PROCEEDINGS OF THE NAMIB–BENGUELA INTERACTIONS WORKSHOP

Occasional Report No 41

held under the auspices of

South African Special Committee for the IGBP

28 to 30 November 1988

Desert Ecological Research Unit, Gobabeb
South West Africa/Namibia

Conveners: Vere Shannon, Mary Seely and John Ward

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INTRODUCTION

The idea of a scientific meeting on the Namib-Benguela was conceived early in 1986, following the publication of a suite of review articles on the Benguela ecosystem. It was evident that information about the Namib such as land morphology, vegetation cover, rainfall and winds, and the transport of material during episodic floods could be relevant to local marine science. Conversely, marine processes such as upwelling, fog generation and sulphur cycling were likely to be important for the functioning of the desert ecosystem. If we assume, as a point of departure, that the two systems are coupled, then it is principally the atmosphere that provides this coupling.

Thus it appeared that those interactive processes which link the two systems and also the meridional similarities and contrasts between some structural features of the Namib and the Benguela were worth examining further - hence the concept of a workshop involving terrestrial, marine and atmospheric scientists. This concept gained further momentum following the launching of ICSU's International Geosphere-Biosphere Programme (IGBP): A Study of Global Change, and the establishment of the South African Special Committee for the IGBP. The primary goal of the IGBP is to advance man's ability to predict elements of global change by means of modelling the global environment. The Namib-Benguela (which spans the region between latitudes 14°S and 32°S) seemed to provide a unique "laboratory" in southern Africa for examining some of the small and medium scale processes linking the geosphere and biosphere, and so a specialist workshop was held at Gobabeb during November 1988 under the auspices of the South African Special Committee for the IGBP.

Workshop objectives were as follows:

1. To bring together key scientists who are active in research in the Namib Desert and in the Benguela ecosystem so as to facilitate the exchange of ideas and information and to stimulate future collaboration.

2. To compare variability in the two systems and to explore the potential utility of long-term data series.

3. To examine the role of marine and atmospheric processes in the aridification of the Namib region.

4. To examine the impact of aeolian and riverine input of material into the Benguela on shelf sediments, chemistry and marine life.

5. To examine chemical cycles which may be regionally important.

6. To stimulate active participation in the National Conference on Geosphere-Biosphere Change in South Africa, 4 to 8 December 1989, and to provide a useful contribution to the IGBP.

The workshop programme was developed so as to provide for both overview and in-depth discussion. It was agreed, however, that the proceedings of the workshop would focus on the discussions, but draw from the overviews where necessary.

PROGRAMME

28 NOVEMBER - MONDAY

EVENING "Meet and Greet"

29 NOVEMBER - TUESDAY

MORNING INTRODUCTION AND OVERVIEWS
Chairman: Vere Shannon

08h30 - 08h40 Introduction

08h40 - 09h10 Weather and climate of the Namib-Benguela region
Janette Lindesay

09h15 - 09h45 Geology and geomorphology of the Namib
John Ward

09h50 - 10h05 Fog in the Benguela-Namib
Jana Olivier

10h10 - 10h40 The desert ecosystem
Mary Seely

10h45 - 11h05 T E A

11h05 - 11h25 Benguela physical processes
Alan Boyd and Vere Shannon

11h30 - 11h50 Shelf sediments and geomorphology
Mike Bremner and Lesley Shackleton

11h55 - 12h10 Chemical cycling in the Benguela
Geoff Bailey

12h15 - 12h45 Marine flora and fauna
Rob Crawford and Penny Brown

12h50 - 14h30 L U N C H

AFTERNOON WORKSHOP SESSIONS

14h30 - 15h30 Latitudinal changes in the Benguela and Namib systems: What correspondences exist?
Discussion leaders - Alan Boyd and John Ward

15h30 - 16h00 T E A

16h00 - 18h00 Temporal variability - system changes, shifts, common links?
Discussion leaders - Vere Shannon, Janette Lindesay and Geoff Brundrit.

30 NOVEMBER - WEDNESDAY

MORNING	WORKSHOP SESSIONS (continued)
08h00 - 10h00	Aridity of the Namib - causes, links, implications. Discussion leaders - Mary Seely and Janette Lindesay
10h00 - 10h30	T E A
10h30 - 12h00	Chemical cycling within and between the Namib and the Benguela (carbon, nitrogen, sulphur). Discussion leaders - Geoff Bailey and John Ward
12h00 - 14h00	L U N C H
AFTERNOON	WORKSHOP SESSIONS (continued) AND CONCLUSION
14h00 - 15h30	Marine sediment budget - inputs, outputs, impact on shelf and on marine and dune biota. Discussion leaders - Mike Bremner, Dave Pollock and Rob Crawford.
15h30 - 16h00	T E A
16h00 - 16h30	Summing up and conclusion Roy Siegfried, Pat Morant and John Mendlesohn

REPORTS ON THE WORKSHOP SESSIONS

WORKSHOP SESSION 1 : LATITUDINAL CHANGES IN THE BENGUELA AND NAMIB SYSTEMS: WHAT CORRESPONDENCES EXIST?

Discussion leaders : Alan Boyd
John Ward

Rapporteur : Geoff Bailey

The workshop was introduced by Alan Boyd who emphasized that it was the existence of equatorward winds around the eastern side of the South Atlantic High Pressure System that primarily caused upwelling in the Benguela System and the aridity of the Namib. The southern boundary of the Namib occurred at approximately 32°S where westerly winds brought rain in winter, whereas the Benguela continued further south as upwelling-favourable equatorward winds occurred in summer. Comparison with other west coast upwelling and desert regions in the world revealed a similar picture - but with upwelling areas extending further polewards than off southern Africa.

A description was then given of how the equatorward margin of the Benguela shifted seasonally, being influenced both by the presence of the warm tropical and equatorial water masses north of the Benguela/Angola front and the substantial drop in equatorward windstress north of 16°S. The Namib's northern boundary lay slightly north of this latitude, indicating the region from 14-16°S did not fall under the influence of the tropical and equatorial rain systems. In this respect substantial differences occurred amongst continents and oceans. The various equatorial circulations show different development and seasonality, and different continental topographic features, for example the Andes in South America which impede the advection of weather systems from the east even at equatorial latitudes.

Despite calls for discussion on these topics, in particular the climatic factors controlling the northern margins of the Namib and Benguela, little discussion arose and there appeared to be general agreement with the above descriptions.

Next, the subject of latitudinal variation within the Benguela and Namib was introduced. The chairman suggested that the factors which led to consistency on a large scale in the Benguela, namely equatorward winds, relatively simple coastline orientation and bathymetry and consistently high light levels should be looked at in more detail, as changes in them would be the prime source of latitudinal variation. He presented a map of the coastline and bathymetry showing areas which protruded further westward than an arbitrary straight coastal trendline into the Atlantic as "exposed" areas, and areas which were set back as "sheltered" areas. This classification was based on previous information which showed the exposed areas off Cape Town and Cape Columbine, Lüderitz and Cape Frio had the strongest equatorward winds, turbulence and upwelling, and because of their steeper bathymetry were also exposed to the intrusion of oceanic water masses (Figure 1). Very lively discussion followed this classification primarily concerning the positions of the wind-maxima in the Namib and Benguela, and the causes of such maxima. This discussion, which enabled information to be shared and compared across the Namib-Benguela boundary in a way not achieved previously, is summarized on the next few pages and in Figure 2.

John Ward introduced information on wind direction and strength based on analysis of sand movement. This showed that peak equatorward winds occurred south of Lüderitz (27-28°S) rather than north of it (25-27°S) as indicated by ships' measurements presented by Alan Boyd (Figure 1). Ian Corbett presented further (very convincing) geological evidence showing a maximum in the strength of equatorward winds south of Lüderitz (from massive yardangs cut in dolomite of the Late Precambrian Bogenfels formation). This wind pattern resulted in the occurrence of a deflation basin south of Lüderitz and a sand sea to the north. He indicated that sand availability appeared the limiting factor in the northward transport of sand with barchan dune trains moving by 30-60m per year.

Geoff Bailey mentioned that some of his data, and an analysis done by the late Niels Bang, also suggested that the coastal winds south of Lüderitz were stronger than those north of it, contrary to the picture given by Boyd based on long-term averages of ships' observations within 60 miles of the coast. The latter "coastal" averages, on the other hand, agreed with measurements further offshore.

A similar discrepancy between geological evidence and ships' records off Northern Namibia was noted. Sand movement indicated the strongest winds off the Haub River and Cape Frio whereas oceanographic measurements placed the maximum further north, the same shift as discussed in the Lüderitz region. Nevertheless there was definite large-scale correspondence in the position of the Lüderitz and Cape Frio regions of wind maxima, and geographic reasons for their existence were now discussed.

The first reason given by Boyd was the westward protrusion of the Lüderitz and Cape Frio areas which would enhance pressure gradients between these sites and the South Atlantic high pressure system. Vere Shannon and Geoff Bailey also noted that the deep bottom topography off Lüderitz and north of Cape Frio would enable cooler water to upwell close to the coast resulting in enhanced cross-shelf pressure gradients which would, in turn, further enhance equatorward winds in a feed-back system. Some reservations about the importance of this mechanism on the medium-scale were expressed by Johan van Heerden but Jana Olivier felt that the inversion layer could respond in this feedback system. On the other hand, the wind maximum off Northern Namibia in the Cape Frio-Kunene River region was suggested to reflect the maximum development of the SE trade winds.

