| Journal of Coastal Research | 9 | 4 | 1129–1135 | Fort Lauderdale, Florida | Fall 1993 |
| --- | --- | --- | --- | --- | --- |

# DISCUSSION

## Discussion of: Dias, J.M.A. and Neal, W.J., 1992. Sea Cliff Retreat in Southern Portugal: Profiles, Processes, and Problems. *Journal of Coastal Research,* 8(3), 641–654.

**F.M.S.F. Marques and C.A.F. Andrade**

Departamento de Geologia
Universidade de Lisboa
Ed. C2, 5º piso
Campo Grande, 1700 Lisboa
Portugal

### INTRODUCTION

The Algarve coast of southern Portugal is indeed one of Europe's fastest growing coastal resort regions. This tendency, initiated around the 1950's without the support of adequate planning, is still remarkable today, in spite of several indicators of saturation. Also, an increasing number of coastal sites where local or nearby human occupation neglected or changed natural evolutionary processes are now endangered, or will most probably be in the immediate future.

The coastal segment between Olhos de Água and Ancão is one example of the aforementioned circumstances along with the Algarve coastal section characterized by the higher cliff retreat rates recorded in the last decades. The same sector has been indicated as the main sand source for the nearby Ria Formosa system, a barrier chain that extends further east until the Guadiana estuary. A few high quality developments located near the cliff edge are now being severely affected by erosion and it is most probable that any attempt to reduce cliff recession by "hard" solutions will affect the fragile equilibrium of the eastern Algarve beaches.

Not surprisingly, this area has been elected as an investigation site since the late 1970's. Several papers and reports describing causes and processes and estimating rates of coastal change have been produced and discussed up to the present. A poor knowledge of the wave regime and a defective set of historical documents (including accurate topohydrographic surveys) justifies that these subjects are still a matter for debate. For example, no agreement exists on the amount of sediment released into this particular coastal sector by cliff retreat, reflecting differences in methods or different estimates of the average recession rate, relative importance of extreme events and time scaling of the retreat phenomena.

Being directly involved in the study and discussion of these aspects, particularly since the mid-1980's through a project released by the Port Authority, the writers were first surprised by the intensity of the retreat process implicit in the paper published by DIAS and NEAL (1992).

Also, the writers found that fundamental aspects of the interpretation and a significant part of the data set published by DIAS and NEAL (1992) are questionable and that they cannot be taken as representative of the whole coastal sector considered in that paper.

On the other hand, DIAS and NEAL (1992) made no clear distinction between general processes of cliff evolution and local significant processes or controls. Field observation and interpretation frequently extrapolated may also be found without sharp distinction of the factual information which allows the authors to jump to conclusions that could have been filtered through a more extensive bibliographic review.

### SETTING AND PREVIOUS WORK

Until recently (1991), several authors pointed out and discussed the rapid sea cliff retreat observed in the Quarteira region (Algarve, southern Portugal) using methods of cartographic comparison (*e.g.*, ANDRADE, 1990; ANDRADE *et al.*, 1989; BETTENCOURT and BRAUD, 1986; BETTENCOURT *et al.*, 1986; GRANJA, 1984). Summary field observations allowing rough estimates of minimum weathering/retreat rates were also reported by DIAS (1988, 1990), for example. Field observations of high water mark changes made by the Port Authority at Quarteira extending as far back as 1914 were presented by VELOSO (1988) and discussed by GUILLEMOT (1979). A study of the same coastal sector including an estimate of the local drift-controlled sand budget may be found in H.P. (1965).

Temporal evolution of the erosion rates at the cliff and at the nearby Faro beach is discussed in D.G.P. (1989). This report connects cliff erosion to contemporaneous changes in the downdrift beaches and establishes a more comprehensive sediment budget for the area that was in turn revised by ANDRADE (1990) and D.G.P. (1991).

In the mid 1980's, the National Environmental Authority started a research programme with the aim of collecting accurate information about recession rates in the Olhos de Água–Quarteira coastal area. A network of fixed ground references was installed and sequential aerial surveys were made, rectified and interpreted.

