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Sea Cliff Retreat in Southern Portugal: Profiles, Processes, and Problems

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ABSTRACT

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Southern Portugal's central Algarve coast is undergoing accelerated cliff retreat due to the combined effects of sea-level rise and natural and anthropogenic erosion. Between Olhos de Água and Quinta do Lago, 10 to 50 m high red cliffs are cut into friable Miocene to Quaternary clastics. This area can be divided into three distinct zones based on natural cliff evolution and human influence. The western zone (Praia de Falésia) is characterized by continuous cliffs, 15 to 45 m high, dominated by natural erosive processes and has retreat rates on the order of 1 m/year. The middle zone cliffs (Forte Novo–Vale do Lobo) are 10 to 20 m in height, interrupted by stream mouths, and subject to retreat rates of more than 2 m/year. Human activities have caused changes, including development of the cliff upland and modification of nearby shorelines, such as at Quarteira. Locally, as much as 6.3 m of retreat have occurred in a single year. The eastern zone cliffs (Quinta do Lago) are now inactive due to the formation of a protective barrier system. The cliffed zones provide a case study for contrasting the impact of shoreline protective structures and the different styles of upland development relative to the proximity of the cliff edge.

Evolution of the cliff profiles shows a repetitive pattern controlled by the dominance of either marine or subaerial erosion processes, including such factors as wave conditions, storm frequency, tidal range, runoff, joint systems, lithologic heterogeneity, cliff-face position of harder and softer layers, clay content, water-rich layers, vegetation, occurrence of earthquakes, and human influences within the area (*e.g.*, updrift jetties, groins, seawalls, digging caves, construction, vibration, and adding water). Future solutions to problems associated with cliff retreat should be based on known retreat rates, the projected sea-level rise, and the past experience of human impact on the cliffs.

ADDITIONAL INDEX WORDS: *Cliff retreat, coastal erosion, hazard mitigation, Portugal (Algarve).*

INTRODUCTION

The Algarve coast of southern Portugal is one of Europe's most famous and fastest growing coastal resort regions. Development to meet the demands for tourism and retirement villages in the coastal zone is infringing on the shoreline, to the detriment of both the natural environment and the coastal population. This paper examines one aspect of the resulting human impact, namely accelerated cliff retreat in the area between Olhos de Água and Quinta do Lago (Figure 1). The shoreline can be divided into three distinct zones: a western zone of more natural conditions in which cliff retreat rates are variable, a middle zone where cliff retreat has been accelerated by human activities, and an eastern zone in which the cliffs have become inactive behind a young barrier system. The objective of this paper is to contrast these zones, and, in particular, to examine the zone of greatest human impact. The growth problems of this area mirror the problems of most developing shorelines.

The tremendous growth of development in the Algarve is indicated by the number of hotel beds, a tourist industry measure. This number increased by 109% between 1966 and 1972, and doubled again by 1977 (CAVACO, 1979). Between 1978 and 1980 villas and apartments increased by 258% and hotels by 8% (MARTIN *et al.*, 1984). Rapid growth continued through the 1980's. The influx of foreign visitors and settlers has been so great as to create unique social problems. For example, a law was passed requiring all advertising signs to carry their message in Portuguese as well as the target group's language. The water resources of this semiarid region have been heavily impacted (MARTIN *et al.*, 1984). One-half of the annual 100,000 tons of waste produced in the Algarve is being generated during the June to August interval (ANGLO-PORTUGUESE NEWS, 1989). And on the shoreline, communities and developments threatened by shoreline erosion are be-

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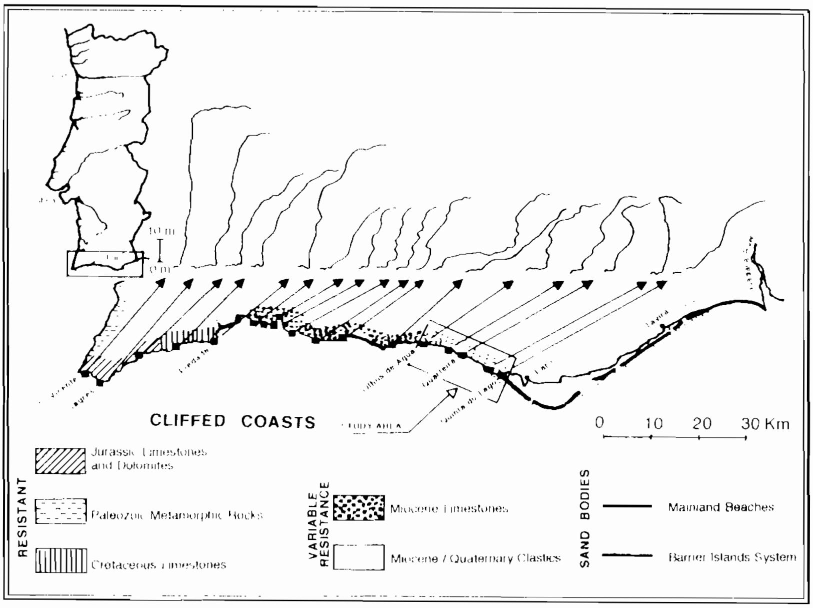

Figure 1. Map of the Algarve Coast (southern Portugal); distribution of cliff resistance by lithology; and representative cliff profiles. The study area is indicated by the boxed area (see Figure 3).

ing encouraged to adopt engineering solutions that are being abandoned in other parts of the world, *i.e.*, seawalls and groins.

