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New considerations on the stratigraphy and environmental context of the oldest (2.34 Ma) Lokalalei archaeological site complex of the Nachukui Formation, West Turkana, northern Kenya Rift

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ABSTRACT

At the northwest end of the Lake Turkana Basin (northern Kenya Rift), intensive fieldwork conducted on the Plio-Pleistocene fluvio-lacustrine Nachukui Formation by the National Museums of Kenya and the West Turkana Archaeological Project (WTAP), led to the discovery of more than 50 archaeological sites aged between 2.4 and 0.7 Ma. Among them is the Lokalalei archaeological site complex, which includes the two oldest archaeological sites (2.34 Ma) found in the Kenyan segment of the East African Rift System. The environmental background of the two sites was described as a succession of ephemeral streams with floodplain palaeosols in which the archaeological sites are situated, bordering the western bank of a large axial meandering river flowing southward. The Lokalalei 1 (LA1) and Lokalalei 2C (LA2C) archaeological sites are of extreme importance in terms of knowledge of hominins' knapping activities. The stratigraphic position of the LA1 and LA2C sites as well as implications on the technical differences between the two sites have been successively discussed by Roche et al. (1999), Brown and Gathogo (2002), and Delagnes and Roche (2005). In terms of stratigraphic position, Lokalalei 2C was estimated to be slightly higher in the section (i.e. younger) than Lokalalei 1. An alternative stratigraphic correlation was proposed by Brown and Gathogo (2002), who suggested that LA2C site should have been approximately 100,000 years younger than LA1.

New considerations on the stratigraphy and environmental context of the Lokalalei sites have been developed following controversy on the stratigraphic position and time interval between the LA1 and LA2C sites. High-resolution lithostratigraphic work based on bed-to-bed field correlations, facies sedimentology and tephra geochemistry confirms that the LA2C site is slightly higher in the section than the LA1 site by about 11.20 m. This represents a time interval of ~74,000 years based on an assumed sedimentation rate of 152 mm/ka. Sedimentary facies analysis indicates that the hominin occupation sites were situated in the vicinity of a lagoon/embayment environment close to the shoreline of an open lake. This lake was part of the broad lake development described across East Africa during the 2.7–2.4 Ma period. Palaeontological data associated with the sites suggest at the LA1 site a lake margin habitat, and at the LA2 sites an habitat with poor and sparse vegetation along channels of an alluvial fan system landward of the lake margin. They also confirm the aridity trend mentioned at the global scale for this period, which is demonstrated in the upper Lokalalei sediment sequence by progradation of an alluvial fan environment over the lake shoreline. Associated conglomeratic deposits could have been the source from

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which the knappers collected their raw materials. In addition, rapid variations from humid to arid episodes in a unique environment such as the East African Rift may have had a major influence in controlling hominin evolution.

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1. Introduction

The East African Rift System (EARS) is an outstanding setting for palaeoanthropological, palaeontological and archaeological investigations of human origins and evolution. Several of the most famous palaeoanthropological and archaeological sites were found in the Afar depression of Ethiopia as well as in the central Kenya Rift (Tugen Hills area) and the Turkana depression of northern Kenya and southern Ethiopia (Leakey et al., 1978; Brown and Feibel, 1986; Hill, 1995, 1999; Roche et al., 1999; Senut et al., 2001; Sawada et al., 2002) (Fig. 1a). In the northern half of the Turkana depression, there occurs several hundreds of metres of sedimentary deposits known as the “Omo Group”. This group comprises three major sedimentary formations: the Shungura Formation along the lower part of the Omo River, the Koobi Fora Formation to the east of the modern Lake Turkana, and the Nachukui Formation to the northwest of the lake (de Heinzelin, 1983; de Heinzelin and Haesaerts, 1983; Brown and Feibel, 1986; Harris et al., 1988; Feibel et al., 1989) (Fig. 1b). These sedimentary deposits have been investigated since the 1970s by several international groups and have yielded abundant skeletal and cultural remains of Plio-Pleistocene hominins (e.g., Arambourg and Coppens, 1967; Leakey and Leakey, 1978; Coppens and Howell, 1985; Feibel et al., 1989; Wood, 1991; Kibunjia, 1994; Roche et al., 1999, 2003; Prat et al., 2003, 2005; Spoor et al., 2007).

On the northwestern shore of Lake Turkana, the 730-m thick pile of fluvio-lacustrine sediments of the Nachukui Formation spans the period 4.35–0.7 Ma (Harris et al., 1988; Feibel, 1997) (Fig. 1b). This formation is of major anthropological importance due to the succession of hominin occupation sites within the time interval 3.5–0.7 Ma (Brown et al., 1985b, 2001; Walker et al., 1986; Leakey et al., 2001; Prat et al., 2003, 2005). Indeed, although the Nachukui Formation led to the discovery of a smaller number of hominin specimens (Prat et al., 2003, 2005) compared to the Koobi Fora and Shungura Formations (Fig. 1b), some of the discoveries have changed the hominin phylogeny. These findings have also provided some important keys to understanding the pattern of skeletal development and locomotor behaviour. Among them,

KNM-WT 15000, the “Turkana Boy” (Brown et al., 1985a; Walker and Leakey, 1993); KNM-WT 17000, the “Black Skull” (Walker et al., 1986) and KNM-WT 40000, the holotype of *Kenyanthropus platyops* (Leakey et al., 2001) deserve special mention.

The Nachukui Formation is also of major archaeological importance. Intensive field work conducted by the National Museums of Kenya (NMK, 1987–1991), and the West Turkana Archaeological Project (WTAP; 1994 onwards, joint project NMK/French *Mission Préhistorique au Kenya*) led to the discovery of more than 50 archaeological sites (Kibunjia et al., 1992; Kibunjia, 1994, 1998; Roche and Kibunjia, 1994, 1996; Roche et al., 1999, 2003; Brugal et al., 2003; Delagnes and Roche, 2005; Delagnes et al., 2006; Texier et al., 2006; Harmand, 2007, 2008). Most of these sites have been test-excavated, and 18 of these extensively excavated. Among them is the Lokalalei site complex, which includes two main archaeological sites and several other sites or localities yielding lithic and/or faunal and hominin remains (Figs. 1c and 2):

- LA1 (03°57'15"N; 35°47'18.3"E) is a large archaeological site, comprising two excavated areas, LA1A and LA1B (Kibunjia, 1994, 1998; Kibunjia et al., 1992).
- LA1 α (03°57'13.4"N; 35°47'18.2"E) is a palaeontological locality which yielded one hominin tooth associated with few other faunal remains (Prat et al., 2005).
- LA1 β (03°56'50"N; 35°47'13"E) is a palaeontological spot.
- LA1-2 (03°56'54"N; 35°46'57"E) is a palaeontological locality corresponding to a large exposure with scattered surface faunal fragments.
- LA2C (03°56'57"N; 35°46'44"E) is a spatially limited archaeological site which has yielded a very rich lithic assemblage associated with 12 mammal species as well as various reptiles and fishes (Roche et al., 1999; Brugal et al., 2003; Delagnes and Roche, 2005; Harmand, 2008). In the close vicinity of LA2C, three other localities with stone artifacts and faunal remains have been identified: LA2A (positive test trench), LA2B (negative test trench; surface items only), and LA2D (no test trench; many stone artifacts scattered on the surface).
- LA3 (03°56'55"N; 35°46'32"E) is a palaeontological locality.

