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Workshops on Marine Research Drilling
(Magellan Workshop Series)

ESF Magellan Workshop Final Report

Southern African Climates, Agulhas Warm Water Transports and Retroflection, and Interocean Exchanges

- S A F A R I -

ESF Magellan Workshop Final Report:

Southern African Climates, Agulhas Warm Water Transports and Retroflection, and Interocean Exchanges

- S A F A R I -

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Location: Institut fuer Geowissenschaften Christian-Albrechts-Universitaet zu Kiel, Germany

Dates: 10th-12th October 2007

Number of participants: 21

1. Aims

The workshop was held in Kiel, Germany between 10-12 October 2007, and was designed to support the preliminary IODP Proposal (#702-pre) '*Southern African Climates, Agulhas Warm Water Transports and Retroflection, and Interocean Exchanges - SAFARI*' (submitted 1/4/06). The aim was to bring together selected key scientists with a range of palaeoceanographic, palaeoclimatic and petrologic expertise in order to further develop the major scientific questions and rationale that drive interest in Scientific Ocean Drilling along the continental margin off southern Africa. As such, the workshop was a key element in the nurturing of the SAFARI science plan and give support to its timely development and progression to full-proposal status. A total of twenty one participants from eight research institutions from five European countries, together with four participants from the United States (3 institutions) and two participants from South Africa attended.

2. Background

Agulhas Current warm water transports and their 'leakage' into the Atlantic form a key link in the global thermohaline circulation (THC) as they feed the warm upper limb of the northward THC in the South Atlantic. The interocean exchange off southern Africa is potentially involved in the initiation, maintenance and stability of North Atlantic THC and thus, it bears importance within the Plio-Pleistocene climate development. On

regional scales it is involved with setting past environmental conditions including patterns of rainfall and vegetation in continental southern Africa with plausible significance for the evolution of large mammals including hominins. The palaeoceanographic evolution of ocean circulation off southern Africa has been the target of scientific ocean drilling several times in the past: DSDP Legs 40 and 75 in 1974 and 1980, ODP Legs 108 and 114 in 1980 and 1987. These Legs obtained sedimentary sequences from the continental slope and rise north and south of the Walvis Ridge in order to (i) determine the age of opening of the South Atlantic and establishment of marine conditions during the early opening phase; (ii) investigate the origin and paleoceanographic history of the Eastern Walvis Ridge; (iii) to examine the nature and forcing of Cenozoic carbonate dissolution cycles. More recently, Leg 175 in 1997 cored a coherent suite of 13 APC and XCB sites along the SE Atlantic margin between 5º and 32ºS which has yielded a wealth of information on the late Neogene history of the Benguela Current and the associated upwelling regime off Angola and Namibia. Leg 208 in 2003 drilled a transect of six sites on Walvis Ridge that provided new insight into short-term paleoceanographic events of the last 70 Ma such as e.g., the P/E boundary climatic warmth excursion and the Early Oligocene cold event.

No single DSDP/ODP site has been drilled within the Agulhas Current domain at the eastern continental margin off southern Africa (south of 15ºS), though oceanographically and paleoceanographically important. Only one site, Site 242, has been drilled within the farther upstream reaches of the Current. The site was occupied during DSDP Leg 25 in 1972 at the eastern flank of Davie Ridge, immediately north of Mozambique Channel and provided data on the structure and geological history between eastern Africa and western Madagascar.

Primary questions regarding Agulhas Current variability relate to:

1. **Warm water transports along the southeast African margin during the late Neogene and their linking with regional to hemisphere-wide climate changes;**
2. **Gateway circulation around South Africa, Indian-Atlantic Ocean exchanges, and their role in changes of Atlantic THC modes during key-periods of the Plio-Pleistocene climatic evolution globally;**
3. **The role of this gateway circulation in conditioning the North Atlantic THC and hence climate in the northern hemisphere for change;**
4. **Southern African terrestrial climates and the evolution of mammals including hominins, and their linkage with the development of ocean circulation in the SW Indian;**

The SAFARI initiative proposes to drill a suite of multiple APC cores along the eastern continental margin off southern Africa and in the Agulhas corridor linking the Indian and Atlantic Oceans. Prospective sites have been chosen on the basis of existing recently recovered sediment cores that indicate the high quality of palaeoceanographic and palaeoclimatic records achievable in the region.