Land-Use Regulations

The central government has authority over the coastal zone, defined as the Maritime Public Domain Area. Local communities may be given some management authority over this zone, and structures are often permitted. Developers are required to file plans for approval before construction, and, usually, significant set-back distances from the shoreline or cliff edge are required. The minimum set-back is 50 m and is increased depending on coastal morphology. Such prudent planning has not prevailed in most cases, and developments have been suffering the consequences of losses to cliff retreat since they were built. Until recently no data base of calculated erosion rates has existed, although shoreline retreat could be documented with reference to old landmarks and a comparison of past generations of aerial photographs, topographic maps, and coastal charts. No special construction requirements exist for buildings because they are in the coastal zone, *e.g.*, construction so that the building can be easily moved if threatened by erosion.

Even when regulations exist, the significant variability of this coast makes uniform application of legal concepts difficult. Figure 1 is a general coastal classification suggesting the coastal variability from the western massive cliffs cut into Jurassic limestones and dolomites that erode very slowly (*e.g.*, Cabo de São Vicente and Sagres), through the spectacular karst Miocene cliffs of Ponta da Piedade, to the rapidly eroding cliffs which are the subject of this paper. To the east is the barrier island system of the Ria Formosa (Pilkey *et al.*, 1989), which partially formed in front of the sea cliff line, rendering the cliffs inactive.

CLIFF PROFILE ANALYSIS

Figure 1 also shows representative Algarve cliff profiles. The analysis of such profiles, using the method of Emery and Kuhn (1982), indicates that marine erosion is dominant over subaerial erosion (Dias, 1984). Retreat of these cliffs is strongly affected by marine erosion along their entire extent. The profiles are typically steep, unvegetated, angular at the top, and lacking debris at the base of the cliff so that the profile angle with the beach is also sharply angular. However, in the easternmost part of the study area (near Quinta do Lago), the cliffs have attained the "fossil" stage as noted above. This inactivity and fossilization is related to the beginning of the barrier-island system (the Ancão Peninsula). The formation of the barrier system isolated the cliffs from the sea and ended wave erosion. As a consequence, later modification of the cliffs by subaerial processes resulted in gentler profiles ranging from rounded cliff edges with deposits at the base of the cliff (not removed by the sea) to well-defined sigmoidal profiles (Quinta do Lago) masked by a cover of pine trees that grow on these gentler profile slopes.

A cliff-retreat model for the study area is proposed on the basis of field observations and in terms of an ideal homogeneous cliff with no structural control and free of human influence. Figure 2 shows the evolution of such a cliff. Profile A is a net instability profile often characterized by a large wave cut notch at its base. Soon, the upper part of the cliff falls, resulting in Profile B with a "smooth" part at the base formed from the collapse blocks and debris. Sometimes the entire profile presents a sigmoidal shape, but usually only the accumulation at the base resembles the lower part of a sigmoidal curve, and the upper part of the profile remains sharp. According to the EMERY and KUHN model (1982) the sigmoidal profile corresponds to conditions where subaerial erosion is dominant over marine erosion. This interpretation is not true for the cliffs of the study area. These profiles are, on the contrary, due dominantly to marine erosion. Sharp angles at the top are due to landslides or block falls induced by the strong marine undercutting at the base of the cliff.

The B phase is truly ephemeral. The time lapse in which this profile exists is variable, depending mainly on wave conditions. If this profile exists at the beginning of summer it can be maintained until the next autumn or winter. The low wave energy and the wide beach profile reduce wave attack of the cliff. Under these conditions, the cliff profile can be smoothed at the top and at the base, evolving to a more sigmoidal profile. In this case the sigmoidal tendency really indicates ephemeral inactivity as indicated by EMERY and KUHN (1982).

However, the B profile is often attained during the winter season. In this case, the next high spring tide or the next storm will remove most of the debris and a new wave-cut notch starts to form (Profile C). If the wave regime is strong (storm waves of 3–4 m or even medium waves of 2 m during high spring tide), and if the beach is narrow with no berm, the cliff profile rapidly changes to D with a large wave-cut notch that induces block falls from the middle part of the profile (just above the notch) forming an even larger wave-cut notch. Rapidly, Profile A will be attained and a new cycle will start. The time span of the entire cycle is quite variable, depending on the beach profile, wave conditions, and the direction of wave attack. Sometimes two complete cycles can occur during a single winter season. However, some cliffs were observed to maintain their profiles with slight modification for at least two years.

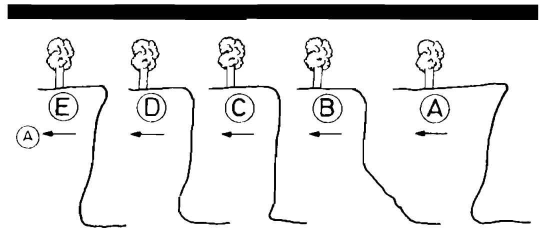

Figure 2. Idealized cliff retreat cycle in beds of uniform resistance.

Cliff retreat velocity (that is, the cycle duration) depends on several factors. One control that seems to be very important is the cliff height. Higher (>15 m) and lower (<8 m) cliffs tend to have higher retreat rates than cliffs of intermediate height (8–15 m). For low cliffs (<8 m) the formation of the wave cut notch rapidly attains the cliff edge, that is, the entire cliff face is eroded by the waves and retreats rapidly. The formation of wave-cut notches in high cliffs creates a significant instability because the overlying weight exerts pressure on the roof of the notch which collapses. In the case of cliffs of intermediate height (8–15 m), the wave-cut notch neither attains the cliff edge nor induces collapse as rapidly as in the high cliffs, and the metastable profile can be maintained longer. This generalization does not hold where cliffs form headlands. High, intermediate, and low cliffs show approximately the same retreat rates where they form protuberances, and are under concentrated wave attack.