Results of an independent, very accurate analysis of aerial photographs taken since 1947 complemented by field measurements, were partly published by MARQUES and ROMARIZ (1991) and MARQUES (1991) following the conclusion that simple chartographic comparisons overestimated recession rates and produced unreliable quantitative information about cliff retreat intensity.

On a larger time-scale, information about coastal recession and single-event importance (earthquakes, tsunamis) is also available, although largely qualitative. Old plans of coastal forts, maps of coastal areas (SANDE DE VASCONCELOS, 1793 (?)), as well as the description of PEREIRA DE SOUSA (1919) are examples of valuable documents.

The analysis of the previously published information suggests that:

(1) Persistent coastal erosion (including cliff recession) is an established, chronic process at this coastal area, documented since, at least, the beginning of this century. Available information suggests that regional rates of coastal change may have increased since about 1910–1920, prior to any significant coastal occupation. Older documents suggest that the process was already present, but with minor intensity.

(2) Simple cartographic (or non-corrected air-photography) comparisons severely overestimate average rates of cliff recession. Corrected figures may reduce inferred retreat rates to one order of magnitude.

(3) Short-term field measurements produce only locally significant results that do not fit with longer term average rates. This conclusion is obviously related to the discontinous pattern of the cliff recession phenomenon, both in time and space.

(4) For the same reason, single events of cliff retreat are extremely large when compared to average figures obtained for any cliff extension affected by retreat.

## DISCUSSION

Some inconsistencies or inaccuracies may be found in the paper by Dias and Neal. A few examples follow:

(1) Abstract, 3rd line, Dias and Neal state that the cliffs are "... 10 to 50 m high ..." but also that in the zone with higher cliffs (Praia da Falésia) these are (5th line) "... 15 to 45 m high ...".

(2) Abstract, 6th line, The Praia da Falésia sector is characterised by retreat rates "... on the order of 1 m/year." However, figures listed in Table 1 are: 0.5; 1.7; 2.0; 2.0 and 1.8 m/year, averaging 1.6 m/year.

(3) Page 652, Column 2, The "two kilometer reach of cliffed coast around the Vale de Lobo" is actually only 1.3 km long.

(4) Page 652, Figure 9, Left and middle profiles are inaccurate. Left profile: Note change in position of reference wall and landwards slope variation, near the cliff top. Middle profile: Note reduction of cliff height with time.

(5) Page 642, Column 1, DIAS and NEAL (1992) state that "until recently no data base of calculated erosion rates has existed". This is not strictly correct. For example, GRANJA (1984) quotes a report from the Port Authority where high retreat rates have been recorded since the first decade of this century at this zone.

(6) Page 643, Column 2, lines 7 through 9, DIAS and NEAL (1992) state that "some cliffs were observed to maintain their profiles with slight modification for at least two years". This statement is in our view correct but not supported by data presented in Table 1. In fact, only profile OA 1 displays a case of nil retreat (August 1983 to April 1984), but the corresponding time period is less than one year.

(7) Page 643, Column 2, 2nd paragraph, lines 10 and 11, Variables "cliff retreat velocity" and "cycle duration" are not clearly defined. Additionally, a velocity can never be equivalent to a duration, as suggested by the authors.

In the same paragraph, DIAS and NEAL (1992) suggest some relationship between cliff height and retreat rate, a relationship previously denied by

ANDRADE *et al.* (1989). Actually, that relationship is not supported by any of the quantitative data presented (Table 1) nor is it relevant at intermediate time scales (years). Furthermore, on a larger time scale (decades), it would lead to the irregularization of the coast, contrary to the observed tendency for "straightness" observed since the beginning of this century.

At the end of the same paragraph, DIAS and NEAL (1992) state that "this generalisation does not hold where cliffs form headlands". In the field, there are no natural headlands with bathymetric expression and thus no protuberances under concentrated wave attack. This fact can be easily chequed using aerial photographs of the area, or Figure 3 of DIAS and NEAL (1992). Bore or swash concentration may exist, but are associated with rhythmic beach topography. No clear relationship between these rhythmic forms and patterns of cliff-nibbling (periodicity of mass wasting events) for this area was found by the writers nor was proposed until today.