3. Description of the scientific content and discussion at the event

The workshop comprised a single plenary session in which a series of presentations aimed at: (i) providing an overview of the dynamics of the Agulhas Current and its linking with the wider ocean and atmospheric circulation in the Indian Ocean, (ii) the scientific importance of the Agulhas region for Plio-Pleistocene climate development, and (iii) providing state of the art overview of relevant research projects. The workshop was introduced with a review of the SAFARI IODP pre-proposal and status of its planning. The objectives of the meeting were clearly set out and discussed in order to inform the attendees and optimize the focus of the workshop activities.

The remaining presentations of the first day had the purpose of providing the general framework of the scientific themes related to the SAFARI proposal. A review of modern ocean circulation and modelling emphasised that the main motivation for modelling the Agulhas region is a proper quantification of the dynamics that drive the current and the ensuing Indian-Atlantic interoceanic water transport, one of the key elements in the global thermohaline circluation. Since the Agulhas region is dominated by mesoscale activity, an eddy-resolving module has been nested by the IFM-GEOMAR climate modelling group into a global, coarser resolving ocean-sea-ice model driven by prescribed forcing of the last 50 years. The model shows excellent performance simulating all known features as the Agulhas Current, its retroflection, the spreading of Agulhas rings, as well as the influence of upstream perturbations in the Agulhas Current. By comparing the high-resolution model with the base model without high-resolution nest, it can be shown that the high resolution is crucial for a proper quantification of the interoceanic transport. This modern perspective was complemented by an updated view on the dynamics and global significance of the Agulhas Current provided by Prof. Johann Lutjeharms (University of Cape Town) who is widely acknowledged as the world-leading expert on the Agulhas Current and its various entities. This presentation was given as an open lecture within *Institut fuer Geowissenschaften Christian-Albrechts-Universitaet zu Kiel* and attended by over 50 participants.

A number of presentations provided detailed state of the art palaeoceanographic studies from the Agulhas region. Millennial to multi-centennial benthic foraminiferal stable isotope, sortable silt mean grain size and benthic foraminiferal Cd/Ca records were presented for IMAGES (International Marine Global Change Study program) core MD96-2080 raised at 2488 m water depth from the western Agulhas Bank Slope off South Africa. The data provide a detailed picture of the interplay between northern and southern component waters as the Atlantic MOC shifted between glacial and interglacial modes. It was suggested that the early phases of Marine Isotope Stages (MIS) 6 and 8, the Atlantic MOC was little different from its interglacial mode. Most of the benthic foraminiferal $\delta^{13}C$ modulation during these stages can be explained by mean ocean $\delta^{13}C$ changes, while, only slight benthic foraminiferal Cd/Ca increases are indicative of a continued influence of Northern Component Waters (NCW) with moderately high nutrient contents similar to the southern extension of NADW today. Later glacial stages are characterized by the progressive incursion of a nutrient-enriched water mass presumably a mixture of upper and lower Southern Component Water (SCW). The MD96-2080 record displays maximum sortable silt mean values during the late glacial ventilation minima suggesting increased near-bottom flow speeds. The combined ventilation and flow-speed pattern indicates an enhanced influence of SCW linked with a northward migration of the Antarctic Circumpolar Current (ACC) which progressively

decreased the influence of well ventilated NCW at site MD96-2080. Recurrent peak anomalies of high seawater Cd concentration (Cdsw, derived from benthic foraminiferal Cd/Ca) were shown to overlap in time with increased deposition of ice-rafted debris (IRD) in the North Atlantic and these plotted outside the $\delta^{13}C$/Cdsw field for water mass mixing in the South Atlantic. These anomalies conceivably are the South Atlantic equivalents of peak Cdsw maxima associated with Heinrich-type events in the North Atlantic and reflect a substantially reduced Atlantic MOC.