Although this cliffed zone tends toward linearity, the coast is not straight. Irregularities form because of differences in retreat rates due to the phase of the cliff evolution cycle, cliff height, and the influence of lithologic and topographic irregularities. In the case of the latter, gullies and small valleys intersect the cliff line at oblique angles. As a cliff retreats, a stage is reached where only a narrow divide separates the beach and the adjacent depression. When this thin cliff divide collapses, the retreat accelerates across the gully or valley floor to the new cliff face wall. This process

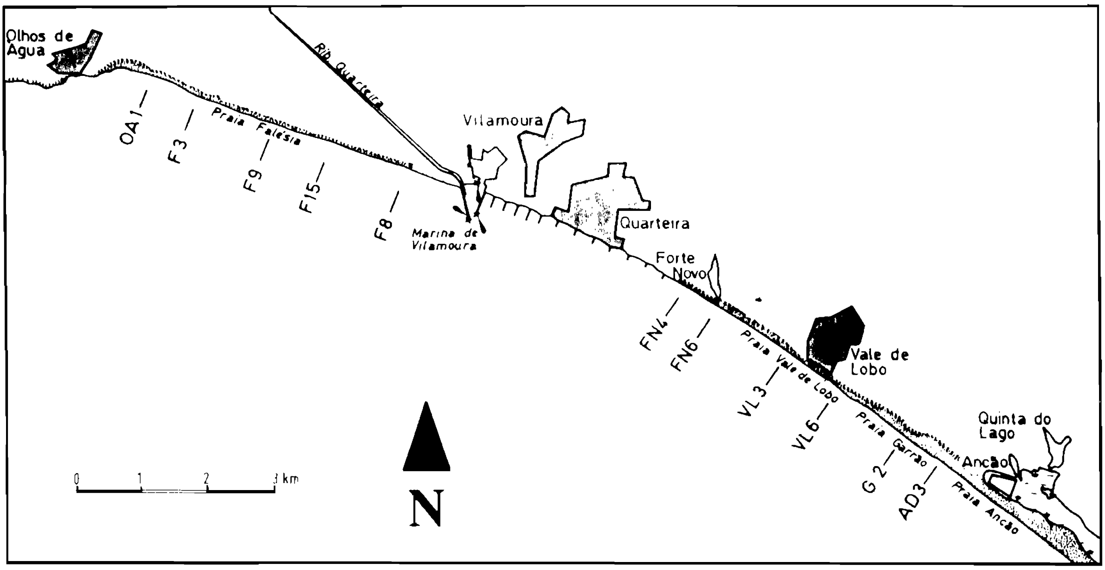

Figure 3. Index map of study area showing the three zones of different cliff behavior. Reference points correspond to Table 1 which shows retreat rates in meters/year.

causes a reentrant in the shoreline. Such openings result in the highest observed retreat rates (8 to 12 m in a single week).

ZONES OF RAPID CLIFF RETREAT

The red cliffs between Olhos de Água and Ancão are cut into the poorly consolidated Quarteira Formation, a stratigraphic unit of variable age (Miocene to Quaternary). The lithologies are heterogeneous (*e.g.*, siltstones, sandstones, gravelly layers), however, the mud content is always very high. Two stratigraphic units are well exposed in the cliff faces, including an upper reddish-tan clayey sandstone separated from the coarser lower unit of clayey, gravelly sandstone by an unconformity. Profiles of small paleo-valleys are often visible in the face of the cliffs; and the coarse clastic fill of these paleo-channels shows evidence of deposition by torrential currents and/or floods. Often, the upper unit has the aspect of density flow deposits, and includes transported snails, wood, and bone fragments. The top of the upper unit appears to be very recent in age (Quaternary), and some authors have assigned it to the Würm

Table 1. *Cliff retreat data set (1983–1988). Values given are field distances in meters from cliff edge to selected reference points. See Figure 3 for monitoring locations. The initial distance is the August, 1983 reading; however, the initial reference points were lost to erosion at seven localities and new reference points were established (*).*

Zone Station	I: Praia da Felésia					II: Forte Novo/Vale do Lobo					
Date	OA1	F3	F9	F15	F8	FN4	FN6	VL3	VL6	G2	AD3
Aug. 83	6.8	5.2	12.5	4.3	9.6	3.7	9.7	3.5	7.2	14.6	5.8
Apr. 84	6.8	4.8	10.2	2.0	8.7	10.9*	8.5	2.8	6.0	14.2	3.9
May 85	5.9	23.2*	10.1	15.8*	6.5	10.5	2.2	8.7*	5.7	11.0	3.1
Feb. 86	5.8	22.9	6.3	14.1	5.9	6.2	9.9*	8.5	1.2	8.9	14.3*
July 87	4.7	22.6	5.6	13.9	1.1	3.3	9.2	4.1	15.6*	8.1	14.2
Dec. 88	4.1	19.9	2.5	10.2	0.8	26.0*	3.8	3.9	13.0	3.4	9.5
X̄ Retreat m/yr.	0.5	1.7	2.0	2.0	1.8	2.9	3.2	1.7	2.0	2.2	2.1
X̄ Zone Retreat m/yr.			1.6 m/yr.					2.4 m/yr.			

Table 2. *Summary of the processes and controls of cliff erosion/retreat under natural and anthropogenic conditions in the Algarve.*

Natural Erosion		Human-Induced Erosion	
Process	Control	Process	Control
Marine Erosion		Local	
Waves	Sea-Level Rise Storms Tides	Loading	Construction Infiltration
		Vibration	Runoff
Longshore Currents		Undercutting	Caves/Graffiti Increase in Beach Gravel
Subaerial Erosion		Regional	
Mass Wasting	Joints Groundwater Vegetation Loss of Toe	Loss of Sand Supply	 Groins Seawalls
Runoff	Rain/Wind	Modification of Currents	
Earthquakes			Jetties

(MANUPPELLA *et al.*, 1987). The lower unit is dominantly non-marine, but some possible marine beds have been identified. Generally, all of the beds are friable and nonresistant to wave attack, breaking down rapidly when eroded from the cliff face and saturated with water.