(8) Page 648, Column 1, DIAS and NEAL (1992) state that erosion has increased in gullies mainly because of surficial impervious surface. It must be stressed that this is only applicable to a small portion of the Vale de Lobo cliffs. However, marine erosion is still dominant in that area, and the total gullied surface is actually declining.

(9) Page 649, 2nd paragraph, DIAS and NEAL (1992) state that "groins and seawalls in the updrift direction have reduced the sand supply. This reduction in the sand supply has been increasing at least since the 1950's". This statement is not supported by any reference and the date is not correct. In May 1958, U.S.A.F. aerial photographs showed that there were no groins nor seawalls in the zone and, on the other hand, that erosion has been reported since the first decades of this century (see, for example, GRANJA, 1984; GUILLEMOT, 1979).

(10) Page 652, The statement "The Forte Novo was located ... well back from the edge of the cliff (built to replace an earlier fort lost to cliff retreat)", is not quoted. It should be noted that in 1947 using R.A.F. aerial photographs, the southern edge of the fort was already near the cliff (about 15 m), and that the first part of that statement could not be supported by direct observation of the authors.

The second part of the statement is not supported by any reference and is in our view untrue. The Forte Novo ("New Fort") has retained its name from at least the late XVIII century, according to descriptions and plans of the coastal fortresses of Algarve made by SANDE DE VASCONCELOS (1793 (?)). The fort was called Novo ("New") because in Quarteira there existed in the late XVIII century in the west part of the town and far away from the shoreline an older tower which was quite damaged that had been named by SANDE DE VASCONCELOS in the late XVIII century as "Torre Velha de Quarteira" ("Old Tower of Quarteira").

(11) Page 653, 1st Column, According to DIAS and NEAL (1992), "in the 12 years between 1964 and 1976, ... total cliff retreat was between 6–12 m and in some cases greater; *i.e.*, the mean retreat was approximately 1 m/year". These figures obtained using an unknown methodology suggest by means of simple arithmetics a mean retreat rate of 0.5 to 1 m/year. Note that comparative measurements using aerial photographs yield a mean retreat rate of 0.5 m/year in the period 1947–1983 (MARQUES and ROMARIZ, 1991).

(12) The extended use of the Emery and Kuhn method of sea cliff profile analysis (EMERY and KUHN, 1982) is in our view unjustified because the existing data allow a more precise analysis. Furthermore, the Emery and Kuhn method does not seem to cope very well with the typical sea cliff profile in the western zone of Praia da Falésia where homogeneous and almost rectilinear profiles exist that slope about 35 to 40°, mainly because the cliff surface is cut into dense, cohesionless sands of Miocene age (MARQUES and ROMARIZ, 1991). The characteristics of this zone were ignored by DIAS and NEAL (1992), although, surprisingly, the profile OA 1 (data presented in Table 1, p. 644), is clearly located within it.

(13) Caption of Figure 1 refers to "distribution of cliff resistance by lithology ...", but there are no further implications made about this relationship. In fact, besides accuracy problems (from right to left, the 2nd, 3rd and 4th profiles depict clear overhanging sections that do not exist in the field), differences of cliff profiles do not correlate with differences in resistance. Note, for example, the 2nd profile (from right to left) and the last one. The former is built up of silty sands with retreat rates 2 to 4 orders of magnitude higher than the latter, cut in the strong dolomitic limestones of Cape St. Vicente.

(14) DIAS and NEAL (1992) present (page 643) a "cliff retreat model for the study area". The writers think that this model is not specific for

the study area. Actually, it corresponds better to the standard evolution of many steep slopes built in various lithologies under conditions of intense toe erosion and slope undercutting. It is also based on the assumption that active slope evolution is dominated by slope mass movements (see, for example, SUNAMURA, 1983) and that toe protection is inhibited by efficient grinding or removal of fallen debris.

The writers agree with DIAS and NEAL (1992) about the effectiveness of wave action in removing toe protection from the beach berm. However, our observations (see MARQUES and ROMARIZ, 1991, for example) indicate that the expansion due to unconfinement is the dominant process of instabilization and is enough to explain both the geometry of the profiles and the temporal continuity of the retreat phenomena, provided that the profile is unable to reach an adequate equilibrium.

