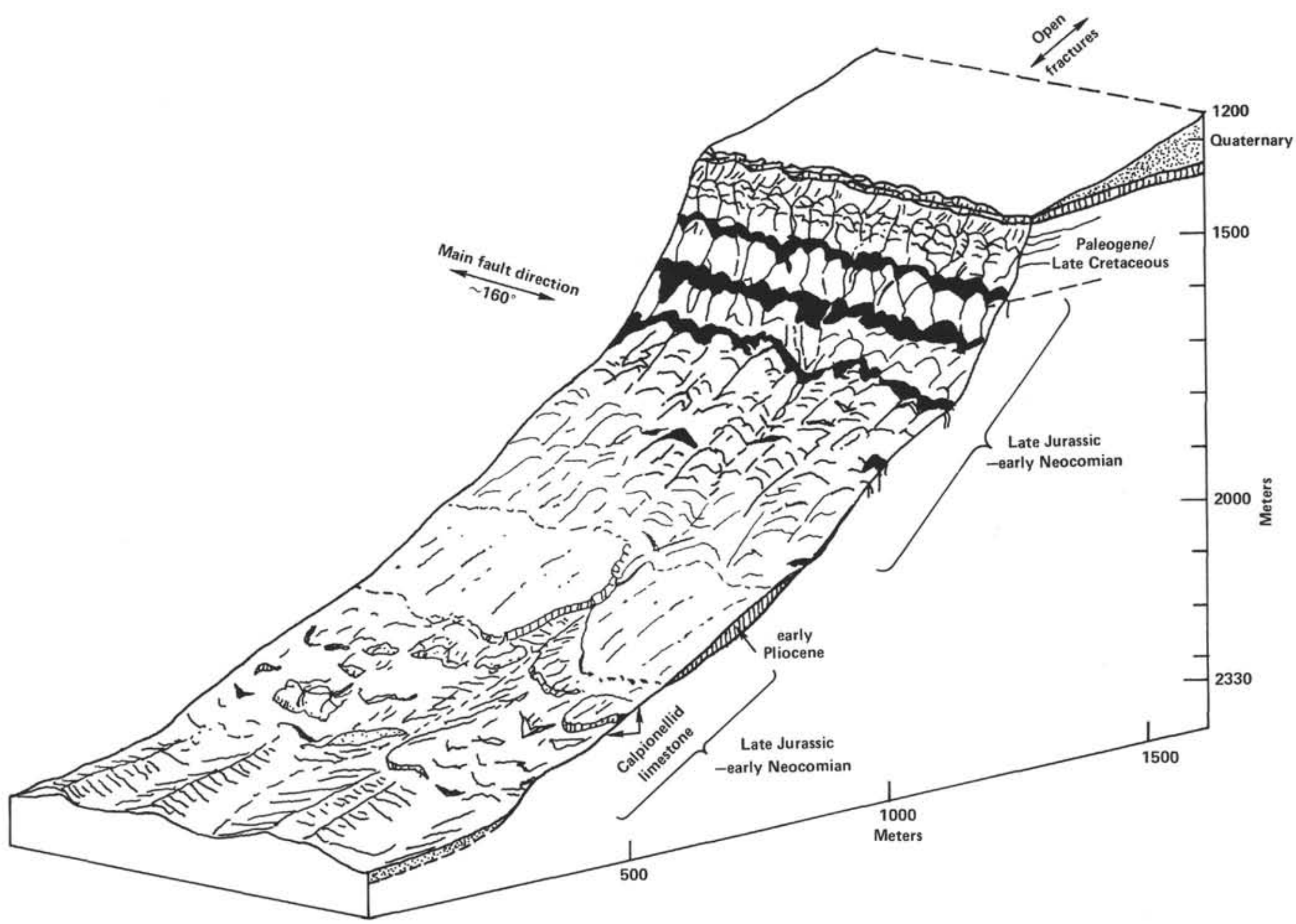

Figure 3. Block diagram of Dive 87 (Y. Lancelot). Slope not exaggerated.

Globigerina-bearing calcisiltites and tectonic breccias found in the area of a fault scarp (water depth: about 1000 m) on the Mazagan Plateau (Dive 92) have a Paleocene age.

