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Palaeoecology of Quaternary Drylands

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With 52 Illustrations, 2 in Colour

Springer

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The Importance of Desert Margins as Indicators for Global Climatic Fluctuations (Introduction)

In various periods throughout the younger earth history comparable changes in climate occurred globally and simultaneously. Such global events can be reconstructed with the help of reliefs, sediments and palaeosoils and their specific morphological, chemical and mineralogical properties. Desert margins represent intersections between arid and humid ecosystems. Their geographical position will react very sensitively on climatic changes. The broad regions of transformation between recent humid ecosystems and the fully arid deserts are the proper areas where palaeoclimatically different phases will be remarkably recognized and interpreted.

Aeolian sediments, e.g. dunes, can be used as palaeoclimatic indicators: palaeodunes in todays more humid climate may indicate arid conditions at the time of their deposition. As an example, fossil dunes are widely distributed in the Sahel south of the Sahara. In resting periods of sedimentation a cover of vegetation appears, and chemical weathering processes and hence soil formation takes place on the sediments in humid climates (see Felix-Henningsen, Heine, Rögner et al., Smykatz-Kloss et al.). In deeper positions of the relief fluvial sediments in wadis and limnic sediments in palaeolakes and playas were deposited. They can be recognized by their sedimentary structures and by characteristic mineral associations, such as for example transformed evaporites (see Rögner et al., Schütt, Heine), by diatomites and lacustrine sediments (see Baumhauer et al.) or by bog ores (see Felix-Henningsen). At some rare occasions the coastline of a former lake is traced by fulgurites (see Sponholz). The organogenic components of soils and sediments mirror the palaeoecological conditions and changes (see Smykatz-Kloss et al.). The pollen communities in upper soils and sediments show the spectrum of the vegetation and thus deliver important criteria for palaeoclimates and relative ages (see Baumhauer et al.). Anthropogenic relicts in soils and sediments are a proof for humid phases. The existence of humid phases and their relative occurrences in the stratigraphical context and the kinds of sediments and palaeosoils allow the reconstruction of the frequency, relative age and character of palaeoclimatic changes (see Rögner et al., Mischke et al.). Absolute dating of aeolian sediments by using luminescence methods such al TL or OSL (see Jäkel, Smykatz-Kloss et al.) and organic substances (^{14}C) – where present – indicate the age position. If the sets of data are sufficiently dense, a picture can be obtained about the time periods of the humid and arid climate phases (Eitel et al., Rögner et al., Smykatz-Kloss et al.).

The signals of arid periods can partly be discovered widely distributed, e.g. over the desert margins to off-shore regions in the oceans. Thus, Leuschner, Sirocko et al. describe layers of (aeolian) dust from Saudi-Arabia in drilling profiles of the Arabian Sea: the geochemical and sedimentological evaluation of these palaeo-loesses in the marine sediment cores contributes to the reconstruction of palaeo-monsoon movements (Leuschner et al.).

Questions on the palaeo-ecological interpretation of drylands and desert margins are explored in the German working group *"desert margins"* and in many interdisciplinary projects. The group conferences are held annually in January at the Rauischholzhausen castle near Gießen. This working group, which has also acted as the German representation for several international geological correlation programmes (all concerned with desert research: IGCP 250, 349, 410), was established seven years ago by the editors of this volume. It is made up of approximately 50 geoscientists of (nearly) all disciplines: geomorphologists, geologists, mineralogists, geochemists, soil scientists, geochronologists, sedimentologists – as well as several palynologists, geobotanists and archaeologists.

At the beginning a pilot project built the core of the research (group) comprising nine projects from the edges of the Sahara (Reichelt, Baumhauer et al., Felix-Henningsen, Rögner et al., Schulz et al., Smykatz-Kloss et al., Sponholz) and of the Namib (Eitel et al., Heine). After a while the study areas were extended towards the north-west (Spain: Schütt, Günster) and – primarily – (north-) eastwards across the Arabic world (Leuschner, Sirocko et al.) towards Central Asia (Grunert & Lehmkuhl; Mischke, Hofmann et al.; Walther). Methodical questions on age analysis (dating of young sediments and aridic soils) and the correlation between chemical weathering (geochemistry, soil science) and palaeoecology are the themes that raise the regional and subject specific results onto a global scale (Jäkel; Eitel, Blümel & Hüser; Felix-Henningsen; Heine; Leuschner, Sirocko et al.; Rögner et al.; Schütt; Smykatz-Kloss et al.).