Three distinct zones of cliff types and retreat behavior are present in this reach (Figure 3). The Praia da Falésia Zone extends from Olhos de Água to Vilamoura and is an area that approximates natural conditions in terms of cliff retreat, *i.e.*, no strong human influence. The continuous cliffs are 15 to 45 m in height, and observed retreat rates are high, usually ranging from 0.5 to 2.0 m/year (Table 1). Observed retreat rates in any given year range from zero to 4.8 m. The urbanized area of Quarteira lacks cliffs and separates the first zone from the Forte Novo–Vale do Lobo Zone, an area of rapidly retreating cliffs that are subjected to significant human impact. This middle zone, east of Quarteira, is characterized by cliffs of 10 to 20 m in height that are frequently interrupted by valley mouths. Observed average cliff retreat rates range from 1.7 to 3.2 m/year, and as much as 6.3 m of retreat was observed within one year (Table 1). Specific examples from this zone are discussed below. The Quinta do Lago Zone is protected from wave attack by the western end of the barrier-island system (Peninsula do Ancão) and the cliffs have attained a fossil stage.

The activity/inactivity of these cliffs is dependent on the adjacent beach. If the beach is wide, as in summer, the waves do not reach the base of the cliff, except under extreme spring tide conditions, and erosion is low. If the beach is narrow at the base of the cliff, the waves reach the cliff easily and rapid erosion occurs. This profile is typical during the more stormy winter season. Because the lithology of the cliff has almost no resistance to the waves, debris from mass wasting is quickly removed, and notch formation is common. Drill hole information suggests that slightly hardened rocks of the same type that occur in the base of the cliff in the western part of the study area form a wave-cut platform that is 4–5 m under the mean water level, and extends beneath the beach.

CAUSES OF CLIFF RETREAT

Cliff erosion is the result of a set of both natural and human-induced (anthropogenic) processes and controls (Table 2). The degree to which these processes are taking place varies within the three zones described above, but marine erosion is the dominant factor in both the Praia da Falésia and Forte Novo–Vale do Lobo Zones.

Natural Processes

The analysis of tide-gauge data from Lagos indicates that the secular trend in the sea-level rise is 1.54 mm/year (DIAS and TABORDA, 1988). Since 1908, sea level has risen almost 15 cm, and it is thought to be one of the causes for the acceleration of the cliff retreat rate. Wave attack of the cliff base occurs mainly during the winter, and well-developed wave-cut notches are often visible.

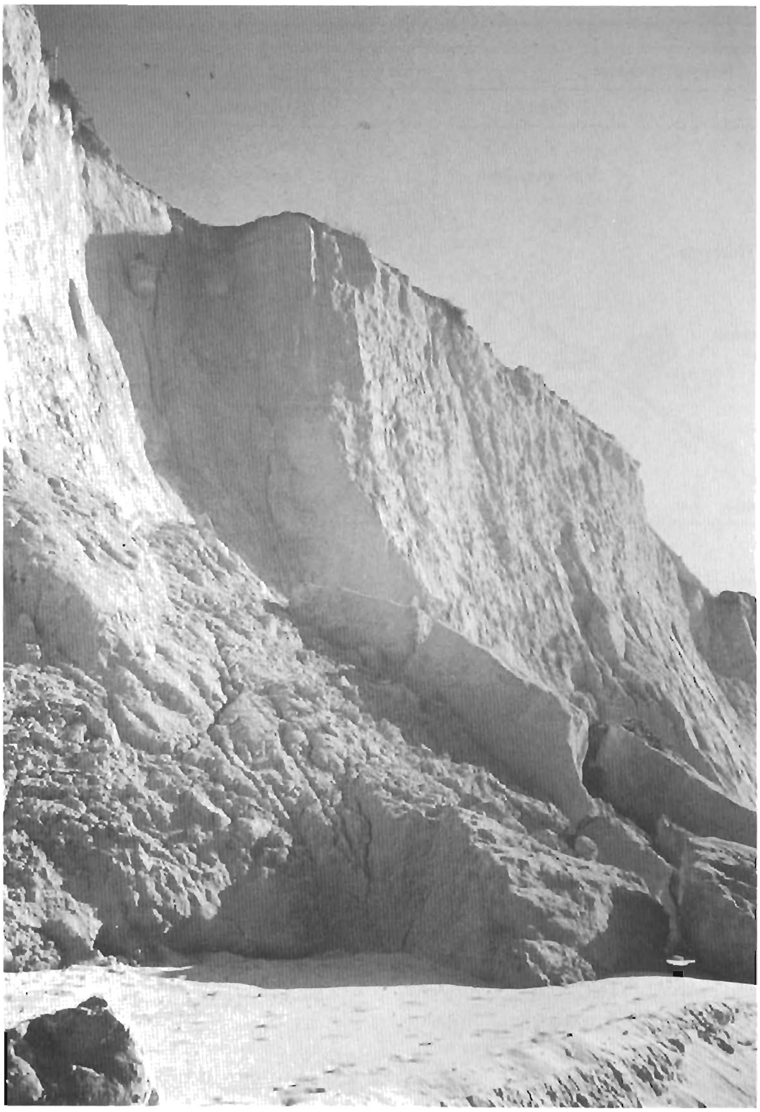

Figure 4. Prismatic blocks of cliff face due to joint control.

The shapes of the notches vary with wave conditions. When the beach is wide, only low-energy waves reach the cliff and a narrow fissure develops. If the beach is narrow, or lacking a berm, breaking waves attack the cliff front and a large notch forms. The large notches are a major contributor to cliff failure. The spring tide range for this area is 3.8 m, and beaches are greatly narrowed at high tide, almost disappearing. When winter storms occur during high spring tides, the cliffs often suffer significant retreat in a single day. Fallen blocks break down rapidly under wave attack, and the sediment is carried offshore and laterally by west-to-east longshore currents.