In this context, the present state of knowledge on applying Nd isotopes as a MOC tracer was reviewed. The published seawater data for the deep Atlantic are consistent with mixing of NADW and AABW/AAIW components (Nd isotopes vs salinity), indicating that Nd can be used to trace water masses. The high resolution Nd isotope record from the deep Cape Basin for the last 100 ka (Rutberg et al. 2000, Piotrowski et al. 2004, 2005), show that Nd isotopes indicate a strong MOC signal during peak Greenland interstadials and weaker MOC signals during Greenland stadials (Dansgaard-Oeschger (D-O) oscillations). It was shown that circum-Antarctic Nd isotopes today are consistent with the mix of NADW and Pacific inputs, and thus good circum-Antarctic Nd records should be the way to quantify NADW export. As the Cape Basin records are already mixtures of circum-Antarctic and NADW inputs they do not allow for quantifying how much northern component water is exported from the Atlantic system. It was highlighted that the Cape Basin Nd records and the Atlantic Pa/Th in detail show some significant differences, e.g. Pa/Th indicates strong export at 19-20 ka while Nd shows a weak NADW signal at 19-20. However, details of a new record for the W. Indian Ocean, extending back to 30 ka BP, were shown and whose present day Nd isotope ratios are consistent with Circumpolar Deep Water (CDW). This core's Nd signal matches closely the Bermuda Rise Pa/Th record to 20 kyr, indicating strong MOC at 19-20 as well as a shut-down associated with H-1 but it further indicates a shutdown of NADW export from ~23-30 kyr, when the Pa/Th record stops. It was discussed whether the west Indian Ocean provides the best opportunity to generate Nd records that would allow quantification of the MOC strength with time. It was agreed that the initial results from cruise *RRS Charles Darwin* 154 to the Agulhas region were very promising. Leachates of core-top Fe-Mn oxides are consistent with seawater concentrations (plotting Nd isotopes vs salinity of bottom waters), suggesting that the reconstruction of water column structure back through time along this margin (i.e. depths of NADW, AABW, AAIW) will be possible. This was considered important information for developing the SAFARI proposal because of the known problems with post-depositional signal alteration in the Atlantic sector of the ACC.

Evidence from magnetic mineral (magnetite) content data from three mid-latitude cores from the South Indian Ocean, in an area where the sediment is principally eroded from the Kerguelen-Crozet plateau and transported by the ACC-CDW was also considered. A detailed age model for the time interval, 30-50 kyr B.P., was derived from geomagnetic correlation with the North Atlantic NAPIS-75 stack. Such an approach will be crucial to the development of robust age models from the proposed SAFARI cores to allow synchronization with similar time series from other parts of the world ocean namely, the northern North Atlantic. Results showed maxima in magnetite deposition at the time of Heinrich events H4 and H5, suggesting a strong ACC-CDW when the NADW was reduced at northern latitudes. This is consistent with an inter-hemispheric see-saw,

with strong ACC-CDW current in the southern hemisphere at the time of the northern Heinrich events. Interestingly there is no evidence for the modulation of the ACC-CDW to the faster rhythm of the northern Dansgaard-Oeschger (D-O) oscillations. Rather, it appears that signals are largely in antiphase with the Bond cooling cycles identified in the Greenland ice. The lack of D-O type variability in the ACC-CDW may suggest a signal smoothing by the inertia of the oceanic system, supposedly in conjunction with the suite of ocean fronts in the subantarctic zone.

Past variation in surface ocean conditions were highlighted in a study of benthic foraminiferal assemblages and the carbon isotope composition ($\delta^{13}C$) of the epifaunal benthic foraminifera *Epistominella exigua* along core MD02-2589 located at the Agulhas Plateau (2660 m water depth). The benthic foraminiferal assemblage (>63 μm) showed large fluctuations in species composition suggesting significant changes in the pattern of ocean surface productivity conceivably related to migrations of the Subtropical Convergence (STC) and Subantarctic front (SAF). Enhanced productivity in surface waters and low seasonality of the food supply are indicated during glacial periods MIS 6, early MIS 3, early MIS 2 and across the MIS3/2 transition, probably caused by northward motion of the SAF and confluence with the more stationary STC above the southern flank of the Agulhas Plateau. The lowest organic carbon supply to the seafloor is indicated for the period from late MIS 5b to MIS 4 as a consequence of increased influence of the Agulhas Front (AF) and/or weakening of the influence of the STC over the region. Episodic delivery of fresh organic matter, similar to modern conditions at the core location, is indicated during MIS5 c-e and at Termination I. The comparison of this paleoenvironmental information with the paired records of $\delta^{13}C$ of *E. exigua* and *Fontbotia wuellerstorfi* along the core suggests that the effect on $\delta^{13}C$ of *E. exigua* of organic carbon flux is constant and that this species calcifies at a constant offset from the $\delta^{13}C_{DIC}$ of ambient bottom water. This makes *E. exigua* potentially a better recorder of the amplitude of deep water $\delta^{13}C_{DIC}$ changes than *F. wuellerstorfi*, notably in settings such as the Southern Ocean that experienced substantial changes in the organic carbon supply to the seafloor during the past.