The linear geometry of the cliff profile in the sector west of Praia da Falésia that the "model" of Dias and Neal does not address is conveniently explained by the development of debris slides of the Miocene cohesionless sands following both toe erosion and, more important, intensive wetting by heavy rainfall.

(15) Overhanging sections and sea notches are frequently referred to by DIAS and NEAL (1992) as elements of cliff instability. Our instrumented field surveys show that clear overhanging by the cliff top is not present, though it may appear to exist by optical illusion when the cliff sloping surface is viewed from the adjacent beach. Actually, profiles drawn in Figure 9, miss indications about surveying methods and an accurate location.

Sea notches in the sense described by SUNAMURA (1983) should not be confused with the concave elements of profile displayed by a large number of cliffs cut into homogeneous sands of the Quarteira–Vale de Lobo area; they correspond to fresh scars of slope mass movements triggered mostly by lateral expansion and shrinkage cracking. These events which are represented by "debris slumps" (VARNES, 1978) affect the whole cliff surface or part of it and produce a pattern of regular nibbling of the upper cliff edge. No traces of any relevant regional joint control was found by the writers and field measurements indicate independency of both the mass movement shear surfaces and pressure release cracks and regional tectonic setting (namely jointing) studied by GRILLOT and ALMEIDA (1982) and referred to by SILVA (1988) among others. Excavation of the cliff toe by breaking waves or wave uprush occurs not only during storms but in high spring waters associated to moderate/low wave activity. However, the resulting under-caving is ephemeral; *i.e.,* textural and lithological constraints induce a very rapid response of the cliff surface, determined by a low cohesion coefficient, poor clay content and the sandy nature of the sediments.

(16) DIAS and NEAL (page 644) also fail to give an adequate textural description of the outcrops cut by the sea cliffs of the Quarteira-Vale de Lobo. For example, on page 644, the authors state that "the mud content is always very high".

ANDRADE (1990) and ANDRADE *et al.* (1989) indicate typical clay + silt content ranging from 15% to 25%. SILVA (1988) presents results of grain size analysis of these formations and, within the study zone, seven samples displayed clay + silt contents ranging from 13% to 20%. Thirty-nine grain size analyses carried out by the first writer indicate an average clay + silt content of 16.5% with a standard deviation of 3.9%. Similar data could be found in ROMARIZ *et al.* (1979).

(17) On page 652, DIAS and NEAL state that "the mean sea cliff retreat rate since the early 1970's is > 2 m/year". This data, of unknown origin, could also be more precise. According to MARQUES and ROMARIZ (1991), at Forte Novo, sea cliff retreat rate averaged 0.5 m/year between 1947 and 1976. Similar figures were found at Trafal and Vale de Lobo between 1947 and 1980. The main erosional event at Forte Novo occurred between 1976 and 1980, involving a total retreat of 30 m according to our estimates.

## THE DATA SET

Experimental information produced by DIAS and NEAL (1992) is of undeniable interest and represent an important contribution to the available data-set. However, it must be stressed that field observation refers to a 5.3 year period including frequent loss of field references (seven of the eleven profiles). It is clear that the average continuous observation period equals the order of magnitude of the expected average time-lag between successive retreat events at all the control sites.

Taking into account the discontinuous pattern of the cliff retreat processes, it is obvious that the observed retreat rates must represent no more than sample information, and that they should not be taken as representative figures for any par-

Table 1. *Cliff retreat of the Eastern zone of Praia de Falésia in the periods 1983-1991 and 1947-1991.*

| Profile | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Retreat 1983–1991 (m) | 3 | 5 | 2 | 5 | 5 | 0 | 1 | 0 | 4 | 4 |
| Retreat rate 1983–1991 (m/year) | 0.4 | 0.6 | 0.2 | 0.6 | 0.6 | 0 | 0.1 | 0 | 0.5 | 0.5 |
| Retreat 1947–1991 (m) | 11 | 14 | 8 | 13 | 16 | 2 | 2 | 9 | 7 | 9 |
| Retreat rate 1947–1991 (m/year) | 0.25 | 0.32 | 0.18 | 0.30 | 0.36 | 0.04 | 0.04 | 0.20 | 0.16 | 0.20 |

ticular coastal segment or time-period. DIAS and NEAL (1992) overlooked this fundamental aspect in two ways:

(1) They compare experimental, short term data with longer-term information, to maintain that human activity increased rates of coastal retreat.