Another cause suggested by Vere Shannon was the positioning of the escarpment inland: where it was well developed and close to the coast equatorward winds would be enhanced. Such a situation of wind maxima occurred at Cape Town, Hondeklip Bay, and around Lüderitz and the Cape Frio-Kunene River regions. Furthermore, off central Namibia around 22°S, where the escarpment is largely absent, equatorward winds are weakest and diurnal winds are well developed according to Alan Boyd and Kurt Loris.

The possibility of differential heating within the Namib was also examined, based on evidence presented by Kobus Agenbag, but results were found to be inconclusive, although high lying areas did seem hotter.

The points which arose during this discussion of Benguela physical oceanography and Namib geology are presented in Figure 2.

During the last part of the workshop session the chairmen solicited information on latitudinal changes in the biota, both terrestrial and marine. Robert Crawford indicated that the variations in upwelling along the coast were reflected in the species inhabiting different regions. Anton McLachlan further noted that there was a major transition off northern SWA to tropical fauna in the intertidal. In addition the mussel *Donax serra* which was intertidal on the warm South African south coast, but subtidal on the west coast, again became intertidal north of Cape Cross. This would reflect the seasonal and periodic intrusions of Angolan water from the north according to Alan Boyd and not so much the variations in upwelling. However Roy Siegfried noted that meso-scale changes concerning intertidal species could be observed in the Hondeklip Bay upwelling centre.

Regarding latitudinal differences in terrestrial species, Mary Seely replied that dune systems had their associated fauna, but that there were differences between the northern and southern dune systems. Naturally there were also major differences in the fauna inhabiting the sandy and rocky parts of the Namib and this reflected, amongst other factors, the prevailing wind intensity and sand supply as discussed earlier. Furthermore, there appears to be a trend in the speciation of certain beetle species from south to north within the Namib sand seas with those in the north being considered more "advanced" than those in the south. However, whether this trend reflects the geological ages of the different sand seas or is a response to sand movement is still subject to considerable debate.

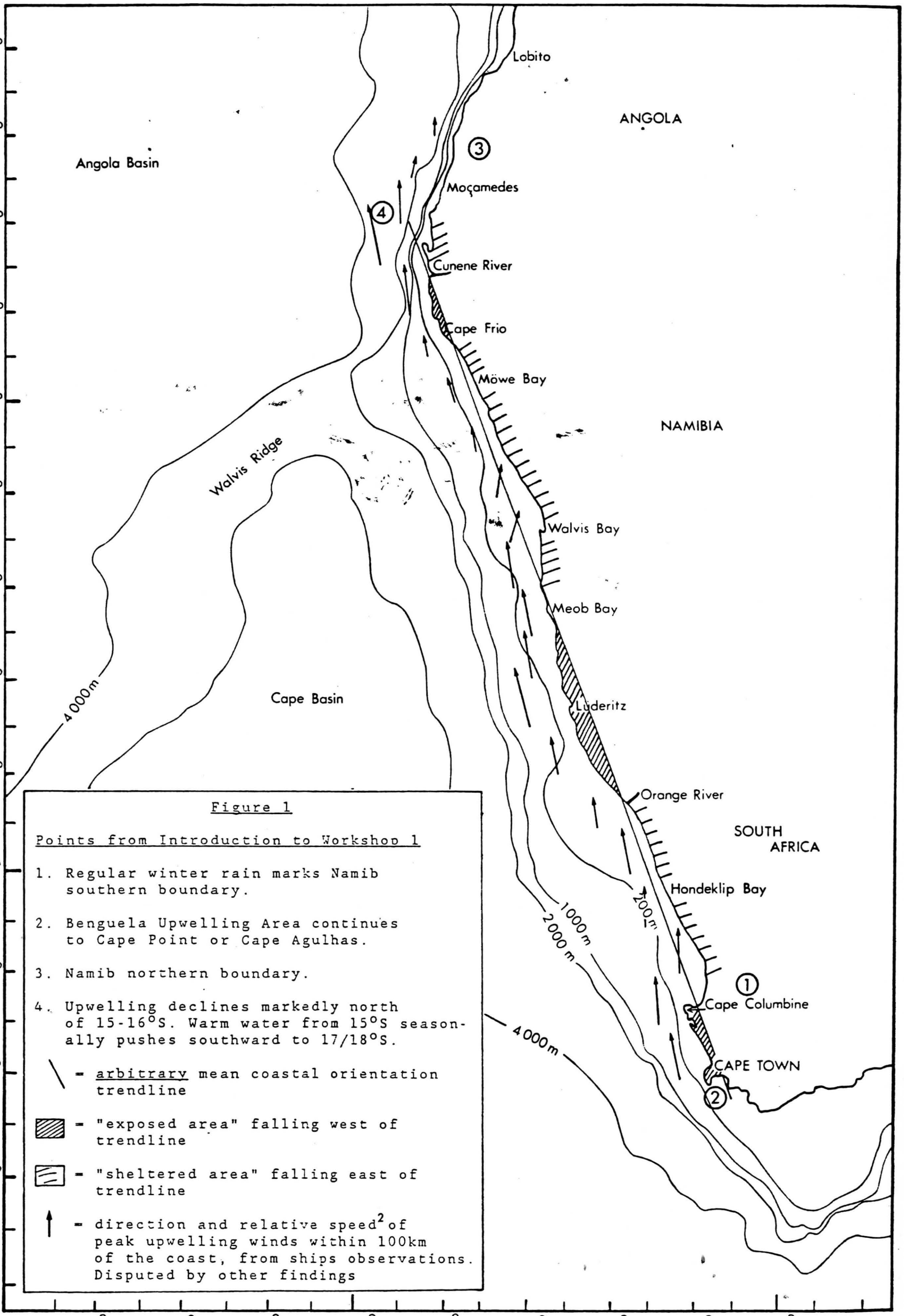


Figure 1

Points from Introduction to Workshop 1

1. Regular winter rain marks Namib southern boundary.
2. Benguela Upwelling Area continues to Cape Point or Cape Agulhas.
3. Namib northern boundary.
4. Upwelling declines markedly north of 15-16°S. Warm water from 15°S seasonally pushes southward to 17/18°S.

\ - arbitrary mean coastal orientation trendline

(hatched box) - "exposed area" falling west of trendline

(lined box) - "sheltered area" falling east of trendline

↑ - direction and relative speed² of peak upwelling winds within 100km of the coast, from ships observations. Disputed by other findings