Semiconsolidated nannofossil marls of Miocene and Pliocene age overly the faulted Jurassic and Cretaceous limestones at many locations at the Mazagan Escarpment.

The thickness of the post-platform series is difficult to estimate from our dives because of faulting and limited exposure. From the seismic data, the Late Cretaceous–Tertiary sequence is up to 500 m thick on the Mazagan Plateau proper. The thickness decreases considerably toward the western edge of the plateau.

PRELIMINARY CONCLUSIONS ON THE EVOLUTION OF THE MAZAGAN ESCARPMENT

Some preliminary observations and ideas on the evolution of Mazagan Escarpment are presented, since our study of the age and facies of the CYAMAZ samples is still in progress (see, also, CYAMAZ group, 1983).

The major unanswered questions from previous studies of Mesozoic and Cenozoic carbonate platforms at passive continental margins are the importance of different constructional and destructional processes, such as the development of the carbonate platform, defacing, progradation, bypass, block-faulting, and back-tilting (see, e.g., Cita and Ryan, 1981).

Development of the Carbonate Platform

From at least the Oxfordian to early Neocomian, the Mazagan Plateau was a stable, slowly subsiding crustal block in front of the Moroccan Meseta rimmed by a developing shallow-water carbonate platform. A precursor of the present Mazagan Escarpment was in existence during the Late Jurassic and enhanced before Albian times; this coincided with the termination of the carbonate buildup due to increased subsidence, deltaic outbuilding, or other causes. A conspicuous result of the CYANA dives is the lack of preserved reef structures in the area of the present-day Mazagan Escarpment over the total vertical distance studied. One possible explanation for the formation of a carbonate bank would be the early cementation and stromatolitic binding of the pelsparites stabilizing the platform margin; the steep platform foreslope environment would then be represented by the calpionellid wackestones. From seismic evidence, which shows foundered blocks seaward of the escarpment, the present shape of the escarpment could also be the result of a small retreat of the cliff due to defacing and block-faulting.

Bypass and Outbuilding

At the beginning of the Cretaceous the subsidence rates may have increased considerably. From mid-Cretaceous to Paleogene times, only pelagic bathyal sediments were deposited on the Mazagan Slope. This proves that the carbonate platform was hardly covered at the escarpment during that time and had subsided to a water depth of at least 1 km at the end of the Cretaceous. The observed cover of well-bedded Aptian–Albian nannofossil oozes or nannofossil marls, flat-lying or lapping onto the slope, and the infilling of small pockets or borings by Late Cretaceous to Paleogene pelagic sediments strongly argue for downfaulting and a certain bypass along the steep sediment-starved escarpment at the beginning of the Cretaceous. The Berriasian to Barremian clastic sequence, observed in the south of the plateau, could represent the erosive remnant of a prograded delta/deep-sea fan sequence. It also correlates well with the flysch sequence sampled in the oceanic basin near the base of the escarpment at DSDP Site 416 (Lancelot, Winterer, et al., 1980).

Erosion and Defacing

Major evidence for erosion was observed at the outer edge of the Mazagan Plateau. Episodic nondeposition and reworking (breccias with angular clasts of platform limestones and thin condensed horizons) and a major mid-Cretaceous to Paleogene hiatus can be inferred from our diving observations and seismic evidence. Most of the defacing happened probably during the Late Jurassic to Neocomian. During most of the past 100–120 m.y., the starved or partly prograded escarpment experienced only little erosion and deposition. The late Miocene to early Pliocene breccias of Site 545 containing Late Jurassic to Berriasian clasts partly in a Santonian micrite matrix suggest episodic defacing of an exposed paleoescarpment (see site report, Site 545, this volume). Open fractures might be due to slope destruction, as similarly observed at the Bahama Escarpment (Freeman-Lynde et al., 1981). The different ages of the thin draping sequences could also be interpreted as a consequence of a small, but permanent retreat of the cliff. Dissolution and biogenic destruction of the limestone face is documented by rounded surfaces of the limestone outcrops and the microkarst relief of the carbonates (CYMOR-2 Group, in press). Small, straight, V-shaped canyons with polished surfaces were incised in the escarpment. Gravitational mass wasting is another important mechanism with progressive spalling of the cliff (Freeman-Lynde et al., 1981). Study of the different small-scale cut-and-fill structures and phosphoritic/ferromanganese encrustations of the CYAMAZ samples will provide additional data for the interpretation of the post-platform evolution of the Mazagan Escarpment.

