

坪沼泽潟湖体系分布区。

C II 层序海侵体系域, 从下向上依次发育潮坪潟湖砂泥岩沉积, 局限台地及开阔台地碳酸盐岩沉积。平面分布非常广泛, 开阔台地碳酸盐岩横贯东西分布, 南北两侧近陆源部位为局限台地碳酸盐岩分布区。

从上述三个层序及其各体系域纵向和横向分布情况来看。C I 层序首先沉积于早海西运动形成的东高西低的古地理格局之上, 随着相对海平面的上升, 先后发育了三个较完整的体系域, 塔东广泛分布东河砂岩为本区石炭纪第一次大规模海侵期产物, Tg2" 反射界面的存在, 说明C I 层序沉积后有一次区域性的抬升运动, C I 的高水位体系域在许多地区被剥蚀, 只在地层较厚, 抬升不太强烈的塔西南有保存。

C I 层低序水位体系域正是在 Tg2" 代表的这期运动形成的格局上沉积的; 东高西低的格局一直延续到C II 沉积结束, 与C I 沉积所不同是C II 沉积期间, 全盆地气候干旱炎热, 蒸发沉积分布广泛。

Tg2" 代表的构造运动, 一改本区东高西低的格局, 使得海水从东西两个方向同时向塔中地区汇集, C II 层序正是在此基础上沉积的, 并达到本区石炭纪最大海侵, 由于 Tg2 所代表的构造运动的深刻影响, 使C II 层序的高水位体系域被剥蚀殆尽。

纵观整个石炭纪, 本区共发生过三次大的海侵及其与之相关的三个影响较为深刻的构造运动, 三次海平面变化不是简单重复的, 而是一次比一次强烈, 石炭纪末期上升幅度最大, 与全球石炭纪海平面变化规律一致。

## The Taklimakan Sand Sea Compared to Ancient Ergs

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### 1. Introduction: a comparison of ergs and the "aging" of sand seas

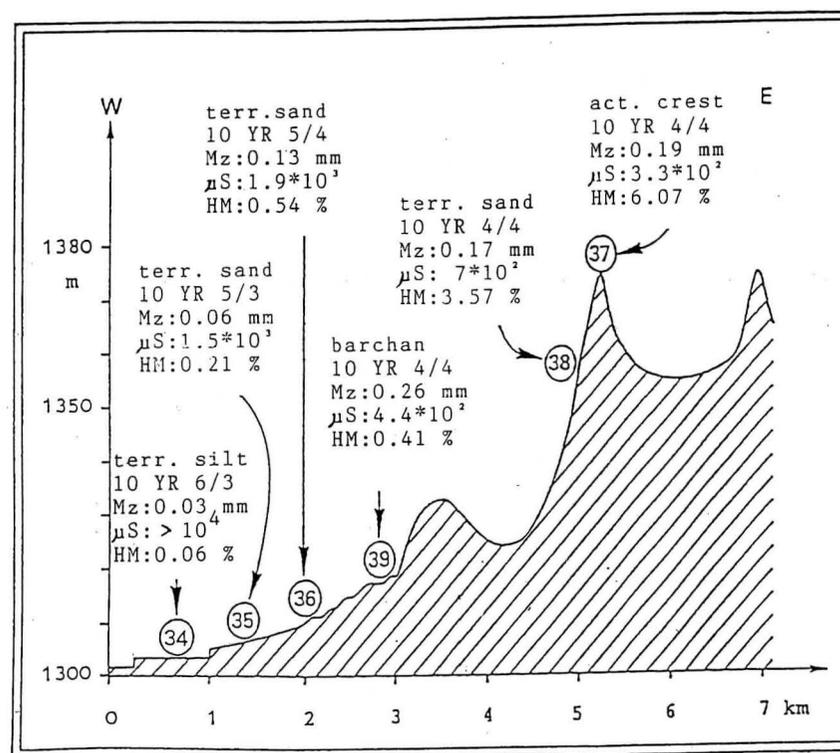


Fig. 1 Cross-section through Keriya terraces north of Yutian with sediment properties (from top to bottom)

granulometric sand type, Munsell colour, mean grain size (Mz), salinity (µS/cm) total heavy-mineral content (HM). "Terr." is terrace; "act." is active