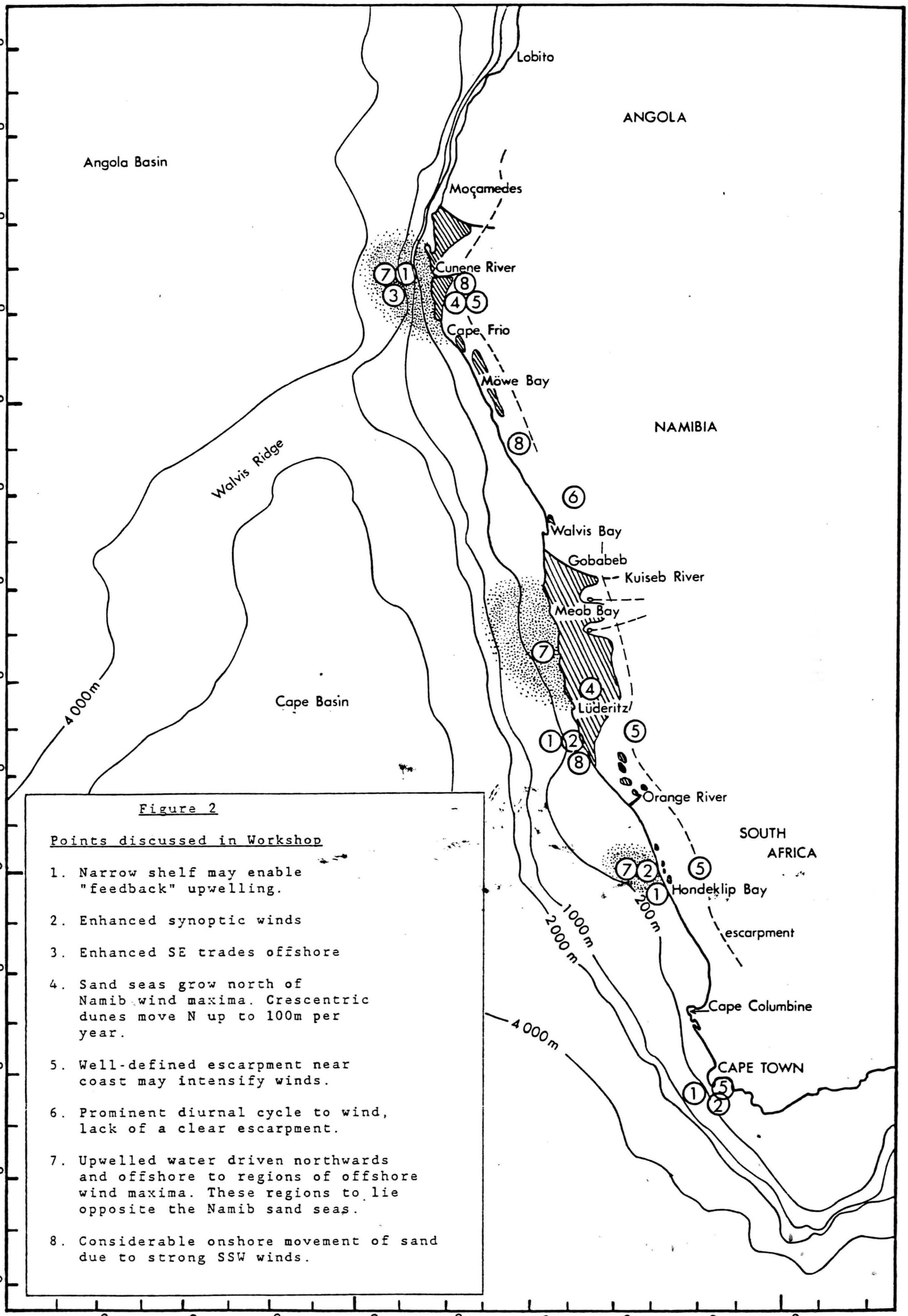


Figure 2

Points discussed in Workshop

1. Narrow shelf may enable "feedback" upwelling.
2. Enhanced synoptic winds
3. Enhanced SE trades offshore
4. Sand seas grow north of Namib wind maxima. Crescentric dunes move N up to 100m per year.
5. Well-defined escarpment near coast may intensify winds.
6. Prominent diurnal cycle to wind, lack of a clear escarpment.
7. Upwelled water driven northwards and offshore to regions of offshore wind maxima. These regions to lie opposite the Namib sand seas.
8. Considerable onshore movement of sand due to strong SSW winds.

WORKSHOP SESSION 2 : TEMPORAL VARIABILITY - SYSTEM CHANGES, SHIFTS, COMMON LINKS.

Discussion leaders : Vere Shannon
Janette Lindesay
Geoff Brundrit

Rapporteur : Lesley Shackleton

The broad goal of this session was to examine available long data series in the light of present understanding of the Namib and Benguela and to compare temporal variability in the two systems. More specific objectives were, *inter alia*:

* To identify system changes and trends
* To document congruent shifts in terrestrial and marine habitats
* To consider episodic events and their impact
* To identify links between changes/trends/shifts in terrestrial and marine ecosystems
* To consider possible causative and linking mechanisms

The discussion was structured around time scales in an attempt to identify ages when changes in the system occurred. On the geological time scale John Ward suggested that the earliest desert phase dates back to the beginning of the Oligocene, with a proto-Namib desert being in existence from 38-20 my ago. Evidence for this includes the existence of ferrocretes in the Spergebied and a vegetation very similar to that found in the desert today. During the period 15-20 my ago there was a significant change in climate and the area went through a relatively wet period. At about 12 my ago the cold Benguela system as we know it today probably became effective, and the present Namib desert conditions date back to 5 my ago. During the Pleistocene and Recent times many changes in sea level have been documented. During the last 500 000 years there have been three high stands of sea level and some of the raised beaches contain evidence of warm water fauna (oysters) that are not found along the coast today. A number of distinctive incision phases linked to these variations in sea level have been identified.

In the discussion common factors to both the formation of the desert and the Benguela current were sought, with climate being the connecting factor. It was felt that the proto-desert could have been formed by the same meteorological conditions that lead to upwelling, but that the water that was upwelled at that period was very different in character from the present Central Water - probably much warmer. Moreover, the general thermohaline circulation in the South Atlantic would have been quite different in the Oligocene, Miocene and Pliocene.

The possibility of coastal warping causing/contributing to the changes in sea level was considered and dismissed as being very unlikely because of the remarkable uniformity of the height of the raised beaches over the whole area. There was speculation about the upwelling patterns during times of considerable sea level variations of the Miocene and Pliocene, and it was suggested that paleo-coastlines might be looked at in this connection.

Other factors mentioned in the discussion included: the data from the Deep-Sea Drilling Programme cores taken on the Walvis Ridge which went back into the Miocene and contained pollen indicating an arid environment; the presence of gravels dredged from depths of 40-60 m, 100-120 m, and 280-300 m; information in Diester-Haas's cores which indicated that the Benguela had moved further north between 13 000 and 27 000 years ago and the presence of wood fibre in the cores indicating a climate in the south that, at 27 000 years ago, was more humid than at present.

The best data available in the 100-1000 year time scale comes from the UCT marine geoscience cores collected in the diatomaceous muds off Walvis Bay. Over the 1000 year period variations in the relative abundance of temperature sensitive microfossils indicate variations in sea surface temperature of about five degrees over periods as short as 100 years. Dr R Johnson has suggested that during the late Holocene the climate seemed to have been in a constant state of flux, with some changes occurring slowly and others quickly. Major changes appear to have a period of 1-3 centuries. A detailed study of the fossil fish scales in an approximately 100 year interval of laminated diatomaceous muds showed pilchard and anchovy relative abundances varying significantly on an approximately 30 year cycle.

On the terrestrial side Mary Seely identified the major rainfall events that occurred every 40-50 years as a driving force. These resulted in major pulses in the flora in the sand dune areas, with the effect of a high rainfall event being felt for decades, if not centuries. Spatial scale also becomes a factor here as different areas have very different rainfalls. It was agreed that the marine environment was considerably more spatially homogeneous than the terrestrial environment, and, although pulses might be detected in both environments, caution should be exercised in using marine events to integrate events on land. It was suggested that some land events might be picked up in the marine sediments, e.g. sediments from the 1934 floods.

On the interannual and interdecadal time scale sea surface temperature data shows Benguela Niño events with an approximately 10 year periodicity. These are usually linked to large-scale events covering most of the South Atlantic, and are also detectable in variations in mean sea level. Cool periods generally preceded Benguela Niños. Shunts in equatorward wind stress have occurred this century. Major changes and shifts have occurred in several fish populations during the last three decades. Some of these are obviously due to fishing pressure, but some appear to be linked to environmental change.

The apparent association between sea surface temperature and rainfall over southern Africa was noted. Preliminary results, which show that SST in several areas of the SE Atlantic and rainfall and fog over the Namib are significantly positively correlated, seem promising. The correlation is being investigated further. It was pointed out that the 1982 rainfall event had had a profound effect on marine biota with widespread fish kills. Janette Lindesay had looked at the possible association between sea surface temperature and Kuiseb flow. In the 60s and 70s she identified a definite warm water event in the season preceding the Kuiseb flow. It was felt that this could also be looked at in relation to fog. It was suggested that there might be a possible 10 year cycle in rock lobster catches.

Robert Crawford spoke of the consistent and persistent changes in the distributions of different species in the Benguela region. Pilchard, horse mackerel, etc had been shifted southwards for a number of years and were now shifted back to the north. The range of bat-eared foxes on land was also known to have expanded and contracted in relation to rainfall. It was stressed that links between land and marine population migrations should not be expected because of the patchiness of the terrestrial environment and the spatial scales involved.

Diurnal scale variations were important in both the marine and terrestrial environments. The positive feedbacks between sea breeze, land breeze and upwelling had been established, especially in the northern Benguela. More work could be done on their influences on the biota, especially in the sea.

WORKSHOP SESSION 3 : ARIDITY OF THE NAMIB - CAUSES, LINKS AND IMPLICATIONS.

Discussion leaders and rapporteurs : Janette Lindesay
Mary Seely

Introduction

It is generally accepted, on the basis of the geological record for the region, that the Namib has probably been arid for some 40 million years (my.) (Ward *et al.*, 1983). The early arid phase or 'proto-Namib' dates to the time when the Atlantic Ocean was already in place but the thermohaline circulation of that ocean was very different from the present and cold waters would not have been upwelled along the west coast. In addition, sea level was different to that of today, and the continental shelf in the area was narrower.

The general aridity was punctuated by a fluvial phase characterised by greater runoff from the escarpment region which began around the Oligocene-Miocene boundary (±20 my). Arid conditions later returned and have prevailed in the Namib region until the present. The cold Benguela upwelling system was established at about 7-10 my (Siesser 1978, 1980) so the Namib-Benguela system as we know it has probably been in existence for about that length of time. The high-energy wind regime which characterises the southern Namib and which today is related to the centre of west-coast upwelling has evidently (from the rock record) been in place for some 30 my, although the wind generally has been south-westerly for some 50 my.

Given that Namib aridity both pre- and post-dates the initiation of cold upwelling along the west coast, the causes of this aridity must be sought not only in the oceanic influences on the region but also in the climate and synoptic-scale circulation of the area.

Causes of Namib Aridity

Two major factors influence the present (and past) aridity of the Namib: climatic and oceanic. These may be considered separately, but there are also important feedbacks and interactions between the two.

1. *Climatic*

The South Atlantic high pressure cell is presently the dominant feature of the circulation off and over the Namib-Benguela region. The presence of this centre of descending, relatively stable air over the region leads to the presence of a subsidence inversion which may be at altitudes of between 500 and ±1200 m and which limits convection much of the time (Preston-Whyte *et al.*, 1977). The anticyclone also limits northward penetration of the mid-latitude cyclones which bring rain to the south-western and southern Cape, and blocks the westward incursion of rain-bearing systems from the summer-rainfall area on the plateau to the east. Predominant winds along the west coast are southerly, thereby leading to the offshore drift of surface water and cold upwelling in the Benguela system. This is particularly marked where the winds are stronger, in the southern Namib near Lüderitz and in the northern Namib around Cape Frio.