Mass-wasting is the second dominant cause of cliff retreat, and in turn is controlled by several joint systems that are parallel and perpendicular to the face of the cliff. As a consequence, prismatic blocks form on the face of the cliff and fall or slump, especially during undercutting by waves. The geometric form imposed by the joint sets is often visible on the cliff front, particularly in the

Figure 5. Missing section of road along the cliff edge due to rock fall/slump.

Forte Novo–Vale do Lobo Zone (Figure 4). The form of the mass wasting is also influenced by the lithology. Wet, clay-rich layers become sliding planes, and the porous units take on groundwater to increase loading which contributes to cliff failure. Visible groundwater seeps are common on the face of the cliff during winter and spring. Plant roots often grow along fractures and joints, opening them or increasing their water content to contribute to the mass-wasting mechanisms. The fallen blocks and debris form a temporary protective mound at the base of the cliff which prevents notch formation and slows the cycle of cliff retreat, until wave attack removes the protective toe and cliff retreat progresses again.

Subaerial erosion by runoff is important locally. Deep canyon-like gullies cut into the upland and intersect the cliff face. The walls of the gullies often show badlands-type topography, or steep walls which collapse by mass wasting in the same manner as the cliff faces. Large amounts of sediment are flushed from the gullies during rainstorms and form small alluvial fans of reddish sediment on the lighter-colored beach in front of the gullies. The cliff face also is attacked by rain and wind. However, these processes are not significant factors in the cliff retreat. Earthquakes affect the study area and are a potential triggering mechanism for large mass-wasting events, as well as generating tsunamis. The famous earthquake of 1755 generated a destructive tsunami in the Algarve; however, no historic record of its impact on the cliffed coast is known.

Human-Induced Erosion

Processes similar to those noted above are mimicked by human activities in the locality of the cliff. Construction at the top of the cliff increases the load on the cliff and consequently increases cliff instability. Because this zone has a sparse vegetation of the type adapted to a short rainy season and to survive a prolonged dry season, developers and property owners often replace the native vegetation with a cover of grass and plant varieties that require heavy irrigation throughout most of the year. Green golf courses, extending to the cliff edge, and lawns require frequent watering, creating additional loading on the rocks of

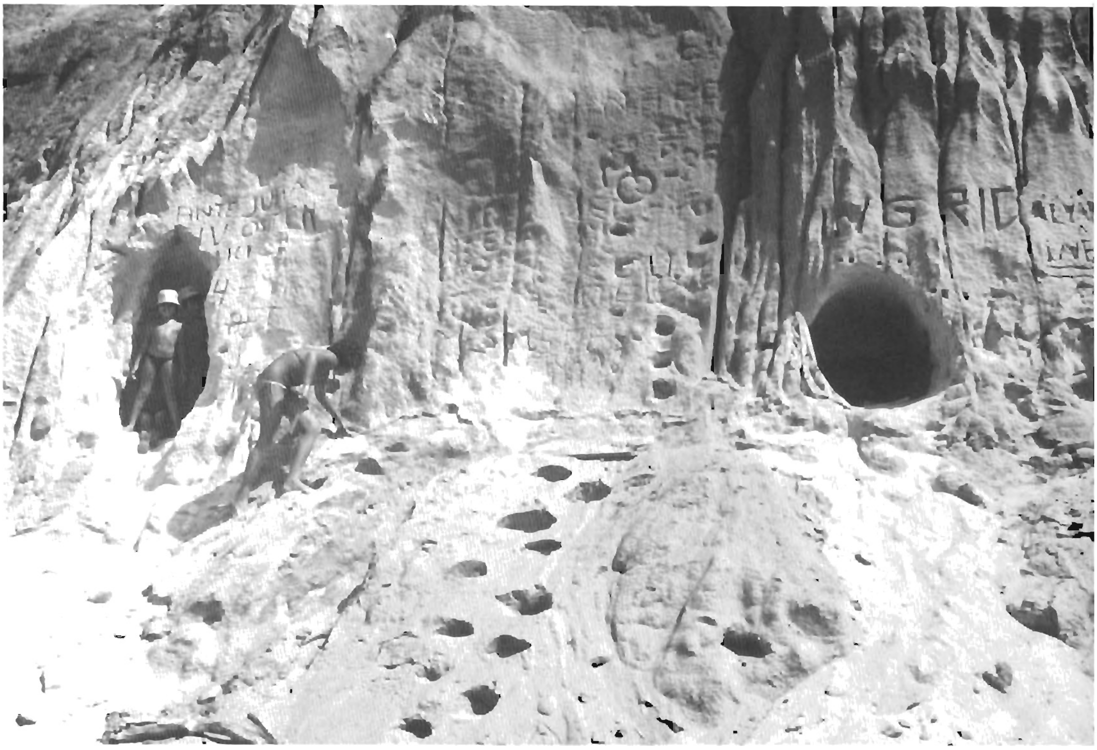

Figure 6. Caves cut by tourists in the base of the cliff at Forte Novo.

the cliff and contributing to other groundwater effects which induce mass wasting. Surface drainage is also modified and runoff increased because of new impervious surfaces (*e.g.*, parking lots, streets, patios). Gullies that were active only during rainy periods are now active even during the dry season. Runoff from villages is diverted to these gullies, along with part of the irrigation water. The increased erosion is evidenced by the red fans at the mouths of the gullies even in summer. Water diverted over cliff edges scores the faces, contributing to cliff retreat.

Vibration during construction as well as vibration caused by traffic in the vicinity of the cliff edge (*e.g.*, cars, campers, off-road vehicles) contribute to cliff collapse. Improvised dirt roads for sightseers along the top of the cliff allow vehicles to drive on top of the vertical to over-steepened profiles, adding weight and vibrating the cliff face. Although a vehicle has never been carried down by a rock fall, segments of the cliff-edge road are regularly lost to cliff retreat (Figure 5). The road is displaced to the new edge and traffic continues. The traffic also kills the sparse ground cover of vegetation, allowing runoff to begin to dissect the upland surface.