Vertical Tectonics

Normal faults are abundant. Estimation of the offset is generally impossible. Open fractures observed in the carbonate platform have not been observed in the layered Cretaceous–Tertiary sequence above.

The transition from the Mazagan Plateau to the deep sea is sharp and characterized by a series of fault blocks with steps ranging from 10 to 200 m (the vertical displacement of individual normal faults observed from CYANA was only a few centimeters to decimeters). From seismic evidence and CYAMAZ observations, the following main fault systems can be mapped:

1. Normal faults striking about 60°. The downfaulted blocks are tilted to the northwest causing the marked northward deepening of the plateau edge. The major 60° faults are remarkably spaced 15 km apart. Structural axes of lows and highs trend parallel to the system (Figs. 1,2). The following examples can be enumerated: (a) Tilted block faults crossing the Mazagan Plateau with a throw up to 200 m. A discontinuous reflection pattern beneath a moundlike structure on the upthrown side is characteristic. (b) Slope-parallel step faults at the northern part of the Mazagan Escarpment with vertical displacements of 1000 m. Due to the steepness of the slope in the seismic lines, they are only mappable as a "fault zone." (c) Northern boundary of tilted gneissic basement block, drilled at DSDP Site 544 with clear evidence on seismic lines.
2. Normal faults striking about 120° (as old as 1).
3. Normal faults with a strike direction of about 150–180°, parallel to the slope in the central part of the Mazagan Escarpment and in the El Jadida Canyon and about 20° (en echelon faults to the 60° direction). They seem to intersect the older faults (1 and 2). These faults are seismically difficult to detect due to complex seismic structures in the deep sea and to the steepness of slope.
4. Open fractures (diaclases) are more or less perpendicular to the previously mentioned fault systems. No displacement is visible in these fractures that could be only observed during the CYANA dives.

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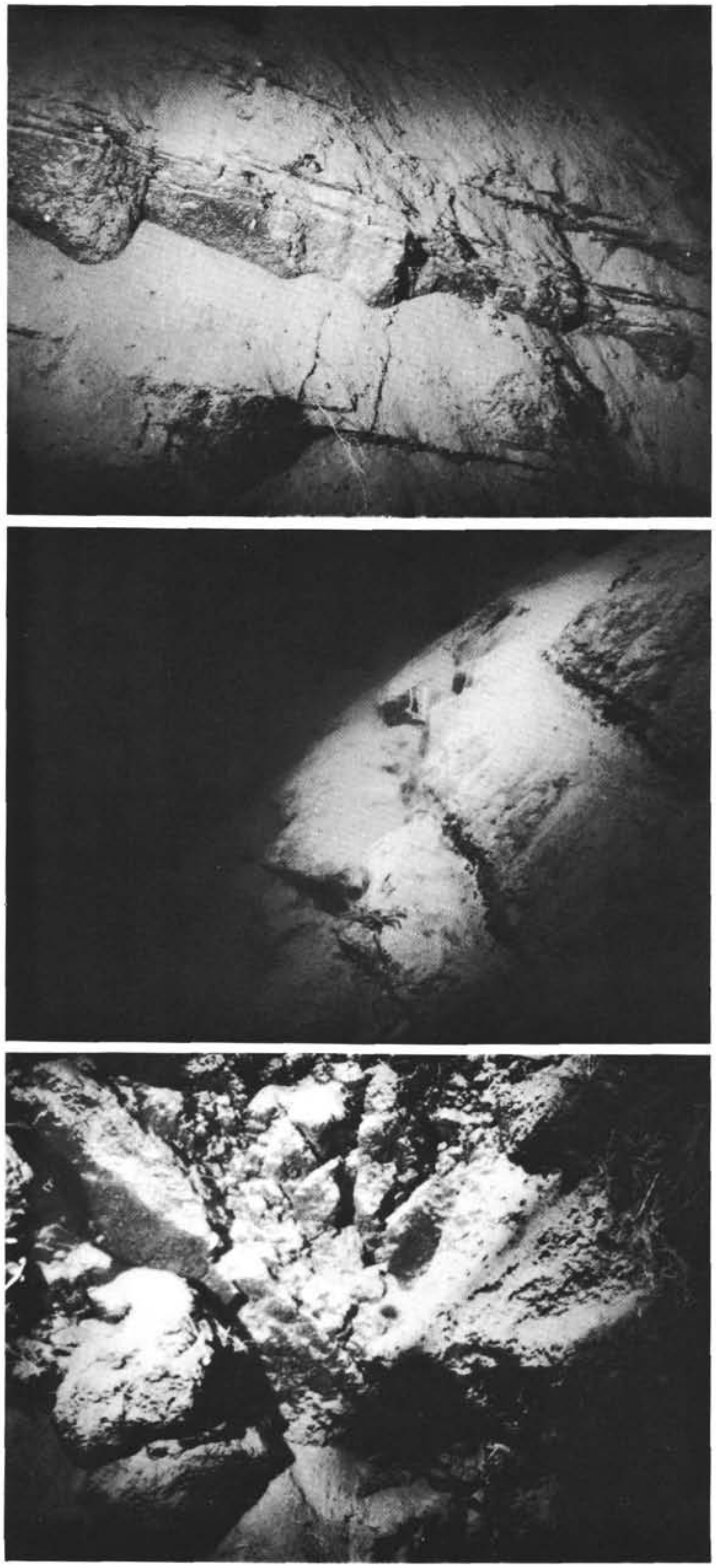