2. *Oceanic*

The major oceanic feature of the region is the presence of cold upwelled waters in the Bengüela system. These serve to limit the moisture capacity of the air in circulation around the South Atlantic high, and to enhance the general stability of the air over the region by cooling the lower layers of the atmosphere over the ocean.

Any adjustments in the aridity of the Namib, such as the shift to a more fluvial phase around 20 my, would necessarily have been due to changes in the climatic regime over the area and would probably have reflected large-scale changes in atmospheric circulation.

The important questions relating to this wet phase are what caused it to begin, and (more importantly?) what ended it? There seem to be three possibilities:

i. A 'climatic jump' may have occurred, in which the atmosphere quite suddenly switches from one quasi-stable state (or mode of operation) to another quasi-stable state for no easily discernible reason. Such 'jumps' are known to have taken place during the present century in various parts of the world, and are also predicted by General Circulation Models (GCMs) of the atmosphere.

ii. The South Atlantic high (or its predecessor) may have altered in position and/or intensity, most likely due to a change in the atmospheric temperature gradient between the tropical and middle to polar latitudes. A weaker anticyclone would reduce subsidence and stability along the west coast, possibly allowing the penetration of mid-latitude cyclones over the area, while reduced southerly winds would reduce upwelling and allow convection of moister air over the region.

iii. The relative positions of the subcontinent and the circulation may have changed. During the period when the Alps were formed (±20 my) Africa moved north to its present position, which could have place the Namib in a more tropical (and wetter) belt than it had been previously.

Possibilities for the return of the system to its present aridity include the beginning of cold upwelling in the Benguela with the establishment of Antarctic Bottom Water, and changes in the atmospheric temperature gradients with concommitant changes in the position and/or strength of the anticyclone.

Answers to these questions are not available as yet, and what is needed is a series of modelling studies to determine the effects of changes in parameters such as sea level, the positions of the continents, sea surface temperatures, air temperatures, temperature gradients between tropical and higher latitudes, and adjustments in wind regimes on arid and wet periods in the Namib. A great deal of scope exists for such studies, both with the aim of understanding palaeoclimates of the Namib and of determining possible future climates of the region.

Links with Namib aridity

The major links of importance are those identifiable by considering what would be altered were the aridity of the Namib to change. These links include the marine environment (which would probably be least affected), the atmospheric environment on the micro- and meso-scales, and the ecology of the area. Atmospheric conditions on a micro-scale are very dependent on the nature of the surface, so a wetter Namib with more vegetation would certainly affect the atmosphere environment close to the surface. On the meso-scale the clearly defined and extremely well developed boundary layer wind systems which presently characterise the Namib (Tyson and Seely, 1980; Lindesay and Tyson, 1989) are dependent on the thermal contrast between cold ocean and unvegetated desert, so this aspect of the atmospheric environment is also vulnerable to a change in Namib aridity. The biota of the area has adapted over a long period of time to the episodic nature of rainfall events in the Namib, (Seely and Louw, 1980), the greater reliability of fog moisture availability, (Pietruszka and Seely, 1985), the extremes of temperature, (Lancaster *et al.*, 1984) etc; flora and fauna would thus be vulnerable to any marked adjustment in aridity.

Differing spatial and temporal scales constitute a problem in attempts to study linkages within the Namib-Benguela system. Climate is certainly a link between the terrestrial and marine environments, but it is not the only one and smaller-scale models may be necessary to conceptualise the links properly. A major spatial problem is the patchiness of available terrestrial information. For example, rainfall events are crucial for the desert biota but are highly variable in time and space (Gamble, 1980; Sharon, 1981). A convective storm is typically limited to precipitating over an area of only tens of square km. In this area the rain has a 'pulse' effect on the biota, which rapidly reaches peak productivity and then gradually (over a period of years to decades) declines to pre-rainfall levels (Seely and Louw, 1980). Different time-scale requirements are also a problem, in that developing an understanding of Namib ecology probably requires a 50 year data set of ecological information, whereas existing problems may need different data over shorter time periods for their solution. It is important that problems to be studied are carefully defined so that wherever possible an attempt is made to serve both short- and long-term goals.

Implications

The implications of Namib aridity are possibly best considered in the framing of a number of questions which emerged from this workshop session, in relation to the importance of several factors in this arid ecosystem. The fact that the questions relate mainly to climatic aspects of the region reflects the importance of climatic parameters at all levels in the understanding of the ecosystem.

1. *Wind*:

Are synoptic-scale winds more important than micro- or meso-scale winds (problem-specific)?
What role does the dune field play in the current wind regime?
What role does the morphology of the coastline play?
What is the role of the escarpment in influencing winds over the area?
What would be the effect of a strengthening/diminution of wind over any part of the Namib?
If winds were shifted north/south, what effect would this have?

2. *Fog and Rainfall*

How best may the spatial scales of fog and rain be defined?
To what extent do the morphology of the coastline and of the escarpment exert a control on fog/rainfall?
What is the influence of land-sea temperature contrasts on fog/rainfall?
What is fog in the Namib (definition)?
What is the difference between stratus and fog?
How best can the cloud physics of the fog be described?
What is the chemistry of the fog water?
Do coastal and inland fog have different influences on the biota?
What is the extent of dependence of the biota on fog precipitation?
Is fog vital for the entire Namib ecosystem to function?
How important is the spatial scale and variation of fog (non-linear variation inland)?
Is fog important in physical processes such as soil formation, mineralization, erosion and weathering?
What is the relative importance of humidity, fog and rainfall for the biota?
What constitutes a rainfall event in the Namib (spatial scale, duration)?
What synoptic conditions are associated with such events?
What prevents rainfall systems from moving westward from the interior of southern Africa over the Namib?

<u>Summary</u>

Causes of Namib aridity, which apparently dates back ±40 my, must be sought in both climatic and oceanic conditions. The links among the terrestrial/ecological, marine and atmospheric parameters associated with this aridity are complex and not yet well defined, although climate seems at present to provide the most comprehensive overall link. It is probably in circulation changes that explanations for past and possible future alterations in the aridity of the Namib must be sought.

WORKSHOP SESSION 4 : CHEMICAL CYCLING WITHIN AND BETWEEN THE NAMIB AND THE BENGUELA.

Discussion leaders : Geoff Bailey and John Ward

Rapporteur : Penny Brown

This session was introduced by Geoff Bailey who proposed that discussion revolve around three themes, viz.

1. Benguela/Namib interactions (gypsum formation)
2. Namib/Benguela interactions (aeolian input)
3. Gases produced from Benguela anaerobic muds and the greenhouse effect.

1. *Benguela/Namib interactions (gypsum formation)*

The correlation between the distribution of gypsum crusts in the Central Namib and Benguela anaerobic muds is suggestive of interaction between the Benguela and Namib systems.

The Benguela shelf "downstream" of Luderitz is seasonally anaerobic largely due to the pattern of carbon loading. Geoff Bailey showed that hydrological conditions in the area between Luderitz and Walvis Bay are favourable for the development of large phytoplankton blooms, particularly in late summer when there appears to be a maximum in the phytoplanktonic detritus sedimenting out of the water column. Anaerobic bacteria in the sediments metabolise the settled organic matter and, in the absence of oxygen, sulphates are reduced to H_2S, some of which is released into the atmosphere and transported onto the land where gypsum ($CaSO_4$) is formed. Some gypsum deposits, such as those at Luderitz, do not fit into this pattern however, as dissolved oxygens are comparatively higher here.

This apparent discrepancy was explained by John Ward. There are, in fact, two types of gypsum deposits;

i. Non-pedogenic "desert roses" - these are deposited in anaerobic coastal pans in localized areas and thus do not influence the Namib to any great extent and are not dependent on the presence of an offshore anaerobic mud source of H_2S. This is the type found at Luderitz.

ii. Pedogenic gypsum crusts - Duricrusts and incipient powder soils that occur in a belt up to 50km wide parallel to the coast and coincident with the inland extent of fog. They overly calcareous deposists in much of the central Namib. The crusts are up to three metres deep and occur on stable substrates. The gypsum is reasonably mobile and its existence therefore reflects the arid climatic conditions. The peak in current gypsum crust development is 24km inland. Fog penetration might be significant in this regard.

Hu Berry wanted to know what the pH of the gypsum is and whether it interacts with the underlying calcrete. No one knew the pH but thought that gypsum ($CaSO_4$) would be alkaline. It was agreed that gypsum forms a harsh environment for plants.

In response to a question from Geoff Brundrit, John Ward stated that the moisture during the fluvial stage would have been sufficient to wash out the gypsum and would not have allowed build-up of gypsum. The calcium source necessary for the formation of gypsum is provided by the desert substrate. Calcrete underlies the gypsum and also occurs in pedogenic and non-pedogenic forms, the former being associated with areas with a stable landform and 350-450mm annual rainfall. Non-pedogenic calcrete is associated with groundwater. In answer to Anton McLachlan, John Ward said that the groundwater was too deep to mobilise the gypsum crust under present day conditions.

