

Aeolian and fluviolacustrine landforms and prehistoric human occupation on a tectonically influenced floodplain margin, the Méma, central Mali

B. Makaske^{1,*}, E. de Vries², J.A. Tainter³ & R.J. McIntosh⁴

1 Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, the Netherlands.

2 Department of Classical, Near Eastern, and Religious Studies, University of British Columbia, 6253 Northwest Marine Drive, Vancouver, British Columbia V6T 1Z1, Canada.

3 Department of Environment and Society, Utah State University, 5215 Old Main Hill, Logan, Utah 84322-5215, U.S.A.

4 Department of Anthropology, Yale University, 51 Hillhouse Ave., New Haven, Connecticut 06520-8277, U.S.A.

* Corresponding author. Email: bart.makaske@wur.nl

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Abstract

The Méma is a semi-arid region in central Mali with a rich archaeological heritage indicating the former existence of large urban settlements. The archaeological data suggest millennia of occupation history of the Méma preceding relatively sudden abandonment by the 14th or 15th century AD. Population numbers have remained low since then and today's human presence in the area is sparse and largely mobile. Geomorphologically, the Méma can be characterized as a graben hosting various generations of aeolian landforms and (presently mostly dry) interdunal channels and lakes, linked to the neighbouring Inland Niger Delta floodplain. Given this setting, and the variability of the Sahelian climate, climatic contributions to the region's sudden abandonment are likely. A geomorphological survey of the region, and interpretation of the observed geomorphological record in terms of climatic history, aimed at providing a basis for understanding the intensive occupation and subsequent abandonment of the Méma. The results of this study underscore dramatic Holocene climatic variability, leading to the region's present geomorphological diversity, but also suggest that neotectonic movements constitute an important additional cause of regional desiccation. Both may have encouraged prehistoric people to abandon the Méma after a long period of occupation.

Keywords: neotectonics, Méma, Mali, geomorphology, archaeology, palaeoclimatology

Introduction

Since prehistoric times, the wet plains of the Inland Niger Delta in central Mali (Fig. 1) have attracted humans from surrounding arid grounds. Being the most important wetland in the semi-arid Sahel of West Africa, the Inland Delta presently is an area of great economic importance for livestock breeding, rice cultivation and fishing. The rich archaeological heritage of the Inland Delta and its margins demonstrates millennia of human occupation culminating in early urbanization (e.g. Bedaux et al., 1978; McIntosh & McIntosh, 1980, 1981; McIntosh, 1998).

Because of generally subtle relief in the interior of the West African craton, and largely in response to great climatic

changes, the boundaries of the Inland Delta wetlands have shifted over long distances during the Holocene. This especially holds for the northern and western margins where the present wetlands are bounded by the ergs of the southern Sahara and dry alluvial plains dissected by abandoned Niger distributaries (Gallais, 1967; Riser & Petit-Maire, 1986; Ori et al., in press). Holocene climatic variability in this region has had a strong impact on geomorphological processes, with alternation of fluviolacustrine and aeolian phases (Tricart, 1959, 1965; Makaske, 1998).

The landscape on the north-western fringe of the Inland Delta hosts many sites of prehistoric human occupation (Bedaux et al., 1978; Togola & Raimbault, 1991; MacDonald, 1994; Togola, 1996). A particularly interesting area in this

respect is the Méma (Fig. 1). More than a hundred archaeological sites are documented from an area of roughly 40×40 km (De Vries et al., 2005, Apps 3 and 4), but likely many smaller sites still remain to be discovered. The largest sites have impressive dimensions, with surface areas of tens of hectares and rising up to 7 m above the surrounding plains. The surfaces of these mounds are scattered with sherds and other artifacts and presumably largely consist of the remains of dried mud buildings. The giant sites are especially intriguing because of their present-day setting: a desolate, sparsely populated plain, receiving only limited water annually during a short rainy season. The sites seem to testify to conditions substantially better than today, but at present our knowledge of former living conditions in the Méma is scant.

It is obvious that systematic site surveys and excavations are essential to improve our knowledge of the occupational history of this area. However, in order to understand human occupation and apparent abandonment, as well as specific site locations, study of the physical environment and its dynamics is just as important. In this paper, we report the results of a geomorphological survey of the Méma, aimed at providing a basis for future in-depth archaeological research. The main landforms will be described and interpreted as to their genesis, age and climatic conditions of formation. Subsequently, we will pay attention to the tectonic framework and the archaeological record. Finally, the response of prehistoric people to

the dynamic physical environment will be discussed. A detailed account of our work (including an evaluation of previous archaeological research in the Méma) is given in De Vries et al. (2005). In this paper the most important findings are summarized.

This work is of a preliminary nature, as our fieldwork in the Méma has remained limited for security reasons. Since we cannot predict when additional sustained research in the area will be possible, we offer this paper as a small contribution toward understanding the geomorphology and prehistory of an archaeologically important area.

This research in the Méma is a sequel to a palaeogeographical study in the southern Inland Niger Delta (Makaske, 1998), that was conducted within the context of an archaeological survey. One of the aims of this earlier study was to enable interclimatic comparison of deltaic/anastomosing fluvial systems, as to geomorphology, sedimentology and genesis. The much investigated Rhine-Meuse delta in the Netherlands was starting point of this comparative study.

Physiography and climate of the study area

The study area covers roughly 1100 km^2 and is bordered to the north and west by an extensive field of longitudinal dunes (Fig. 2). The southern border of the study area is formed by a horst known as Boulel Ridge, which consists of Tertiary sandstones and their weathering products. The ridge is largely

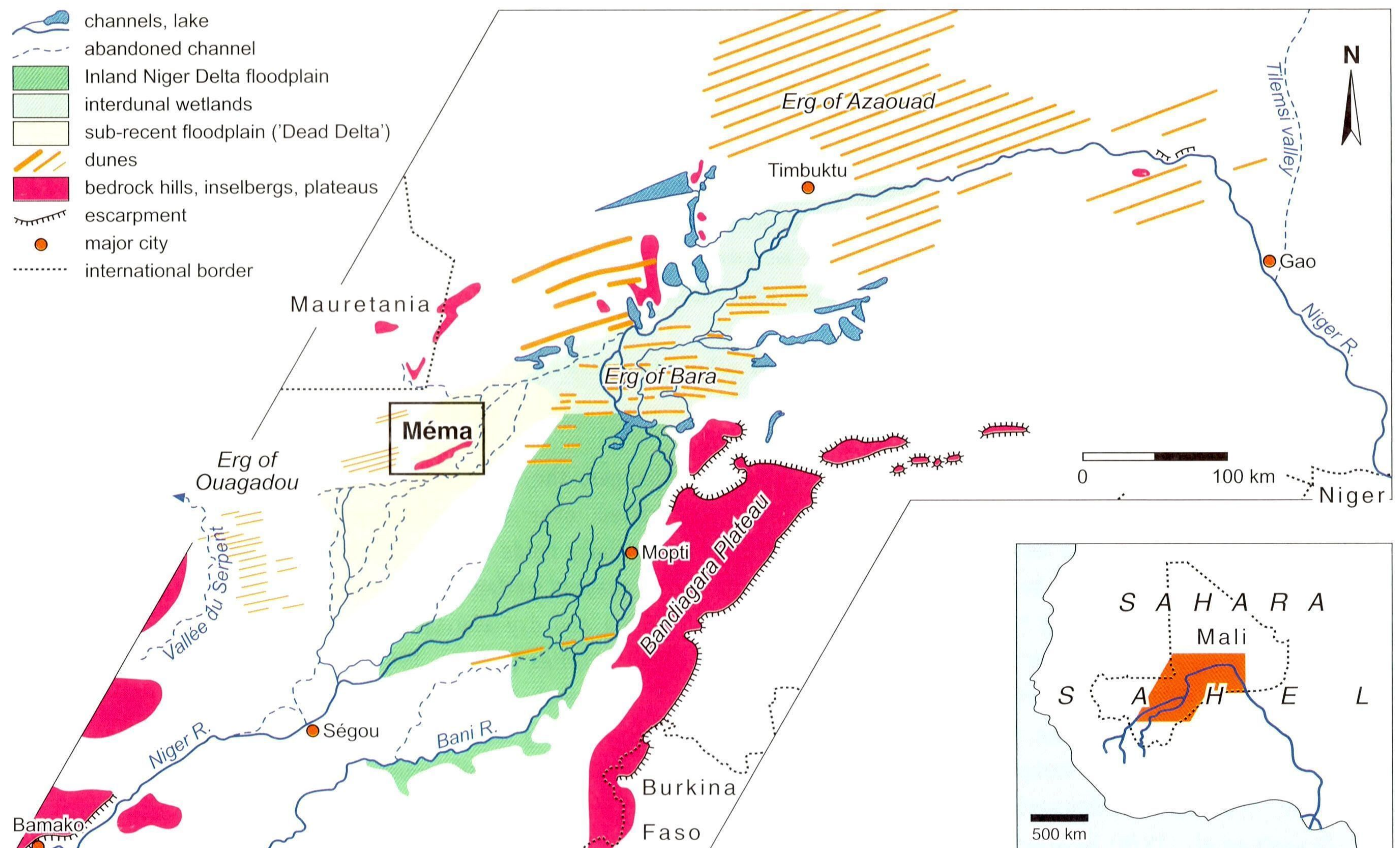


Fig. 1. Map of the Middle Niger region and its main morphological features, showing the location of the Méma. Rectangle indicates location of Fig. 2. The present Inland Niger Delta *sensu stricto* consists of the floodable plains south of the Erg of Bara. Associated interdunal wetlands and dry alluvial plains exist to the north and west.