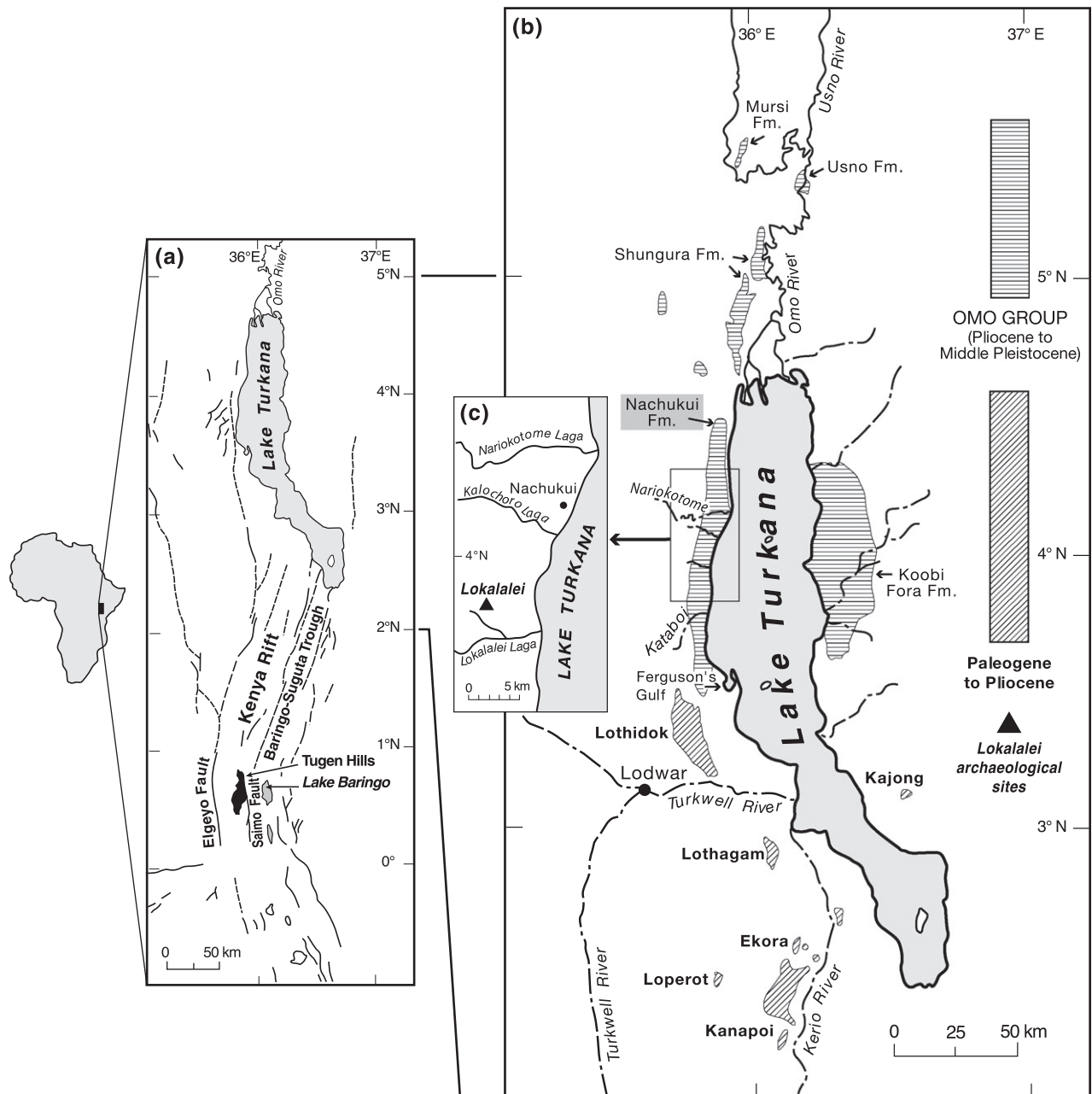


Fig. 1. (a) Location of the major palaeontological and archaeological sites in the central (Tugen Hills) and northern (Turkana) segments of the Kenya Rift (redrawn from Hill, 1999). (b) Regional map of the Lake Turkana Basin, showing areas of outcrop of the Plio-Pleistocene “Omo Group” deposits, that include the Mursi, Usno and Shungura Formations (North Turkana), the Koobi Fora Formation (East Turkana), and the Nachukui Formation (West Turkana). The Paleogene to Pliocene sedimentary deposits associated to rift basins precursors of the present-day Lake Turkana are also shown (redrawn from Feibel et al. (1989) and Morley et al. (1999)). (c) Location of the Lokalalei archaeological sites complex in the Nachukui region.

With an estimated age of 2.34 ± 0.05 Ma, LA1 and LA2C are the two oldest archaeological sites so far within the Kenya Rift (Roche et al., 1999). They are sub-contemporaneous with the Omo sites from the Shungura Formation (Howell et al., 1987; de la Torre, 2004), and the sites from Hadar in the Ethiopian Afar (Kimbel et al., 1996). They all belong to the small number of Plio-Pleistocene localities, of which the Gona sites (2.6 Ma) in the Ethiopian Afar are the oldest (Roche and Tiercelin, 1977, 1980; Semaw et al., 1997, 2003; Semaw, 2000). The study of the Lokalalei assemblages showed unexpected technical skill and evident diversity during the early stages of lithic production (Delagnes and Roche, 2005).

The Lokalalei site complex occurs during one of the most crucial periods of human evolution in terms of archaeological, palaeoenvironmental and palaeoanthropological perspectives. Indeed, this time period corresponds to the beginning of humankind, with the discovery of a few cranial specimens belonging to the genus *Homo*. They are represented by the temporal bone KNM-BC 1, recovered at Chemeron, Kenya, dated 2.4 Ma (Hill et al., 1992; Sherwood et al., 2002); the mandible UR 501 from Uraha, Malawi, ca. 2.45 Ma, allocated to *Homo rudolfensis* (Schrenk et al., 1993; Bromage et al., 1995); the maxilla AL 666-1 from Hadar, Ethiopia, 2.33 ± 0.07 Ma, ascribed to *Homo aff. H. habilis* (Kimbel et al., 1996); and teeth from the Omo Basin, Ethiopia, 2.3–2.4 Ma (Suwa et al., 1996). Indeed, the first lower molar (KNM-WT 42718) discovered at site LA1 α is the oldest occurrence of the genus *Homo* within the Turkana Basin (Prat et al., 2005). It implies that the

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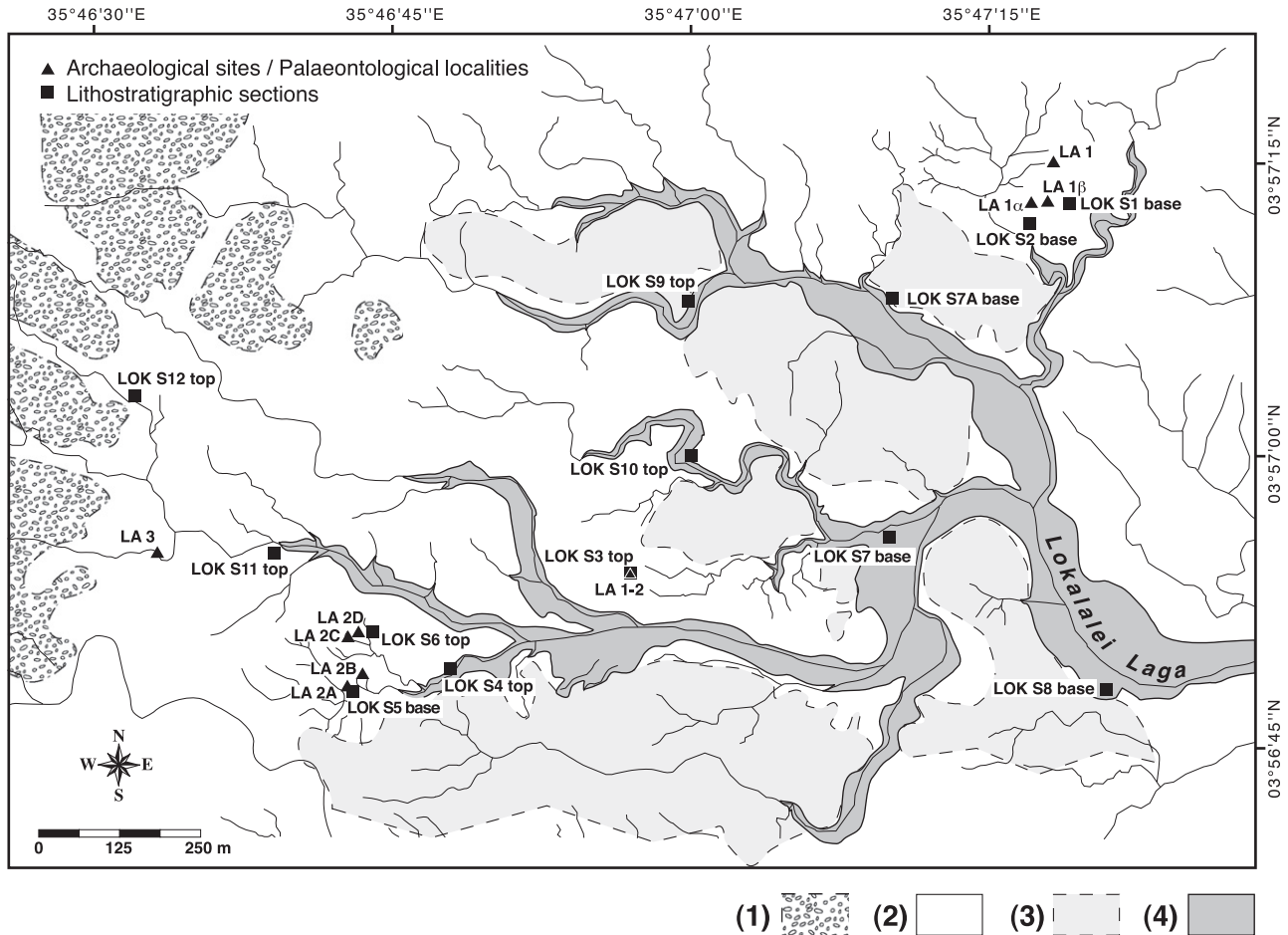


Fig. 2. Location map of the Lokalelei archaeological sites, palaeontological localities, and lithostratigraphic sections established during the 2002, 2005 and 2007 field campaigns. In this area, the early Pleistocene sediments belonging to the Nachukui Formation dip gently at $\sim 10^\circ$ toward the west. The upper topographic surface corresponds to a roughly sub-horizontal pebbly unit (1) with Holocene dated oyster bioherms and microbialite crusts that unconformably overlies either the Nachukui Formation deposits (2) or middle Pleistocene conglomerates (3). Cuts by little gullies (4) adjacent to the main Lokalelei Laga provide few continuous exposures within the Nachukui Formation.

Turkana Basin and particularly its western part, imaged by the Nachukui Formation, was one of the cradles of humanity.

