PROCEEDINGS OF THE NAMIB-BENGUELA INTERACTIONS WORKSHOP

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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

CONTENTS

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.

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

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.

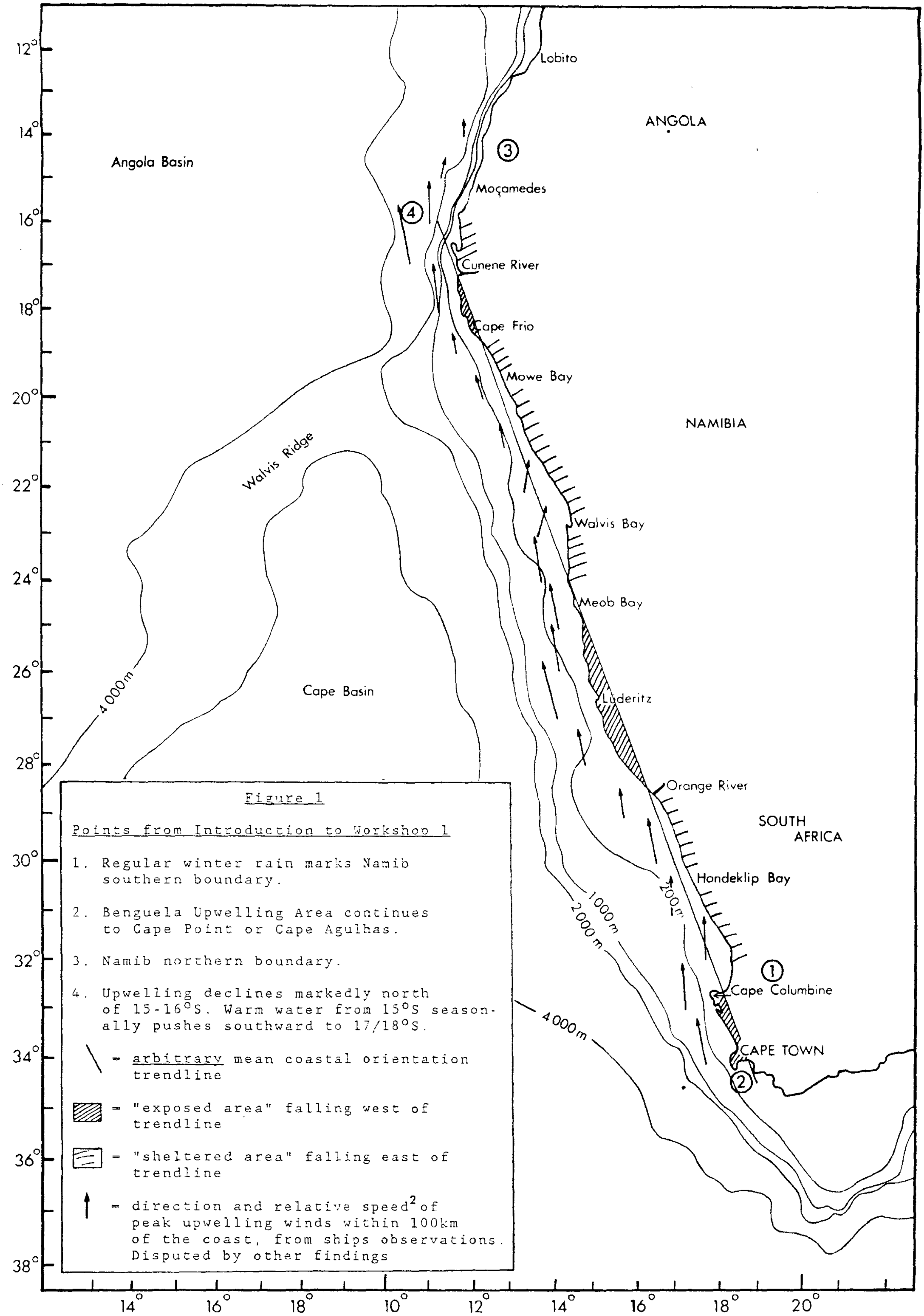


Figure 1

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) = "exposed area" falling west of trendline

(lined) = "sheltered area" falling east of trendline

↑ = direction and relative speed[2] of peak upwelling winds within 100km of the coast, from ships observations. Disputed by other findings

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.

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.

2. *Oceanic*

The major oceanic feature of the region is the presence of cold upwelled waters in the Benguela 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.

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.

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.

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.

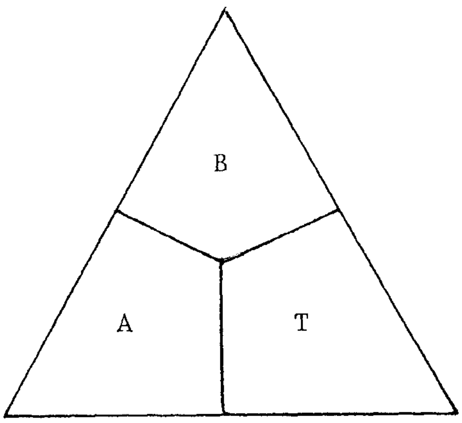
WORKSHOP SESSION 5 : MARINE SEDIMENT BUDGET - INPUTS, OUTPUTS, IMPACTS.

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)

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.

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 <u>increased</u> 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.

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