Character of Lake Floor Sediments from Central Lake Abaya, South Ethiopia

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Abstract

Lake Abaya is the largest lake of the Main Ethiopian Rift Valley. In the presented study the spatial distribution of Lake Abaya's lake floor sediments is analysed to achieve information on lake hydraulics. The area investigated is located within a bottleneck that separates the larger northern part from the smaller southern part of the lake.

A total of 238 lake floor samples have been extracted and analysed on bulk parameters. Results allow a distinct differentiation between sediments incoming from tributaries discharging directly into the bottleneck of central Lake Abaya. Furthermore, the characters of the lacustrine sediments indicate an existing interchange between the water bodies of the northern and the southern Lake Abaya subbasins.

Keywords: tropics, bulk parameters, Lake Abaya, sediments

1 Introduction

Ethiopian Rift Valley tributaries are characterized by high concentrations of suspended load. Most of this suspended load originates from soil erosion processes in the drainage basin areas due to a strong increase of the population and coinciding intensification of land use since the middle of the 20th century (Schütt et al. 2002, Schütt & Thiemann 2004).

Most of the suspended load reaches the receiving Rift Valley lakes without or with only short intermediate deposition. Due to the paleogeography of the Rift Valley, origin and composition of parent rocks alternate small scaled. Consequently, also fines deposited in the receiving lake basins vary in composition corresponding to their origin. Thus, source can be identified clearly. That way, the spatial distribution of lake floor sediments seems to be an ideal indicator to study hydrodynamics of the lake systems.

In the study presented the feasibility of lake sediment's bulk parameters (like colour, magnetic susceptibility and contents of organic and inorganic carbon), to reconstruct lake hydraulics, is tested. The study site selected is Lake Abaya in the southern Ethiopian Rift Valley which has an N-S-extension of 80 km; a bottleneck separates the larger northern Lake Abaya subbasin from the smaller southern one. As this bottleneck is most likely an area of distinct hydraulic exchange between both subbasins, influenced by two entering rivers and their fluvio-lacustrine deposits, the reliability of most recent lake sediment bulk characters is tested to conclude on lake hydraulics.

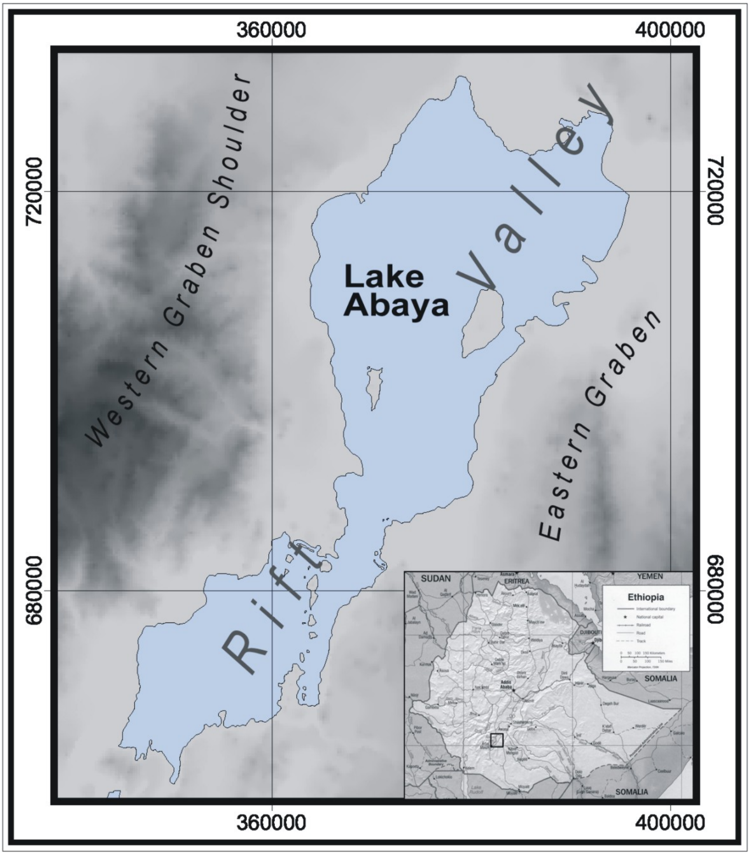

Figure 1 Geographical setting of Lake Abaya.