(2) They use single point, short-term averages to characterize extensive sectors of the cliff coast.

Data contained in Table 1 may be chequed against other sources of information and questioned as to what extent it actually confirms further interpretation of the authors:

Zone I—Praia da Falésia. The western profile indicates a retreat zone of 0.5 m/year while profiles F3, F9, F15 and F8 display mean retreat rates of 1.7 to 2.0 m/year. The meaning of an average of 1.6 m/year with such data deviation is obviously questionable. More, it is not supported by other sources of information. BETTENCOURT (1991), based on accurate photogrammetric rectification of aerial photographs taken in 1980 and 1986, calibrated by surveyed ground marks, could only demonstrate that, within zone I the retreat rate was quite variable from place to place but always less than 1 m/year. MARQUES and ROMARIZ (1991), based on comparative measurements performed on aerial photographs of 1947, 1958, 1974, 1980 and 1983, completed with field surveys in 1990 and 1991, found mean retreat rates for the period 1947–1991 typically lower than 0.5 m/year, with a global average (20 profiles) of 0.25 m/year.

Table 1 details average information published by MARQUES and ROMARIZ (1991), pertaining to an area equivalent to profiles F15 and F9 of DIAS and NEAL (1992). Disagreement between the two data sets is obvious: According to DIAS and NEAL, total retreat expected in 5 years within this coastal sector would equal a 40–50 year time-period of coastal evolution at the rates found by MARQUES and ROMARIZ (1991) or BETTENCOURT (1991).

On the other hand, one can use the average rates of cliff recession published by DIAS and NEAL (1992) to estimate the average amount of sand released onto the adjacent beach. Such an approach would lead to the conclusion that the beach should be fattening very quickly, particularly in the near vicinity of the Vilamoura marina western jetty.

Actually, no change of this type happened in the last two decades and the data set of DIAS and NEAL (1992) miss any sign of mitigation of the retreat intensity at this location as expected. The interested reader may also note that Figure 7 (page 649) of DIAS and NEAL (1992) shows beach and not cliff recession in its left (western) and central portions.

Retreat rates computed at sites F3, F9, F15 and F8 of Praia da Falésia (DIAS and NEAL, 1992) are similar (average 1.9 m/year) to those found eastwards of Forte Novo (sites VL3, VL6, G2, AD3—average 2.0 m/year). No explanation is given for this, but simultaneously, the coastal defense works of Quarteira-Vilamoura are considered by DIAS and NEAL (1992) as a serious obstacle to littoral drift. Actually they indicate explicitly the downdrift (eastern) area as an example of acceleration of cliff retreat resulting from human activity.

Even at Forte Novo located close to the groinfield of Quarteira, retreat rates indicated by DIAS and NEAL (1992) are only about 50% more intense (2.9 m/year and 3.3 m/year) than the figures indicated by these authors for Praia da Falésia (1.7 m/year to 2.0 m/year).

The writers agree with DIAS and NEAL (1992) that the coastal defense works built at Quarteira and Vilamoura changed the local sediment budget. However, information supplied by the latter do not validate this conclusion, which becomes readily apparent using other published data (BETTENCOURT, 1991, or MARQUES and ROMARIZ, 1991, for example).

Data presented by DIAS and NEAL (1992) for zone II: Forte Novo/Vale de Lobo is consistent with other information (BETTENCOURT, 1991; MARQUES and ROMARIZ, 1991), but the time scale considered is clearly too small to allow reliable estimations of future retreat. It also does not account for the most important erosional event that occurred between 1976 and 1980 at Forte Novo, about 30 metres in four years. It should also be added that the retreat rate east of Quarteira before the construction of the jetties and the groin field was a steady figure of about 0.5 m/year, and that figures obtained after 1980 strongly suggest a decline of the retreat intensity.

The last recommendation of DIAS and NEAL (1992), page 653, following the statement contained in last paragraph (Column 2) of page 645 is, in the opinion of the writers, quite obscure.