Vere Shannon asked whether the presence of a stable substrate was not perhaps the factor limiting the gypsum crusts to the Central Namib. John Ward agreed that stable substrates did appear to be a limiting factor but not the only one. He mentioned that the crusts occurring at Chamais Bay and north of the Kuiseb River, outside of the central Namib, were also outside of the dunefield/sand sea areas.

Roy Siegfried wanted to know whether there are gypsum deposits in the southern Benguela which are equivalent to the Namibian ones. Geoff Bailey replied that gypsum of the "desert rose" type had been found inland of St Helena Bay. However, in view of their formation in localised anaerobic pans, they were not necessarily associated with the seasonal development of anaerobic conditions in St Helena Bay.

Geoff Bailey suggested that the discussion be directed towards the mechanism of transport of the H_2S from the marine environment to the desert. He presented figures depicting wet and dry bulb readings taken at sea which suggest that relative humidity is higher off Walvis Bay than off Luderitz. This poses a number of questions.

a. Is fog more predominant off Walvis Bay than Luderitz?
b. In view of southwesterly winds predominating more at Walvis Bay that at Luderitz, is the southwesterly an important mechanism for transporting fog into the desert?

Mary Seely said that word of mouth stated that there is less fog at Luderitz. Jana Olivier agreed saying that, on average, there were more fog-days at Walvis Bay (139) than at Luderitz (117). This may be a reflection of fog formation being inhibited by stronger winds and colder water at Luderitz, as well as the predominance of SW wind at Walvis Bay. Most significantly, Bruce Tomlin noted that in contrast to the Walvis Bay area, fog did not appear to extend further than 5 km inland at Luderitz. Kobus Agenbag showed satelite images of the west coast of southern Africa which, although not resolving the question of relative fog abundance at Walvis Bay and Luderitz, suggest that the area north of Walvis Bay is, in turn, less cloudy.

Turning to the source of the hydrogen sulphide, Anton McLachlan asked whether the H_2S leave the surface in episodic events. Geoff Bailey replied that "sulphide eruptions" have been known to result in the formation of mud islands and the emission of large volumes of H_2S. These are episodic occurrences but there is probably a more steady and less spectacular supply in the form of bubbles of the gas reaching the surface. The surface waters smell strongly of H_2S at several hydrological stations on this coast.

Patrick Morant queried whether any other sulphur compound might cause gypsum formation and whether the mechanism responsible for formation in the presence of hydrogen sulphide was not a form of acid rain. Geoff Bailey thought it unlikely that other sulphur compounds were involved as they would have to be transported inshore dissolved in fog droplets or as an aerosol. If H_2S were to dissolve in fog it would lower the pH but Mary Seely had said in a previous session that the fog water collected at Gobabeb was virtually distilled water. However, H_2S can sometimes be smelled at Gobabeb (i.e. far into the desert), probably brought inland attached to particles during sea breeze events, as suggested by Geoff Brundrit. The meeting concluded that the atmospheric chemistry involved was most important and that Geoff Bailey would investigate whether chemical analyses of the fog water could be done to answer some of these questions.

2. *Namib/Benguela interactions (aeolian input):*

Geoff Bailey announced that this session would be mostly concerned with the possible input of silica and iron from the Namib into the Benguela. More specifically, does the aeolian input of desert dust during easterly winds influence the silicate and iron budgets offshore where diatom production may be limited?

Figures depicting the horizontal distribution of silicate were presented. Dissolved silicate in surface waters of the Central Namib coast show high concentrations (about 20 µg.at/l) in the upwelling region near Luderitz and even higher levels south of Walvis Bay. While supplies are more than adequate inshore, silicate generally decreases in concentrations with distance offshore, suggesting possible silicate limitation of diatom production further offshore (most other types of phytoplankton do not require silicate).

Satellite images show dust being transported up to 200 km offshore. The question is whether this plays a role in the supply of this essential element to offshore waters and whether anyone has analysed the dust and compared it with the terrestrial bed rock composition. During the William Scoresby expedition some analyses of dissolution of desert-derived dust were done. However, there is still some uncertainty as to whether the experiments were to be performed in distilled water or sea water.

John Ward agreed that the bedrock from which the dust was derived was important. There are latitudinal changes in terrestrial bedrock composition in the Namib, therefore one would expect different proportions of mica and silica in the dust, depending on the geographical location. For example, in the central Namib, between the Kuiseb and Ugab Rivers, micaceous schists of the late Precambrian Damara Sequence crop out extensively. Micaceous dust is therefore prevalent during winter east winds. Further south, towards Luderitz, the Namib sand sea is dominated by quartz sands and the dust content is comparatively low. Quartz sand is introduced into the marine environment both during easterly and southerly winds. Mike Bremner mentioned that on the landward side of the diatomaceous muds there are high concentrations of mica which is predominantly biotite from Swakopmund northwards. This ties in with the pattern of east winds. Terrestrially-derived dust is an input to the marine sediments (about 5-7%), but this is small relative to the biogenic input. Geoff Bailey pointed out that this was inshore and that the proportions might be different offshore during easterly winds.

Lesley Shackleton wanted to know how often the east wind blows. Roy Siegfried quoted Vere Shannon as having said that in one day of berg winds, substantial dust input into the ocean could be expected - possibly comparable with suspended sediment input from the Orange River. Vere Shannon replied that these estimates should not be taken too seriously. East winds might not be frequent enough for dust to have a very substantial impact on the marine ecosystem.

Patrick Morant asked whether aeolian dust would stay in the euphotic zone long enough. Penny Brown agreed that it was important to know the dissolution rate of silicate from the dust if one is to assess its impact on the phytoplankton. Some work on this sort of thing has been done in the Northwest African upwelling region.

Anton McLachlan queried whether anything was known about the terrestrial groundwater contribution to the marine water column silicates. This had been found to be an important source of nutrients on the east coast. In answer, Geoff Bailey pointed out that because of upwelling and recycling from the sediments, nearshore waters were adequately supplied with silicate and it was offshore that a mechanism such as aeolian input was required. The input of groundwater would in any event be dealt with in a later session.

Hu Berry wanted to know whether anything was known about the composition of the airborne particulate matter. Mary Seely replied that traps had been deployed to collect particulate matter, but so far there were no results. Vere Shannon added that information on particle size of dust in the marine atmosphere is necessary if satellite imagery is to be used to estimate dust input into the sea.

As far as the aeolian input of iron was concerned Geoff Bailey explained that work by John Martin of Moss Landing had suggested that this element might also limit primary production if insufficient quantities were available. Antarctic ice cores from Vostok have been cut up and analysed to construct an historical record of atmospheric CO_2 and iron. John Martin has shown that a minimum in atmospheric CO_2 coincided in earlier times with a maximum in atmospheric iron and suggests that the latter led to higher levels of primary production and therefore lower atmospheric CO_2. Although it is thought unlikely that iron would be a limiting factor in upwelling areas, the possiblity of iron limiting photosynthesis should be considered.

Mike Bremner said what the sources of iron might be, other than groundwater. Upwelling and recycling from the sediments are important sources but iron could be tied up as iron sulphide in anaerobic areas, according to Geoff Bailey.

3. *Gases produced from Benguela anaerobic muds and the greenhouse effect*

Atmospheric warming as a result of increasing atmospheric CO_2 is one of the most important facets of the IGBP programme. Here again there is a link between the Namib and the Benguela. Janette Lindesay mentioned that atmospheric warming would probably lead to a southward migration of the ITCZ and the Namib would certainly become wetter. The Benguela system plays a role as a source of the 'greenhouse' gases, methane and N_2O (nitrous oxide) and also as a sink for some of the excess CO_2. Dissolved carbonate is assimilated in the upper layers of the sea during photosynthesis and organic carbon is exported, so that excess CO_2 from the atmosphere should be taken up by the sea, either as carbonate in deep-sea sediments or as organic carbon on shelf systems such as the Benguela where sedimentation and accumulation is rapid. However, the increase in atmospheric CO_2 with time suggests that the global ocean system is not coping with recent excesses. Globally, methane and nitrous oxide are also increasing in the atmosphere (at a rate of 1% per annum in the case of methane).

Geoff Brundrit wanted to know whether nitrous oxide could provide nuclei for fog formation and assist in gypsum formation. Geoff Bailey replied that a certain species of phytoplankton in the Antarctic and temperate regions produces a compound, DMS (dimethyl sulphide), which may provide nuclei for moisture condensation but he did not know of any such phenomenon in the Benguela region. As the time for this session had expired, no further discussion was possible on the topic of the greenhouse effect and how this might effect the Namib climate in the long-term.

Vere Shannon concluded by saying that atmospheric chemistry is likely to play an increasingly important role in answering these sorts of questions, and particularly if we are involved with the IGBP programme.

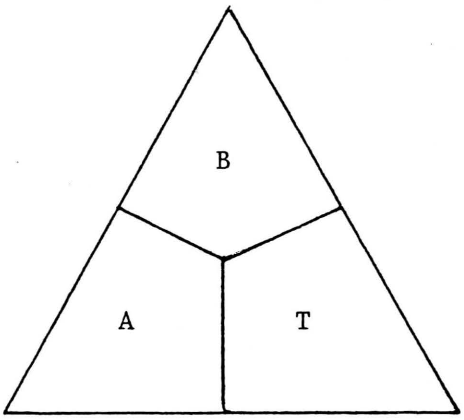
WORKSHOP SESSION 5 : MARINE SEDIMENT BUDGET - INPUTS, OUTPUTS, IMPACTS.