The greater sand seas (or ergs) of the world look very much alike. Characteristics are large longitudinal mega-dunes (or draa) and relatively sharp boundaries, apart from

the upwind margins. Especially similar in this respect are the Namib Erg in Namibia<sup>[1]</sup> and the Wahiba Sands in Oman<sup>[12]</sup>. In general, active dunes are superimposed on the stable draa which have heights around 100 m and wavelengths around 2 km<sup>[6]</sup>.

The Taklimakan, at a first glance, looks quite different and seems to be dominated not by longitudinal draa but by transverse dunes. This is due to a denser pattern of superimposed dunes which conceal the subdued draa beneath. The abundance of transverse dunes—also reversing with changing wind direction—seems to be a consequence of finer-grained sands and/or stronger winds compared to other ergs. Topographic maps<sup>[9]</sup> reveal that the draa below the dunes in the Keriya area of the Taklimakan also have wavelengths around 2 km (compare Fig. 1). The land surface below the draa east of the Keriya and north of Yutian was radiocarbon-dated around 28000 years B. P.<sup>[9]</sup>. Therefore, these draa belong to the oldest parts of the Taklimakan. Compared to Namib dunes which exist since the late Tertiary or early Pleistocene<sup>[4]</sup>, the late Pleistocene Taklimakan draa, however, are rather young.

The different age of draa or dunes is also revealed by sedimentological properties of the sands. Sometimes, already the colour gives a clue: The southern Keriya draa, for example, have a more reddish hue than the surrounding sands. Therefore, on old maps, they are named "Kysyl Kum" which is the Uigur expression for red sands. More decisive for the different age of aeolian sands are other properties like salinity, types of grain size distribution, and heavy-mineral content.

There seem to exist general rules for sand properties changing with time of aeolian activity within one sand sea and also rules for sediment properties changing from one aeolian cycle to another. The following is an attempt to introduce a model for the sedimentary evolution of sand seas. Knowledge was gained from numerous investigations of ergs in northern and southern Africa, Arabia and the Taklimakan. Because of the limited number of pages, this introduction necessarily is very brief and incomplete.

## 2. A model for the sedimentary evolution of sand seas

### 2.1 The first aeolian cycle in the Taklimakan

The sands in the Taklimakan have a juvenile aeolian sedimentology which means that there is still fluvial input of sediments, contrary to most other ergs in the world. A juvenile sedimentology in this connection also means that the main sources of alluvium are various types of rock with the exception of aeolianites. Therefore, the "aeolian aging" of sediments can be studied from the beginning, especially well along a transection through the Keriya terraces north of Yutian (Fig. 1). The lowest terrace, characterized by phragmites growth, may still be seasonally flooded. The second one is a sloping tamarix terrace. The high terrace (dated) is concealed by 20 to 30 m high draa densely covered with small dunes (for details see [5]).

Along the profile in Fig. 1, there is a significant change in sediment properties with statistically relevant correlations, if also samples from other transections are included:

(1) The intensity of the reddish hue is increasing with the height (and therefore age) of the terrace from pale brown (10 YR 6/3) to dark yellowish brown (10 YR 4/4).

(2) The mean grain size is steadily increasing because of constant aeolian reworking by shifting and winnowing and dust export. (The coarse exception, No. 39, will be explained later).

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(3) The salinity is constantly decreasing because the salts, adhering to fine particles, are abraded and exported with the dust. There exists a high negative correlation with the terrace height ( $r = -0.9$  at level 0.05). But it should be noted that even the oldest sands are still saline, contrary to most other ergs (exception no. 39 explained later).

(4) The heavy-mineral content is increasing with the height of terrace and draa. This is a consequence of the constant export of lighter materials. Therefore, there exists a significant positive correlation between heavy-mineral content and mean grain size ( $r = +0.8$  at level 0.01). Typical for the first aeolian cycle is the dominance of unstable heavy minerals, in this case  $> 90\%$  hornblende<sup>[10]</sup>.