2 Study Site

Lake Abaya is part of the Lake Abaya – Lake Chamo system. It drains via a sill into the neighbouring Lake Chamo which in turn is lacking an outlet, thus, Lake Abaya – Lake Chamo system is endorheic. The Lakes Abaya-Chamo-Basin covers an area of ca 18100 km² and is located in the south of Ethiopia within the East African Rift Valley. It is characterized by strong topographical differences between the Rift floor, the slopes and the basaltic highlands over short distances.
The Rift Valley floor is covered by Quaternary sediments and volcanics, the slopes and the highlands are predominantly composed of Tertiary basalts, locally subordinated by Precambrian basement (Mohr 1961). The strong topographic characteristics control the expected tropical climate, soils, natural vegetation and as a result the population distribution.

Climate of the Lake Abaya – Lake Chamo drainage basin is characterized by a bimodal annual rainfall distribution with short rains (belg) in spring and long rains (krempt) in summer (Tato 1964). Due to strong altitudinal differences, there is a distinct altitudinal classification which is based on thermal and vegetational differences (Endlicher 2000, Hurni 1982).

The dominating soil types in the highlands and along the graben flanks are Nitisols, Acrisols, Luvisols, and Vertisols, while on the graben floor and around the lakes Fluvisols predominate (Schultz 2000).
The natural vegetation consists of savannah-type and deciduous vegetation on the Rift floor and the lower slope and afromontane forests on the upper slope and the highlands (Westphal 1975). Agriculture is mainly rain fed and dominated by mixed systems with both crop and livestock (Getahun 1978).
The basin of Lake Abaya is composed of the larger northern subbasin and the smaller southern subbasin. In the northern subbasin maximum water depth totals 26 m (Bekele 2001; Figure 1), while the southern subbasin is even more shallow and has a maximum water depth of 14 m (Gebremariam et al. 2004). Both subbasins are separated by a bottleneck of about 8 km width and a maximum depth of 12 m. In the following explanations focus will be on this bottleneck (Figure 2).

3 Methods

During two field-campaigns in March and August 2002 a total of 238 sediment samples have been extracted with a grab-sampler from the lake floor along transects. The area of interest covers the central part of Lake Abaya, the bottleneck between its northern and southern basin.
Altogether, eight transects with a displacement of about one kilometer have been placed in northwest-southeast direction with increased density of sampling around the delta regions of incoming tributaries (Figure 2). In situ texture classes of the samples were estimated using finger-test (Bodenkundliche Kartieranleitung 1995). After standard sample-processing (air-drying, homogenizing) the sediment's colour was quantified by means of the spectrometer CM2500d (Minolta) in the CIE-L*a*b-colour-system.

Magnetic susceptibility was measured with a MS2B (Bartington Instruments). Total as well as inorganic carbon content was analyzed with a carmhograph (Wösthoff); organic carbon content was calculated as the difference of both values.Based on the numerically scaled characters of the lake floor sediments a cluster analysis was carried out to outline areas of related sediment characters.

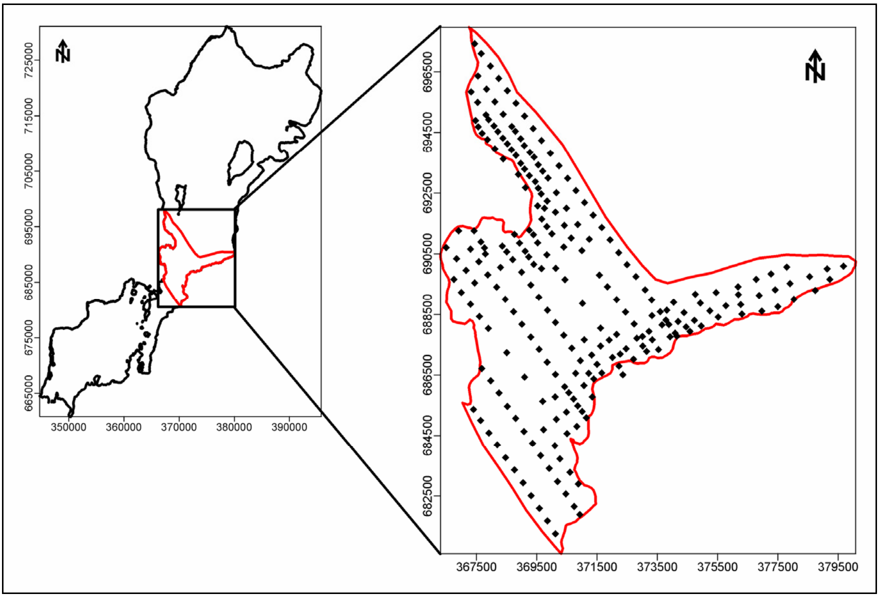

Figure 2 Investigated area of Lake Abaya and spatial distribution of sampling points.