Discussion leaders : Mike Bremner
Dave Pollock
Rob Crawford

Rapporteurs : Alan Boyd
Pat Morant

Introduction

A ternary diagram that broadly classifies offshore surficial sediments (<10 cm depth) into major components provides a useful basis for discussing individual sediment budgets:



B = Biogenic
- Fish
- Diatoms (opal)
- Organic matter (Corg x 1.8)
- $CaCO_3$

A = Authigenic
- Phosphorite
- Glauconite

T = Terrigenous
- Erosion products from land i.e. gravel, sand, mud (silt and clay)

Biogenic sediments

Fish

Both north and south of the Orange River mouth, rock-lobster catches have declined. In detail (Figure 1), the late 50s saw a decline followed by a recovery in the early 60s. A further serious decline took place in the late 60s which has persisted until the present (SWA early 60s: - 6 000 tons, now - 2 000 tons; Namaqualand early 60s: - 2 000 tons, now - <200 tons; i.e. yields are now about 10 to 30% of stable pre 1965 levels). In addition, lobsters are now smaller at maturity than in the past and the whole stock appears to be confined to a narrow, shallow-water zone close inshore.

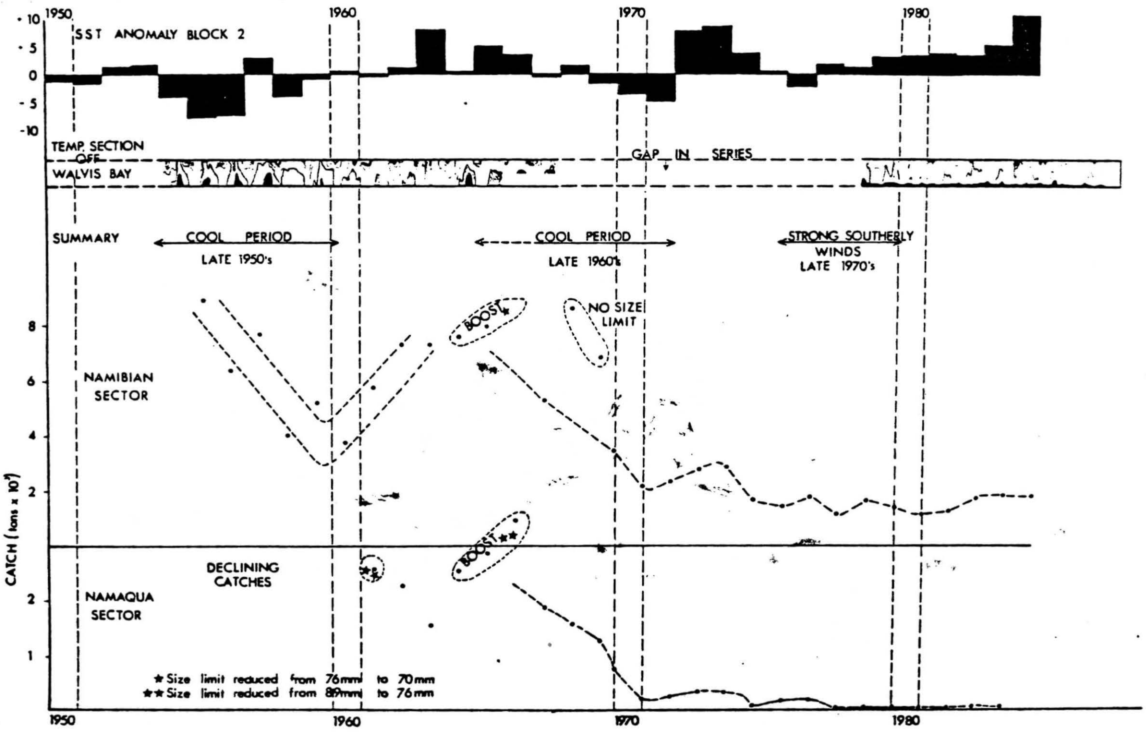


Figure 1. Time series of sea surface temperatures (SST), temperature sections off Walvis Bay, and lobster catches of Namibia and Namaqualand, 1950-1983.

The question has been posed whether decreased lobster yields resulted from bad management and overfishing, or from environmental changes involving a decrease in the dissolved oxygen content of bottom water. Two theories have been proposed with regard to the latter possibility:

A. Primary productivity has increased due to more intensive upwelling which, in turn, has led to increased oxygen consumption during phytoplankton decay.

B. "Walsh" hypothesis - grazing of phytoplankton by herbivores decreased because the pilchard stock collapsed. This could have led to increased sedimentation of unutilized phytoplankton. (Pollock and Shannon, 1987).

At present neither hypothesis adequately accounts for the observed ecosystem changes. A: There is no evidence that upwelling has remained consistently higher since 1965 than previously. B: If oxygen depletion resulted indirectly from pilchard depletion, why has the system not adjusted as other herbivores (anchovies, zooplankton) filled the niche left by the pilchards?

Some discussion then took place about the prevalence and persistence of oxygen-depleted waters in the nearshore region of the Namib coast, and whether there were any other indications that the nearshore environment had changed since the 1960s. It was pointed out, that while the lobster stocks were declining and shifting to shallower depths, another benthic fish species - the sole - was also showing signs of stress. A fairly stable sole fishery off the Orange River mouth declined drastically from a catch of about 1 000 tons pa to a level only a fraction of this within the space of five or six years during the late 1960s (Payne, 1979). Soles, by nature of their bottom-dwelling habit, are also likely to be affected by oxygen-depleted bottom water.

Robert Crawford reported that several changes have been documented in the pelagic ecosystem off Namibia. For example, after the pilchard collapse, anchovies and pelagic gobies increased in abundance and this was followed by shifts in the diets of seals and birds onto the latter resources. No obvious alteration of the terrestrial Namib biota has been discernable during this period suggesting that marine and terrestrial biota behave independently.

It was reiterated that the production of oxygen-depleted water is the result of oxidation of organic matter produced by planktonic organisms (mainly diatoms) in the intensely productive central and northern parts of the Benguela ecosystem. The production of organic carbon, its oxidation, and its burial in the sediments is directly linked to the utilization and deposition of biogenic silica in the so-called "diatomaceous oozes" between ca 18 and 25°S off Namibia.

It is therefore vitally important to understand the processes which govern the silica and carbon budgets, as well as all other aspects of sedimentation in the Benguela system.

Mike Bremner continued at this point to present an overview of the major sedimentary processes.

Diatoms (opal)

The maximum age for the the diatomaceous mud belt is estimated to be of the order of 5 000 years. From detailed sampling, the physical dimensions of the mud belt have been established as: length 740 km, mean breadth 46 km (max 83 km) and mean thickness 5,1 m (max 15 m).

From primary-production calculations involving C (based on a mean primary production of 4 $gCm^{-2}d^{-1}$, which was then converted to Si) the amount of Si utilized by diatoms has been determined to be about 36 x 10^6 tons/annum. This quantity is tentatively balanced in the following way (quantities in tons/annum):

Input

1.	Fresh upwelled South Atlantic central water	$22x10^6$ (items 1 and 2)
2.	Regeneration - ex water-column and sediment	
3.	Rivers	$14x10^6$
	Total	$36x10^6$

Output

1.	Sedimentation	$5x10^6$
2.	Utilization in water-column and sediment	$30x10^6$
3.	Exported out of system	$1x10^6$
	Total	$36x10^6$

This tentative silica budget needs to be refined. However, the following deductions can be drawn:

(i) <u>Input</u> of Si from the marine environment (Items 1 and 2) adequately accounts for the <u>output</u> due to sedimentation (Item 1).

(ii) The amount of Si regenerated from the water column and sediment (<u>Input</u>, Item 2) is probably substantial whereas the amount introduced by "fresh" South Atlantic Central Water (SACW) (<u>Input</u>, Item 1) is likely to be relatively small.

(iii) Si contributed by rivers (<u>Input</u>, Item 3) may be important since concentrations measured in the subterranean Kuiseb River at Gobabeb by the Department of Water Affairs appear to be much higher than the Si concentrations of bottom waters on the shelf (±30 mg/l SiO_2 (in river) vs 1,9 mg/l SiO_2 (= 32 µg at. Si/l)).

Thus although the total input of riverine water to the system is probably negligible compared to marine water influx (48 500 km^3/year), high Si-concentrations in the vicinity of the four major desert river mouths could explain the correlation that exists between the distribution of the diatom *Delphineis karstenii* in the sediments, and the position of these river mouths. It appears as if the river mouths may be acting as point sources for this nutrient (Figure 2).