(5) Apart from these properties, all sediments have typical grain size frequency distributions (Fig. 2) which also form a causal sequence. According to many investigations there seems to be only a limited number of granulometric sand types in all deserts of the world<sup>[10]</sup>. Grain size distributions shown in Fig. 2 represent dune material of different ages and sources. A description of the samples in Fig. 2 follows.

No. 34: This distribution with a high percentage of silt and clay  $< 0.063$  mm represents the youngest sediment input by water and dust on the phragmites terrace.

No. 36: This distribution is typical for fluvial terrace sands with aeolian reworking, found on the tamarix terrace. Without the tail of coarser grains it is typical for active crests of young dunes (various types). Characteristic is the high and narrow peak in the fraction 0.063—0.125 mm.

No. 37: This distribution is typical for active crests of older draa and dunes. The narrow maximum at 0.125—0.25 mm world-wide represents the aeolian main fraction.

No. 39: This distribution is typical for old barchan dunes after a long time of migration or after having fallen down a scarp. In this case, the sand was sampled on the tamarix terrace from a dune which obviously has come from the high terrace. This explains the exceptional properties of colour, mean grain size and salinity, similar to the high-terrace crest sands. Characteristic for this granulometric sand type is the bimodality with a main maximum at 0.25—0.5 mm and a secondary maximum at 0.063—0.125 mm which after a longer migration may vanish.

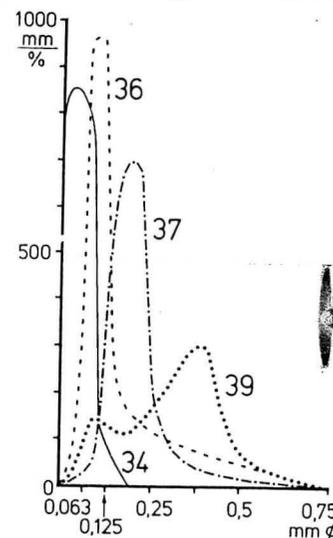


Fig. 2 Grain-size frequency distributions, representing granulometric sand types of the sediments in Fig. 1

From this sequence — corroborated in other deserts — a first general rule may be deduced: With increasing aeolian age the maximum in the grain size distribution of sediments is shifting to coarser fractions. (Aeolian age is understood as a function of time, wind velocity and pre-existent landform)<sup>[7]</sup>.

In the Keriya area, terrace sands (no. 36) with 38% are the dominant granulometric sand type. Only 28% are active crest sands (no. 37). This distribution of sand types is typical for a young sand sea and is not found in ancient ergs. But even in the Keriya area, different "aeolian ages" can be distinguished by their heavy-mineral content<sup>[10]</sup>. In the Kysyl Kum sands the average heavy-mineral content in crest sands (usually the highest) is 5.2%. In the dune field east of the Keriya flood-out, also consisting of draa and superimposed dunes, the average content is only 1.8%. Respectively, the mean grain size is lower, the salinity is higher and the colour is lighter (10 YR 5/4). This sedimentology corroborates the assumption of a different age in the map of dunefield evolution by Jakel (1991)<sup>[9]</sup>.

From these results (terrace sequence and dunefield sequence), a second general rule may be deduced: With increasing aeolian age the sands become coarser, less saline and richer in heavy minerals.

## 2.2 The second and third aeolian cycles in the Namib

The Namib sands have a much longer history. The first aeolian sediment derived from non-aeolianites seems to have been the Etjo Sandstone in the Karoo Sequence. This was eroded and partly deposited in the coastal area where it was reworked by wind into a proto-erg of the Namib during Oligo/Miocene time. The Tertiary proto-erg is preserved in the Tsondab Sandstone which is found everywhere below the modern sand sea. From the weakly cemented sandstone in the second aeolian cycle, the proto-erg can be reconstructed in its final stage before Miocene planation<sup>[8]</sup>.