4 Results

Grain size distribution

Grain size of lake floor sediments extracted from the Lake Abaya bottleneck shows distinctly coarser fractions in the litoral zones than in the lake centre. While in the delta areas of Shope and Gelana River lake sediments are of medium to coarse grained sand, in the central part of the lake clays predominate.

Colour

The sediments extracted from the lake-floor are of reddish-brownish to yellowish-brownish colour; this is also reflected by the sediment's a-b-ratio of the CIE-L*a*b-colour-system (Figure 3). Reddish-brownish sediments dominate in the area of the Shope River delta and in the central part of the bottleneck. With change over to the Gelana River delta sediments are characterized by more yellowish-brownish colours.

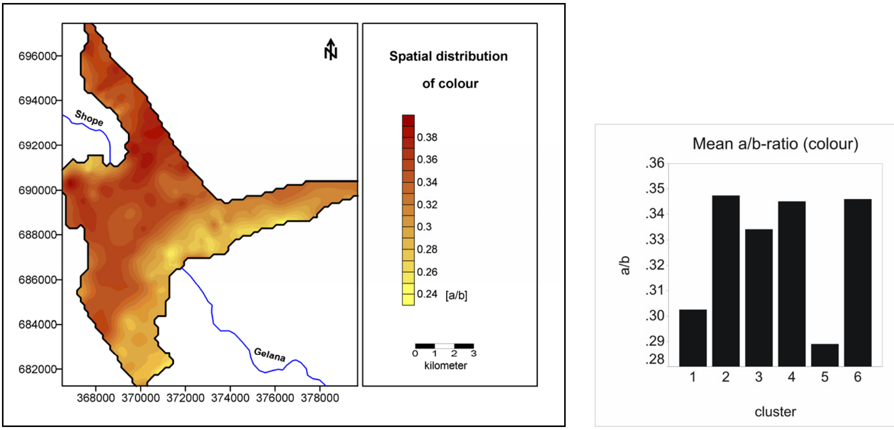

Figure 3 Spatial distribution of a-b-ratio (CIE-L*a*b-colour-system) in the lake floor sediments of the Lake Abaya bottleneck (left) and mean a-b-ratio of colour within the sediment samples for the six clusters differentiated (right).

Magnetic Susceptibility

Values of *magnetic susceptibility* (SI) are conspicuously high in the fluvio-lacustrine sediments from the Shope River delta (Figure 4). With transition from the delta to Lake Abaya bottleneck the values decrease and become lowest in its centre. In the area of the Gelana River delta SI-values of sediments again increase but remain distinctly smaller than in the area of the Shope River delta.

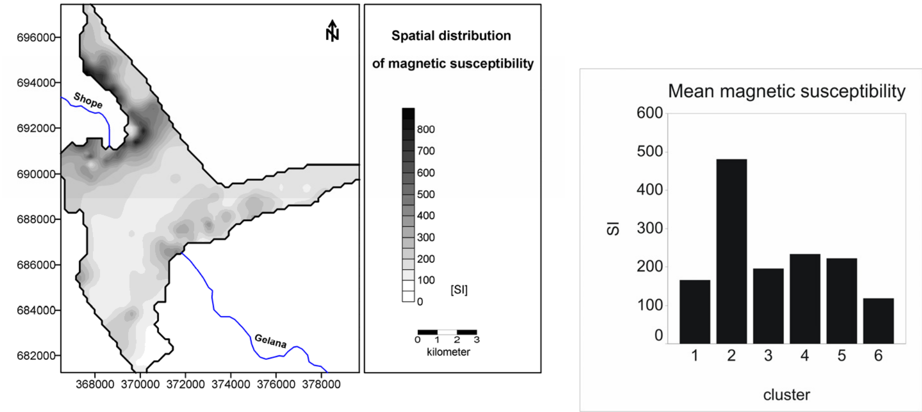

Figure 4 Spatial distribution of magnetic susceptibility in the lake floor sediments of the Lake Abaya bottleneck (left) and mean magnetic susceptibility within the sediment samples for the six clusters differentiated