The stratigraphic position of the LA1 and LA2C archaeological sites has been presented by Roche et al. (1999), who estimated Lokalelei 2C to be slightly higher (i.e. younger) in the section than Lokalelei 1. Later, an alternative stratigraphic correlation of the two sites was proposed by Brown and Gathogo (2002). These authors suggested that LA2C site should be placed much higher in the section than assumed by Roche et al. (1999), and therefore this site should have been approximately 100,000 years younger than LA1. The regional and local palaeogeography and palaeoenvironments of the Lokalelei archaeological sites have also been described in a series of publications (e.g., Harris et al., 1988; Brown and Feibel, 1986, 1991; Feibel et al., 1989, 1991; Kibunjia et al., 1992; Rogers et al., 1994; Roche et al., 1999; Haileab et al., 2004; Delagnes and Roche, 2005). In these papers, the environmental context of the Lokalelei sites is attributed to a lateral fluvial drainage that originated from the volcanic strata (i.e. the “Turkana Volcanics” as described by Bellieni et al. (1981) and Zanettin et al. (1983)) that form to the west the Turkana Basin watershed. Roche et al. (1999) indicate in the Lokalelei exposures a succession of ephemeral stream facies with floodplain palaeosols in which the archaeological sites are situated, separated by lacustrine deposits that belong to the “Lokeridede lacustrine phase” defined at 2.5 Ma in the Turkana Basin (Feibel, 1988, 1997). This lateral fluvial drainage is interpreted as verging towards the east on one large

axial meandering fluvial system flowing north to south, representing an ancestor of the Omo River that today feeds Lake Turkana at its northern end (Feibel et al., 1991) (Fig. 1a and b).

In this paper, we present new considerations on the stratigraphic position of the Lokalelei archaeological sites based on 13 high-resolution lithostratigraphic sections logged over the Lokalelei area, and new tephra geochemical analyses and correlations. Sedimentological analysis and palaeontological investigations also contributed to the reconstruction of palaeoenvironmental and palaeoecological conditions that prevailed during the lower Pleistocene hominin occupation at Lokalelei. Implications of these data are then discussed in terms of archaeological and hominin occurrences.

2. Geological and chronological background of the Nachukui Formation

Almost 10 km of rift deposits, including hundreds of metres of volcanics and thousands of metres of fluvio-deltaic and lacustrine sediments, have been inferred from surface and subsurface investigations in the Turkana depression. These deposits relate to the existence of a suite of N–S-trending deep rift basins that are only imaged by reflection seismics and two oil exploration wells (Eliye Springs-1 and Loperot-1 wells) (Morley et al., 1992, 1999; Mugisha et al., 1997; Hautot et al., 2000; Tiercelin and Lezzar, 2002;

Tiercelin et al., 2004) (Fig. 3). These basins range in age from Cretaceous (?) through Eocene–Oligocene to Plio-Pleistocene and can be considered as precursors of the modern Lake Turkana, the largest water body within the Eastern Branch of the EARS (Morley et al., 1992, 1999). From the upper Eocene, several major phases of volcanic activity resulted in this region in the deposition of thick (up to 2.5 km) piles of lavas: the “Turkana Volcanics” to the northwest of Lake Turkana (Bellieni et al., 1981, 1987; Zanettin et al., 1983; McDougall and Brown, 2009; Thuo, 2009; Clément et al., in preparation); and the “Asille Group” to the northeast of the lake (McDougall and Watkins, 2006). The Turkana volcanism extended to 15 Ma, while the “Asille Group” extended to younger than 13 Ma (Zanettin et al., 1983; McDougall and Watkins, 2006; McDougall and Brown, 2009) (Fig. 3b). From 4 to 0.5 Ma, some relatively minor volcanic activity occurred in the region west of Lake Turkana, while extensive flows occurred at the southern part of the lake and the entire area east of the lake (Morley et al., 1999; McDougall and Watkins, 2006).

In the northern part of the Turkana depression, the Pliocene to Middle Pleistocene “Omo Group” (Fig. 1b) relates to the initial phase of development of the present-day Lake Turkana Basin (de Heinzelin, 1983; Feibel et al., 1989; Morley et al., 1999; Haileab et al., 2004) as the result of a late Miocene–Pliocene extensional episode leading to the development of the North Kerio and Turkana Basins (Morley et al., 1999) (Fig. 3). The Nachukui Formation discussed in this paper forms part of the infill of the hanging wall side of the Turkana Basin (Figs. 1b and 3b). It corresponds to a succession of fluvial and lacustrine deposits that relate to phases of low and high lake levels alternating with episodes of alluvial fan and fluvial inputs issued from the western fault-bounded side of the

basin (i.e. the N–S oriented Murua Rith-Lapur Border Fault escarpment) (Fig. 3b). The Nachukui Formation has been stratigraphically divided into eight members, each marked at base and top by tephra layers that are geochemically correlated with other tephras characteristic of the Koobi Fora and Shungura Formations (Brown et al., 1985b; Harris et al., 1988; Feibel et al., 1989; Brown, 1994; Gathogo and Brown, 2006; McDougall and Brown, 2006; Gathogo et al., 2008) (Figs. 1b and 4a). Among these eight members is the Kalochoro Member (Fig. 4b), the lower section of which includes the Lokalalei archaeological sites complex.

3. Lithologic and stratigraphic context of the Lokalalei archaeological sites complex

The type-section of the Kalochoro Member was described in the Laga Kalochoro by Harris et al. (1988) (Figs. 1b and c and 4b). With a total thickness of 87 m, the Kalochoro Member is divided into three parts: a lower part made of a 40-m thick pile of upward-fining cyclic sandstones to claystones; a 27-m thick middle part with predominantly laminated claystones and siltstones, and a 20-m thick upper part mainly characterized by sandstones with minor interbedded conglomerates. Stratigraphically, the Kalochoro Member is known to contain six tephra beds (Harris et al., 1988) (Fig. 4b). The lower limit of the member is defined by the Kalochoro Tuff, which is compositionally indistinguishable to Tuff F of the Shungura Formation dated 2.34 ± 0.04 Ma (Brown et al., 1985b; Harris et al., 1988) (Fig. 4). The top of the Kalochoro Member is marked by the KBS Tuff, which is dated 1.869 ± 0.021 Ma (Brown et al., 1985b; Feibel et al., 1989; McDougall and Brown,

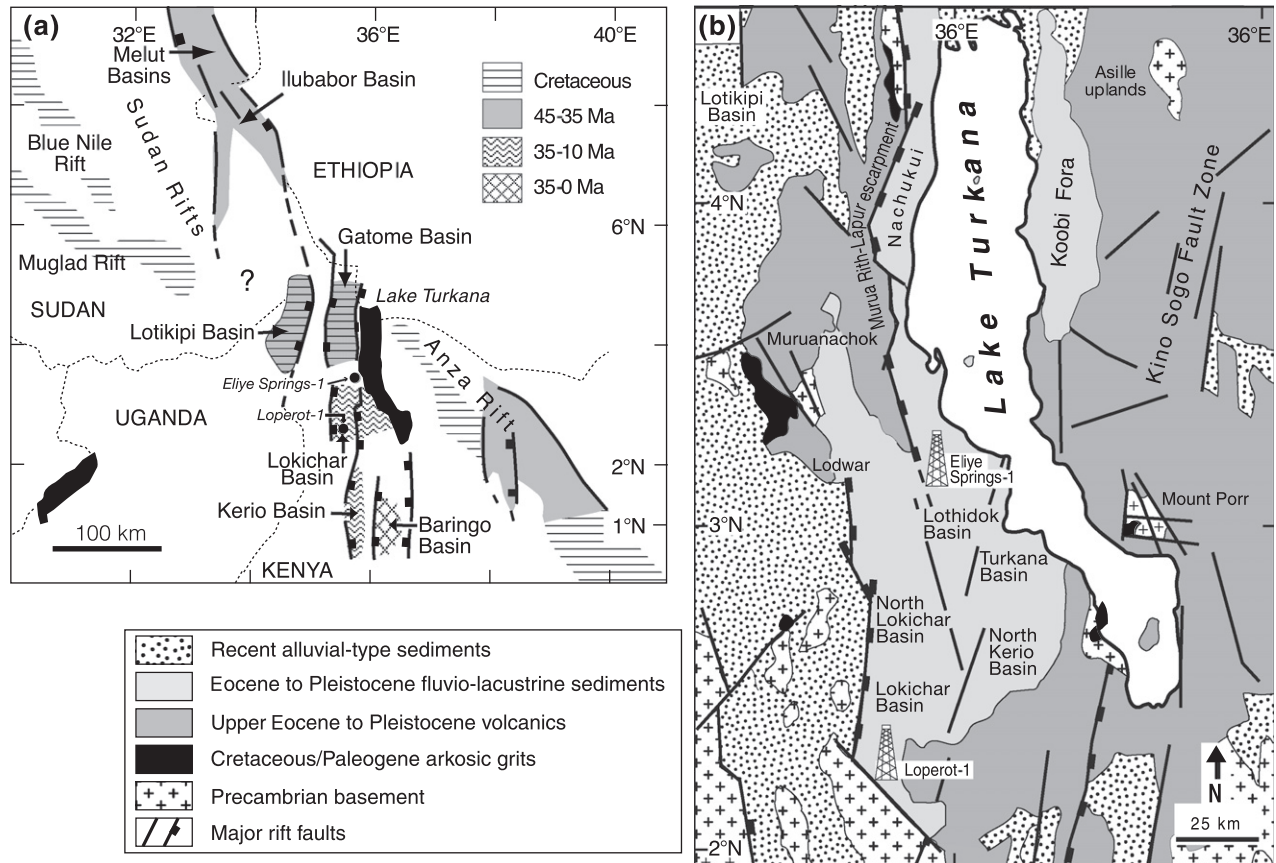


Fig. 3. (a) Distribution map of the Paleogene to Plio-Pleistocene rift basins in northern-central Kenya (modified from Tiercelin et al., 2004). (b) Schematic geological map of the Lake Turkana Basin, showing to the northwest the limits of the Plio-Pleistocene Nachukui Formation and the different geological formations forming the Murua Rith-Lapur Border Fault escarpment and range (including the upper Eocene-middle Miocene “Turkana Volcanics”).