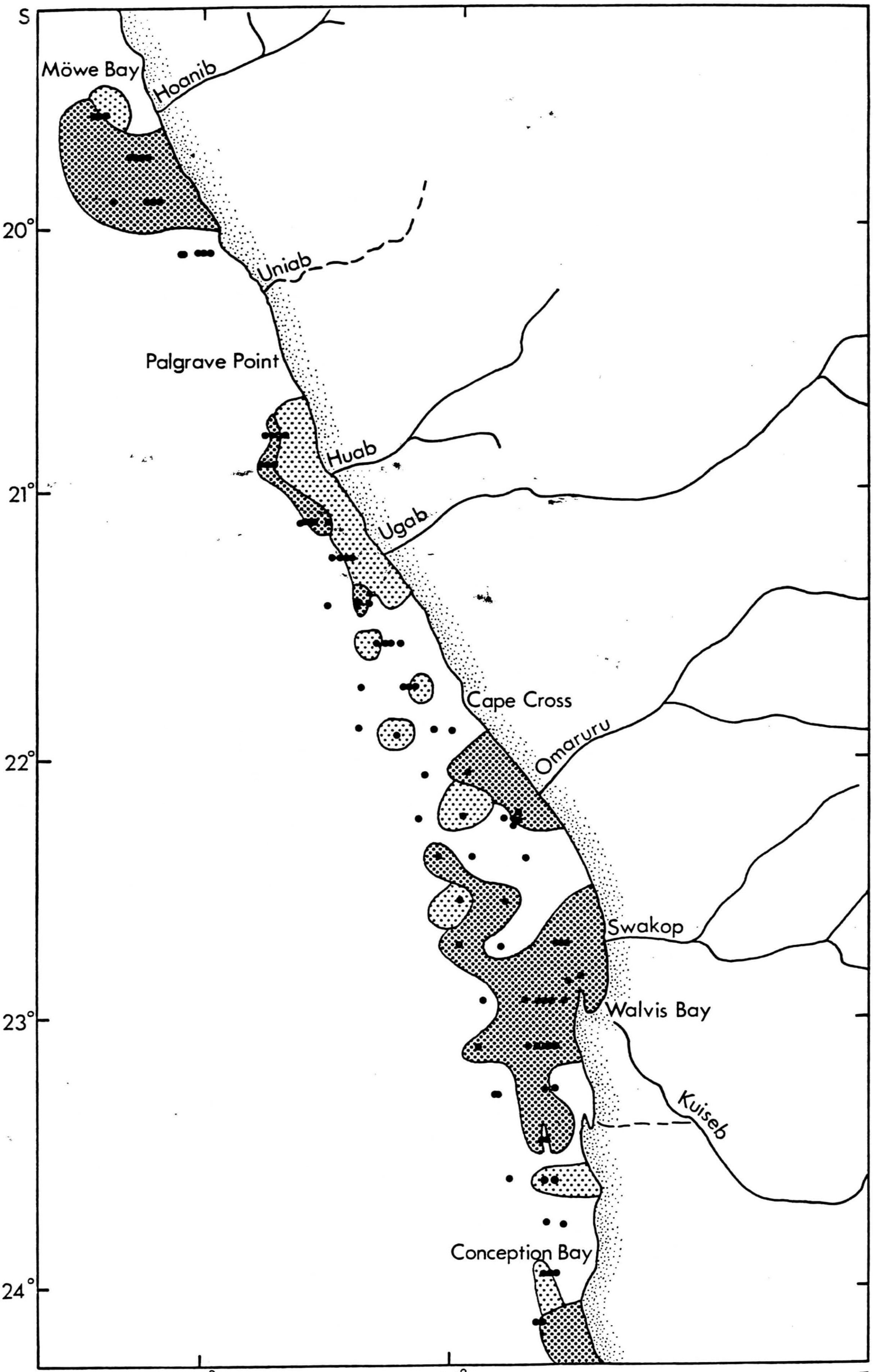


Figure 2. Distribution of relative abundance of Delphineis karstenii. Dark shading: >15%; light shading: 8-14%; white: <8%. (Redrawn from Schuette and Schrader 1981).

Organic matter

The 7% organic matter isopleth and the 5% opal isopleth have almost identical spatial distributions in the surficial sediment. Furthermore, the mean organic matter concentration of 142 samples of diatomaceous mud is about 10% by weight (max 24,6%). Thus, one can say that the organic matter is almost entirely diatom-derived, and is many orders of magnitude richer than the average concentration of "world" continental shelf sediments (0,5% organic matter).

The sedimentation rate has been calculated to be 2,4 x 10^6 m^3 organic matter per year, and the total volume in the diatomaceous mud belt comes to 1,2 x 10^{10} m^3. Evidence from sonar profiles across the mud belt, and from coring, suggests that the inner shelf-break exists because of upbuilding of the inner shelf, i.e. alternating C-rich diatomaceous sediments and terrigenous sand (the latter representing dunes of the Namib Sand Sea that migrate onto the inner shelf during each sea-level regression).

A hydrocarbon resource is therefore speculated to exist at depth close to the inner shelf-break, and the petroleum potential of the existing mud belt has been calculated, based on figures from southern California, to be 6,1 x 10^7 barrels. Unfortunately, no drilling has yet been conducted in this area to test this possibility.

$CaCO_3$

The carbonate content of marine sediments increases from less than 5% by weight on the inner shelf to over 75% on the upper slope. It consists of relict beds of mollusc shells and benthic foraminifera predominantly on the middle shelf, and planktonic foraminifera on the outer shelf and upper slope. The carbonate content of coastal sediments is thus likely to be very low (<5%), and derived from comminuted shellfish attached to shallow reefs and rocky headlands.

Authigenic sediments

Phosphorite and glauconite

Both of these minerals have a marine origin and are today situated in discrete deposits, mainly on the middle shelf. Phosphorite, with a specific gravity of about 3,2, is not likely to have been moved far from its place of origin, and glauconite, whose specific gravity is similar to that of quartz (2,5 to 2,8) forms preferentially on bathymetric highs where coarse terrigenous sediment, e.g. sand, is unable to interfere with the growth of the particles. Neither are therefore believed to have contributed at all to the onshore sediment spectrum.

Of passing interest, however, are the phosphate and potash resources respectively that exist offshore. These are very conservatively estimated at 3 000 million tons and 500 million tons of phosphorite and glauconite respectively.

Terrigenous sediments

Sediment brought down by the Kunene and Orange Rivers is fractionated at the river mouths in exactly the same way, i.e. bedload (sand and gravel) is dumped just off the mouth and is then slowly moved northward by littoral and aeolian processes; suspended load (silt and clay, i.e. mud) is carried further offshore where it is entrained in southward-moving counter currents.

The result is that sand and gravel from the Orange River is transported northwards along the Namibian coast, and mud (particularly the clay mineral montmorillonite) is transported southwards from the Kunene River along the Namibian outer shelfbreak.

Following the breakup of Gondwanaland about 125 my ago, more than 7 km depth of sediment was deposited between alternate mouths of the Orange River, namely a Cretaceous mouth near Alexander Bay, a Palaeogene mouth near the present Olifants River exit, and a reversion to the Alexander Bay mouth during the Neogene and Quaternary. This works out to annual sediment discharge rates of 15 x 10^6 tons during the Cretaceous, 3 x 10^6 tons during the Palaeogene and 0,5 x 10^6 tons during the Neogene. In historical times, the sediment discharge of the Orange River increased dramatically, due to agricultural malpractices, to a maximum of 119 x 10^6 tons/annum. With the topsoil gone and hardpan calcrete exposed, the sediment yield then declined to 34 x 10^6 tons/annum in the 1960s, and to less than 17 x 10^6 tons/annum in the 1970s due to the construction of major impoundments in the river catchment. During the 1988 Orange River flood, 81 x 10^6 tons was transported to the mouth in three months of which 5% was bedload i.e. ±4 x 10^6/tons. This material (sand, gravel and "diamonds") will be transported at a rate of about 1 x 10^6 tons/annum up the coast (Swart) during the next four years, and will eventually contribute to the mobile coastal dunes of the Namib Sand Sea. It follows that the bulk of the flood sediment, the 77 x 10^6 tons of suspended sediment, moved southward to be deposited along the Namaqualand coast. These facts are given here to illustrate that man's influence during the present century has significantly increased the annual volume of sand being added to the Namib Desert, and this should be evident along the mobile coastal strip by an increase in the size and/or number of the dunes.

Another interchange of sediment between the desert and marine environments is brought about by "Berg winds", which are most frequent and strongest during the months of June and July (Whitaker, 1984). Considerable research still needs to be done to quantify this transfer, since estimates made on one large dust plume that occurred both sides of the Orange River estuary on 9 May 1979 vary between 50 x 10^6 tons (Shannon and Anderson, 1982) and 0,5 x 10^6 tons (Johnson, pers. comm., 1988; Whitaker, 1984).

Discussion took place about the impact of the floods on marine fauna. Lobsters south of Luderitz did not appear to have been adversely affected either by sediments or reduced salinities whereas, to the south of the Orange River mouth, severe damage was caused to intertidal and shallow subtidal marine life, especially shellfish. This was the result of greatly reduced salinities in the nearshore zone.

Conclusions

Many views were expressed on biological and sedimentological components off the Namib coast, but very little consensus was reached about the interchange of these components between the sea and the land. Following is a summary of where future research should be conducted in order to identify and quantify these exchanges:

Biogenic sediments

Fish - Has the climate since the 1960s changed at all and if so: is this evident in the desert biome; and on the adjacent escarpment; and in the intensity of upwelling; and hence in the distribution of oxygen-depleted water?

Diatoms - Is the subterranean seepage of Si-rich freshwater from Namib rivers sufficient to influence the productivity (and/or dissolution rate) of diatoms, *Delphineis karstenii* in particular?