Carbon contents

Sediments with highest carbon contents were found in the area of the Gelana River delta (3-10 mass-%). In contrast, in the fluvio-lacustrine sediments of the Shope River delta carbon contents oscillate between 0-4 mass-% (Figure 5).
Maximum concentrations of inorganic carbon (>2.5 mass-%) were found in the sediments originating from a small cove south of the Gelana River delta (Figure 6).
The pattern of lake-floor sediments' *organic carbon* concentration shows lower concentrations in the central part of the Lake Abaya bottleneck than in the adjoining delta areas (Figure 7). Comparison of both delta areas points out that in the Shope River delta organic carbon contents of the topset-beds remain below 3 mass-% while in the topset-beds of the Gelana River delta they reach up to 10 mass-%.

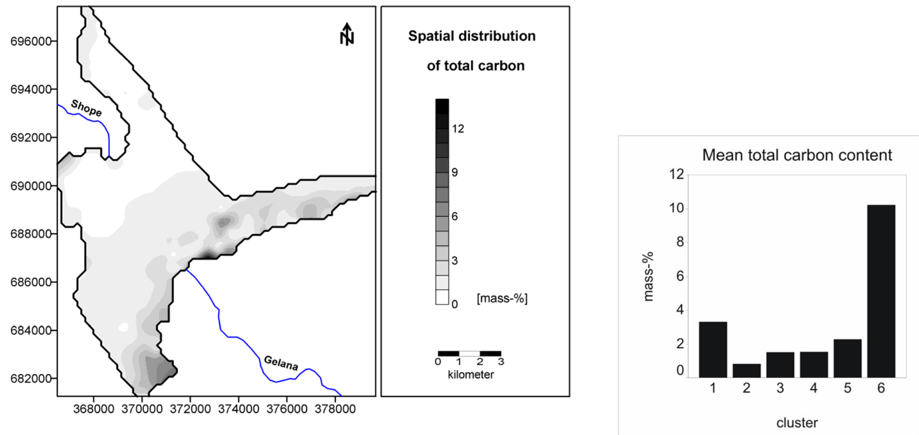

Figure 5 Spatial distribution of total carbon concentrations [mass-%] in the lake floor sediments of the Lake Abaya bottleneck (left) and mean total carbon concentrations [mass-%] within the sediment samples for the six clusters differentiated.

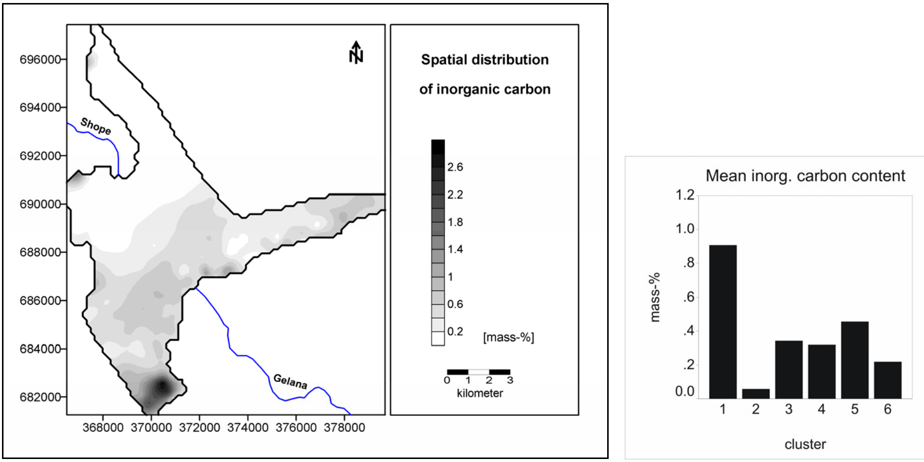

Figure 6 Spatial distribution of inorganic carbon concentrations [mass-%] in the lake floor sediments of the Lake Abaya bottleneck (left) and mean inorganic carbon concentrations [mass-%] within the sediment samples for the six clusters differentiated.