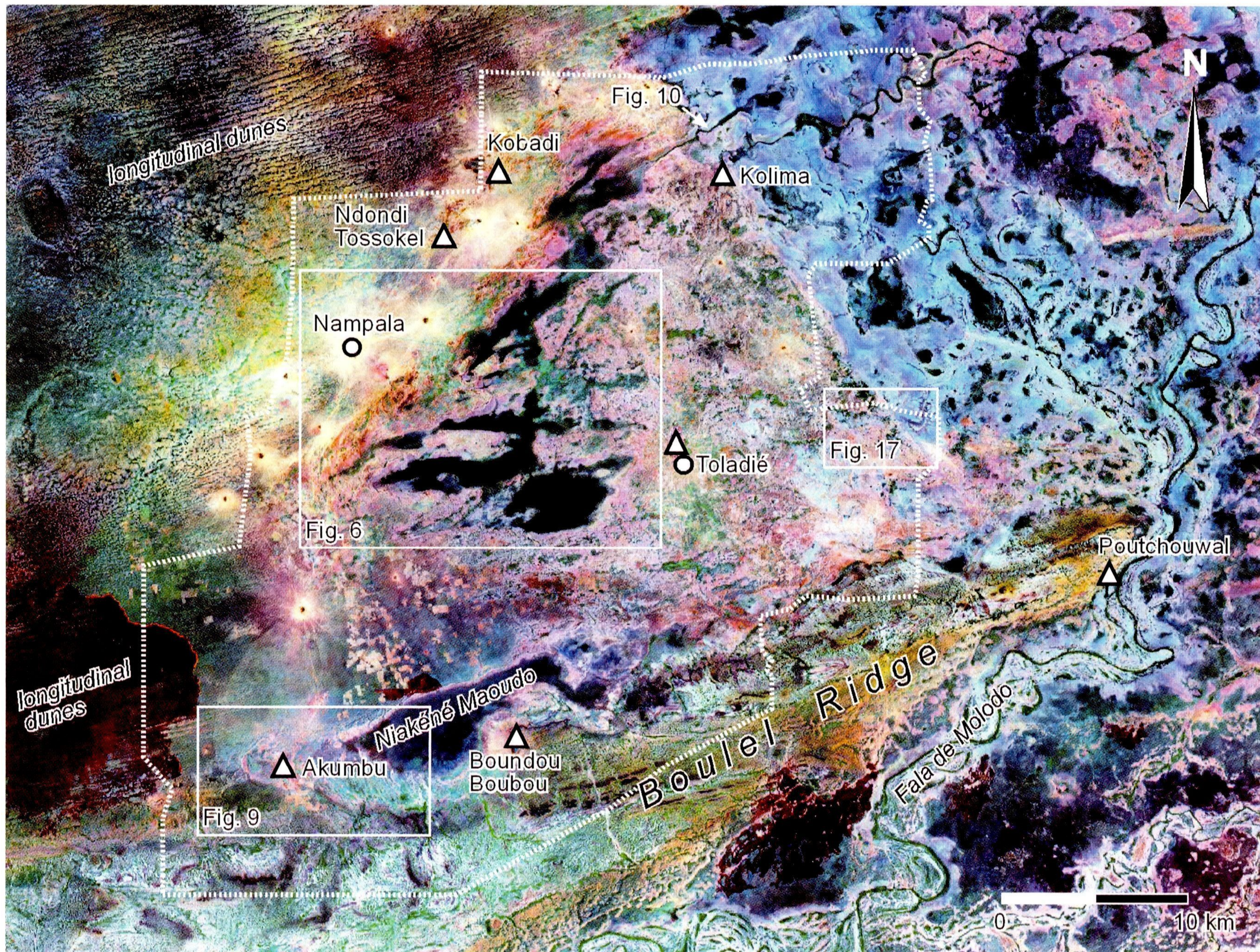


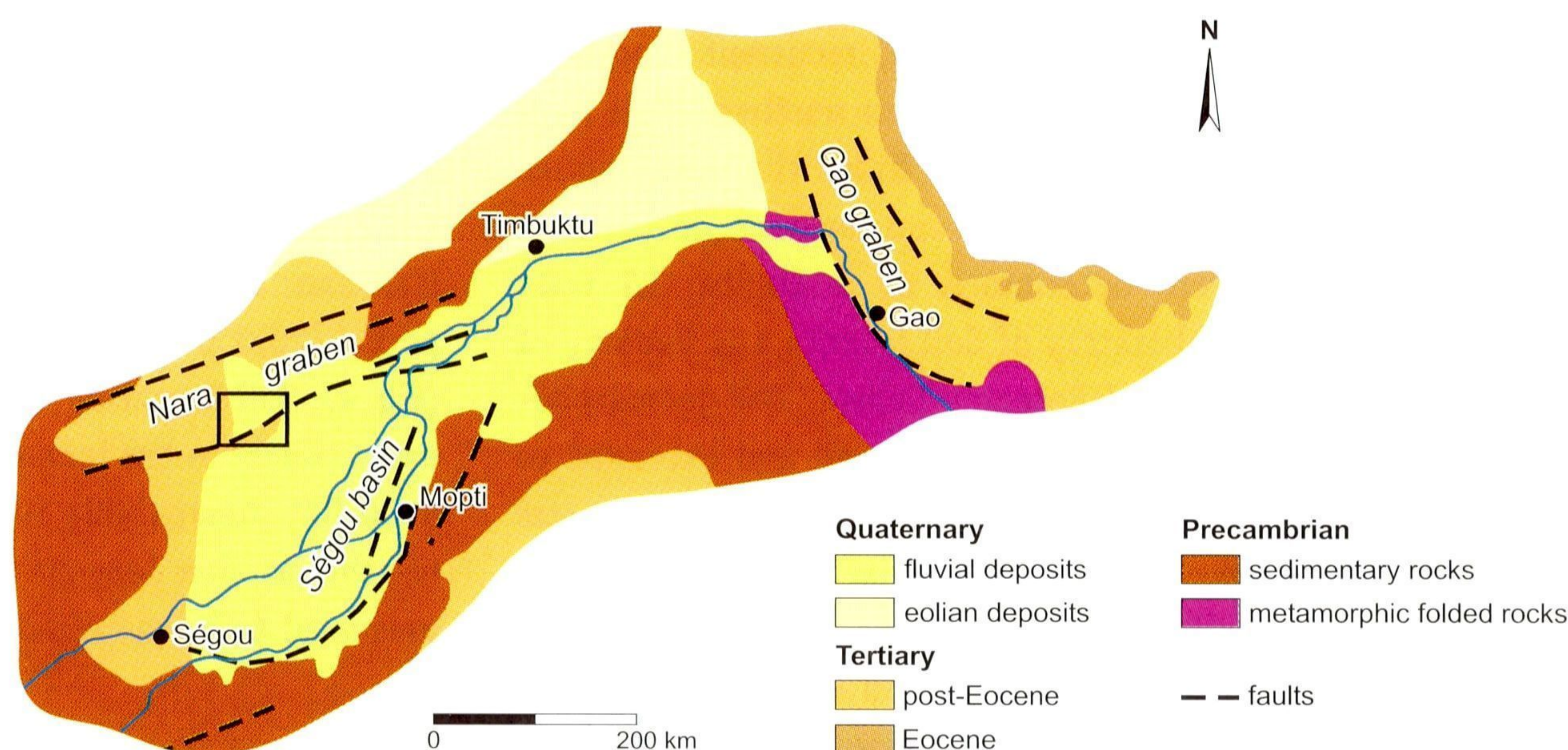
Fig. 2. LANDSAT image of the Méma showing the major physiographic features. Localities and archaeological sites (triangles) mentioned in the text are also indicated, as well as the outline of the geomorphologically mapped study area (dotted line) (Fig. 5) and the locations of Figs 6, 9 and 17.

covered by ferricretes and rises some 40 m above the surrounding plains. Immediately north of Boulel Ridge, the Nara graben underlies the study area (Fig. 3). This graben runs ENE-WSW and is bounded by faults that seem still active.

South of Boulel Ridge runs the Fala de Molodo, an abandoned channel that once fed an extensive floodplain that bounds the study area to the east. The study area is dominated

by a northern chain of connected seasonal interdunal lakes and a single large seasonal lake in the south. The northern chain of lakes is called the Bras de Nampala, and is connected to the floodplain in the east by a narrow channel in the north of study area. A now abandoned channel formerly connected the southern lake, Niakéné Maoudo, with the Fala de Molodo.

Fig. 3. Geological map of the Middle Niger region (after Makaske, 1998). Surficial aeolian deposits are omitted. Rectangle indicates location of Fig. 2.



Presently, the study area has a semi-arid climate, with variable annual precipitation between 300 and 500 mm. Rainfall is concentrated in heavy showers during a wet season that lasts 3 to 4 months (June - September). The dry season is dominated by a north-east trade wind known as the Harmattan. Daily maximum temperatures vary over the year, roughly between 30 and 40° C.

In average years, lakes and channels in the study area only collect water from local rainfall. Niger River waters can reach the Méma in case of extremely high flood levels. The Fala de Molodo is reported to have functioned during extreme Niger floods until its modification in 1932 as a part of the 'Office du Niger' irrigation works (Blanck & Tricart, 1990, p. 311), which are located upstream 50 km south-west of the study area. ORSTOM (1970, p. 19) reported that floodwaters from the Niger may penetrate the area from the east.

Climatic changes that have deeply impacted geomorphological processes and opportunities for human occupation have occurred in the Inland Niger Delta region during the Holocene (Fig. 4). Present climatic conditions can be classified as relatively dry, when compared to early-Holocene and mid-Holocene wet (pluvial) periods. Very dry conditions with large-scale dune formation occurred at the end of the Pleistocene and during the middle Holocene (8000 - 7000 BP). The late Holocene (from ca 4000 BP onwards) is characterized by, on average, semi-arid conditions, although many oscillations have occurred. Under the present semi-arid climatic conditions all aeolian landforms are fixed by vegetation.

Methods

Field data in the study area were collected in January 2000. This included observation and description of the main landforms and collection of sediment samples. Sampling was limited to sediments at the surface and in a few small pits. A geomorphological map was prepared of an area measuring approximately 15 × 12 km surrounding the site of Akumbu, where an archaeological excavation was started. Unfortunately, the fieldwork had to be ended after two weeks (three weeks were planned) when we learned that bandits were approaching the Méma. Since our forced evacuation, recurrent reports of new outbreaks of banditry and killing in northern Mali have kept us from returning to the field to finish the work begun.

After the fieldwork, grain size distributions of thirteen sediment samples were determined by a Coulter LS laser particle sizer at the Laboratory of Soil Science and Geology of Wageningen University and Research Centre. The geomorphological map made in the field was improved and extended to cover the whole study area (~ 40 × 45 km). Mapping was based on stereoscopic analysis of 41 aerial photographs (scale 1 : 50,000, taken in 1975) supplied by the Direction Nationale de la Cartographie et de la Topographie in Bamako. Additional data sources were 1 : 200,000-scaled topographical maps (IGN,

Paris, 1956) and a satellite image (LANDSAT 4/5) from ca 1990. The map was stored in a GIS and published in De Vries et al. (2005). A reduced version of the map is given in Figure 5. This map is a preliminary product, awaiting further ground-truthing in future fieldwork.