Small caves and graffiti excavated by tourists in the lower face of the cliff are also an erosion factor (Figure 6). The graffiti often provides an absolute time reference for measuring erosion. Tourists write their names and the date on the cliff face, typically carving the inscription to a depth of around 2 cm. Inscriptions of the past year are rarely visible the next summer, even where mass wasting has not occurred, indicating that the general abrasion rate of the face of the cliff is greater than 1 to 2 cm/year. The caves are 1 to 2 m deep and are analogous to the wave-cut notch in their destabilization effect. These features provide references for measuring cliff retreat. The caves do not persist from one summer to the next, and when the tourists return, a fresh vertical cliff face is awaiting the next excavation. Waves penetrate the caves, collapse follows, and the debris is removed by wave erosion. Although it is difficult to separate the amount of natural retreat from

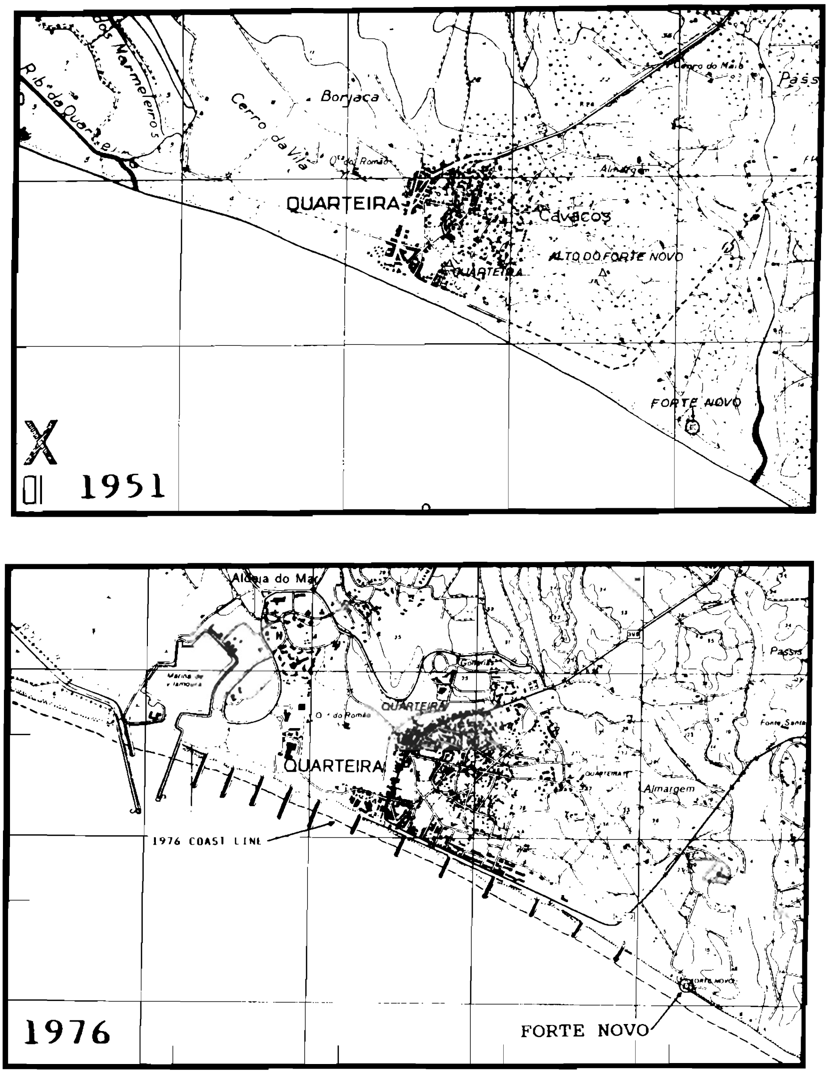

Figure 7. Topographic maps of Quarteira–Forte Novo area, 1951 and 1976. Comparisons depict the growth of Quarteira; construction of the jetties at the Vilamoura marina; the groin field and its downdrift impact; general shoreline displacement; and the cliff retreat at Forte Novo.

that induced by the caves, humans can certainly take credit for a portion of this 1–2 meters of obvious retreat.

Human activities along the shoreline outside the immediate area of the cliffs can also accelerate cliff retreat. Groins and seawalls in the updrift direction (as well as in front of the cliffs) have reduced the sand supply to the protective beaches which front the cliffs. This reduction in the sand supply has been increasing at least since the 1950's. Quarteira, in the up-drift direction from the Forte Novo–Vale do Lobo Zone (Figure 7), is built to the sea's edge, and the front street is regularly overwashed during storms. To protect the ocean-front buildings rip-rap seawalls and groins have been constructed. In 1973 the Vilamoura marine jetties were built, reducing the effectiveness of the Quarteira groin field. More groins were added, raising the number to 14, resulting in further reduction of the sand supply to the east (Forte Novo and beyond). Each year the terminal part of some of the groins is damaged (due to the lack of sand)

Figure 8. Views of Forte Novo: (A) 1976, (B) 1978, (C) 1988, and (D) 1989, remains of the fort in the beach are partially submerged during low spring tide.