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Plate 1. Photos from the Mazagan Escarpment, taken during CYANA dives. **1.** Well-bedded pelagic foraminiferal limestone (biomicrite; Paleogene). Upper part of southern Mazagan Escarpment (1481 m water depth). Dive 88, photo 266. Note steep slope (30°–50°). **2.** Well-bedded Late Cretaceous nannofossil marl (Coniacian-Santonian)). Lower part of central Mazagan Escarpment (2850 m water depth). Dive 98, photo 94. **3.** Massive Jurassic to Upper/lower Neocomian shallow-water limestone (foraminiferal algal grainstone) with subvertical fault parallel to escarpment. Central Mazagan Escarpment (2387 m water depth). Dive 96, photo 14.

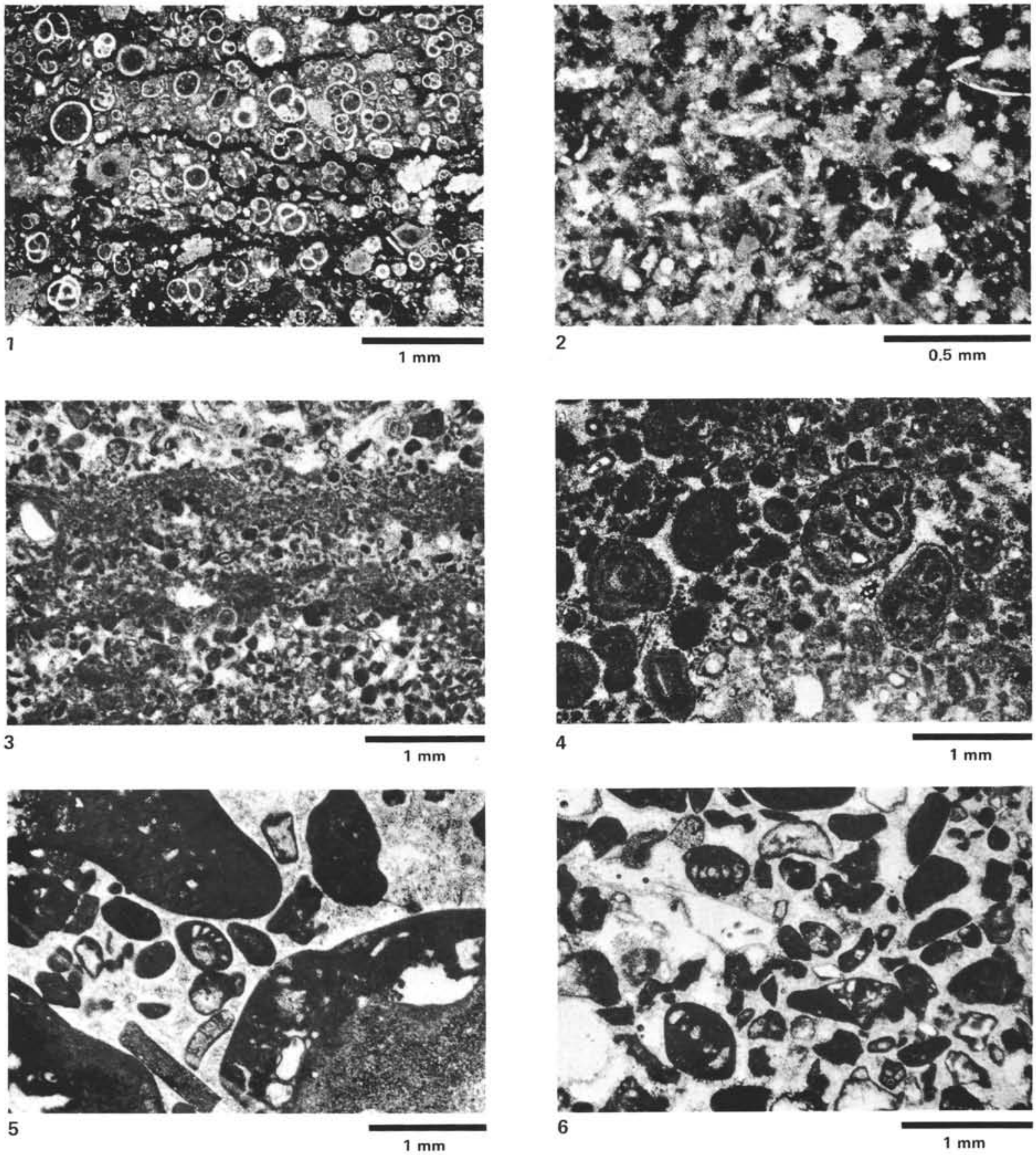

Plate 2. Thin-section photomicrographs of selected limestone types found at the Mazagan Escarpment (T. Steiger). **1.** Phosphatized foraminiferal glauconite packstone of Eocene age. This sediment is formed in pockets of massive Jurassic rocks. Condensed deposition marked by manganese interlayers. (CZ 88 - 9, 1503 m water depth). **2.** Sandy bioclastic peloidal packstone with calpionellids (Tithonian to early Neocomian), deposited on the seaward tectonic blocks of the Mazagan paleoescarpment. (CZ 89 - 2, 2237 m water depth.) **3.