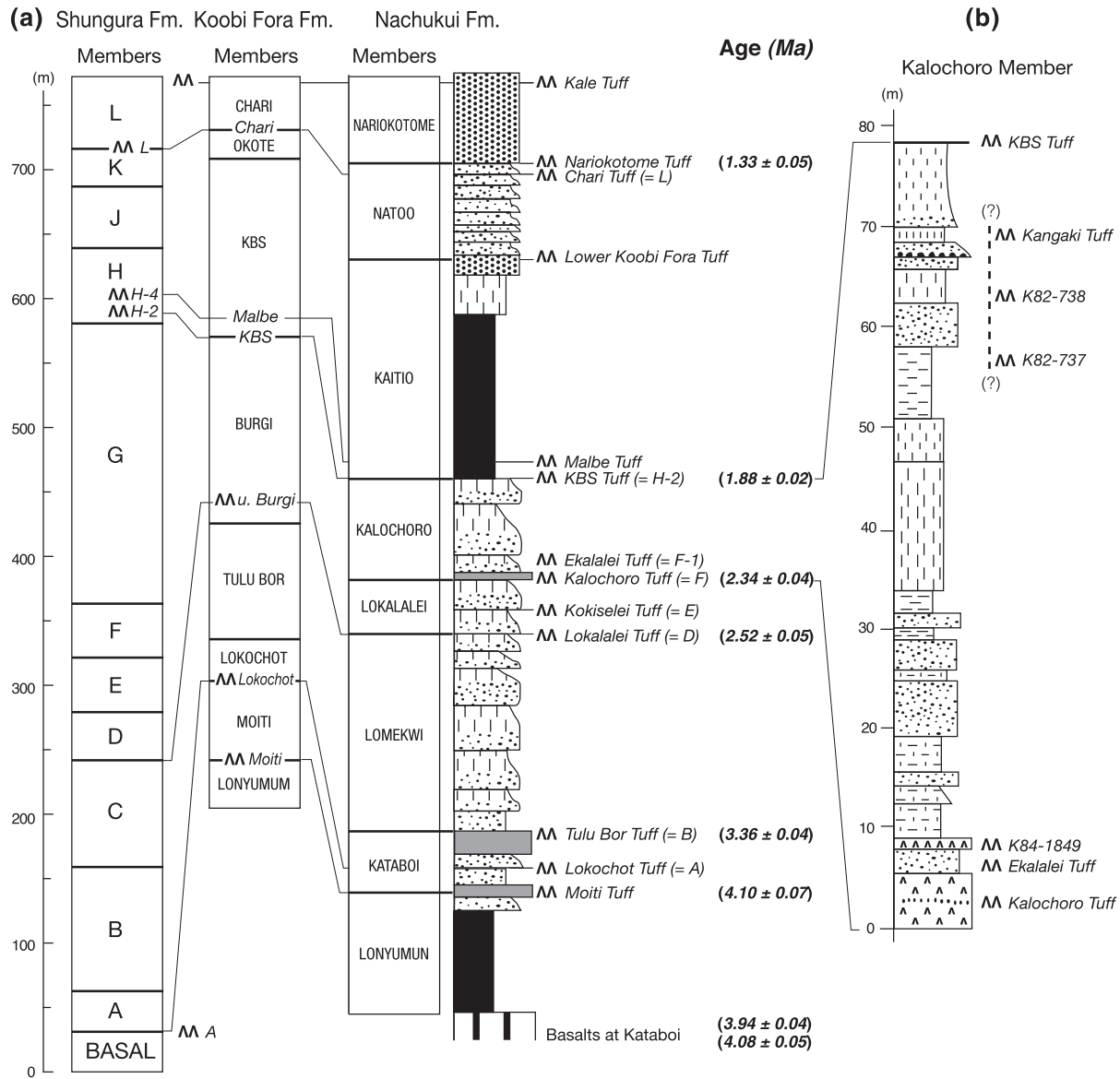


Fig. 4. (a) Lithostratigraphy of the Plio-Pleistocene Nachukui Formation and tephrostratigraphic correlation with the Koobi Fora and Shungura sedimentary successions. (b) General stratigraphic log of the Kalochoro Member (redrawn from Harris et al. (1988) and Feibel et al. (1989)).

2006). Four metres above the Kalochoro Tuff is the Ekalalei Tuff, which is compositionally very similar to the Kalochoro Tuff (Harris et al., 1988). The Ekakalei Tuff correlates to Tuff F-1 of the Shungura Formation, and thus is considered as slightly younger than 2.34 ± 0.04 Ma (Harris et al., 1988) (Fig. 4). Eight metres above the Kalochoro Tuff is another tuff named K84-1849, well exposed along the Kalochoro Laga (Fig. 1c) with a thickness of up to 5.5 m. Among the three other tuffs that are identified in the upper part of the Kalochoro Member, only the uppermost has been named and is referred to as the Kangaki Tuff (Harris et al., 1988) (Fig. 4b).

Based on a previous stratigraphic work conducted at the LA1 and LA1 α sites during the 2002 and 2003 field trips (Prat et al., 2005), an extensive lithostratigraphic survey was carried out during the 2005 and 2007 field campaigns in the areas of the LA1 and LA2 sites. A bed-to-bed correlation, accompanied by precise bed measurement and sedimentary facies description of 13 critical exposures have been completed within an area of 2.5 km² characterized by a low hill morphology (Fig. 2). Latitude and longitude positions have been measured for each lithologic section generally

at base and/or top using Magellan SporTrackMap and Garmin 12XL GPS equipment. All sections have been located with pinpoint accuracy using the World Geodetic System 84. They are all labelled with reference to the Lokalalei locality (LOK) (Figs. 2 and 5).

Two lithostratigraphic sections, LOK S1 and LOK S2, have been described close to the LA1 and LA1 α sites, in a small tributary on the left bank of the Lokalalei Laga (Prat et al., 2005) (Fig. 2). Four other sections (LOK S3–S6) have been established on both banks of a small tributary running from the LA2 sites and joining the Lokalalei Laga on its right bank. The LOK S5 and S6 sections contain the LA2A, 2B and 2C archaeological sites. Six complementary lithostratigraphic sections (LOK S7–S12) have been measured in the area between the LA1 and LA2 sites, in order to establish a precise stratigraphic positioning of both sites. The LOK S11 section contains the LA3 palaeontological site (Figs. 2 and 5). In this lithostratigraphic work, individual sedimentary beds were described in detail at a cm to dm scale. Sample collection of various lithofacies and tephra layers identified in the sections support the stratigraphic correlations and palaeoenvironmental reconstructions presented herein. The fine-grained facies have also been character-