Sea level rise is clearly an important background factor of stress and may be one cause of coastal erosion at the Algarve or elsewhere. However, until today, no positive acceleration of the rate of mean-sea level rise has been demonstrated for the Algarve coast in the 20th century.

It is, of course, possible that an exponential or power fitting curve adjusted to the secular series of tide-gauge data of Lagos would produce such a conclusion. However, such a conclusion would rely on a speculative best-fitting method, more adequate to the design of a "pessimist" scenario for the immediate future. On the other hand, this would conflict with the comparison of results for sea-level change, reported by KING (1959) and DIAS and TABORDA (1988), both referred to Lagos, but using different time series: The first estimate relies on the time series available in the 1950's and the second one is extended until the late 1980's. However, the average rates published by both authors are identical, about 1.5 mm/year, suggesting that a linear regression analysis of tide-gauge information is more adequate.

Finally, ANDRADE (1990) estimated the amount of total erosion due to sea-level rise according to BRUNN's (1962) theory. Results, though largely conservative, indicate a maximum contribution of only about 10% to the observed erosion at this coastal site.

## CONCLUSION

The writers agree that sea-level rise, unplanned occupation of the littoral area, impermeabilization of the seaward edge of the cliffy outcrops or coastal defense hard structures interfere with the coastal budget, changing the previously established balance between sources and sinks of sediment for any coastal area. The writers also agree that the coastal sector between Olhos de Água and Ancão contains examples of several of these mismanagement practices.

However, the approach presented by DIAS and NEAL (1992) is far from representing the actual knowledge of this problem in Portugal. It ignores previous contributions and contains, to the best of our knowledge, uncompatibility between data set, interpretation and conclusions. Also, an important fraction of geological processes and controls described by those authors, do not apply to this particular area: They are neither clearly nor conveniently documented, and are not hierarchically presented.

The data set presented by DIAS and NEAL (1992) also does not support the main purpose of the paper, expressed in the introduction (1st Column, lines 7 to 15), "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 . . .", nor the splitting of the study area into three zones of contrasting sea cliff retreat rates induced by external causes.

The writers firmly believe that adequate coastal management must be supported by solid data and clear relationships must be established between processes and effects in order to reduce geological risks. Hasty estimates and generalisations, besides being unreliable, do not contribute to the credibility of hazards studies, which are particularly important as a basis for land use regulations and coastal protection policies. At this area, the value of the land located in the coastal fringe is very high, and conflict between land owners, developers and authorities already exist and is expected to increase in the near future.

## LITERATURE CITED

ANDRADE, C.A.F., 1990. O ambiente de barreira da Ria Formosa. Algarve-Portugal. Ph.D. Thesis, Lisbon University.

ANDRADE, C.A.F.; VIEGAS, A.L.; TOME, A.M.B., and

ROMARIZ, C., 1989. Erosão do litoral cenozóico do Algarve. *Geolis,* 3, 261–270.

BETTENCOURT, P., 1991. Erosão em quatro sectores da costa algarvia: Avaliação das causas, processos e consequências. (Abstract) *Sem. "A Zona Costeira e os Problemas Ambientais" (Eurocoast).* University of Aveiro.

BETTENCOURT, P. and BRAUD, F., 1986. Remobilização das areias e trânsito sedimentar costeiro na costa oriental do Algarve (Sotavento). (Abstract) *II National Congress of Geology, Lisbon, Maleo,* 2(13), 12.

BETTENCOURT, P.; FROIDEFOND, J.M., and PERA, M.T.R., 1986. Geomorfologia e evolução recente do cordão arenoso no sotavento algarvio. (Abstract) *II Cong. Geology, Lisbon, Maleo,* 2(13), 13.

BRUNN, P., 1962. Sea-level rise as a cause of shore erosion. Reprinted in SWIFT D.P. and PALMER H.D. (eds.), *Coastal Sedimentation,* pp. 37–50, 1978.

D.G.P., 1989. *Estudo* do *litoral entre o Porto de Recreio de Vilamoura e o Molhe Oeste do Rio Guadiana.* Unpublished report, Direcção Geral de Portos, Lisboa.