** Crustose pelsparite (= grainstone composed of superficial ooids, peloids, intraclasts, echinoderms, and molluscan shell debris). The sediment is occasionally interlayered by micritic horizons, and peloids are bound by cyanobacterian cement. These early lithified surfaces are also dome-shaped. Major lithotype of the inner carbonate platform. Late Jurassic to early Neocomian. (CZ 96 - 6, 2187 m water depth.) **4.** Ooid grainstone. This facies is associated with crustose pelsparites. The ooids show numerous layers and irregular contours. Peloids and small ooids are bound to grapestones. Late Jurrassic to early Neocomian. (CZ 91 - 6, 2356 m water depth.) **5.** Coarse lagoonal grainstone composed of echinoderm remains, rounded micritic intraclasts and foraminifers (*Protopeneroplis striata* Weynschenk) and, not visible in the photo, coral fragments and dasycladacean algae. The echinoderm in the lower right is overgrown by the encrusting alga *Lithocodium* cf. *morikawai* Endo. Late Jurassic to early Neocomian. (CZ 89 - 3, 2160 m water depth.) **6.** Lagoonal grainstone containing *Nautiloculina oolithica* Mohler, textulariids, echinoderm remains, intraclasts, and molluscan shell fragments. Late Jurassic to early Neocomian. (CZ 91 - 2, 2914 m water depth.)