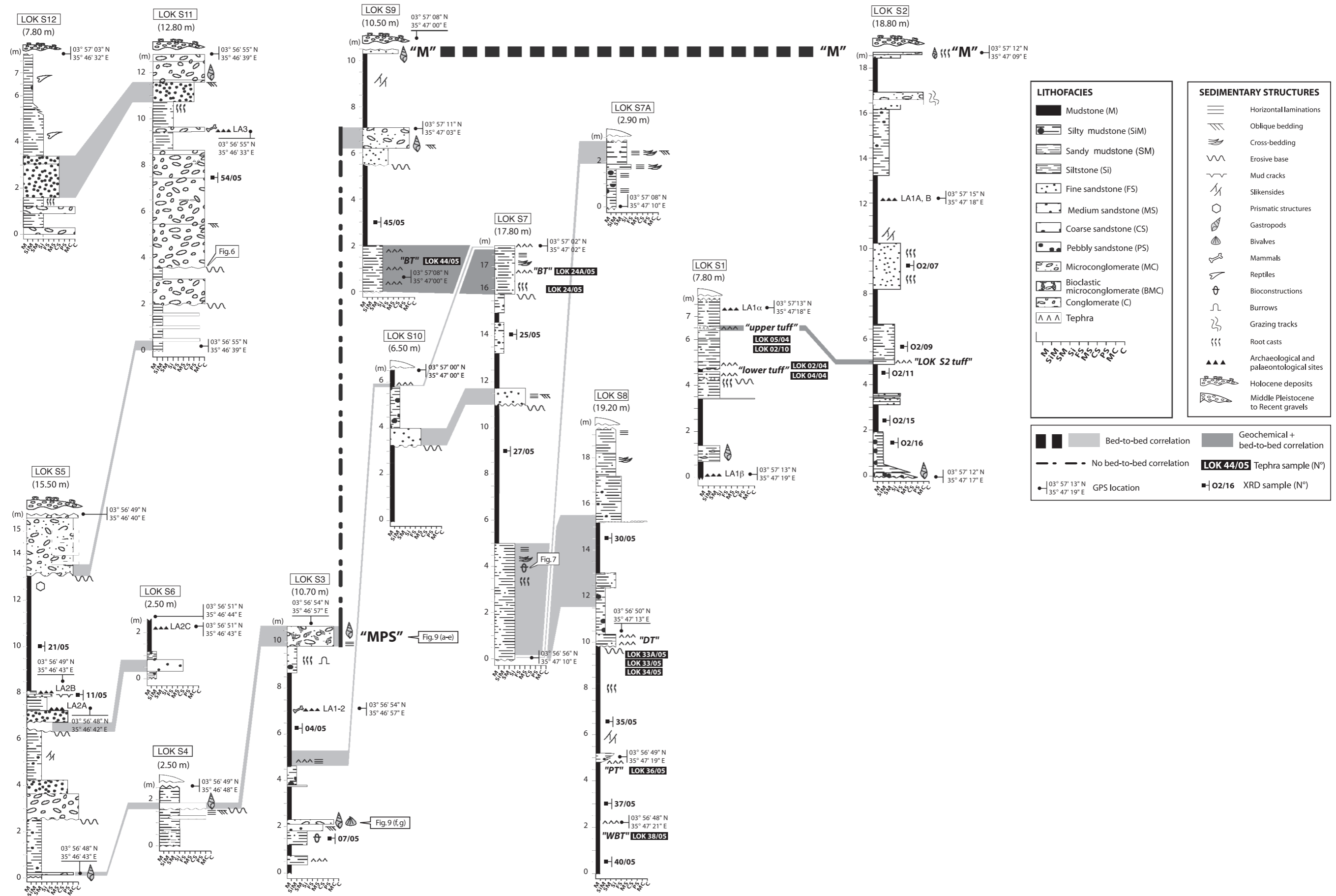


Fig. 5. Detailed lithostratigraphic sections showing correlations between the different Lokalalei archaeological and palaeontological sites.

ized in terms of clay mineralogy using XRD analysis. Informal but descriptive names (mainly based on peculiar sedimentary characteristics) have been attributed to the different tephra layers identified in our sections, in order to facilitate the descriptive and analytical work, and their comparison with the tephra terminology already established for the Nachukui Formation (Harris et al., 1988).

3.1. Lithofacies description

Six major lithofacies characterize the sedimentary succession associated with the Lokalelei archaeological sites (Figs. 2 and 5):

Facies 1 is a massive or crudely stratified, matrix- or clast-supported conglomerate with subrounded pebbles and cobbles ranging in size from 1 to 10 cm (Fig. 6). It represents about 25% of the whole series and is prominent at the top of the succession (sections LOK S5, S11, and S12). Sedimentary structures present are mainly horizontal and oblique bedding, and only locally root marks. Distinct, irregular erosion surfaces are locally visible at the base of this facies (Fig. 6a and b). Bed thickness ranges from decimetric to plurimetric scale. Each constituent gravel bed is up to 0.10–0.20-m thick with flat bases and a sheet-like geometry with good lateral continuity (Fig. 6c and d). Clastics (sand grains and pebbles) are all of volcanic origin, derived from erosion of the “Turkana Volcanics” forming the Murua Rith-Lapur Border Fault escarpment. The relatively large size of clasts and the presence of substantial amounts of mud and sand matrix as well as the presence of erosive bases reflect high energy (debris flow) dynamics (Miall, 1992, 1996). Mud matrix is predominantly smectite-rich with little amounts of kaolinite and minor chlorite (section LOK S5; Fig. 5; Table 1). This facies is interpreted here as

Table 1

Clay mineralogy of mudstone and siltstone facies in the sedimentary succession associated to the Lokalelei archaeological sites area, Nachukui Formation. See Fig. 5 for sample location.

| Section | Sample no. | Sediment facies | Smectite (%) | Illite (%) | Chlorite (%) | Kaolinite (%) |
|---------|------------|-----------------|--------------|------------|--------------|---------------|
| LOK S2 | LOK 02/11 | Silty mudstone | 93 | 3 | 2 | 2 |
| LOK S2 | LOK 02/15 | Mudstone | 93 | 5 | 3 | 2 |
| LOK S2 | LOK 02/16 | Silty mudstone | 76 | 4 | 8 | 13 |
| LOK S2 | LOK 02/09 | Siltstone | 93 | 5 | | |
| LOK S2 | LOK 02/07 | Siltstone | 88 | 5 | | 5 |
| LOK S3 | LOK 04/04 | Mudstone | 95 | 5 | | |
| LOK S3 | LOK 07/05 | Mudstone | 93 | 5 | 2 | 1 |
| LOK S5 | LOK 11/05 | Fine sandstone | 82 | 4 | 4 | 10 |
| LOK S5 | LOK 21/05 | Mudstone | 84 | 3 | 3 | 11 |
| LOK S7 | LOK 25/05 | Silty mudstone | 96 | 4 | | |
| LOK S7 | LOK 27/05 | Mudstone | 94 | 6 | | |
| LOK S8 | LOK 40/05 | Mudstone | 80 | 10 | 6 | 4 |
| LOK S8 | LOK 37/05 | Mudstone | 88 | 7 | 1 | 4 |
| LOK S8 | LOK 35/05 | Mudstone | 88 | 5 | | 8 |
| LOK S8 | LOK 30/05 | Mudstone | 98 | | | 2 |
| LOK S9 | LOK 45/05 | Mudstone | 90 | 3 | 3 | 4 |
| LOK S11 | LOK 54/05 | Mud matrix | 90 | 2 | | 8 |

having been deposited by ephemeral streams downstream of an alluvial fan complex.

Facies 2 is a coarse to very coarse, locally pebbly, olivine and pyroxene-rich sandstone, only seen on the LOK S7 and S10 sections. Sedimentary structures include horizontal and oblique bedding, and erosive bases. Bed thickness is less than one metre. This facies suggests a medium energy fluvial process and can be interpreted as a distal/lateral equivalent of the above cited alluvial fan facies. The peculiar mineralogy of this facies indicates a sediment



Fig. 6. Facies 1: (a) Conglomerate facies at the top of the LOK S5 section showing sharp erosive base above mudstone facies. (b–d) Horizontally bedded coarse to pebbly sandstone facies changing laterally to an heterolithic conglomerate, locally horizontally stratified at top of LOK S11 section. Lithic clasts are all volcanic rocks issued from erosion of the “Turkana Volcanics” forming the Murua Rith-Lapur Range.

source from the west, from porphyritic rocks belonging to the “Turkana Volcanics”.

Facies 3 is a fine sandstone to siltstone facies, well represented on sections LOK S7, S7A and S8 by a up to 5-m thick bed. On each of these sections (Fig. 5), this bed shows lateral variations expressed through three different types of sedimentary structures. On the LOK S8 section, this bed is made of very loose sand that is almost structureless except for faint horizontal laminations. On the LOK S7 section (Fig. 2), the same bed appears massive and locally shows abundant bioturbations, mainly rhizoliths, insect nests and galleries that are clearly seen thanks to differential cementation and weathering (Fig. 7). At about 350 m to the north (Fig. 2), the LOK S7A section (Fig. 8a) shows fine sandstone with tabular cross-beds containing some small pebbles within laminations (Fig. 8b), wave ripple cross-laminations and muddy drapes in troughs (Fig. 8c). Clay component is dominantly smectite (80–85%), with smaller amounts of kaolinite (up to 11%) and little illite and chlorite (Fig. 5; Table 1).

Facies 4 is a mudstone facies, often massive (*Sub-facies 4a*), or more rarely finely laminated (*Sub-facies 4b*):

Sub-facies 4a is a massive, generally dark brown mudstone that represents about 35% of the whole series and is prominent all over the basal and middle parts of the sedimentary succession, with a plurimetric bed thicknesses (Fig. 5). Root marks, burrows, prismatic structures and slickensides testify to the development of pedogenetic processes, and suggest temporary immersion. Dessication cracks are rarely preserved as negative prints by an overlying thin layer of fine sandstone (Facies 3). In terms of clay mineralogy, in addition to a dominant smectite assemblage (sometimes up to 85–95%), the mudstone facies is sometimes marked by the presence of kaolinite with percentages ranging from 2 to 13% that supports a pedogenetic process, and little illite and chlorite (up to 4%) (Fig. 5; Table 1). This mudstone facies may resemble flood plain facies that develops in fluvial context. However, its relatively significant thickness suggests a longer-lasting water-body consistent

with a wide, almost permanent backshore lagoon environment or a larger embayment situated in a gently subsiding area. Small lenses of sand, subrounded granules and gravels mixed with abundant small shells of gastropods (*Melanoides* sp.; *Bellamya* sp.) are locally present within the mudstone facies, as seen at the base of section LOK S1 (Fig. 5). This may indicate a wash-over dynamics during strong wavy episodes.