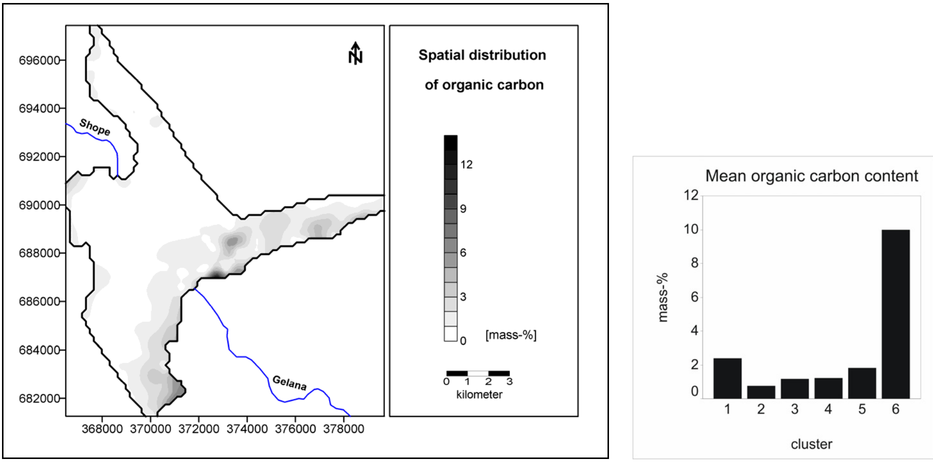

Figure 7 Spatial distribution of organic carbon concentrations [mass-%] in the lake floor sediments of the Lake Abaya bottleneck (left) and mean organic carbon concentrations [mass-%] within the sediment samples for the six clusters differentiated.

5 Discussion

Bulk parameters

The sediment's magnetic susceptibility is affected by its mineralogical and chemical composition. High magnetic susceptibility values are caused by the occurrence of ferromagnetic substances like iron or nickel, while low values are generated by diamagnetic substances, e.g. like bound in calcite or silicates.
Susceptibility series can be described as follows: magnetite > hematite > olivine > biotite > clay minerals > calcite > feldspar > quartz > organic matter > water > kaolinite (Dearing 1994).
Therefore, high magnetic susceptibility values in the topset-beds of the Shope and Gelana River deltas reflect the relatively high concentrations of iron-oxides, quartz and silicates in these areas. However, due to the complexity of susceptibility a significant statistical relationship to single mineral concentrations is lacking. Next to this, the reddish-brownish sediment colours are generally due to the occurrence of hematite (Schwertmann & Lentze 1966). The close statistical relationship between colour and magnetic susceptibility contents in the lake-floor sediments from Lake Abaya bottleneck points out this relationship.

Carbon content

Differences in the sediment's organic carbon content within in the topset-beds of Shope and Gelana River deltas are predominantly due to the local sedimentary architecture of the topset-beds. Topset-beds found can be characterized as clayey, finely laminated, poorly consolidated and high in water content. They are overlying a typical littoral facies, characterized by densely condensed sandy strata with high contents of plant detritals (leaves, roots).
As extraction of undisturbed lacustrine sediments using a coring plumb line in the framework of the superordinate project shows (cf. Krause et al. 2004, Schütt & Thiemann 2004, Schütt et al. 2005) thickness of topset-beds in the Shope and the Gelana River delta differ distinctly.
In the Shope River delta thickness of topset-beds reaches in general more than 50 cm and locally increases up to 80 cm. In contrast, in the Gelana River delta thickness of topset-beds recorded remains below 20 cm. Thus, high concentration of organic carbon in the samples from Gelana River delta is most likely due to a sample mixture by topset-beds with underlying littoral facies and is a consequence of using the grab-sampler for sampling.

Carbon is made available by decomposition of organics (Meyers & Ishiwatari 1993). High water temperature as well as high pH values cause a decrease of the carbonate's solubility product and afford its precipitation (Sonnenfeld 1984). Thus, in shallow water areas like in the coves south of the Shope and Gelana River deltas carbonate precipitation such as calcite is improved by the local environmental conditions, resulting in maximum concentrations of inorganic carbon.