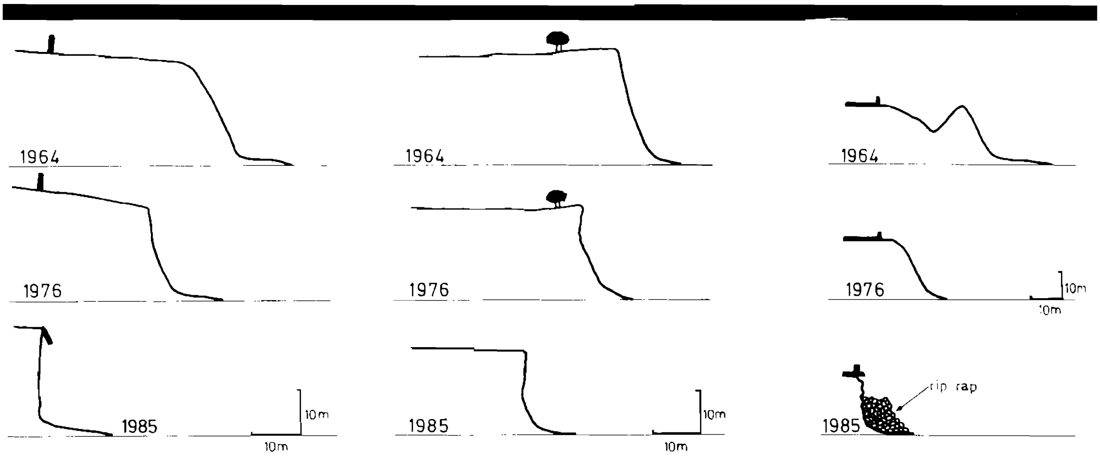

Figure 9. Sequence of cliff profiles for three locations at Vale do Lobo: 1964, 1976, and estimated for 1985. The three profiles are located between monitoring stations VL3 and VL6 (see Figure 3).

and reconstruction is necessary (BETTENCOURT, 1985).

As a consequence of the reduced sand supply, the erosion of beaches east of the jetties and groin field has increased and cliff retreat rates have also increased. The mean cliff retreat since the early 1970's is >2 m/year, and since 1983 it has averaged 2.4 m/year. Note that the higher retreat rates are at locations FN4 and FN6, and that the latter has experienced the greatest one-year retreat (6.3 m, Table 1). Where tourist villages and other construction have taken place in the cliff zone, concern has grown in proportion to the increasing rate of cliff retreat. Cases of cliff erosion become spectacular when static human structures and developments are placed in this dynamic zone. Two cases are presented here to illustrate the danger.

Forte Novo

The Forte Novo fortress originally was located approximately 100 m east of Quarteira (Figure 8A), well back from the edge of the cliff (built to replace an earlier fort lost to cliff retreat). In 1970 the fortress was on the cliff, but by 1977 only part of the seriously-damaged fort remained at the cliff edge; the other half having fallen to form a pile of blocks on the beach. By the early 1980's all of the fort had fallen, and at present the remains of the fort are visible partly submerged during low spring tides (Figures 7 and 8).

East of the Forte Novo cliffs is a small river, the Ribeira da Carcava (near FN6, Figure 3). At its mouth, isolated from the sea by a barrier beach, an old marsh deposit is exposed at low tide. Two beds make up the deposit: a lower darker silty mud, with higher organic content, which yielded a Carbon-14 date of 1,330 ± 50 years BP, and an upper lighter, sandy mud, with plant remains in place, and which was dated at 760 ± 60 Carbon-14 years BP. The exposure of these more landward deposits buried by beach facies indicate a transgressive sequence, which denotes coastal retreat. Similar marsh deposits are being exposed at the mouth of Vale do Lobo and other valley mouths of this area.

Vale do Lobo

Three kilometers east of Forte Novo is the tourist village of Vale do Lobo. This development is located along on a two-kilometer reach of cliffed coast around the Vale do Lobo. The construction began in the 1960's when erosion problems were less apparent (no adjacent threatened properties) and perhaps less severe because there was less impact on the sand supply from structures to the west. Houses and support buildings were built at a considerable distance from the cliff and no residences had been damaged. But at the beginning of the 1980's the situation changed dramatically. Cliff retreat began to encroach into the central recreational area of the village. The golf course was eroding and greens were threatened. The oceanside of the platform and foundation of the swimming pool were exposed, and water pipes were damaged. Water from ruptured pipes contributed to additional erosion. In 1984/85 a riprap seawall was built in front of the swimming pool and part of the complex of restaurants and shops near the valley mouth. Surface runoff and mass wasting continued to threaten the area behind the seawall, including one of the gift shops. By 1986 the effects of wave attack due to diffraction caused by the seawall could be seen, especially east of the swimming pool. Cliff retreat was accelerated (Table 1, VL3 and VL6). Viewed from the top of the rip-rap wall, the westward and eastward beaches showed different alignments. The eastward beach was narrower and offered less protection to the cliffs. As a consequence, the eastward cliffs began retreating faster, with damaging consequences for the next tourist villages of Vale do Garrão and Areias Douradas, where small riprap seawalls had to be improved. An additional protective stone revetment was placed in front of the Vale do Lobo beach-service buildings which were threatened by wave damage at the east end of the seawall. More recently, beach replenishment has been proposed.

Figure 9 presents topographic profiles along sections in the Vale do Lobo area for 1964, 1976, and 1985 (estimated). In the 12 years between 1964 and 1976, well before the construction of the jetties at the Vilamoura marina and just after that construction, total cliff retreat was between 6–12 m and in some cases greater, *i.e.*, the mean retreat was approximately 1 m/year. After 1976, and probably as a consequence of the construction of the jetties and enlargement of the Quarteira groin field, cliff retreat rates increased significantly to 2–3 m/year (Table 1). During the construction of the rip-rap wall it was found that only 2 m of beach sand overlay a marine platform cut into the same red sandstone as exposed in the cliffs.