Mapped landforms

Massive dunes

In the central part of the study area, very large degraded longitudinal dunes occur, which are termed massive dunes. In spite of degradation and although they are partly covered by younger landforms, an east-west orientation, accentuated by surrounding interdunal lakes, can be recognized (Fig. 6). The degraded dune surfaces show hardly any relief, except for the occurrence of subtle, small-scale transverse dunes that can be recognized on air photos. The massive dune remnants in the study area are on the order of 2 km wide and 10 km long. About 100 km east of the study area, much more intact dunes of comparable dimensions constitute the Erg of Bara (also called Erg of Niafunké) and obstruct the Niger River in the northern Inland Delta (Fig. 1). These dunes are reported to be 5 to 10 m high (Rognon, 1993, p. 50). In the study area, the massive dunes are much lower, but satellite images indicate that they basically represent the same dune field as the dune cordons in the Erg of Bara. Although exact measurements are lacking, the massive dunes are estimated to rise no more than a few metres above the interdunal depressions. In the southern Inland Delta, comparable massive dunes were described by Makaske (1998, pp. 122-123).

The massive dune deposits in the study area are distinctly red in colour, and grain size analysis indicates a relatively fine ($D_{50} \sim 140 \mu\text{m}$) and poorly sorted sand fraction, and significant proportions of clay (6%) and silt (16%) (Fig. 7). This resembles massive dune sediment characteristics reported from the southern Inland Delta (Makaske, 1998, pp. 150-151). The fine component in massive dune deposits probably originates from remote source areas (Maley, 1982). The top of the massive dune deposits underwent soil formation (Fig. 8). The cemented upper soil horizon is relatively erosion-resistant.

Although no absolute age determination of these dunes has been carried out in the Inland Delta region, the red massive dunes are inferred to be of Ogolian age (Rognon, 1993, p. 50; Makaske, 1998, p. 159). The Ogolian period is a hyperarid period (20,000 - 12,500 BP) marking the end of the Pleistocene (Fig. 4). Soil formation in the top of the massive dunes probably dates largely to the long early-Holocene humid period (12,500 - 8000 BP). Comparably well-developed soil profiles are absent in other aeolian deposits in the study area, which are therefore presumed to be more recent.

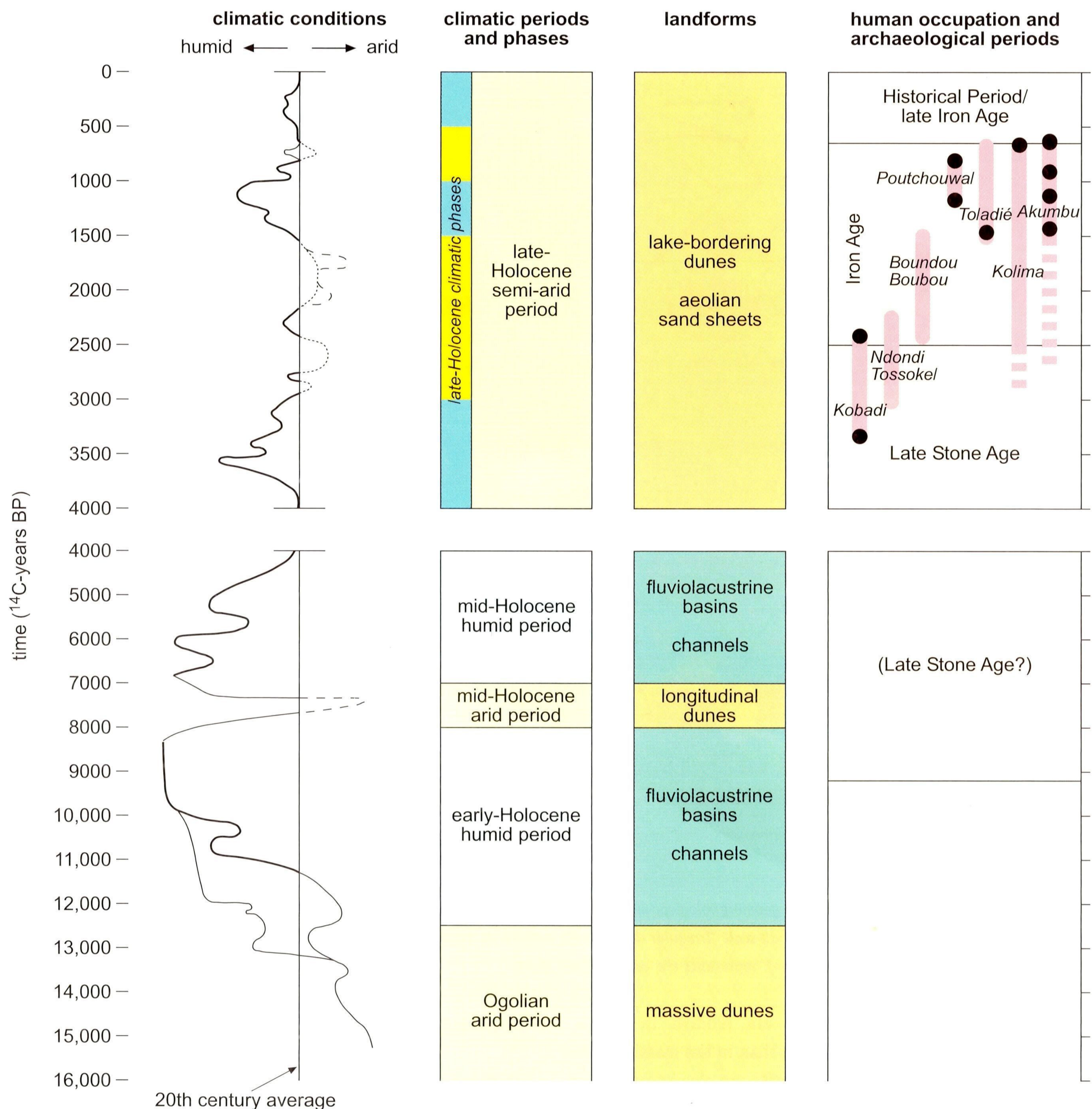


Fig. 4. Late-Pleistocene and Holocene climatic periods in the Inland Niger Delta region, interpreted time periods of formation of landforms described in this paper, and estimated time periods of human occupation of important archaeological sites of the Méma. Black dots represent selected radiocarbon dates of archaeological strata, mentioned in this paper and from Togola (1996) (Akumbu site cluster). No indicators of human presence before ca 4000 BP have been found in the Inland Niger Delta region. Note that in our chronology the late Iron Age, starting approximately the 14th century AD, overlaps with the Historical Period. Graph on the left indicating relative climatic conditions, after McIntosh (1998). Dashed and stippled parts of the curve are less certain in the sense that detailed information about the intensity of the arid conditions indicated is lacking. Double curves indicate the existence of considerable spatial variation in climatic conditions within the Inland Niger Delta region.

Longitudinal dunes

A vast field of straight-crested longitudinal dunes that are much smaller than the massive dunes borders the study area to the west and the north-west (Fig. 2). Individual longitudinal dunes measure 200 to 300 m across and may be tens of kilometres

long. Their orientation is ENE-WSW. They are convex-up in cross-section and, because the narrow interdunal depressions are more densely vegetated than the crests, they clearly stand out on remote sensing images. Generally, they are a few metres high (< 4 m). To the east, these dunes seem to fade out in the study area, in parts gradually being covered by younger landforms.

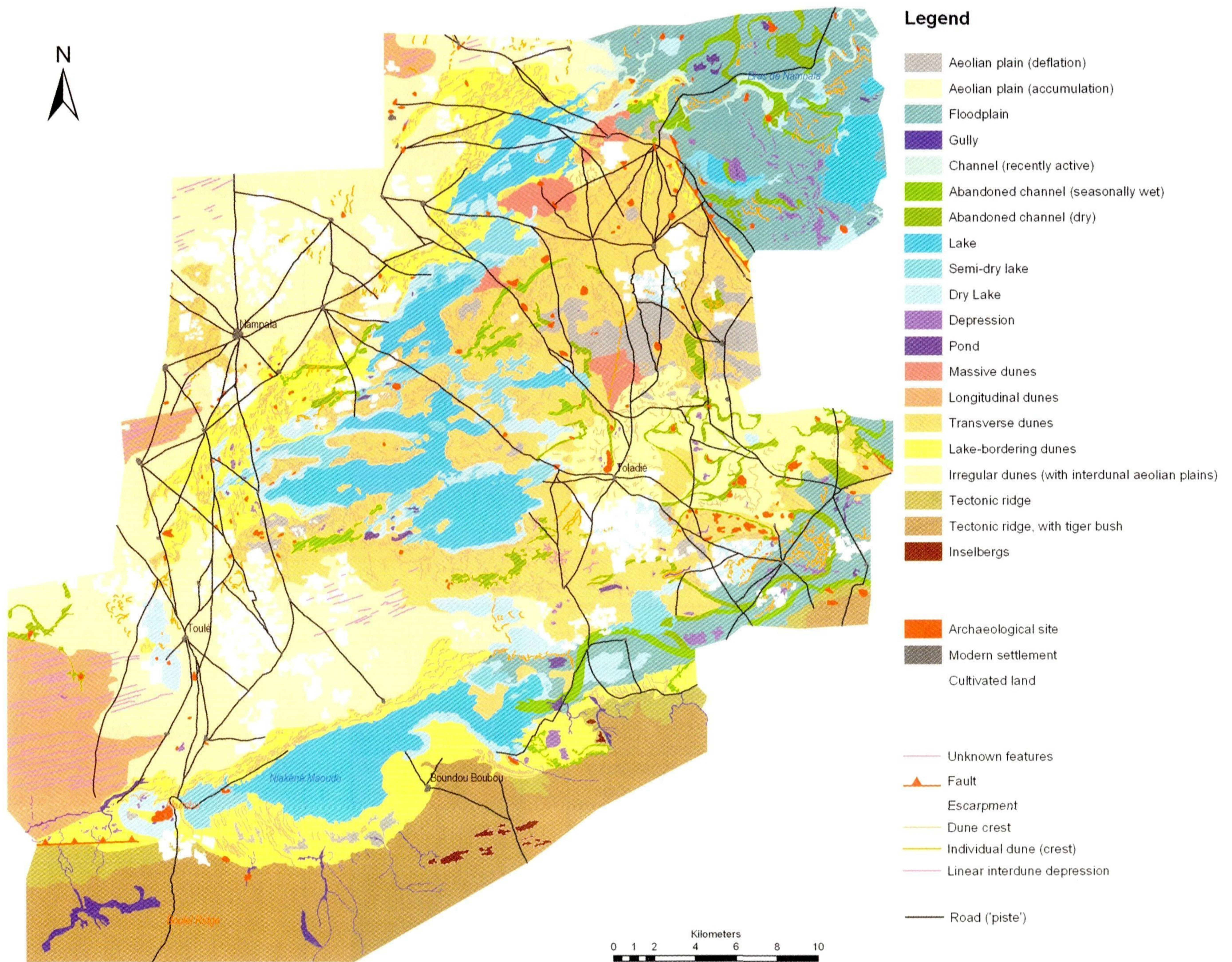


Fig. 5. Reduced version of the preliminary geomorphological map of the Méma published by De Vries et al. (2005). The small-scale 'Transverse dunes' mostly cover massive dune surfaces. The small-scale 'Irregular dunes (with interdunal aeolian plains)' are believed to be superimposed on a desiccated floodplain. The 'Aeolian plain (accumulation)' represents the aeolian sand sheet.