Sub-facies 4b is a finely laminated (millimetre-scale laminations), beige and light brown mudstone observed in the LOK S7A section. In terms of clay mineralogy, this mudstone facies is essentially smectite-rich (Fig. 5; Table 1). It is interpreted as representing lacustrine deposits, as it looks very similar to banded muds of Holocene-recent age cored from the central-northern part of Lake Turkana. This well-laminated character is related to seasonal flooding of the Omo River (Yuretich, 1979; Barton and Torgersen, 1988; Johnson et al., 1991).

Facies 5 consists of an arenaceous bioclastic facies which shows two main sub-facies.

Sub-facies 5a is an assemblage of well-preserved gastropod shells, *Melanoides* sp. and a few *Bellamya* sp., forming up to 98% of the entire sediment, sometimes mixed with a few clasts of various origins (subrounded gravels, fish teeth, fish and mammal bone fragments). Bed thickness is decimetric to pluridecimetric. At section LOK S3, this shell accumulation is up to 0.85 m thick, with east-oriented oblique bedding (2–5°) (Fig. 9a–c). The large number of shells (more than 5×10^5 shells per cubic metre of sediment) demonstrates a very high biogenic productivity. Both *Melanoides* sp. and *Bellamya* sp. are elongated forms that have clearly differentiated ends, and the pointed end is thought to point up-current to the direction of the flow (Potter and Pettijohn, 1963; Nagle, 1967; Allen, 1982) (Fig. 9d). Lateral variation of this facies is represented by mollusc-packed microconglomerate and sandstone where reworked mollusc shells represent only 10–20% of the whole assemblage. Such facies forms decimetre-thick beds. Bioclastic dykes are locally seen at the base of the bed (Fig. 9e). Associated fine

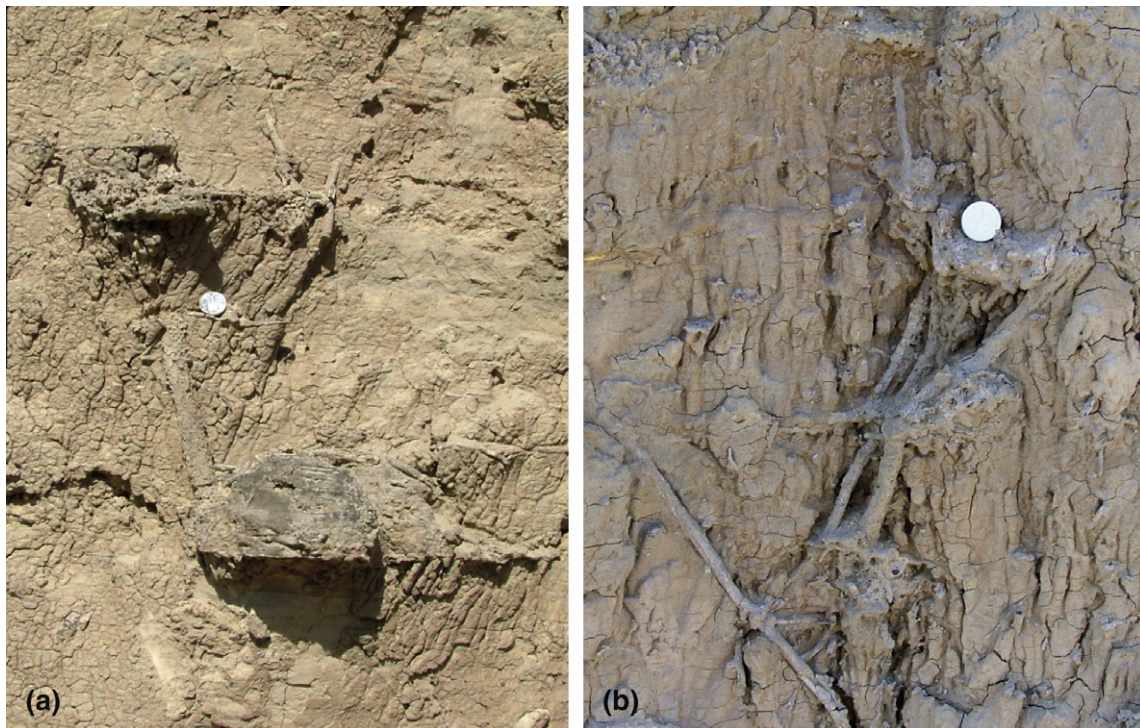


Fig. 7. Facies 3: Two examples of fossil insect nests and galleries from fine sandstone/siltstone facies in the LOK S7 section. (a) Termite nest with typical ball shape (average diameter of about 15 cm) and flattened base. Note the presence of a large vertical gallery. (b) Possible ant nest showing flat and thin horizontal chambers connected by sub-vertical galleries (e.g., Hasiotis, 2003; Tschinkel, 2003, 2004; Düringer et al., 2007). For scale: the One Kenya Shilling coin is 23 mm in diameter.

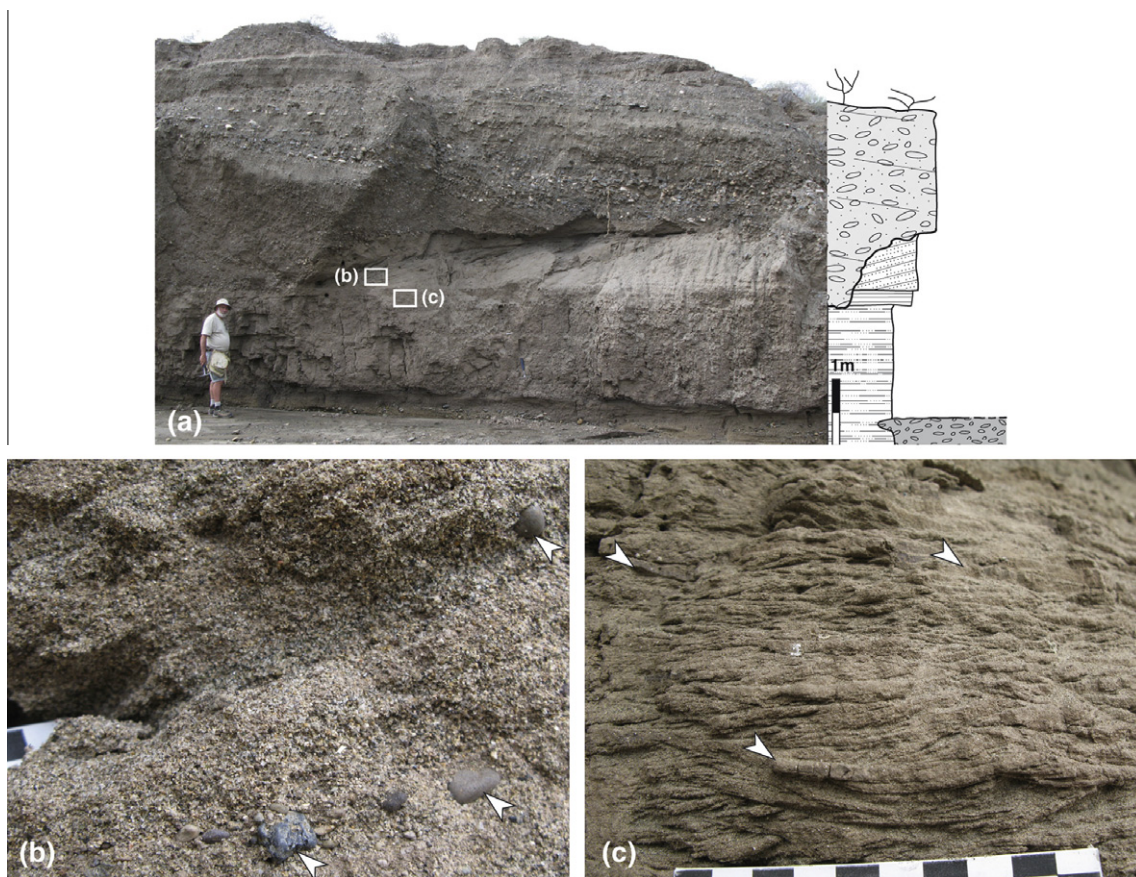


Fig. 8. Facies 3: Fine sandstone facies from the LOK S7A section. (a) General view of the outcrop showing tabular cross-bedding oriented landward (i.e. west). Note the deep incision of ubiquitous middle Pleistocene conglomerates (see Fig. 2 for legend). Scale bar is 1 m. (b) Detailed view showing rounded/subrounded volcanic granules and pebbles (max. ~1 cm diameter) (see white arrow heads) which are set between the tabular cross-laminations. (c) Detailed view from the ripple cross-laminations showing some more muddy drapes (see white arrow heads). The black and white scale is 10 cm long.

sandstone shows fossil traces interpreted as gastropod grazing tracks. *Sub-facies 5a* indicates a high-energy, wave-dominated lake shoreline characterized by beach-bars formed through repetitive accumulation of a large number of floated shells and few coarse sand and granules. Lakeward oblique bedding (15°) results from successive episodes of floated shell accumulation along the strand (Renaut and Owen, 1991). The preferential orientation of the shells may reflect the swash and backwash action of medium- to high-energy waves. Downward-injected bioclastic dykes probably occurred as a result of cyclic wave-loading during episodes of high-energy waves (Poulos, 1988; Martel and Gibling, 1991). Thin beds of mollusc-rich fine sandstone with grazing tracks reflect shallow backshore ponds.