The second day of the workshop focussed on providing an overview of terrestrial records of climate variability from eastern and southern Africa and land/ocean climate linkages. On longer timescales, stretching back to the Pliocene there seems to be a rhythm of vegetation shifts, between grassier (C4) and woodier (C3) vegetation. These cycles seem to be quite strong and appearing at various semi-cyclical scales, e.g. the 4 ka we have in stalagmites, the 23 and 41 ka in longer records. A continent wide "event" at ca. 1.7 Ma appears in many records. This event has recently been postulated to reflect the impact of a change in the Walker circulation. Additional faunal shift appear at about 0.7 Ma, the Mid-Pleistocene transition (MPT). All of these shifts have implications for the evolution of the vertebrate (and other) fauna of Africa, including the human evolutionary record. For instance, by 1.7 Ma Homo was more common in the landscape while in South Africa hominins, formerly frequent, disappear from all known sites as the faunal assemblage change at the MPT.

Terrestrial data that will be crucial for addressing SAFARI objectives are available from South Africa, Botswana, Malawi, Tanzania, Kenya. Virtually no data is available from Zambia, Zimbabwe, Mozambique, i.e between the latitudes of 11°S and 26°S. Proxy archives include lake sediments, peat sections, speleothems (see: Appendix 1).

Climate variability across southern Africa is highly dependent on Indian Ocean conditions and establishing links between terrestrial records and marine archives is an important goal. At present, such studies are limited and only a single example of such work is available from core MD96-2048 recovered off the Limpopo River mouth (660 m water depth). The sedimentation is slow, but probably continuous. The upper 450 cm (down to ~240 ka) have been analysed for pollen, spores, and dinoflagellate cysts at millennial resolution. The terrestrial pollen assemblages indicate a pattern of interglacials with lowland forest and glacials with open mountainous and drier vegetation. Such a pattern of vegetation change corroborates inferences from terrestrial sites. The decline of the glacial vegetation and the start of forest growth at the end of a glacial period, however, began very early. In case of Termination II, the vegetation responded as early as 150 ka, i.e. 15 ka before the termination. The palynological results fit the development in sea surface temperatures (SST) measured using Mg/Ca ratios in planktonic foraminifera showing a first minor maximum at 140 ka. The SST in this area are thought to be associated with the local atmospheric conditions rather than align with the global deglaciation. Insolation at 30°S would constitute an important forcing mechanism of the terrestrial climate in Southeast Africa. Core MD96-2048 might be the first core to pin down differences in timing between global ice volume variation and terrestrial climate change in the region south of the east African lakes.

Considerable discussion focussed on how marine records could assist in understanding the climate evolution on land. It was agreed that such data would facilitate:

- the interpretation of stalagmite isotope data;
- the understanding of forcing factors for cyclicity in vegetation and rainfall;
- the understanding behind the shift from apparent precessional forcing to other (NH?) forcing at 80 ka;
- understanding of zonal and meridional atmospheric circulation pattern and development of Walker ciculation;
- identification of the timing and frequency of flood events.

The final session of presentations provided a detailed review of seismic data collected on the southern South African continental margin and Agulhas Plateau. The seismic data suggests strong erosion on the shelf, slope, in the Agulhas Passage and on Agulhas Plateau. In parts, the entire sedimentary column appears to have been eroded and basement forms the seafloor. For the shelf, slope and the Agulhas Passage specific depth intervals were identified where erosion is particularly prominent. These intervals span the water depths of 900-1700 m, 2000-2600 m, 2800-3000 m, and 4000-4500 m, and comprise the present-day depth ranges and core layers of the Agulhas Current, AAIW, NADW, and AABW. In contrast it was shown that on the Agulhas Plateau, erosion occurs over the whole depth range of the seafloor. Thicker sediment bodies are observed in between basement highs, and larger well stratified deposits appear only on the southern plateau where basement topography is not that rough. On the northern Agulhas Plateau it appears that the paths of the Agulhas Retroflection and the AAIW and hence deposition/erosion are primarily influenced by the basement topography.