The investigation of the desert margins as suitable indicators for global climatic fluctuations belongs to the basic research in palaeoecology. The obtained results contribute to the efforts of several earth scientific disciplines in order to understand and reconstruct the causes, frequencies and time periods of palaeoclimatological events and changes. This is especially important on the background of the recent global temperature increase, which is mainly anthropogenetically initiated, and of regional climatic catastrophes. The prognosis of long-term consequences on the base of modelling exhibits many uncertainties concerning the frequency, duration and amplitude of natural climatic fluctuations.

Additionally, the results of studies on desert margins enrich our knowledge on the complexities of landscape formation and on the distribution pattern of their resources (e.g. soils and groundwater) in dependence on extremely different climatic conditions and changes. Ecosystems of savannahs and semi-deserts in the regions of desert margins and the people living there are endangered in their existence by short- and long-term climatic fluctuations. The research data of the working group contribute to a more pronounced understanding of these ecosystems: not only the studied structures and processes, but their development in time, their formation and disappearance under the influence of global climatic changes have to be regarded. Geomorphological research in these climatic regions (e.g. the desert margins) will only be effective if the various geo- and bioscientific disciplines will work together. The contributions in this volume may proof this. The realisation of these projects has been made possible due to the support of numerous friends, members of staff, helpers and organisations. We would like to thank all of them, mainly all the reviewers and correctors, very especially our experts of desert research and production, Simon Berkowicz (Jerusalem) and Wolfgang Klinke (Karlsruhe), and above all the "Deutsche Forschungsgemeinschaft" (German Research Foundation) for its generous financial support.

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The chemistry of playa-lake-sediments as a tool for the reconstruction of Holocene environmental conditions - a case study from the central Ebro basin

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Abstract

The focus of the presented study is the reconstruction of the Holocene limnic and drainage basin conditions of the Laguna de Jabonera, a today playa-lake-system in the Desierto de Calanda, central Ebro Basin, using the inorganic characters of the lacustrine sediments. Mineralogical fabric helped to reconstruct the overall geomorphic processes and gives clues to the synsedimentary limnic environment (paleosalinity). The chemical composition of the lacustrine sediments largely reflects the mineralogical composition, but the higher resolution of the geochemical data compared to the mineralogical data enables to stratigraphically split the extracted core profile into three stratigraphic units. Supplementally, it is demonstrated that statistics between chemical compounds point to the synsedimentary intensity of weathering and soil forming processes.

As for the lacustrine sediments investigated there are no data yet available a preliminary chronological framework is derived by comparison with results from neighbouring areas. Based on this the hypothesis is put forward that during the so-called *Little Ice Age* subhumid to dry-subhumid environmental conditions occurred. Also possibly during the *late Subboreal* distinct wetter environmental con-

ditions than today prevailed. Additionally, it is demonstrated that in the most recent past human impact is causing increased erosion rates and, thus, increased deposition of detritals in the most recent lacustrine sediments.

1 Introduction

Core-based paleoenvironmental investigations of lacustrine settings have been mostly dominated by micro-paleontological and pollen-based studies. Inorganic features of lake sediments are predominantly studied using mineralogical analyses to characterize lake typology (depth of water column, lake phase, salinity). The focus of this research is the reconstruction of Holocene weathering conditions of a today playa-lake-system in the Desierto de Calanda, central Ebro Basin by the analyses of the chemical character of lacustrine sediments, supplementing information about the limnic environment derived from the mineralogical character.

2 Site description

The region of the Desierto de Calanda southwest the town of Alcañiz is characterized by a plain built of slightly cemented Miocene clay strata with paleochannels of calcareous sandstone (Riba et al., 1983). The receiving stream of the Desierto de Calanda is the Rio Guadalope, a tributary of the Rio Ebro.