The longitudinal dune deposits are reddish in colour, although the red colour is less intense than in the massive dune deposits. The longitudinal dune deposits are also coarser than the massive dune deposits (Fig. 7) ($D_{50} \sim 200 - 300 \mu\text{m}$), with lower silt and clay content (3% clay and 7% silt). There is hardly any soil formation in the longitudinal dunes, but the sediments at the surface are slightly cemented.

In absence of absolute age determinations, longitudinal dunes of this type are interpreted to have formed in the Inland Delta region during the mid-Holocene arid period (8000 - 7000 BP) (Rognon, 1993, p. 50; Makaske, 1998, p. 163) based on morphological relationships with other landforms. Although relatively short and less severe than the Ogolian dry period (Rognon, 1993), the mid-Holocene arid period has been identified throughout the Sahel (Street & Grove, 1976; Rognon, 1976; Alimen, 1987).

Fluviolacustrine basins

Extensive lacustrine basins exist in the interdunal areas in the northern and central part of the study area (Fig. 6) and on the southern margin along Boulel Ridge (Fig. 9). The northern and central lacustrine basins are connected by relatively narrow gaps in the dune cordons and are linked to the extensive floodplain east of the study area by a channel (Fig. 10). The southern lacustrine basin (called Niakéné Maoudo) is linked to the Fala de Molodo by an abandoned channel. In many places, recent and sub-recent lakeshores are marked by approximately 0.75-m-high beach faces (Fig. 11). At present, the lacustrine basins only collect water from local seasonal rainfall, but the northern lake system is reported to have received floodwaters from the Niger River in the early 1950s (Mauny, 1961, p. 206). There is no supply from groundwater, which is generally 50 m or more below the surface.

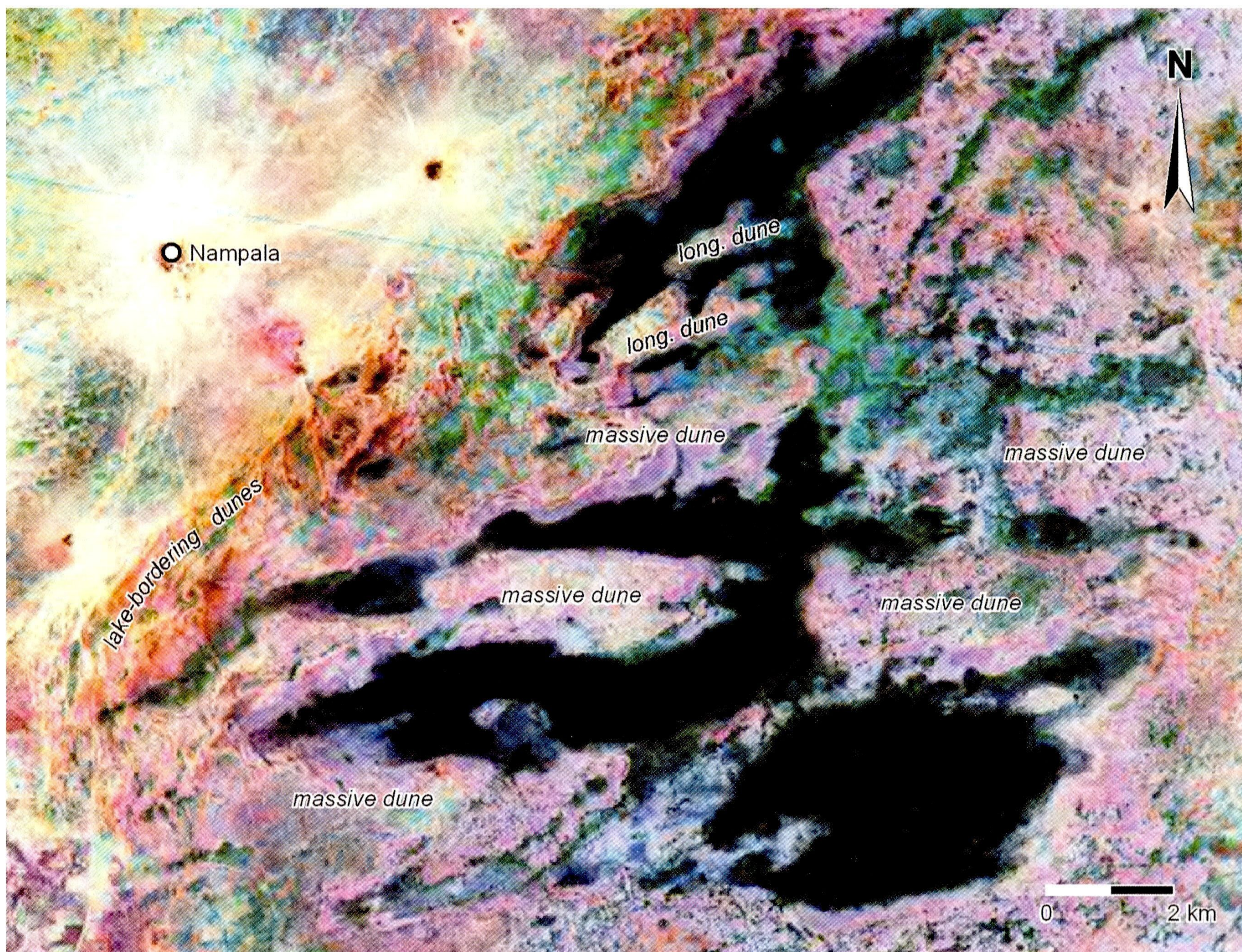


Fig. 6. LANDSAT image of the central part of the study area (see Fig. 2 for location), showing remnants of massive east-west trended dunes, surrounded by lacustrine basins. A field of younger lake-bordering dunes occurs to the west. In the upper part of the image degraded ENE-WSW trended longitudinal dunes occur.

Sediments filling the lacustrine basins are grey to dark-grey in colour and are rich in silt and clay (Fig. 12), although great textural variation exists depending on position within the basin. A sample from the middle of the southern basin Niakéné Maoudo contained 29% clay and 45% silt (Fig. 12, Sample 8). A sample from the margin of the basin, approximately 50 m from the north-western shoreline, contained 18% clay and 24% silt (Sample 9). A third sample from a sub-recent beach nearby contained only 4% clay and 6% silt (Sample 10). This seems to indicate selective transport of sand-sized lacustrine sediments to the lakeshore by wave action. The beach sands have been a source of sediments for the formation of lake-bordering dunes (see next section).

The high clay content of the lacustrine sediments is attributed to fluvial input, which was especially strong during wet climatic periods. The lacustrine basins must have initially formed in response to high Niger flood levels during the early-Holocene humid period (12,500 - 8000 BP). During this period even the nowadays hyperarid central Sahara received significant

precipitation (Petit-Maire et al., 1990), and Niger River channels and lakes extended into the Erg of Azaouad (Fig. 1), for at least 100 km north of Timbuktu (Urvoy, 1942; Riser & Petit-Maire, 1986; Jacobberger, 1988; Rognon, 1993; Ori et al., in press).

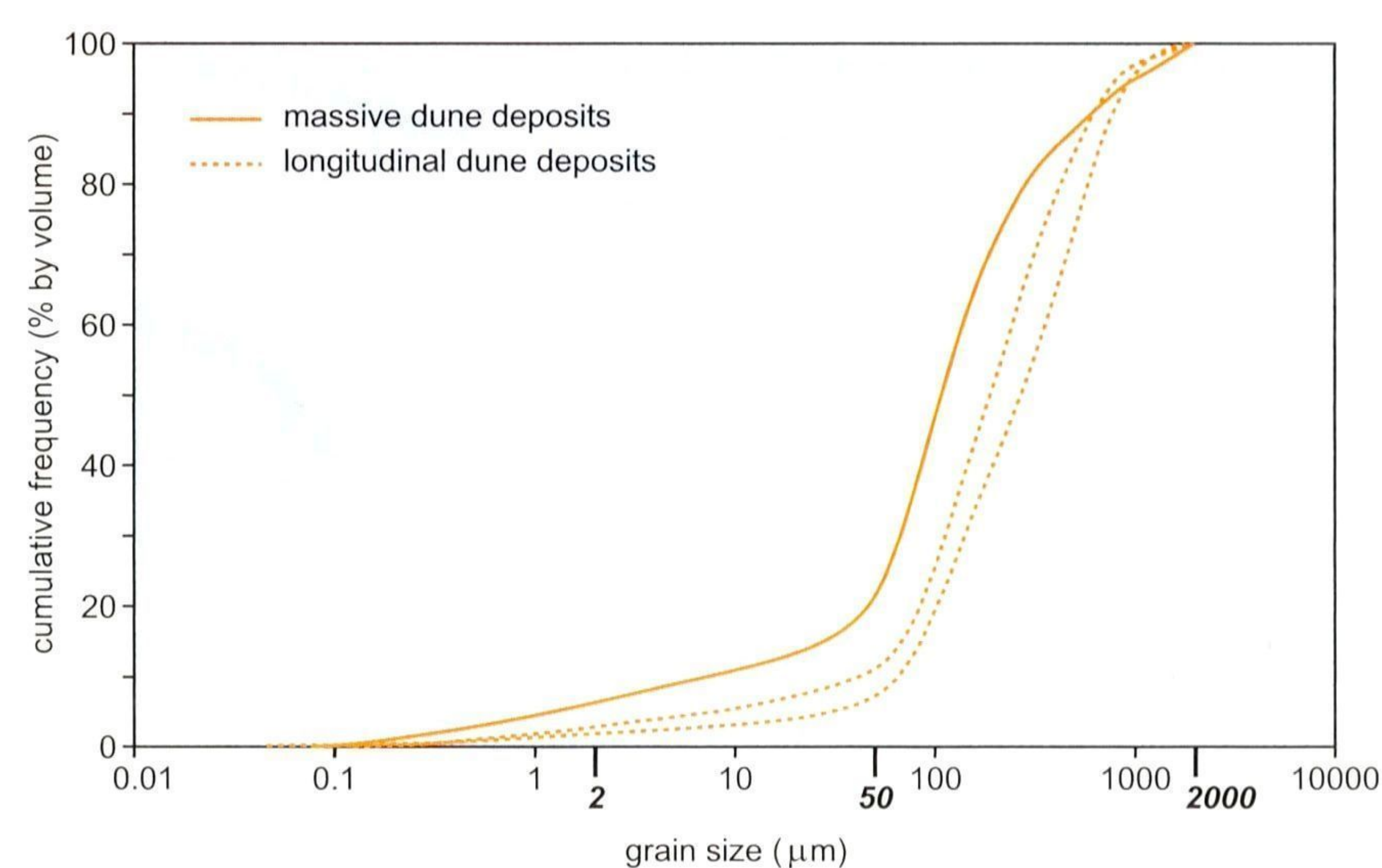


Fig. 7. Cumulative grain size distributions of aeolian deposits from massive and longitudinal dunes.