According to granulometric sand types (Table 1), there has still been fluvial input at the margins (16% terrace sands). But with 27%, active crest sands of older dunes (and draa) are dominant. There is also a large amount of old barchan sands (24%) and inactive dunes (14%). In general, the erg before planation seems to have been older than the dunefields in the Taklimakan. But, as in the Taklimakan, heavy minerals are mainly unstable, with pyroxene being dominant. And as in the Taklimakan, we find a correlation between heavy-mineral content and mean grain size, according to the aeolian age of the deposit (Fig. 3). If only crest sands are compared, the average heavy-mineral content in the proto-Namib is high (9.8%) than in the Taklimakan (5.1%). But this (as also the granulometry) is not necessarily an indication of greater age as the heavy-mineral content was inherited from the Etjo Sandstone<sup>[8]</sup> which also may be true for the grain size distributions. Because of the dominance of unstable heavy minerals, chemical alteration and/or strong diagenesis was neither effective in the Etjo Sandstone nor in the Tsondab Sandstone. According to thin section analysis, only the former one was partly silicified to silcrete (ortho-quartzite) which could have happened in an arid flood-out environment. But there is another indication for a greater aeolian age of the proto-erg: Contrary to the Taklimakan, 50% of the sandstones are not saline ( $<10^2 \mu\text{S/cm}$ ).

The Tsondab Sandstone was eroded during the late Tertiary and redeposited in alluvial fans which were one source of the modern erg, representing therefore the third aeolian cycle. Again, all unstable heavy minerals are inherited, pyroxene being still domi-

nant. A comparative analysis of sandstones and sands close to their sources shows that the processes of aeolian reworking in each locality result in a higher heavy-mineral content, reduced salinity and coarser granulometric sand types<sup>[4]</sup>. Now the average heavy-mineral content of crest sands is 12.9%, and inactive dune sands (38%) are the dominant type, accompanied by a high amount of deflated dune sands (Table 1). Now all sands are not saline.

Table 1 Granulometric sand types (%) —> mean grain size increasing

	terr. sands and silts	young dunes	dome draa	active crests	inactive dunes	plinths	deflated dunes	old barchans	sand sheets
Taklimakan; Keriya Dunes	38	19	11	28				2	2
Proto-Namib	16	3		27	14		11	24	
Namib (incomplete)	2			31	38	2	24		3
Sahara; Azaouad	3			22	28	34	9		3
Tenere		7		13			17	17	47

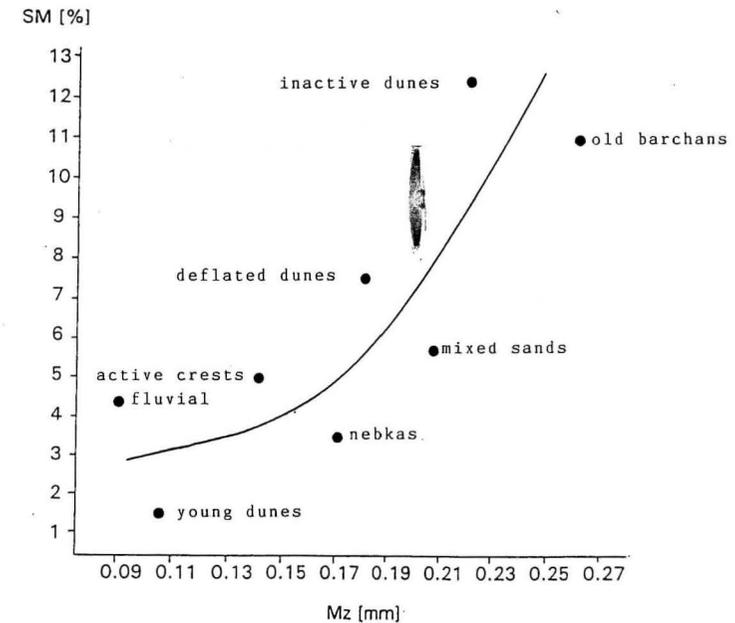


Fig. 3 Total heavy mineral content and mean grain size of the Tsondab Sandstone

From these findings, a third general rule may be deduced: If between the aeolian cycles, there are no humid periods with chemical alteration, mean grain size and heavy-mineral content are continually increasing, and salinity is reduced.