The present climate of the area is subarid Mediterranean with mean annual precipitation between 300-350 mm. Precipitation peaks during autumn and spring when the region is under the influence of westerlies. Summer aridity lasts for four months. Present-day climatic conditions in the Desierto de Calanda induce a mean annual precipitation-evaporation-ratio (P/pET) of 0.45 (Garcia de Pedraza and Reija Garrido, 1994), that means, according to the classification of the aridity-indices as quoted by UNEP (1991), the Desierto de Calanda belongs to the semi-arid dryland regions. Under present conditions, the mean annual groundwater influx into the endorheic basins of the Desierto de Calanda amounts to c. 60 mm, the mean annual surface inflow comes to 15 mm (data estimated according to Sanchez Navarro et al., 1991).

In the Desierto de Calanda endorheic basins were formed by the combined processes of subsurface erosion of underlying gypsum layers and deflation of out cropping clay strata (Ibañez, 1973; Fig. 1). Thus, in an area of approximately 100 km^2 more than 20 endorheic basins varying in size were built (Sanchez Navarro et al., 1991, 23). The largest of these basins are several hundred metres in diameter and get periodically flooded. Only some basins, predominantly located in the northeast of the Desierto de Calanda, are completely desiccated (Ibañez, 1973). Paleochannels form the boundary of the endorheic basins and elevate up to 20 m above the lake floor. Present processes of surface erosion occur, but forms are peri-

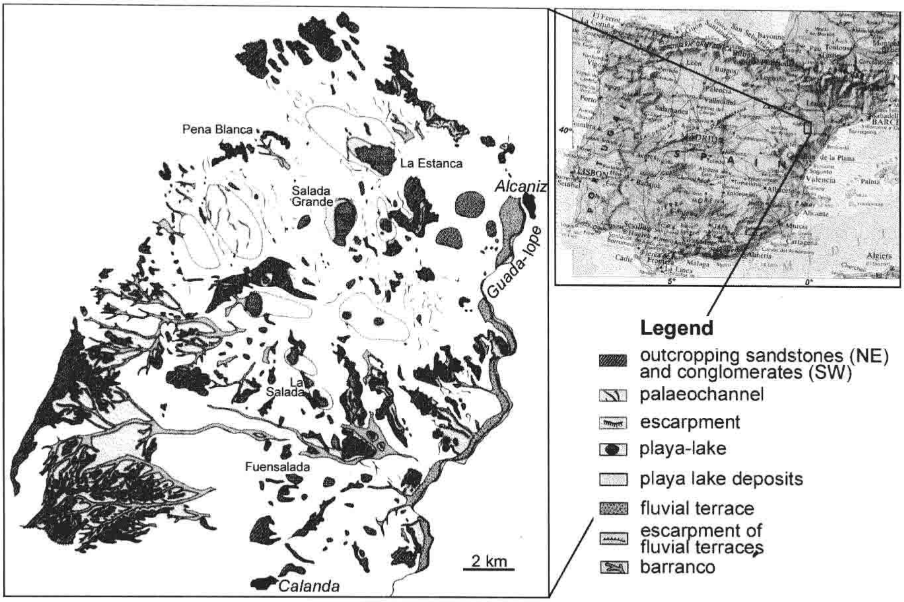

Fig. 1. Geomorphological-lithological map of the Desierto de Calanda (copy from Ibañez, 1973, 23)

odically removed by ploughing of the fields. The present solution of evaporitic rocks is reflected in high groundwater salinity (5765 mg/l TDS, n=13). Predominance of sulphates in the solutes (μ=3640 mg/l SO_4^{2-}, std.=2207, n=13) reflects their origin from solution of solid Miocene sulphates. Composition of cations also points to solution of sulphates with calcium, magnesium, and sodium ions predominating (μ_{Ca}=526 mg/l Ca^{2+}, std.=143; μ_{Mg}=457 mg/l Mg^{2+}, std.=305; μ_{Na}=569 mg/l Na^+, std.=730; n=13). During sampling in March 1994 table of perched groundwater varied between -0.8 m to -5.2 m below surface (all data are based on field data sampled from wells in the watershed of the Desierto de Calanda in March 1994).

Presently the area is being used for dry farming in which fallow land is used for pasture.