The ensuing discussions focussed on assessing the implications of the project results for the positioning and optimization of the proposed SAFARI drill sites. The status of the scheduled and planned pre-site survey cruises was also considered in the light of the new results and the scientific scope of the SAFARI drilling proposal expanded based on the

insight gained from the current research and the additional expertise available from workshop participants.

The development of a robust framework for age modelling and time scale construction was identified as one task that will require substantially effort. Synchronization of time scales is an ultimate prerequisite in the core-to-core comparison of palaeoclimatic time series from marine sediment and polar ice cores and specifically, terrestrial records of climate variability for the African domain. This will involve the combined use of radiogenic isotope decay series, fine-scale and globally synchronous stratigraphy from geomagnetic palaeo-intensity variations, and mapping of proxy marker events.

Substantial discussion was directed at the defining the detailed objectives of the upcoming multi-channel seismic (MCS) and hydroacoustic pre-site survey scheduled in the Agulhas region with the RV METEOR in March 2008 (PI Ralph Schneider, Dar es Salaam - Cape Town). This survey cruise will carry out deep-penetrating surveys for a selection of the planned drill sites (Figure 1).

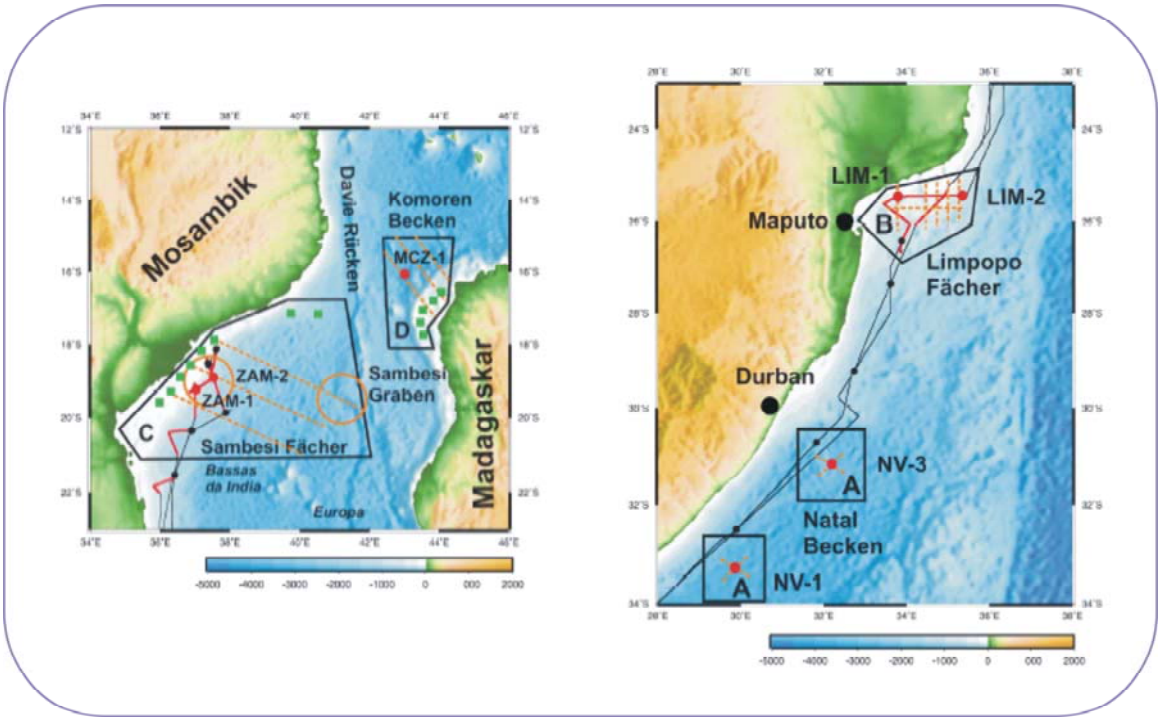

Figure 1. Schematic showing proposed SAFARI pre-site seismic surveys to be carried during the spring 2008 RV METEOR cruise.