### 2.3 The more advanced cycles in the southern Sahara

The aeolian sands in the southern Sahara (and the Sahel) have a different and/or Djado Sandstones (Cambro-Ordovician and Devonian, already partly aeolianites), Continental Intercalaire (Permian to Cretaceous), and Continental Terminal (Tertiary) which were accompanied by chemical alteration and pedogenesis, partly even lateritization. During the Pleistocene and the Holocene, the sands were reworked into several draa and dune generations, separated by humid periods of weathering and pedogenesis. Therefore, the sands are almost pure quartz and very poor in heavy minerals ( $< 1\%$ ). Only the stable minerals are preserved with a dominance of zircon (70–80%)<sup>[10]</sup>. Therefore, they are of no use for a differentiation.

Nevertheless, ancient draa generations may be distinguished by grain size distributions, even if the sands are not fixed by vegetation and/or soil. In northern Mali, for example<sup>[2]</sup>, the crest sands of the Ogolien draa (20–15000a B.P.) correspond in age and grain size distribution to the draa in the Kysyl Kum (Keriya area; Fig. 2; No. 37). The distributions in pre-Ogolien draa show a maximum reduced below 400 $\mu$ m. This seems to be the threshold value between active crests and inactive dunes (compare Table 1)<sup>[7]</sup>. But there are still older draa which consist throughout of very coarse grains, usually only found in plinth sands at the base of draa (see Table 1). High wind velocities are needed for their accumulation.

The most degenerated and deflated sand sea most probably is the Tenere in the Republic of Niger<sup>[3]</sup>. Here, sand sheets with desert pavement are dominant, even on draa surfaces (Table 1). These sands consist of a thin veneer of coarse material protecting the main fraction 0.063–0.125mm.

The respective grain size distributions resemble no. 36 in Fig. 2, but with a long tail of coarse grains. The high amount of old barchan sands (17%) is partly incorporated with the draa. This does not mean that they are older than the Ogolien draa in Mali. But their aeolian age is higher because winds seem to have been always stronger (no mountain barrier as in Mali), and because the sands were driven down scarps (Falaise de Bilma, Falaise de Fachi) where most fine grains could be blown out (compare no. 39 in Fig. 2)<sup>[3]</sup>. Moreover, the sands seem to have been derived from coarser (Partly already bimodal) sandstones. This means that sands of the granulometric type "active crests" (in Table 1) represent a different "rejuvenating" sediment input.

From these relations a fourth general rule may be deduced: If the bulk of heavy minerals has been destroyed during humid periods between (aeolian) cycles, there are still dominant granulometric sand types to distinguish between draa and dune generations and to indicate the aeolian age or—in comparison with the source sandstones—the stage of sedimentary evolution.

### 3. Conclusion: The sedimentary future of the Taklimakan

These thoughts on the sedimentary evolution of sand seas are only an attempt to see the "red line" in the main recycling process. Increasing amounts of samples may shift the results but will not change the tendencies completely. Many side-processes have been neglected. For example, input of juvenile sediments, lake formation because of climatic change, tectonic movements, and human impact may complicate and alter the se-

quence.

The latter, at present, is most effective in the Taklimakan. Because of increasing irrigation projects, the river floods are reduced and therefore also the transport capacity and the sediment input. The processes are enhanced by glacier retreat. At the same time, the aeolian export of fine and light materials (silts, clays, salts) is going on at the same or at a higher rate (human activities in search for oil). Therefore, the clock for the aeolian age is running faster.

Nevertheless, in the definition of aeolian age human impact has not been included because it seems to have not yet reached geological dimensions in deserts.

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## 塔克拉玛干沙漠与古沙漠的对比研究

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### 摘要

本文通过对北非-南非和阿拉伯地区沙漠以及塔克拉玛干沙漠的调查研究, 认为在同一沙漠地区存在着沙物物质性质随风力活动的时间而变化的一般规律以及沉积物性质随着