In the Desierto de Calanda cores were taken in the endorheic basins of the Salada Grande (easting 735 000, northing 4548 000; UTM coordinate system), the Laguna Pequeña (easting 733750, northing 4547 500; UTM coordinate system) and the Laguna de Jabonera (easting 736 600, northing 4547 500; UTM coordinate system). As sediments of all three endorheic basins point to the same sedimentary history, results shown in this paper are from the Laguna de Jabonera, an endorheic basin with a depth of c. 20 m and a lake floor diameter of c. 1 km. The lacustrine sediments discussed were extracted in the centre of the basin; coring went down to the Miocene bedrock in 310 cm depth below lake floor.

3 Methods

In general, cores were taken in the centre of the playa-lake-systems. To avoid core loss and to control sediment compaction by drilling, two parallel cores were taken with about 0.5 m vertical displacement. A modified Kullenberg corer with a hydraulic core catcher and a diameter of 40 mm was used to obtain undisturbed sediment samples.

Analyses of the sediments included first a sedimentological description to identify stratigraphical units by macroscopic characters. Preparation of samples started with drying them at 50° C in a drying cabinet and homogenizing them in an agate swing sledge mill. Organic and inorganic carbon contents were determined by an infrared cell in a LECO after burning in an O_2-flux (detection limit = 0.02 mass-% C). Analyses of mineralogical compounds were carried out by X-ray powder diffraction analyses using Cu K_α-radiation in the range of 2-70 °2θ with steps of 0.01 °2θ and each step measured for one minute. Concentrations of calcite and dolomite were estimated by calibrating of the intensity of major diffraction peaks of calcite and dolomite (cps) by inorganic carbon contents (Behbehani, 1987). The position of dolomite's major diffraction peak was determined to obtain data about the Mg-Ca-ratios of the carbonates after calibration of the diffractogram with reference to the major diffraction peak of quartz (Tennant and Berger, 1957; Langbein et al., 1981); data were traced with two decimals but are presented with three decimals wherever they show average values. Bulk chemistry of samples was determined by X-ray fluorescence analyses (Siemens SRS 2000). For interpretation

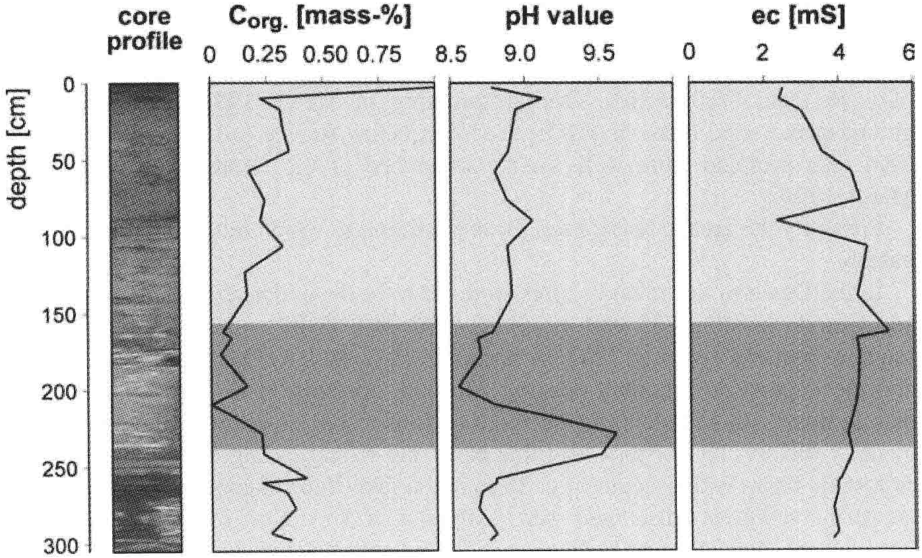

Fig. 2. Bedding of the core profile, organic carbon content (mass-% $C_{org.}$), pH-value, and electric conductivity (ec mS) of lacustrine sediments

and discussion of the lacustrine settings exposed sediments are subdivided into stratigraphic units which are defined by their mineralogical and chemical composition.

Because of very low contents of organic carbon in the playa-lake-sediments, the technique of OSL-dating was chosen to obtain data, executed at the *Forschungsstelle Archäometrie* (Heidelberger Akademie der Wissenschaften, Max-Planck-Institut für Kernphysik). As data are not available yet correlation with investigations from neighbouring areas give a preliminary time scale.