Bridget Wade provided an overview of the IODP pre-proposal 'Tanzania to Offshore Paleogene Survey (TOPS): Tropical climate modes during greenhouse to icehouse conditions (IODP 711-pre)'. The proposal aims to extend the Tanzania Drilling Project to drill a series of sites from a transect onshore using Mission Specific Platforms to offshore using JOIDES Resolution Drilling. Drill sites target key intervals in Paleogene extreme climate evolution, spanning the Cretaceous/Paleogene boundary, greenhouse

early Eocene and cryosphere development through the late Paleogene. It was agreed that the Neogene sediment that would potentially be acquired within the TOPS framework would be a significant complimentary suite of material for extending the SAFARI objectives to the North. It was noted that Site TOPS-8A (15°50'S, 41°23'E, 2100 m water depth, close to DSDP Leg 25, Site 242) and SAFARI site MZC-01(16°00'S, 46°00'E, 3000 m water depth) within the Mozambique Channel offer some possible overlap and Wade highlighted the fact that TOPS currently have no scheduled opportunity obtain site survey for this Site. It was extensively discussed if the combined objective of these two sites could be achieved either at a single location or at separate but nearby locations. Following the discussion it was decided that the objectives of site MZC-01:
(i) reconstruct Mozambique Current warm-water transports during periods of orbitally modulated and sub-orbitally accelerated climate changes;
(ii) assess the influence of upstream forcing i.e., monsoonal, Indonesian Throughflow and Red Sea outflow, on SE African warm water transports.

Consensus was reached that these objectives could be accomplished at a Site within the region of TOPS-8A/Site 242 on the Davie Ridge. It was therefore agreed to abandon the scheduled MCS survey of Site MZC-01 within the forthcoming RV METEOR cruise and instead conduct the survey at the TOPS-8A location. A new SAFARI site will then be proposed based on the results of this MCS survey, and the data will be made available to support the TOPS proposal.

4. Outcome

The future actions agreed are the following:

Objectives and named individuals to contribute to developing the text for the SAFARI full proposal:

1. Overview of Agulhas dynamics and links to climate, modern observations and modelling; writing team: *Arne Biastock* with as appropriate.
2. Overview of Agulhas Current, palaeoceanography (including salt leakage, Red Sea Water, ITF); Objectives: questions and drilling targets; writing team: *Sid Hemming, Ralph Schneider, Ian Hall and Rainer Zahn.*
3. Overview of deep water palaeoceanography (including vigour of NADW /MOC per se (i.e., NADW flux to Southern Ocean); architecture of deep water column; carbon storage; linking MOC with Agulhas); site-specific objectives and drilling targets; writing team: *Steve Goldstein with Steve Barker, Chris Charles and Gregor Knorr.*
4. Overview of land-ocean linkage, terrestrial climate variations, human evolution (including long-term development of easterlies-westerlies variability; winter vs summer rainfall in southern Africa, monsoon variability and forcing, ENSO moisture source variability influence/relationship between (marine) climate and biogeography; Questions, objectives and drilling targets, specific southern African objectives; writing team: *Lydie Dupont with Karin Holmgren, Martin Trauth, Ralph Schneider and John Compton.*

5. Basement questions, objectives and drilling targets; writing team: *Gabriele Uenzelmann-Neben* with as appropriate.
6. Proxies / analytical strategy / time scales (including time series analysis); writing team: *Ian Hall, Rainer Zahn, Alain Mazaud and Martin Trauth*.

It was agreed that submission of the full SAFARI proposal attempts to meet the 1st April 2008 deadline.

5. MAGELLAN WORKSHOP Programme

Southern African Climates, Agulhas Warm Water Transports and Retroflection, and Interocean Exchanges

- SAFARI Programme -

Day 1- 10th October 2007

1000-1030	Arrival & Coffee
1030-1045	Welcome -- SAFARI Overview – status of planning
1045-1100	Open Discussion
1100-1120	Rainer Zahn- *Late Pleistocene Agulhas Current warm-water transports during orbital and faster climate changes*
1120-1140	Arne Biastoch - *The importance of small-scale dynamics on Agulhas leakage*
1140-1200	Sidney Hemming - *The Agulhas Current -- Today vs LGM*
1200-1220	Steve Goldstein - *Late Quaternary variability of the MOC from Nd isotopes*
1220-1240	Antoni Rosell - *Pleistocene Southern Ocean and South Atlantic surface conditions*
1240-1300	Open Discussion
1300-1400	Lunch
1400-1420	Paula Diz - *Paleoceanography of the Southern Agulhas Plateau during the last 150 kyr*
1420-1440	Alain Mazaud - *Variations of the ACC-CDW during MIS3*
1440-1500	Syee Weldeab / Ralph Schneider - *Sambesi runoff and Indian Ocean SST during the last deglaciation.*
1500-1520	Open Discussion
1520-1600	Tea break
1600-1620	Chris Charles – Southern Ocean circulation insights from stable isotopes
1620-1700	Open Discussion
	Evening Lecture
1730-1830	Prof. Johann Lutjeharms – *The Agulhas Current: An Updated View on its Dynamics and Global Significance*
1830-1930	Wine reception