Fig. 8. Soil profile in massive dune deposits (diameter lens cap 6 cm). Note the dark topsoil (above the lens cap) that seems enriched in organic matter.

The lacustrine basins were (partly) restored in the mid-Holocene humid period after aeolian degradation during the mid-Holocene arid period. Probably, the early-Holocene lacustrine basins extended further to the west than the mid-Holocene basins,

and are presently partly covered by longitudinal dunes. Since the middle Holocene, the lacustrine basins are believed to have shrunk further, in response to late-Holocene aridification. Near the town of Nampala (Fig. 2), west of the present lacustrine basins, we observed a 90-cm-thick package of light-grey to dark-grey clayey/silty deposits, which we interpreted as early to mid-Holocene lacustrine deposits (Fig. 13).

Lake-bordering dunes and aeolian sand sheets

The western margins of the lacustrine basins are fringed with dunes and aeolian sand sheets, which are described together in this section because they have very similar lithological properties. Most of the dunes are basically transverse dunes, although dune crests tend to more or less parallel (recent and sub-recent) lakeshores. In some places parabolic shapes occur as well. These dunes are mostly 0.5 to 2 metres high, although in some places isolated higher (~ 5 m) lake-bordering dunes occur. An exceptionally high (~ 25 m) lake-bordering dune occurs on the extreme western end of Niakéné Maoudo. Lake-bordering dunes have strongly variable dimensions, typically measuring a few tens to more than a hundred metres across and a few hundred metres to more than a kilometre in the longitudinal direction. In some places, dunes of this type also border floodplain areas with abandoned channels. These dunes would be better termed aeolian river dunes, but for simplicity we apply the name lake-bordering dunes to these dunes also.

West of the present lacustrine basins, large areas can be classified as aeolian plains. These slightly undulating areas are covered with an aeolian sand sheet (Fig. 14). Locally, the sand sheet is absent and grey fluviolacustrine deposits or red massive dune deposits with palaeosoils are exposed. In this area isolated complexes of lake-bordering dunes occur, marking the position of former lakeshores. The relief of the aeolian sand sheets is partly determined by the topography of the underlying longitudinal dunes. To the west, the sand sheet gradually thins and the longitudinal dunes are exposed.

Fig. 9. Detail from the geomorphological map of De Vries et al. (2005), (see Fig. 2 for location) showing the western end of the Niakéné Maoudo lacustrine basin, with the archaeological site of Akumbu, lake bottom associated with various lake stages (blue colours), and lake-bordering dunes marking successive positions of the shoreline. The map also shows some land-use and vegetation features such as modern cultivated fields and the extent of tiger bush on Boulel Ridge (indicated by subtle difference in colour explained in lower left corner).

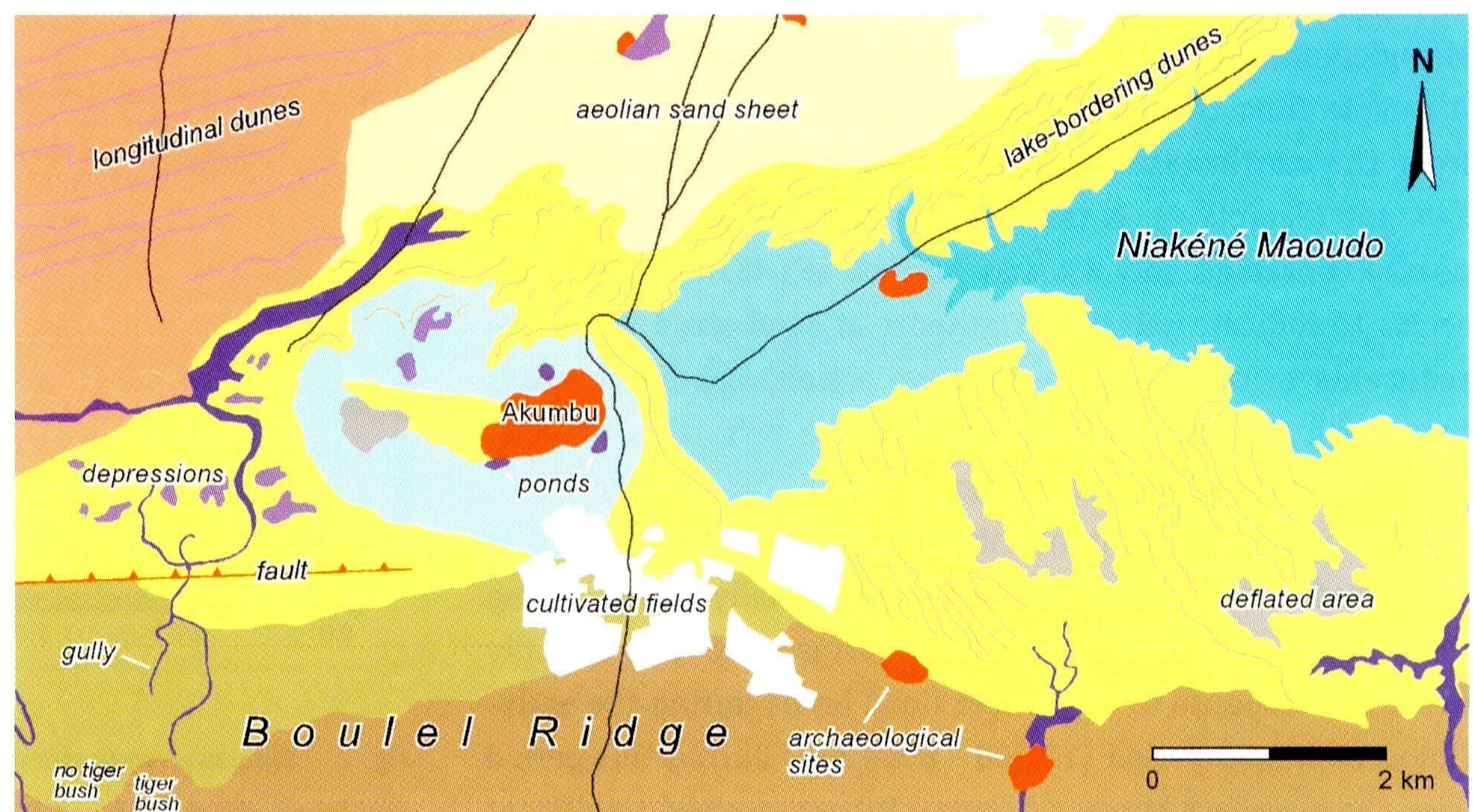




Fig. 10. Channel in the north of the study area (Fig. 2), connecting the interdunal lake system to the Fala de Molodo floodplain. Trees grow on the banks, but not on the bed, indicating that the channel has carried water recently. The channel is approximately 100 m wide and 1 m deep.

Lake-bordering dune deposits and aeolian sheet sands generally are yellow, and have low proportions of silt (~ 3 - 4%) and clay (~ 1 - 3%) (Fig. 15). These deposits have variable texture, but they may be significantly coarser than longitudinal and massive dune sands (D_{50} 180 - 400 μm). The sands are loose and traces of soil formation are lacking.

This lithological immaturity suggests that the deposits are relatively young, and largely postdate the mid-Holocene humid period. Beaches will have been a source of sand for the formation of the lake-bordering dunes. These dunes probably formed during humid phases of the late-Holocene period, under conditions of high lake-levels and continuous sand transport to the beach by wave action. Because the landscape was well vegetated during these humid phases, the lake-bordering dunes could not wander far inland. Some very high lake-bordering dunes consist of more reddish deposits and are hypothesized to be older and to have experienced wet conditions during the humid mid-Holocene period. Like the lake-bordering dunes, the aeolian sheet sands also exclusively occur west of the lacustrine basins and gradually thin in a westerly direction. This suggests that the sandy lakeshores were a prime sediment source for these deposits. It is conjectured that during the relatively dry late-Holocene phases, degradation of the lake-bordering dunes took place, with redistribution of lake-bordering dune sands over large,

scarcely vegetated areas. The Late-Pleistocene cover sands in north-western Europe (Koster, 1988, 2005) more or less represent a periglacial counterpart of this sedimentary unit.

Other landforms

Several other landforms were mapped, but not systematically studied in the field. These include small-scale (mostly a few decimetres high) irregular dunes that have no preferred pattern or orientation, and transverse dunes that almost exclusively occur on the old massive dune complexes. Some aeolian plains seem the result of erosion rather than accumulation and were mapped as deflated areas. Some large deflated areas occur in the east-central part of the study area. Channels and floodplains predominantly occur in the eastern part of the study area and penetrate the area from the Fala de Molodo floodplain. Channels also are abundant around and east of Toladié (Fig. 2), in an area that was mapped as a plain with irregular dunes. Irregular dune formation here probably represents late-Holocene degradation of a desiccated floodplain (with dune irregularity reflecting influence of underlying floodplain morphology), but this interpretation awaits ground-truthing. Small depressions and ponds of variable origin can be found all across the study area. They may be anthropogenic clay pits, interdunal depressions, abandoned channel segments or parts of floodbasins.



Fig 11. Shoreline of the dry lake Niakéné Maoudo (lake bottom on foreground and on the left). Sandy beach deposits in the middle of the photo were a major source of sediment for the formation of lake-bordering dunes (on the right).