Cluster analysis

The cluster analysis results in six clusters containing between 5 and 93 sampling-points (Figure 8). Each of the clusters derived from the cluster analysis is reflecting the interaction of local depositional conditions and availability of the prevailing substances.
Sampling-points belonging to cluster 1 are predominantly concentrated in the cove south of the Gelana River delta; locations are marked by conspicuously high inorganic carbon contents (Figure 7). Samples involved into cluster 2 are characterized by high SI-values corresponding to a high magnetic susceptibility and are exclusively found around the Shope River delta (Figure 4).

In contrast, samples that are merged in clusters 3 and 4 are broadly scattered and do not show any significant spatial accumulation; these samples are characterised by high concentrations of below-average inorganic carbon contents and above-average a-b-ratios of colour in the CIE-L*a*b-colour-system while the same time also magnetic susceptibility remains average.

Cluster 5 and 6 include exclusively sampling-points which are located in the Gelana River delta; they are labelled by above-average inorganic carbon contents, below-average a-b-ratios of colour in the CIE-L*a*b-colour-system (cluster 5; Figure 3), and above-average concentrations of organic carbon (cluster 6; Figure 7).
Qualitative comparison of texture class distribution with results from cluster analysis points out a close correlation between the occurrence of sandy material and the distribution of clusters 5 (Gelana delta) and 2 (Shope delta).

Summarizing, cluster analysis emphasizes that the spatial pattern of sediment characters in the Lake Abaya bottleneck is highly controlled by local transport and deposition processes (corresponding to local hydrodynamics). However, also the availability of substances as they are provided by the input from the tributaries is reflected by the pattern of lake-floor sediments.

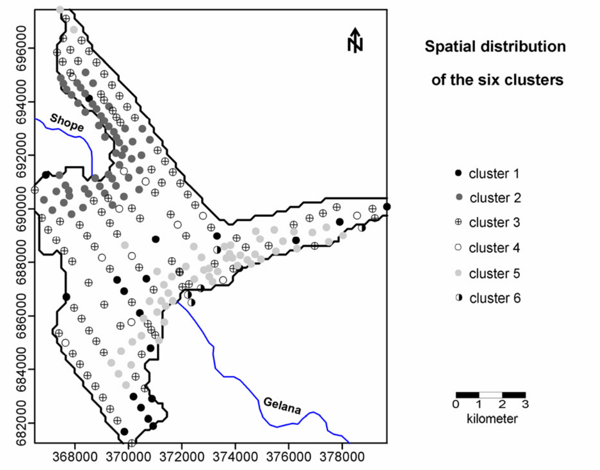

Figure 8 Spatial distribution and classification of sediment samples in consideration of the six clusters for Lake Abaya bottleneck.

6 Conclusion

Distinctly different bulk characters of the lacustrine sediments in the bottleneck of central Lake Abaya indicate imposingly that an interchange between the water bodies of the northern and the southern Lake Abaya basin exists. Sediment characters consulted are less single mineral or chemical element features but spatial patterns and associations of bulk parameters. Altogether, three different depositional sections can be identified within the Lake Abaya bottleneck:

The spatial distribution of sediments in the (1) Shope River delta and (2) Gelana River delta is dominated by currents of entering rivers and correspond to typical fluvio-lacustrine facies with topset-beds deposited. (3) Correspondingly, fines deposited in the central part of the Lake Abaya bottleneck are typical pelagic facies (Tucker 1985).
However, the question of difference in thickness of topset-beds in the Shope and Gelana River delta is left unanswered. As it is shown for other delta areas from Lake Abaya, typical topset-beds are most recent deposits and correspond to soil-sediments and their mobilization and final deposition is due to soil erosion processes (cf. Schütt et al. 2002, Schütt & Thiemann 2004).

In the Shope River drainage basin high accessibility causes a high population density – especially along the major traffic routes – and, thus, high land use intensity. Correspondingly, expected soil erodibility in the Shope River drainage basin is high and results in high deposition-rates of topset-beds.

In contrast, accessibility of the Gelana River catchment area is poor as main roads are lacking. In consequence, population density and land use intensity are low, thus, also expected soil erodibility remains relatively low (Lal 1990) – resulting in relatively small input of suspended load into Lake Abaya. Accordingly, it can be confirmed that volume of topset-beds is controlled by the input of suspended load and indicates intensity of soil erosion processes in the hinterland.

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