Day 2- 11th October 2007

0900-0920	Karin Holmgren - *Overview of available proxy records from southern Africa: Late Pleistocene and Holocene*
0920-0940	Lydie Dupont - *Land ocean linkages off the Limpopo River mouth: MIS1-7*
0940-1000	Open Discussion
1000-1030	Coffee Break
1030-1050	Martin Trauth - *High- and low-latitude forcing of Plio-Pleistocene East African climate and human evolution*
1050-1110	Open Discussion

Day 2- 11th October 2007, continued

1110-1130	John Compton - *Continental margin dynamics on glacial/interglacial timescales*
1130-1150	Gabriele Uenzelmann-Neben - *Sedimentary deposits on the southern South African continental margin: indications for the strength of oceanic currents*
1150-1210	Open Discussion

1210-13 Lunch

Round table discussions - Strategic topics:

1315-1400	Drilling objectives: Agulhas Current, Indian-Atlantic exchanges, inter-hemispheric correlation, time scales
1400-1500	Review of proposed drilling sites
1500-1530	Tea Break
1530-1600	Bridget Wade – Review of TOPS pre-proposal
1600-1700	Open Discussion
1700-1800	Status of pre-site surveys and planned survey cruises
1800-1830	Palaeoclimate proxies, laboratory schedules; post-cruise projects and funding, student mobility (national, ESF, EU)

1900- Joint dinner at the GALILEO restaurant, University science park, Neufeldt Haus

Day 3- 12th October 2007

0900-1000	IODP Proposal submission guidelines
1000-1200	Proposal development and writing, project visibility, deadlines
1200-1300	Lunch
1300-1500	Wrap up
1500	Finish

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6. Participants list:

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Appendix 1. Summary of terrestrial climate records relevant for addressing SAFARI objectives

Location	Parameter	Proxy	Time span	Dating method, accuracy	Reference	Comments	Rationale of the method	Marine cores motivation
Sterkfontein	c3-c4	bovid fossils	2.5-1.7 Myr ago (Plio-Pleistocene)		Luyt and Lee-Thorp 2003	Global-scale climate shifts on terr. Env. Poorly understood. Results suggest major shift from wooded environment to open savanna at c. 1.7 Myr, i.e later than the climate shift at 2.8-2.4 Myr ago that led to NH glaciation	Tropical grasses follow C4 photosynthetic pathway, while trees, shrubs and herbs follow the C3 pathway. C3/C4 index from C13 analysis of fauna provide infor mation on the open, grassy or closed woody nature.	Is the changes in trop climate at 1.7 Ma related to onset and intensfication of the Walker circulation?
Tswaing Crater	XRF, TIC, TOC, TN	lake seds	200kyr-present		Kristen et al. 2007	200-80 kyr, high rainfall coincides with local summer insolation maxima and a strong 23 kyr periodicity. 80-10 kyr high rainfall is out of phase with solar maxima and occurs at 73-68, 54-50, 37-35, 15-10 inferred to reflect southward shift of ITCZ and/or changes in ocean circ.		Age model poorly constrained and tuned to the summer insolation, circulation argument
Buffalo Cave, South Africa, 24 08 S, 29 11 E	O18, C13 (on calcite and organic infills)	flow stone	2-1.7 Myr (MIS 7)	Biostratigraphy, paleomagnetism, orbital tuning	Hopley et al. 2007	Env. recons. Essential for understanding of early hominin evolution. O18 dispaly precession periodicity (18-23 ka), C13 obliquity periodicity (40 ka) in common with pollen record in marine sediment off west Africa (Dupont). Savanna turnover at 1.78-1.69 Myr ago. First occurrence of Homo erectus in East Africa was at ca 1.7 Myr	O18 show changes in isotopic comp. Of rainfall and monsoon intensity, little data on pre-Holocene variability of rainfall O18 over southern Africa available, strong link between O18rain and IOD (interannual variability in the Indian Ocean)	Test precessional forcing of monsoon intensity? Test the forcing behind the obliguity periodicity in vegetation: CO2, temp., preciptation?