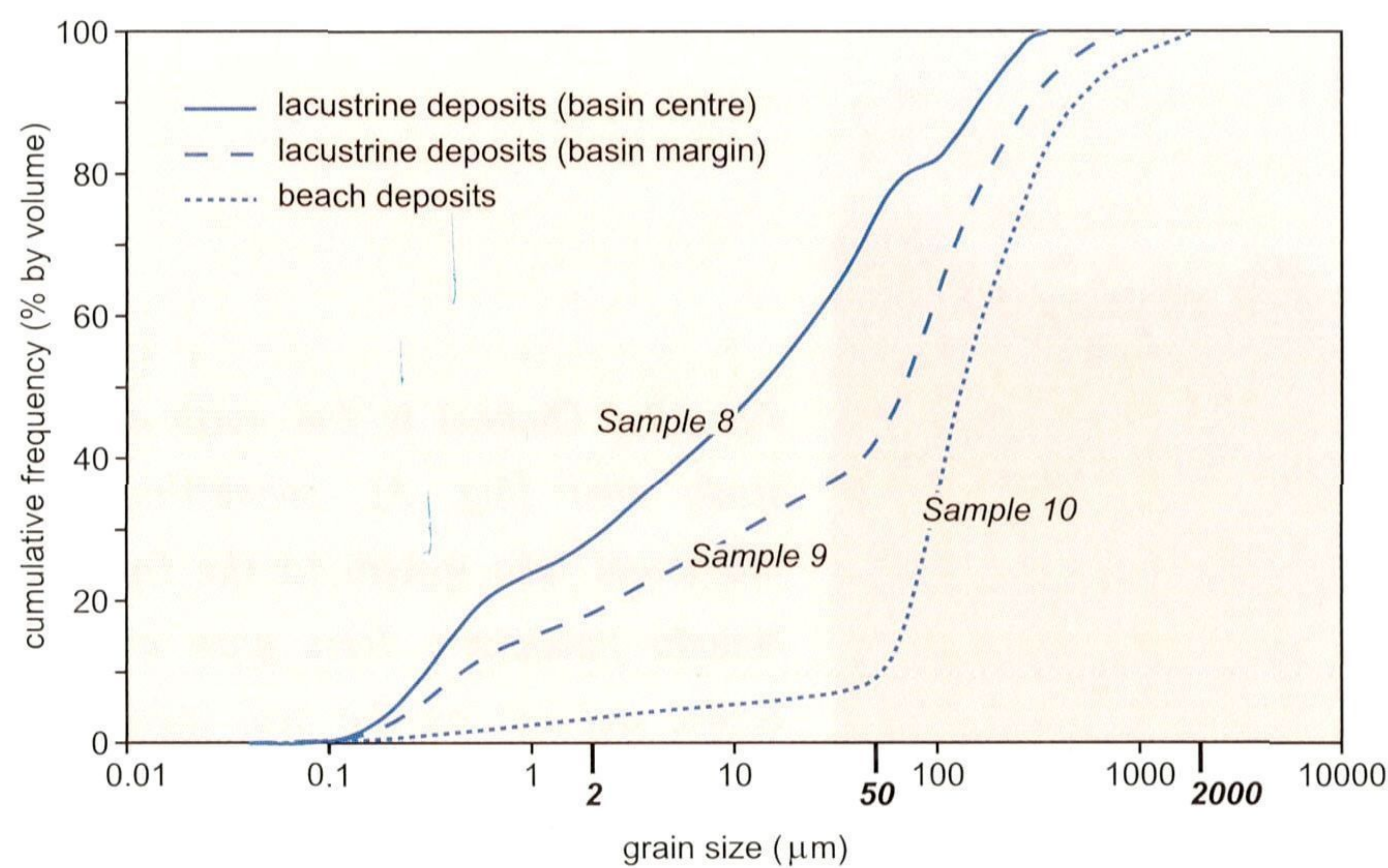


Fig. 12. Cumulative grain size distributions of lacustrine and beach deposits.

The tectonic framework

On the geomorphological map only a few fault segments that have a geomorphological expression are indicated. Based on field observations, distribution of mapped landforms, and literature, a number of faults are inferred that influenced the geomorphological evolution of the study area.



Fig. 13. Light-grey lacustrine deposits grading upward into dark-grey lacustrine deposits, exposed in a pit near Nampala (Fig. 2). Knife measures 23 cm.

The most pronounced fault runs NW-SE through the eastern part of the study area (Fig. 16, fault a) and separates the Fala de Molodo floodplain in the east from higher, mainly aeolian, grounds in the west. Since the fault clearly stands out geomorphologically, tectonic movements probably have taken place fairly recently, and may continue today. The relative uplift to the south-west of the fault severed channels and lakes in the study area from the Fala de Molodo, and strengthened processes of desiccation, resulting in dry lakes and the formation of fields of irregular dunes with deflated areas. Unfortunately, this fault was not studied in the field. The remote sensing images suggest a clear step in the terrain, but altitude points on the topographic map do not indicate significant differences in elevation. Given this, we do not expect step height to exceed one metre. Nevertheless, this fault has had great impact on geomorphological evolution (e.g. Fig. 17).

While the southern boundary fault of Boulel Ridge (Fig. 16, fault b) was first described quite recently by Blanck & Tricart (1990), the northern boundary fault (c) was already known as the southern fault of the Nara graben (DNGM, 1987, fig. 3). This fault approximately follows the boundary between the old ferricreted surface of Boulel Ridge and the recent aeolian and fluviolacustrine landforms. In the eastern part of the study area, south-west of the Akumbu site, fault c can be recognized as a clear straight-lined step in the terrain. This step is a few metres high and is dissected by gullies draining the neighbouring parts of the ridge. More to the east, this step disappears below lake-bordering dunes along the southern shore of Niakéné Maoudo.

Based on our geomorphological observations we hypothesize that there is another fault (d) present in the zone immediately north of Boulel Ridge, which runs along the remarkably straight northern shore of Niakéné Maoudo. More to the east, this fault is believed approximately to follow the northern margin of the floodplain of the former feeder channel of Niakéné Maoudo. Further east, in the wide floodplain east of the study area, it cannot be recognized. West of Niakéné Maoudo the interpreted fault d converges with fault c. The area immediately north of Boulel Ridge seems to have experienced greater subsidence than the central part of the study area, which explains the existence of the lacustrine basin Niakéné Maoudo (and the connected elongate floodplain to the east). Unlike the large interdunal lakes in the area, Niakéné Maoudo has an ENE-WSW orientation that cannot be attributed to massive-dune topography.

The archaeological record

Now having sketched the physical environment and its dynamics, what does the archaeological record of the Méma tell us? How did human societies in the deep past deal with the dramatic environmental changes suggested by the geomorphological and palaeoclimatological data? The Méma has



Fig. 14. Loose yellow sand on the aeolian plain north of the Niakéné Maoudo lacustrine basin.

received archaeological attention since the 1930s, with a number of high-quality archaeological expeditions in the 1970s, 1980s and early 1990s. An overview of these is given by McIntosh (2005a). Here, it suffices to highlight some of the most important sites, facts and interpretations that shed light on interactions between prehistoric man and his physical environment. In Fig. 4 a timeframe is given with estimated periods of habitation of the archaeological sites discussed below.

Early human presence in the Méma was recorded at the site of Kobadi (Fig. 2). This site is located on the beach of a palaeolake and consists of an elongate mound (360 × 15 m) rising only 2 m above the former lake bottom. Early investigations in the 1950s yielded much bone (especially fish), ceramics, mortar stones and two bone harpoons (Monod & Mauny, 1957; Mauny, 1967). Later, radiocarbon dates from this Late Stone Age site became available ranging from 3335 ± 100 to 2415 ± 120 BP (the Late Stone Age in the Sahel spans the period 9200 - 2500 BP (Alimen, 1987)), and remains of many aquatic species were recorded: fish (especially Nile perch and

catfish), tortoise, crocodile, hippopotamus and lamantin. Next to these, remains of land animals (including several antelope species) and stone tools, such as points and tiny axes, were collected. The ceramics found had affinities with Stone Age ceramics from the southern Sahara (Azaouad, Fig. 1), and therefore the findings were interpreted to indicate migration of humans into the Méma in response to the progressive desiccation of the southern Sahara (Raimbault & Dutour, 1989).

Five kilometres south-west of Kobadi a cluster of eight small (≤ 1 ha) Late Stone Age sites exists in the aeolian plain. This site cluster is named Ndoni Tossokel (Fig. 2) and is quite different from Kobadi because it has abundant cattle remains. Remains of sheep and goat were found, and terracotta statues of cattle. Mainly based on finds from surface examination MacDonald (1994) interpreted these pastoral sites to date from the period 1300 - 300 BC.

An important Iron Age site cluster is Kolima (Fig. 2) (metallurgy arrived in the Sahel by 2500 BP (Alimen, 1987)), which was excavated in 1930 (described by Mauny (1961)). It consists of at least six sites of which the largest is 7 m high and covers 14 ha. This site cluster is located near the end of an abandoned channel that penetrates a dune area from the Fala de Molodo floodplain in the east. Among the objects collected in the early excavation were pottery, statuettes of horsemen, agate beads, ceramic bed supports and an iron lance (Mauny, 1961). Later, the upper strata of the site were radiocarbon dated at 665 ± 40 BP (Fontes et al., 1991). The extensive early excavation was followed by some smaller excavations (Mauny, 1961; MacDonald, 1994), underscoring that human occupation at Kolima dates back to the Late Stone Age and suggesting variable means of subsistence (fishing, herding and agriculture) by the inhabitants.