Organic matter - No significant exchange except terrestrial input to the marine environment during exceptional flooding.

$CaCO_3$ - Minimal (<5%) from the marine environment to the coastal dunes.

Authigenic sediments

Phosphorite and glauconite - marine minerals - no transfer.

Terrigenous sediments

Erosion products - The input of sand from the Orange River Delta to the coastal dunes is fairly well understood. The reverse scenario involving the transfer of sand from the desert to the continental shelf by way of "berg" winds needs further study.

CONCLUDING COMMENTARY

by

W Roy Siegfried (Incorporating views of Pat Morant and John Mendlesohn)

The IGBP is aimed at improving man's ability to model the global environment in order to plan for the consequences of human-induced changes that are taking place within it. In this context, it is particularly important to appreciate how an overall global change in climate is related to climate and other environmental changes on a regional scale. This requires an improved understanding of the interactive physical, chemical and biological processes that regulate the earth's systems at different temporal and spatial scales of operation.

Given the aforegoing rationale, the Namib-Benguela workshop was convened to explore the feasibility of using information on interactions between the Benguela upwelling system and the Namib desert as a base for a potential case-study and/or observatory site of the South African IGBP (SA-IGBP). There are several reasons why the Namib-Benguela area was considered for this, including the fact that its boundaries have been in place for more than 50 million years and its climate regime has been much the same for most of the last five million years or so. The Benguela system differs from other eastern boundary-current systems in that it is bounded to both the north and south by areas of relatively warm water.

A dichotomy

The workshop set itself the task of reviewing all appropriate physical, chemical and biological data sets dealing with marine (Benguela)-terrestrial (Namib) interactions via the linking atmosphere. The review revealed the strengths and weaknesses of the available database, as expected, but more importantly it strongly underlined differences in philosophy, methodology and interpretation of scientific research between the marine and terrestrial environments. Since this dichotomy began to manifest itself very early in the workshop and persisted throughout the proceedings, I requested independent commentaries from John Mendelsohn and Patrick Morant who provided terrestrial and marine perspectives, respectively. These commentaries, taken together with my own views, are summarized as follows:

1. The marine scientists are visitors to, whereare the terrestrial scientists are resident in, the region - yielding different perspectives.

2. The marine scientists, being ship-based, sample the environment differently to the terrestrial scientsts with regard to both time and space scales.

3. The marine scientsts obtain synoptic information from satellite imagery to a much greater extent than terrestrial scientists. The terrestrial scientists tend to be more concerned with individual populations than the marine scientsts whose studies tend to be more systems based.

4. The marine scientsts are orientated towards resource exploitation (e.g. fisheries and diamond mining), whereas the terrestrial scientsts tend to take a more theoretical/academic approach to their studies.

5. The terrestrial scientsts are more aware of, and attach greater importance to, the marine input than do the marine scientsts to the terrestrial input. In this context, the assumption made by the workshop that the Namib and the Benguela comprise one system (largely depending on one another for their properties) may not be true (but see below).

6. Since the marine biologists have found that none of the nutrients in upwelled water is limiting primary production (?Fe the exception), they tend to ignore the land except as the boundary against which upwelling takes place. The marine geologists, however, are very aware that continental-shelf sediments have large terrestrial components (fluvial and aeolian).

7. The terrestrial scientists are focused strongly on the central Namib, with relatively little work having been done in Namaqualand to the south and southern Angola in the north. In contrast, the marine scientists' studies have been more widely spread from St Helena Bay (biogeographically) speaking, the Namib's southern limit is at the mouth of the Berg River) to Porto Alexandre in Angola.

8. The terrestrial and marine geologists tend to be moving along different pathways, with little interaction between the two groups, in elucidating the palaeo-history of the two systems. The relationship of apprently aeolian deposits on the continental shelf with past sea levels might provide a solution to some of the biogeographical problems attending present-day dune organisms in the Namib.

9. As alluded to in the preceding remarks, perceived differences in scaling contributed significantly to members of the workshop "talking past east other" more often than not. This phenomenon manifested itself even between members of seemingly "homogeneous" groups. For instance, several terrestrial ecologists failed to appreciate that rainfall in the Namib normally occurs as localized small (<40-50 km-wide) storm cells, and not over broader fronts as occurs in some deserts in other parts of the world. Consequently, rainfall events are extremely patchy in their dispersion both in space and time. The implications of this for the survival of the biota are profound (e.g. storage of plant seeds in refugia). A perhaps related example concerns avian nomadism. The relatively high incidence of nomadic species in the avifaunas of the area and semi-arid areas of southern Africa might be vested in the patchily dispersed nature of much of the region's rainfall.

Omissions

These differences were bridged, to some extent, by the few climatologists and systems ecologists who attended the workshop. The climatologists, in particular, displayed a sound grasp of the macro- and meso-scale wind patterns. Wind, as I shall conclude later, is of paramount importance in shaping the two environments and their components and interactions. Hence, it was cause for regret that climatology was under-represented in the workshop. The atmosphere, as the link between the marine and terrestrial environments, merited more attention. In particular, atmospheric chemistry did not feature. Consequently, little was said about the constituents of fog, their potential importance to plants and their role in the formation of gypsum. Even the formation of fog was shrouded by ignorance and clouded by speculation. Other notable under-representations and omissions included reviews of intertidal systems and the marine littoral. Here, for example, one thinks of the biotic input from the sea to the desert ecosystem, which might be important locally and in the vicinity of seal colonies and in sheltered bays.

These factors compounded to create the impression that the Namib and the Benguela are separate systems. Indeed, the workshop did far more to focus on differences and on apparent paucity of vital interactions between the two environments than it did on commonalities and links between them. Placing the emphasis on the latter might have led to a different impression.

The workshop, in spite of having been organized under the auspices of the SA-IGBP, gave scant attention to the following "greenhouse" forces which might promote dramatic changes in the Benguela and Namib ecosystems in the foreseeable future: change in sea-level; ambient temperature increase; UV (especially UV-B) increase; CO_2 increase; and change in episodic events, such as fogs, "berg" winds and floods. Perhaps it was expecting too much of the workshop to consider likely impacts, by way of scenarios, of these factors. It might have been interesting, however, to have examined potential change in the flood regime of the Orange River, in terms of its discharge of sediment and ultimate contribution of sand to coastal dune fields. Here it is worth mentioning, in view of my subsequent remarks, that the workshop, or at least some members of the workshop, agreed on sand and not wind being limiting in the formation of coastal dunes.

No attempt was made to grapple with the problem of scaling down predictions of GCM's (General Circulation Models), which typically operate on 500 x 500 km grid squares, to local climate domains. (This remains a central problem within the IGBP). Interestingly, however, the workshop produced some evidence for the same factors determining macro-, meso- and micro-scale happenings on land as well as in the sea. Wind was regarded as pre-eminent in this regard. Moreover, it was disappointing to note that very few participants in the workshop made special attempts to place their presentations and remarks within the framework of the IGBP. Indeed, there is a lesson here for those who would learn from it: the IGBP, and particularly the SA-IGBP, needs to do more in publicizing itself amongst the scientific community.

Synthesis

Irrespective of the degree that the Namib and the Benguela environments could be interdependent or not, the two systems are linked by the atmosphere. Wind transports water and inorganic and organic matter, both ways between the land and the sea, affecting energy flows and nutrient cycling in both systems. Wind, above all else, shapes the physical environment and also elements of the biota, at sea and on land. For example, wind drives longshore sediment transport which influences major coastal features such as at Conception, Sandvis and Walvis bays and Bahia dos Tigres. In contrast to the world's other major eastern-boundary currents abutting on desert systems (e.g. Humboldt-Atacama), pelicans are not a striking feature of the otherwise comparable Benguela-Namib system. I submit that the wind stress of the Benguela coast is simply too strong for these birds' aerial manoeuvres, apart from at a very few sheltered sites such as Walvis Bay. The Namib's vascular plants tend to be grasses and xerophytic shrubs, the shrubs, characteristically, having small and narrow leaves. Many rely on fog and groundwater for survival during non-rainfall periods. Succulent shrubs, with relatively large swollen leaves and stems, in which water is stored, are unusual in exposed sites, as compared to parts of the Karoo which are more arid than the Namib. I speculate that the evolution of relatively fragile succulent growth forms has been limited by strong wind in the Namib. The physical effects of wind appear to be most pronounced where the continental shelf and the distance from the coast to the escarpment are narrowest, that is, where the linear conveyor belts (see below) are squeezed together laterally. The terrestrial ecologists might explore this proposition further by comparative studies of the biota.

If wind is the agent linking the land and the sea, this is not necessarily evidence for interdependency of the two systems. This point has been made before, but it is worth repeating. Indeed, one could view the Benguela and the Namib as two largely separate conveyor belts, moving parallel to each other in a northerly direction with some lateral connections between them as they shed air, water, nutrients and sand at their interface. The physical properties as well as the properties of the biotas of these two systems are consequences of their positions on the western side of a continent, at a latitude where they are exposed to winds driven by the mid-Atlantic anti-cyclone. This engine is an exceptionally powerful one, so linear flow rates of energy through both systems and between the southern temperate and northern tropical regions, could be fast. Will studies of this phenomenon improve our understanding of climate change and its consequences at global and regional scales, which is the primary mission of the IGBP?

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