CONCLUSIONS

The Algarve cliffs cut into Miocene through Quaternary red friable sandstones and associated lithologies provide an example of three zones of specific cliff retreat behavior. The Praia da Falésia Zone is an area of rapid cliff retreat under natural conditions, whereas the Forte Novo–Vale do Lobo Zone is strongly influenced by human activities superimposed on the already high natural rates of erosion. The Quinta do Lago Zone represents inactive, or "fossil" cliffs. Tourist and retirement village developments, although set back from the cliff edge in their initial development, are ultimately threatened because cliff retreat catches up to the static position of the development. Human activities in other coastal areas, especially in the up-drift direction, unexpectedly create new conditions (*e.g.*, loss of sand supply, accelerated erosion rates) that shorten the planned life of a development and its support facilities.

Solutions are not simple, but should be guided by the general geographic setting and geologic processes that have been documented for the study area. Strict enforcement of set-back requirements and prohibition against construction in the Maritime Public Domain Area are encouraged. This zone can be used for recreation and conservation without placing structures in danger's path, or engaging in activities which accelerate cliff retreat (*e.g.*, traffic, irrigation, excavation). Up-drift communities as well as those within the zone of cliff retreat should seek soft solutions for beach conservation (*e.g.*, beach replenishment and moving structures back as opposed to constructing seawalls and groins). In all cases, the projected rise in sea level should be taken into account when developments are being planned.

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LITERATURE CITED

Anglo-Portuguese News, 1989. Waste problem not yet alarming. 11-5-89, 11.

Bettencourt, P., 1985. Géomorphologie et Processus d'Evolution Récente de la Côte Sotavento (Algarve Sud Portugal). Thèse D.E.A., Université de Bordeaux I, Bordeaux, France, 92p.

Cavaco, C., 1979. *Turismo e Demografia no Algarve.* Relatório C1, Centro de Estudos Geográficos, Universidade de Lisboa, 76p.

Dias, J.M.A., 1984. Evolução geomorfológica das arribas do Algarve. *3° Congresso Sobre o Algarve-Textos das Comunicações*, 2, 705–712.

Dias, J.M.A. and Taborda, R.P.M., 1988. Evolução recente do nível médio do mar em Portugal. *Anais do Instituto Hidrográfico*, 9, 83–97.

EMERY, K.O. and KUHN, G.G., 1982. Sea cliffs: their processes, profiles, and classification. *Bulletin Geological Society of America*, 93, 644–654.

MANUPPELLA, G.; RAMALHO, M.; ATUNES, M.T., and PAIS, J., 1987. *Notícia Explicativa da Folha 53-A (Faro) da Carta Geológica de Portugal (1/50,000)*. Serviços Geológicos de Portugal, Lisboa, 52p.

MARTIN, L.; BENNETT, R.J., and GREGORY, D.J., 1984. The thirsty Algarve. *Geographical Magazine*, 56, 321-324.

PILKEY, O.H., JR.; NEAL, W.J.; MONTEIRO, J.H., and DIAS, J.M.A., 1989. Algarve barrier islands: A non-coastal-plain system in Portugal. *Journal of Coastal Research*, 5, 239–261.

□ RESUMO □

No sector central da costa Sul do Algarve o recuo acelerado da arriba deve-se efeito conjunto da elevação do nivel do mar e dos processos de erosão naturais e antrópicos. Entre Olhos de Água e Quinta do Lago as arribas, de 10 a 50 m de altura, são talhados nas materiais friáves de idada entre o Miocénico e Quaternário. Reconheceram-se, na dinâmica desta área, três sectores distintos, tendo em conta a evolução natural da arriba e a influência da acção humana. O sector ocidental (Praia da Falésia) caracteriza-se por uma arriba contínua, de 15 a 45 m de altura, que recua cerca de 1 m/ano, devido a processos naturais. O sector central (Forte Novo–Vale do Lobo), apresenta uma arriba de 10 a 20 m de altura, cortada por fozes de rios, em pue o recuo é superior a 2 m/ano, em consequência das modificações causadas pela actividade humana, quer na ocupação da parte superior das arribas, quer na alteração da dinâmica litoral na linha de costa anexa (Quarteira). O sector oriental (Quinta do Lago) caracteriza-se pela presença de uma arriba morta cuja evolução marinha foi impedida pela formação das ilhas barreira.

A evolução dos perfils das arribas mostra uma repetitividade tipológica contralada quer pela dominância dos processos da erosão marinha, quer pela dos processos subaéreos, incluindo nestes todos os que actuam nos diferentes elementos naturais do sistema litoral e os provocados pela actividade humana. Todas as soluções para o planeamento desta área terão de ter em conta o conhecido recuo acelerado da arriba e as suas causas.

□ RÉSUMÉ □

La dynamique du secteur central de la côte sud de l'Algarve est caracterisée par le recul rapide de la falaise, à cause de la remonté du niveau de la mer et de l'érosion provoquée par les processus naturels et anthropiques. Entre Olhos de Água et Quinta do Lago les falaises hautes de 10 à 50 m, sont entaillées dans les matériaux friables du Miocène au Quaternaire. Selon l'évolution naturelle de la falaise et l'influence de l'action humaine, on a distingué dans cette région trois secteurs de dynamique différente. Le secteur occidental (Praia da Falésia) montre une falaise continue, de 15 à 45 m de haut, qui recule 1 m/an sous l'influence des processus d'éosion naturelle. Le secteur central (Forte Novo–Vale do Lobo) présente une falaise de 10 à 20 m de haut, recoupé par les embochures des fleuves côtiers, qui recule plus de 2 m/an, en conséquence des modifications de l'homme sur la côte, soit in situ, au sommet des falaises, soit sur la ligne de côte voisine (Quarteira). Le secteur oriental (Quinta do Lago) est caracterisé par une falaise morte, dont l'évolution marine est été interdite par le développement des iles-barrière.

L'évolution des profils des falaises montre une repétitivité typologique, controlée par la dominance soit de l'érosion marine soit des processus d'érosion subaérienne, naturels et anthropiques. Pour l'aménagement de ce littoral il serait absolument nécessaire connaitre le rythme du recul des falaises et de ses causes.