An impressive site cluster is Akumbu (Fig. 2), which is located at the western end of the Niakéné Maoudo lacustrine basin. The main site cluster is surrounded by a palaeolake

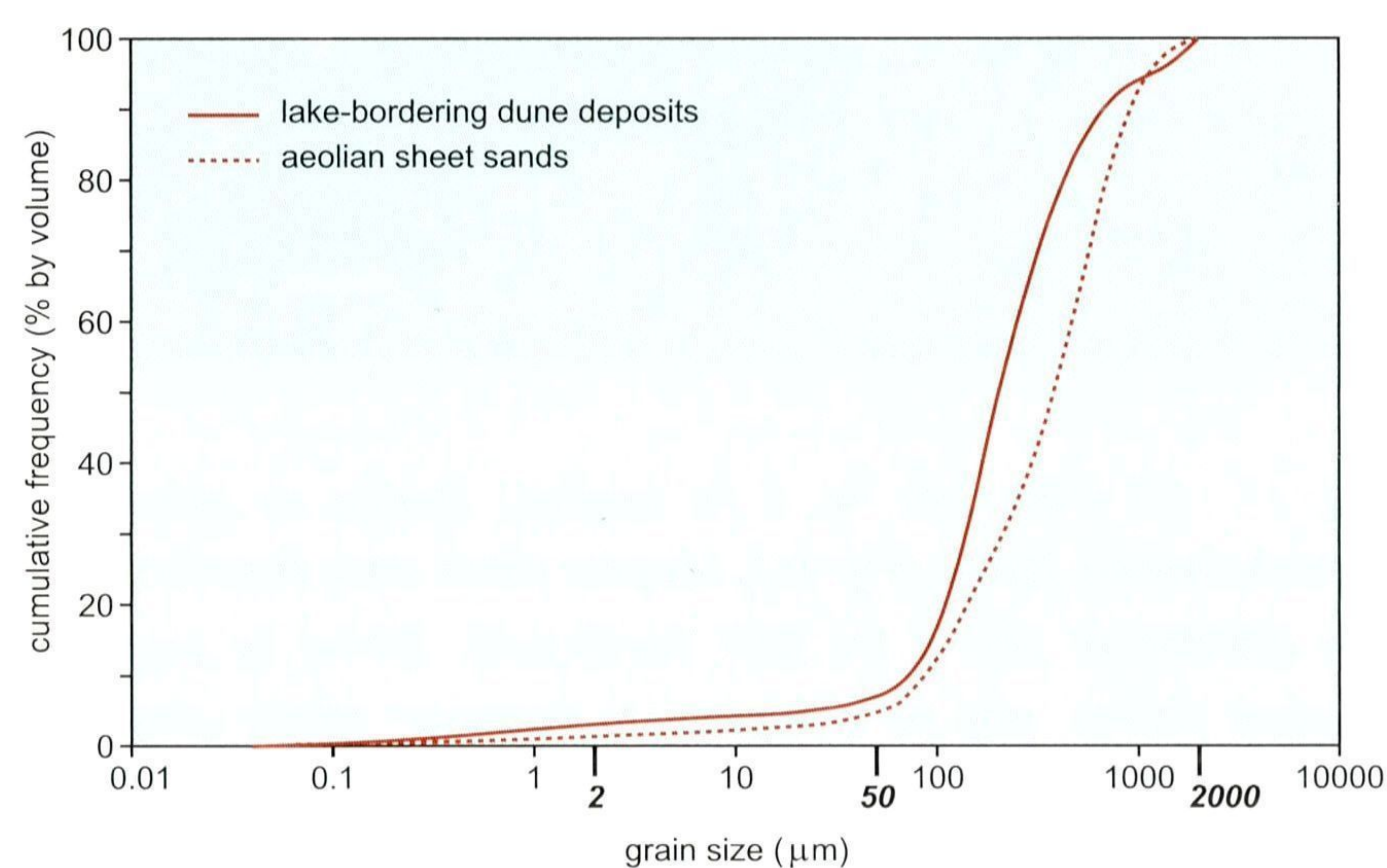


Fig. 15. Cumulative grain size distributions of lake-bordering dune deposits and aeolian sheet sands.

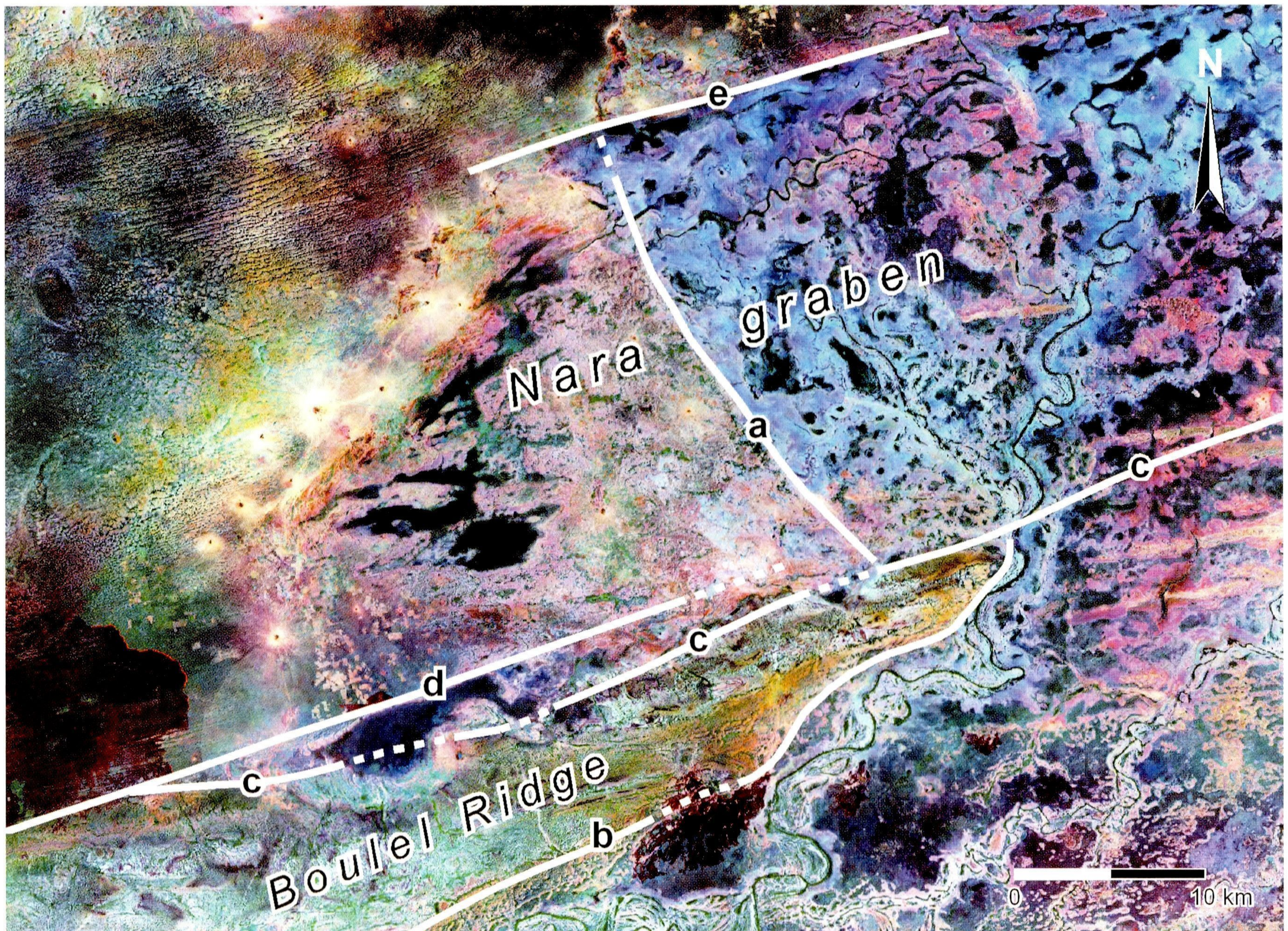


Fig. 16. The tectonic framework of the study area. Faults a, d and e were interpreted in this study from the satellite image and geomorphological observations. Faults b and c were described by Blanck & Tricart (1990) and DNGM (1987, fig. 3), respectively.

bottom that is fringed by lake-bordering dunes (Fig. 9). This cluster consists of eight sites, of which the largest covers 21 ha, while one of the mounds is 7 m high. Despite the impressive size of the site archaeological research at Akumbu has been limited, with excavations having been carried out by Togola (1993). In 2000 an excavation was started by R.J. McIntosh and M. Cisse, as a part of our survey, but had to be aborted. The present archaeological data show that Akumbu predominantly represents Iron Age habitation, with the size of the individual sites and the cluster morphology suggesting an urban settlement (Togola, 1993), analogous to the extensively investigated Jenne-jeno site in the southern Inland Delta (McIntosh & McIntosh, 1980, 1981).

Other remarkable site clusters are Toladié and Boundou Boubou (Fig. 2). Toladié is even bigger than Akumbu, with the main site (out of five) measuring 2 km in length and covering 76 ha. It is located in a desiccated plain with abandoned channels and small-scale irregular dunes. Limited research suggest middle Iron Age habitation, which is supported by one radiocarbon date of 1465 ± 60 BP from the lower strata of the habitation mound (Raimbault, 1986). The Boundou Boubou cluster is remarkable for its extreme number of sites: 31. Most

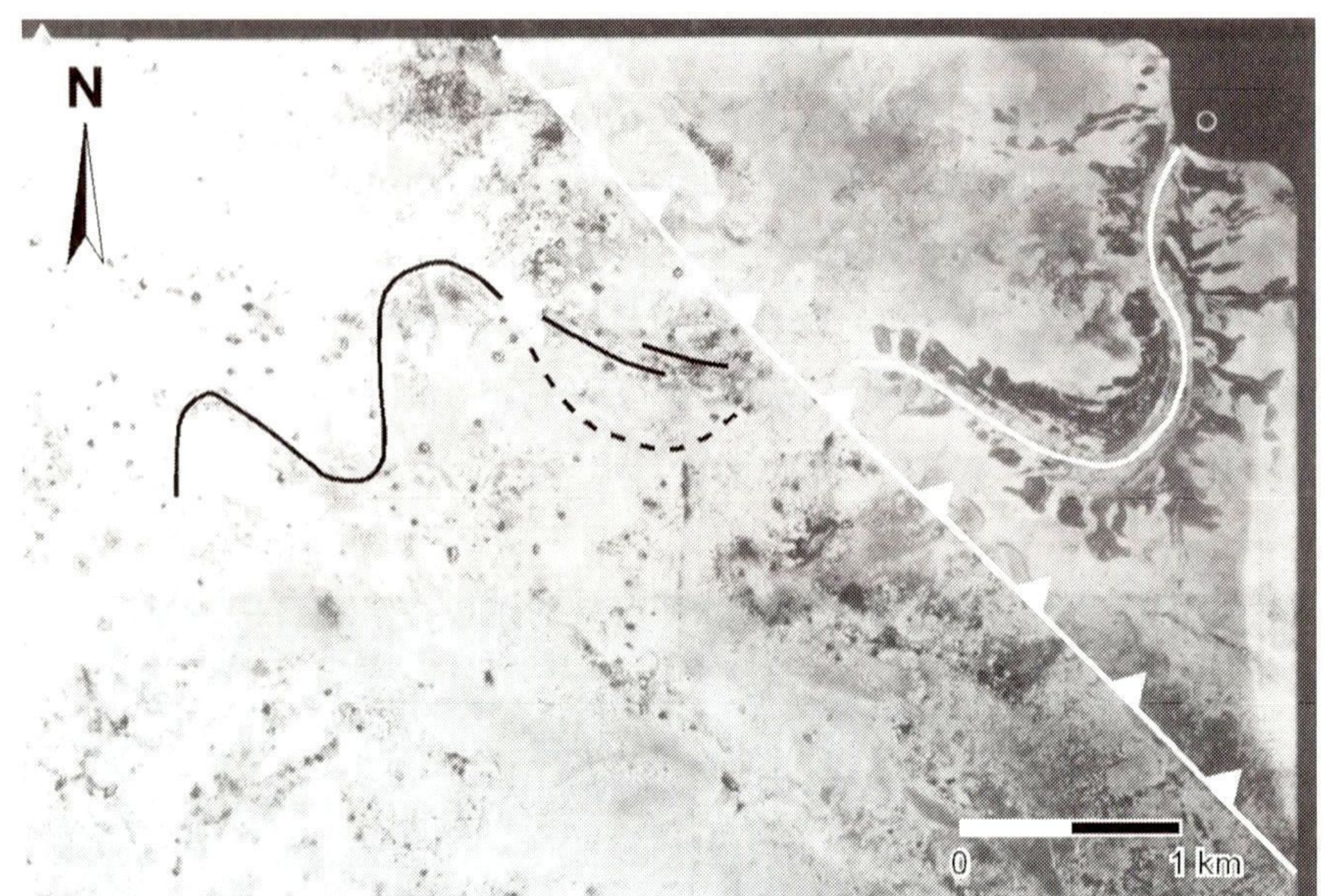


Fig. 17. Air photo (see Fig. 2 for location) showing an abandoned channel crossing fault a (Fig. 16). Irregular levees along the channel on the downthrown side of the fault (north-east), formed by abundant crevasse activity, may be a response to backwater effects caused by vertical differential movements along the fault during channel activity. Degraded channel morphology characterizes the uplifted side of the fault (south-west). Air photo supplied by the Direction Nationale de la Cartographie et de la Topographie, Bamako.