Cold Air Cave, RSA	O18, C13 (on calcite)	stalagmite	24kyr-present	U/Th	Holmgren et al 2003	Temperature shift 5-6 deg between LGM and Holocene. Dry, cool at 23-21, 19.5-17.5 (max cool), 15-13.5 (ACR?). Rapid warming after 17.5. Oscillations: 2.5-4 ka; ~1ka; ~100yr		
Southern Africa, winter rain reg.	synthesis				Chase and Meadows 2007	Evaluate the role of equatorward expansion of WRZ. 186-128 kyr (OIS 6, penultimate glacial period), increased humidity along west coast as a reulto fwesterlies shift northwards. 128-71 kyr (OIS 5, Last Interglacial), aridification along the west coast, increased easterly flow, diminished westerlies. 71-24 kyr (OIS 4-3), ca 70-40-lgm cool moist,	LGM 5deg cooler, YD controversial, Early HA, Neoglacial and LIA. Cockrofts model generally valid.	Did WRZ expand how far north-east during glacial conditions
Lake Malawi, 11 S, 34 5 E, Lake Tanganyika 6 S, 29 5 E	chemistry, biostratigraphy, seismicity	lake sed	145-75 kyr	C14, OSL	Scholz et al. 2007	135-75 kyr, enhanced variability, drier than LGM. Transition towards wetter at 70 kyr coincides with diminished eccentricity, reduction in precession climate forcing. Stimulated expansion of humans?	Wetter conditions after 70 kyr, and DO-like events suggest links between tropics and high lats. Wetter although globally less precip is explained due to southward shift of Hadley Cell during glaciation. My comment: shift or contraction?	Pronounced precessionscal variability 150-75 kyr observed here and in cores from Congo Fan and Angola, outside Somalia (Bard) also observable in southern Indian Ocean?
Lake Malawi, 11 S, 34 5 E, Lake Tanganyika 6 S, 29 5 E	diatoms, deuterium	lake sed	25 kyr-present	C14	Barker et al 2007	wet-dry intervals with a c. 2.3 ka periodicity, dry event correspond to cool episodes in Greenland	SST-forcing	

Lake Massoko, Tanzania, 9 20 S, 33 45 E	pollen	lake sed	45Kyr-4.4Kyr	C14	Vincens et al. 2007	Changes in rainfall seasonality inferred to indicate shifts in ITCZ. Wetter at 45-33 kyr and 16-14 kyr, driest between 33-23 kyr. Increase in rain at 23kyr in specific steps at 23-19 and 15-11.8 kyr, i.e. during LGM and YD. Vegetation composition suggest decreas in dry season length rather than higher wet seson rains. Southward shift of ITCZ is proposed. Major shift towards drier at YD/hol trans..	Southward shift only or contraction of belts as well?	LGM and YD, wet and not dry! Shifting YD pattern, wet, dry at different places. Wet in Namibia and Botswans- Dupont, dry in RSA, EA. Role of the ITCZ position?
Lake Rukwa, Tanzania, 8 S, 33 E	pollen	lake sed	23kyr-present	C14	Vincens et al. 2005	23-20 kyr cooler (3-4 deg) and somewhat dryer than today, warmer and drier at 16.5-12.3 kyr, wetter at 12.1-5.5, drier since then		
Lake Tanganyika 6 43 S, 29 50E	geochemistry, sedmntology	lake sed	60 kyr-present		Felton et al. 2007	32-18 kyr - dry, wetter before and after, 60-50 kyr as wet as today, mid-hol aridity. On-set of drier conditions at 32 kyr coincides with NH glaciation (MIS 2)		
Lake Tanganyika 6 43 S, 29 50E	geochemistry, sedmntology	lake sed	20-10 kyr		Tierny and Russell 2007	reduced winds, weakend SW Indian Monsoon and a southerly position of ITZC at YD, Interalleröd cold period, OD and H1		
Marine cores, Agulhas current	radiogenic isotopes		LGM and Late Holocene	C14	Franzese et al. 2006	Sr, Nd to infer provenance and ocean circ pattern	LGM: weaker glacial Agulhas current, decreased Agulhas leakage	