Sub-facies 5b is a dense structureless assemblage of shells of various species, gastropods (*Melanoides* sp., *Bellamyia* sp., *Cleopatra* sp.) and bivalves (*Corbicula* sp., *Mutela* sp.) forming a 0.20-m thick bed at section LOK S3 (Fig. 9f and g). Below this bed is a 0.30-m thick coarse sandstone with abundant small *Melanoides* sp. and *Bellamyia* sp. shells concentrated in oblique bedding resembling *sub-facies 5a* (Fig. 5). *Sub-facies 5b* reflects a much higher energy and short-termed deposit that reworks mollusc shells from various biotopes (Plaziat and Younis, 2005). It can be related to storm event(s).

Facies 6 is a tephra facies, represented in the lithological succession by six individual tephra layers, to which informal names have been attributed (Fig. 5).

The “*Big Tuff*” (*BT*): This tephra forms the top of the LOK S7 section. It is a massive, 2-m thick blue-grey silty tuff overlying in sharp contact a light brown silty mudstone. It is intermixed with

silts and fine sands and shows aggrading cross-laminations. The upper metre of this bed contains nodular silicifications. At its top is a beige, finely laminated, tuffaceous layer that is also visible in the LOK S3 and S10 sections.

The “*Double Tuff*” (*DT*): This tephra layer is visible in section LOK S8. It consists of two successive beds of massive blue-grey tuff. The lower bed is 0.30-m thick and shows an erosive base above a brown mudstone. The upper bed is 0.25-m thick and has a layer of pumice cobbles up to 10 cm in diameter at its top.

The “*Pinched Tuff*” (*PT*): This 0.40-m thick beige to grey-blue tuff layer is located 4.60 m below the base of the “*Double Tuff*” in the LOK S8 section. This tuff pinches out quite rapidly within a beige mudstone bed. It has consequently been named the “*Pinched Tuff*”.

The “*White and Black Tuff*” (*WBT*): This tuff, located 7.50 m below the “*Double Tuff*” and about 2.50 m below the “*Pinched Tuff*” in the LOK S8 section, is a 0.30-m thick white clayey tuff characterized at its base by a 0.10-m thick black layer delineating the contact between the tuff and the underlying dark brown mudstone. It also pinches out rapidly towards the west.

The “*lower tuff*” and “*upper tuff*” were described in the LOK S1 section (Prat et al., 2005). The “*lower tuff*” consists of a pair of 0.30-m thick beds of blue-grey tuff both with erosive bases, separated by a cm-thick layer of beige laminated mudstone. The “*upper tuff*” is a 0.20-m thick light grey tuff lying 1.30 m above the “*lower tuff*”. It pinches out rapidly towards the north.

The “*LOK S2 Tuff*” was described in the LOK S2 section (Prat et al., 2005) as a 0.20-m thick bed composed of alternating 1–3 cm-thick layers of blue-grey tuff and cm-thick silty mudstone layers.



Fig. 9. Facies 5: Wave-accumulated arenaceous bioclastic facies. *Sub-facies 5a:* (a) Dense accumulations of oriented gastropod shells (essentially *Melanoides* sp. and *Bellamyia* sp.) with subrounded gravels and other debris form at the top of the LOK S3 section a 0.85-m thick bed that caps the tabular top of the surrounding hills (shown by black arrows). This facies is cemented by calcite with the degree of induration varying from very dense, highly cemented to porous, partially cemented. This bed is identified as the “MPS” bed. (b and c) These accumulations are locally organized as 3–5-cm thick low-angle oblique sets oriented N90°. (d) On this photograph, the elongate conical shells (mainly *Melanoides* sp.) show an east–west orientation, with approximately half of the shells pointing in one direction and the other half pointing in the opposite direction. For scale, the 20 Kenya Shillings coin is 25 mm in diameter. (e) Downward-injected bioclastic dyke (shown by black arrow) at the base of “MPS” bed. For scale, the green pencil is 15 cm long. *Sub-facies 5b:* (f and g) Near the base of LOK S3 section (Fig. 5), a 0.20-m thick dense accumulation of mollusc shells of various species – large forms of *Melanoides* sp. and *Bellamyia* sp., *Cleopatra* sp., *Corbicula* sp. and *Mutela* sp. – is embedded within a fine-grained sandstone matrix with few sub-angular to rounded granules and gravels.

Three of these tephtras show sedimentary features such as cross-bedding, 3D current ripples laminations, mixing with sand, and erosive bases, that reflect deposition and/or reworking in fluvial or lacustrine settings inducing various hydrodynamic conditions (“Big

Tuff”, “lower tuff”, “LOK S2 Tuff”). In addition, morphological types of glass shards deduced from SEM observation (using the Heiken classification; Heiken, 1972; Katoh et al., 2000) have been used to define the depositional environment of these tephtras (Fig. 10). Rare