sites are small, covering less than 1 ha. They are scattered on the southern shore of Niakéné Maoudo on the edge of Boulel Ridge. Togola (1993) presumed early Iron Age occupation based on examination of surface finds.

Also worth mentioning, but just outside of our study area, is the site of Poutchouwal (Fig. 2), on the banks of the Fala de Molodo, south of Boulel Ridge. Remains of furnaces and massive slag heaps testify to former iron production. Evidence from excavation of the site indicates industrial-scale iron production during the middle Iron Age (four radiocarbon dates ranging from 1170 ± 90 to 810 ± 60 BP), which is likely to have affected the landscape in the region (Haaland, 1980). Haaland came to the preliminary conclusion that middle Iron Age conditions were wetter than today, and she suggested that large-scale tree-cutting to fuel the furnaces led to serious ecological degradation in the region. These developments may have affected our study area.

Evaluating the archaeological record of the Méma, three aspects are striking:

1. the archaeological record testifies directly (e.g. faunal evidence) and indirectly (the sheer presence of large sites on presently dry lakes and watercourses) to wetter conditions in the past;
2. the archaeological sites tend to cluster, with the largest sites strongly suggestive of prehistoric urbanism;
3. there is no evidence for significant human occupation after the 14th or 15th century AD, until a small reoccupation by Bambara (an ethnic group) farmers after 1591 (Togola, 1993).

It is believed that study of the physical environment and its history will yield clues for a better understanding of these fundamental aspects of the archaeological record of the Méma. In the next section we will discuss the present insights and hypotheses.

Discussion

Variability in geomorphological processes driven by climatic oscillations resulted in a diverse landscape in the Méma, which was attractive for prehistoric people. The mosaic of landforms and soils facilitated various means of subsistence, such as agriculture, cattle herding and fishing, in close proximity. Less diverse landscapes exist to the north and west (extensive dune fields) and to the east and south (mainly floodplains). In this respect, the fact that the Méma hosts many archaeological sites is not surprising.

On the other hand, the period of human occupation since ca 3350 BP (~ 1630 cal yr BC) was characterized by climatic oscillations, with recurrent periods of conditions drier than today (Fig. 4). How did prehistoric people cope with these periods of climatic stress? When trying to answer this question, it should be taken into account that living conditions in the Méma, during previous late-Holocene dry phases may have been less severe than would be expected on the basis of present-day

conditions. Although precipitation in the area was significantly reduced during arid phases, the supply of surface water through the Fala de Molodo may have been better than at present. In the absence of absolute dates, Gallais (1967) believed that this channel was mainly active during his third humid period (the early-Holocene wet period in our chronology), whereas Blanck & Tricart (1990, p. 311) suggested that it still functioned during the Neolithic (Tricart's (1959) Neolithic humid period is comparable to the mid-Holocene humid period in our chronology). At present, the Fala de Molodo is an abandoned channel that is almost totally filled up with suspended load. The timing of its abandonment is unknown, but abandonment in this case is likely to have been a gradual process, induced by: 1) ongoing subsidence of the present Inland Delta and 2) progressively increasing aridity since wet early-Holocene conditions (Makaske, 1998, p. 111).

Indicative of late-Holocene activity of the Fala de Molodo are the aeolian sand sheets in the Méma. These relatively coarse sands are young, lacking traces of mid-Holocene soil formation. The coarse texture (relative to massive and longitudinal dune deposits) fits with the proximity of the sources: the fluviolacustrine basins. The volume of the sand sheet deposits indicates ample fluvial input of sand into the basins, requiring activity of the Fala de Molodo. It is hypothesized that during wet phases in the late Holocene substantial volumes of sand were introduced into the fluviolacustrine basins and transported to the beaches and the lake-bordering dunes, whereas sand sheet formation occurred during arid phases in the late Holocene with degradation of the beaches and lake-bordering dunes.

The response of prehistoric people to these recurrent late-Holocene arid phases is believed to have been specialization, since specific skills and knowledge are needed to sustain subsistence activities under difficult and unpredictable climatic circumstances. Based on the archaeological data, it is proposed that people formed specialized communities of farmers, herders, gatherers, fishers and hunters (McIntosh, 1993). These specialized groups were interdependent, exchanging goods and services. Even today, this pattern of specialized ethnic groups, living as separate communities, persists in the Inland Niger Delta region. The diverse landscape of the Méma, offering multiple means of subsistence, suggests that specialized groups in this area were living in close proximity, and perhaps the clusters of archaeological sites can be explained as traces of interdependent, but separate, specialized communities. It is hypothesized that ever-larger growing clusters gradually evolved into urban centres during the Iron Age (McIntosh, 2005b). In short, this is the course of events that needs to be tested by further archaeological research in the Méma. Linked geomorphological and palaeoclimatic research should shed light on the opportunities for the various subsistence activities in the past.

The work of Togola (1993, 1996) suggests that after millennia of occupation the Méma was rather abruptly abandoned in perhaps the 14th or 15th century AD. This occurred during a phase of variable drought (Fig. 4). It has been logical to link drought and regional abandonment. On the other hand, not only climatic causes should be considered. As pointed out by Tainter (2005), a people's decision to abandon a region in response to environmental stress also depends on social, political and economic factors. Information on these factors may be inferred from the archaeological record, which underscores the need for further archaeological surveys and excavations. In addition, we explicitly need data on the nature of the desiccation leading up to and during the 14th and 15th centuries AD. The geomorphology indicates that neotectonic movements have contributed to regional desiccation.

A fault bounds the higher, predominantly aeolian grounds in the east-central part of the study area from the lower Fala de Molodo floodplain that extends far to the east (Fig. 16, fault a). Some abandoned fluvial channels cross the fault (Fig. 17). Presuming activity of these channels during the wet mid-Holocene period, which seems not unreasonable, formation of significant morphologically visible fault offset should postdate the humid mid-Holocene. Accepting a model of slow synsedimentary neotectonic movements, one could imagine the following course of events. During humid mid-Holocene times fluvial aggradation east of the fault was sufficiently rapid to prevent formation of relief, enabling flood-channels to spill water across the fault into the Méma. In response to late-Holocene aridification and lowering Niger River flood levels, less sediment was transported to these remote parts of the Inland Delta floodplain. Therefore in this period vertical displacement rates along the fault outpaced fluvial aggradation rates east of the fault, giving the fault its present geomorphological expression. Due to this interplay of tectonics and climatic change the largest part of study area gradually became detached hydrologically from the Inland Niger Delta floodplain during the late Holocene. Alternatively, one could equally well propose a model of more abrupt tectonic movements during the late Holocene.

Whether slow or abrupt, neotectonic movements have profoundly influenced the opportunities for human occupation of the Méma. Supply of surface water to all major prehistoric settlements of the Méma relied on channels crossing the fault. Even without completely blocking the channels, the fault controlled the volumes of floodwater that could enter the Méma. Future work in the area should focus on determining the rate and timing of these neotectonic movements.

Conclusions

The Méma region in central Mali is located on the distal margin of the Holocene Inland Niger Delta floodplain. This area rarely receives floodwaters today, but the presence of an abandoned

Niger distributary (the Fala de Molodo) indicates that supply of surface water was much better in the past. The time of abandonment of this channel is unknown, but it probably still functioned in the late Holocene (after 4000 BP).

Late-Pleistocene and Holocene climatic oscillations resulted in alternating dominance of aeolian and fluviolacustrine geomorphological processes, shaping the diverse Méma landscape. Various generations of aeolian landforms can be distinguished by sediment composition, degree of soil formation, size and morphology. The major periods of aeolian activity were the Ogolian (20,000 - 12,500 BP) and mid-Holocene (8000 - 7000 BP) arid periods, and the arid phases of the late-Holocene (4000 BP - present) semi-arid period. Interdunal areas host lacustrine basins, floodplains and channels formed during intervening humid periods and phases. Holocene geomorphological evolution also seems strongly influenced by fault tectonics.

The archaeological record of the Méma suggests intensive Late Stone Age and Iron Age human occupation since ca 3350 BP (~ 1630 cal yr BC), and testifies to prehistoric environmental conditions wetter than today. The size and morphology of a number of archaeological sites suggest urbanization. The absence of signs of significant human occupation after the 14th or 15th century AD indicates abandonment of the Méma, until it was reoccupied after 1591. Various environmental developments (e.g. climatic change, human-induced environmental degradation and abandonment of the Fala de Molodo) can be proposed as a driving force of this abandonment. The present study suggests that neotectonic movements, controlling the amount of surface water that can reach the Méma, are an important factor as well.

Archaeological data suggest that the Méma is an important area in which to study the origins of Sahelian agriculture, metallurgy and urbanism. The apparent attractiveness of the Méma as a settlement location for prehistoric people seems largely determined by its physical environment: a mosaic of landforms and soils facilitating various means of subsistence, such as agriculture, cattle herding and fishing, in close proximity. Repeated drastic changes in the environment during the late Holocene must have profoundly impacted the way of life in prehistoric societies in the Méma, and may have encouraged technical and organizational innovations as well as massive migrations. Further linked archaeological and physical geographical research is needed to obtain a more detailed picture of the relationships between humans and their dynamic physical environment in the deep past.

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