D.G.P., 1991. *Estudo do litoral entre* o *Cabo de Sagres* e a *Marina de Vilamoura.* Unpublished report, Direcção Geral de Portos, Lisboa.

DIAS, J.A., 1988. Aspectos geológicos do litoral algarvio. *Geonovas,* 1, 113–128.

DIAS, J.A., 1990. A evolução actual do litoral português. *Geonovas,* 11, 15–29.

DIAS, J.M.A. and NEAL, W.J., 1992. Sea cliff retreat in southern Portugal: Profiles, processes, and problems. *Journal of Coastal Research,* 8(3), 641–654.

DIAS, J. and TABORDA, R., 1988. Evolução recente do Nível médio do mar em Portugal. *Anais, Inst. Hidrogr.,* 9, 83–97.

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

GRANJA, H., 1984. *Etude géomorphologique, sédimentologique et géochimique de la Ria Formosa (Algarve-Portugal).* Thèse e[ème] cycle, University of Bordeaux I, 254p.

GRILLOT, J. and ALMEIDA, C., 1982. Tectonique cassante posthercynique dans l'Algarve (Sud du Portugal). Incidence sur l'hydrologie karstique. *Rev. Geol. Dynamique et Geol. Physique,* 23(2), 119–130.

GUILLEMOT, E., 1979. Le littoral de la region de Faro. Étude de Morphologie Littoral. Thése D.E.A., University of Paris, 131p.

H.P., 1965. Porto de Vilamoura. Anteprojecto. Report 5424. Hidrotéchnica Portuguesa, Lisboa.

KING, C., 1959. *Beaches and Coasts.* Edward Arnold, 401p.

MARQUES, F.M.S.F., 1991. Sea cliff retreat rates in the southern coast of Algarve and their importance in geological risk evaluation. *Proc. Sem. "A Zona Costeira e os Problemas Ambientais" (Eurocoast),* 18–20 Sept. 1991, Aveiro, 1, 100–108. Aveiro (in Portuguese).

MARQUES, F.M.S.F. and ROMARIZ, C., 1991. Preliminary note about the evolution of sea cliffs. *Proc. 4th Nat. Cong. Geotechnique,* 2–4 Oct. 1991, Lisbon, 1, 57–66 (in Portuguese).

PEREIRA DE SOUSA, F., 1919. O Terramoto de 1 de Novembro de 1755 em Portugal. *Mem. Serv. Geol.* Portugal, Lisboa.

ROMARIZ, C.; OLIVEIRA, M.; ALMEIDA, C.; BAPTISTA, R. and CARDOSO, J., 1979. Contributions to the geology of Algarve, Portugal. I—The Miocene facies of Olhos de Água. *Bol. Mus. Lab. Min. Geológico Fac. Ciências,* 16(1), 243–251.

SANDE DE VASCONCELOS, 1793 (late XVIII century, probably 1793). *Fortalezas do Algarve. Feito S[do]. a ordem do Ill[mo]. S. Conde D'Val D'Reis G[or]. e Cap. General do mesmo Reino.* Manuscript. Sec. Arq. Mil., Lisbon.

SANDE DE VASCONCELOS, late XVIII century. *Fortalezas do Algarve.* Map. Inst. Geog. Cadastral, Lisbon.

SILVA, M.L., 1988. *Hidrogeologia do Miocénico do Algarve.* Ph.D. Thesis, University of Lisbon. Ed. Dep. Geology, 377p.

SUNAMURA, T., 1983. Processes of sea cliff and platform erosion. *In:* KOMAR, P.D. (ed.), *CRC Handbook of Coastal Processes and Erosion.* Boca Raton, Florida: CRC Press, pp. 233–265.

VARNES, D.J., 1978. Slope movements and types and processes. *In: Landslides: Analysis and Control.* Washington, D.C.: Transportation Research Board, National Academy Sciences, Special Report 176, pp. 11–33.

VELOSO, E.S., 1988. Evolução da costa entre Quarteira e Vale de Lobo. Implicações Geológicas e Geotécnicas. (Abstract) *Painel. Evolução do Litoral Portugês.* S.P. Geotecnia. Lab. Nac. Eng. Civil, Lisboa.