Parallel to coring drainage basin characters were surveyed. Among the study of geological, geomorphological, and land use settings main emphasis was put on hydrological conditions. In the watershed level of perched-groundwater was measured in the wells using a light plumb line. Additionally, water samples from wells were taken and chemical composition was analysed in the laboratory using ion chromatography.

4 Sediment character

4.1 General sedimentary fabric

Lacustrine sediments from the Laguna de Jabonera are of a greyish brown at the basal layers (7.5 YR 4/4) and to the top continuously change to a more reddish colour (2.5 YR 5/4 in 240 cm depth), repeatedly interstratified by fibrous gypsum. From 240 cm depth to the surface sediments are uniformly brownish grey. The organic carbon contents in the sediments reach 1.02 mass-% $C_{org.}$ close to the lake-bed surface but decrease rapidly below 5 cm depth only to oscillate around μ_{Corg}=0.19 mass-% $C_{org.}$ (std.= 0.153, n=24). The sediments are slightly basic (μ_{pH}=8.9, $std._{ph}$= 0.23, n=25), only between 230 and 250 cm depth the pH rises to 9.6 (Fig. 2).

4.2 Mineralogical composition

The whole core is characterized by the simultaneous occurrence of quartz, gypsum, and calcite with gypsum predominant in the parts below 130 cm depth, and carbonates in the upper part (Table 1). Thin sections show that along the whole core the mineralogical composition is idiomorphic carbonates and gypsum embedded in an alternating medium- to fine-grained groundmass of carbonates and gypsum; only in the most recent sediments carbonates are detrital. Dehydrated sulphates (anhydrite) can be detected along the entire core profile as traces. Other than sulphates halites exist as evaporitic minerals. Their concentration decreases to the top. They mainly appear as a minor component in the core section below

Table 1. Mineralogical composition of lacustrine sediments

stratigraphic unit	depth [cm]	Carbonates: Calcite	Carbonates: Dolomite	Sulphates: Gypsum	Sulphates: Anhydrite	Halite	Quartz	Phyllo-silicates	Goethite
	3	+++	++	++	+	++	+++	++	+
	10	+++	++	+	+	+	+++	++	+
	18	+++	++	++	+	+	+++	++	
	29	+++	++	++	+	+	+++	++	+
	45	+++	++	++	+	+	+++	++	
3	58	+++	++	+++	+	+	++	++	
	77	+++	++	++	+	+	+++	++	+
	91	+++	++	++	+	+	+++	++	+
	108	+++	++	+++	+	+	+++	++	
	125	+++	++	++	+	+	+++	++	
	141	++	++	+++	+	+	+++	+	+
	165	+	+++	++	+	+	+++	++	
	169	+	++	+++	+	++	++	+	
	180	++	+++	+++	+	++	++	++	
2	201	++	++	+++	+	++	++	++	
	213	+	++	+++	+	+	+	+	
	232	++	++	+++	+	++	++	+	
	246	+	+++	+++	+	+	+++	+	+
	261	++	++	+++		++	++	+	
	265	++	++	+++	+	++	++	+	
1	271	+	++	+++	+	++	+++	+	
	282	+	++	+++		++	+++	+	+
	292	++	++	+++	++	++	++	+	
	303	+	++	+++	+	+	+++	+	

(shaded) max.counts p.s. +++ major components
++ minor components + traces

165 cm depth (stratigraphic units 1 and 2) and only as traces above (stratigraphic unit 3). Calcite contents continuously increase from bottom to top ($\alpha<0.001$) while above 165 cm depth dolomite contents decrease continuously ($\alpha<0.05$).

The dolomite contents alternate strongly below 165 cm depth (Fig. 3). Between 180 and 220 cm depth the average dolomite content amounts to 8.8 mass-%, in 246 cm depth its content rises up to 18.3 mass-% and fluctuates below 246 cm depth between 4.6-13.6 mass-%. Dolomite's major diffraction line varies along the whole core profile about μ_{dol100}=30.828 °2θ Cuk_α (std.= 0.046, n=25). In stratigraphic unit 2 the position of dolomite's major diffraction line averages $\mu_{dol100;2}$=30.859 °2θ Cuk_α (std.= 0.042, n=6) and, thus, does not differ significantly from the angles of diffraction in the underlying and overlying sediments ($\alpha>0.05$).