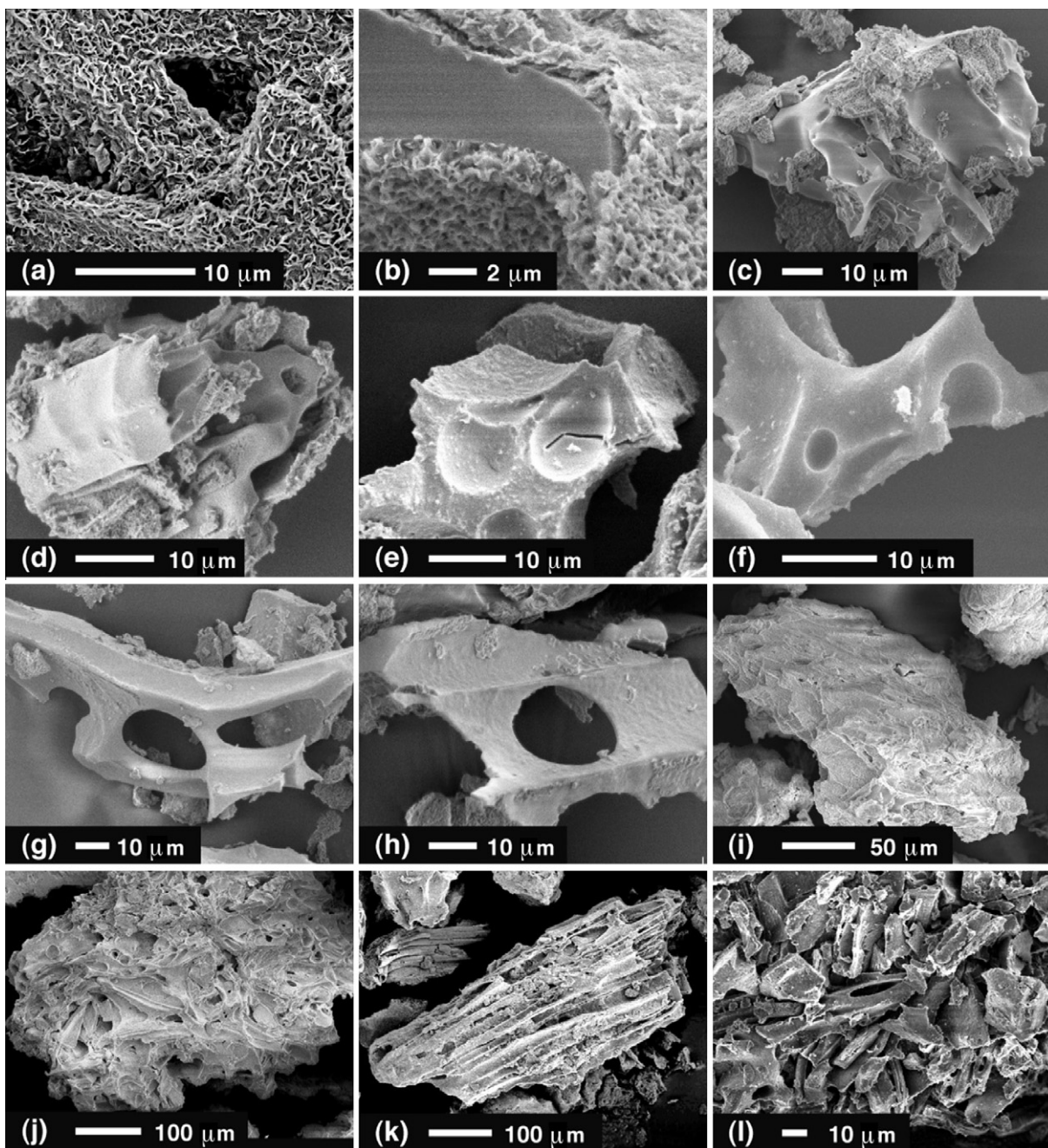


Fig. 10. Facies 6: Morphological characterization of glass shards of tephra identified in the area of the Lokalelei archaeological sites, Nachukui Formation. (a and b) Ekalalei Tuff, upper bed (LOK 01/04 sample) (see Fig. 5) and “White and Black Tuff” (LOK 38/05 sample). SEM images from individual glass shards with “honeycomb” coatings resulting from chemical weathering. Such coatings are possibly formed by authigenic clay (smectite?) resulting from contact with alkaline waters (Yuretich and Cerling, 1983). (c and d) “Double Tuff” (sample LOK 33/05). Blocky fragments of glass shards up to 70 μm in length, with a melted-ice surface aspect that suggests chemical dissolution processes. (e and f) “Big Tuff” (sample LOK 24/05). Vesicular glass fragments up to 50 μm in length. Vesicles exposed at the grain surface are spherical, up to 8–12 μm in diameter, and vesicle walls are up to 2 μm thick. These fragments appear to have been broken from areas between large vesicles. Fracture surface of glass between vesicles is possibly characteristic of hyaloclastic ash. (g–j) Ekalalei Tuff, lower bed (LOK 04/04 sample). Two different morphological types of glass shard have been observed: (g and h) The first type corresponds to elongated glass fragments 80–120 μm in length, showing sharp edges and elongated vesicles up to 30 μm . As for the *Big Tuff*, fragments appear to have been broken from areas between large vesicles and may suggest a hyaloclastic origin. (i and j) The second morphological type is characterized by chains of spherical, pod-like and pipe vesicles forming blocky fragments 250–600 μm in length with a pumice aspect. This pumice morphology may suggest an ash fallout initially transported and sorted by wind effects, then briefly transported and deposited in a fluvial or lake shore environment. (k) Ekalalei Tuff, upper bed (LOK 02/04). Fibrous glass shard with pipe vesicles 10–20 μm in diameter. Vesicle walls are 1 μm thick. (l) LOK S1 “upper tuff” (sample LOK 05/04). 20–50 μm long, relatively thick, broken angular blocky shards may indicate transport and deposition in a fluvial environment.

diatoms have also been observed in two tephra layers during SEM investigation (Fig. 11a–d). In the LOK S1 “upper tuff” (sample LOK 05/04), several broken and partially weathered diatom frustules are visible. These are pennate diatoms that suggest the presence of a shallow water body (Fig. 11a–c). In the “Double Tuff” (sample LOK 33/05),

one frustule of *Aulacoseira* sp. was observed (Fig. 11d). This is a planktonic diatom which indicates a deep lake environment. The poor status of preservation due to chemical weathering does not permit a better identification. Also, given its rarity, a wind-reworking from other deposits for this diatom is not excluded.

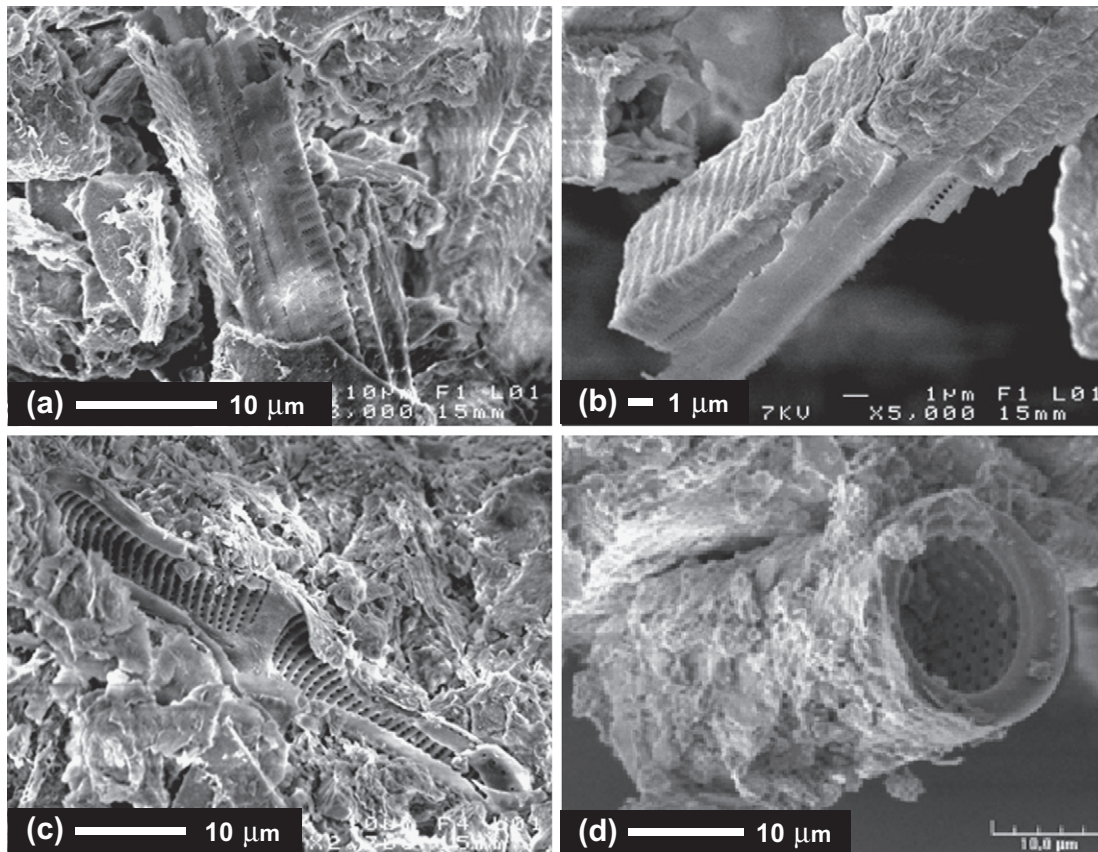


Fig. 11. SEM photographs of diatoms found associated with the LOK S1 “upper tuff” (a–c), and the “Double Tuff” (d), respectively. (a–c) Broken and partially chemically weathered diatom frustules. These are pennate diatoms that could indicate shallow water bodies. (d) *Aulacoseira* sp. is a planktonic diatom which indicates a quite deep lake environment.

3.2. Tephra geochemistry and chronostratigraphic correlations

In order to strengthen the chronostratigraphical position of the Lokalelei 1 and 2 archaeological sites, the six tephra layers identified in our lithologic sections (see Section 3.1) have been geochemically analysed using a Cameca SX50 electron microprobe (“Microsonde de l’Ouest”, Centre de Brest de l’IFREMER). Analyses have been conducted on polished epoxy-impregnated thin sections, with a minimum of 50 individual glass shards analysed for each sample. These analyses were obtained at 15 kV accelerating voltage with a sample current of 15 nA. The average geochemical composition of the glass shards of each tuff layer is presented in Table 2.

3.2.1. “Big Tuff” (BT)

Two samples of the “Big Tuff” have been collected at the main BT outcrop on the LOK S7 section, at base (LOK 24/05) and top (LOK 24A/05) of the tephra bed, respectively. Sample LOK 44/05 was collected at the base of the LOK S9 section (Figs. 2 and 5). Chemical discrimination diagrams (FeO total versus Al_2O_3 and TiO_2 versus Al_2O_3) show a similar range composition for the three samples (Fig. 12a; Table 2). This confirms the stratigraphic correlation established in the field between the LOK S7 and S9 sections, as indicated on Fig. 5.

3.2.2. “Double Tuff” (DT)

Three samples of the “Double Tuff” were collected at the LOK S8 section (Figs. 2 and 5). Samples LOK 34/05 and 33/05 were collected in the 0.25-m thick lower bed and in the 0.30-m thick upper bed, respectively. The LOK 33A/05 sample corresponds to a fragment of a pumice pebble at the top of the upper bed. The chemical discrimination diagrams FeO total versus Al_2O_3 and TiO_2 versus

Al_2O_3 for the three samples show that the chemical character of the LOK 33A/05 sample (pumice pebble) is clearly dominant within the two other 33/05 and 34/05 samples (Fig. 12a; Table 2). This confirms that pumice clasts and underlying tephra originate from the same eruptive event.

3.2.3. “Pinched Tuff” (PT) and “White and Black Tuff” (WBT)

Samples of the “Pinched Tuff” (LOK 36/05) and “White and Black Tuff” (LOK 38/05) were collected at the LOK S8 section (Figs. 2 and 5). The geochemical diagrams FeO total versus Al_2O_3 and TiO_2 versus Al_2O_3 for the LOK 36/05 and 38/05 samples show that these tephra are compositionally indistinguishable despite the fact that they are stratigraphically distinct (Fig. 12a; Table 2).

3.2.4. The LA1 site tephra

These tuffs were first sampled during the 2002 field campaign. The LOK S1 “lower tuff” was geochemically demonstrated to be the Ekalalei Tuff (Prat et al., 2005; p. 233, Fig. 2). This tephra was re-sampled during the 2004 field trip in a nearby, freshly eroded exposure showing there two distinct tephra layers. The LOK 04/04 sample was taken from the lower tephra layer. The LOK 02/04 sample comes from the upper layer (Figs. 5 and 12b). The chemical discrimination diagrams FeO total versus Al_2O_3 and TiO_2 versus Al_2O_3 for the LOK 02/04 and 04/04 samples show that these two stratigraphically distinct layers are compositionally indistinguishable from each other and correlate with the LOK S1 “lower tuff” (equivalent to the Ekalalei Tuff) as presented in Prat et al. (2005) (Fig. 12b). The “LOK S2 Tuff” (sample LOK 02/10) is clearly geochemically distinct from the LOK S1 “lower tuff” and correlates with the “upper tuff” seen in section LOK S1 (sample LOK 05/04) (Fig. 12b).

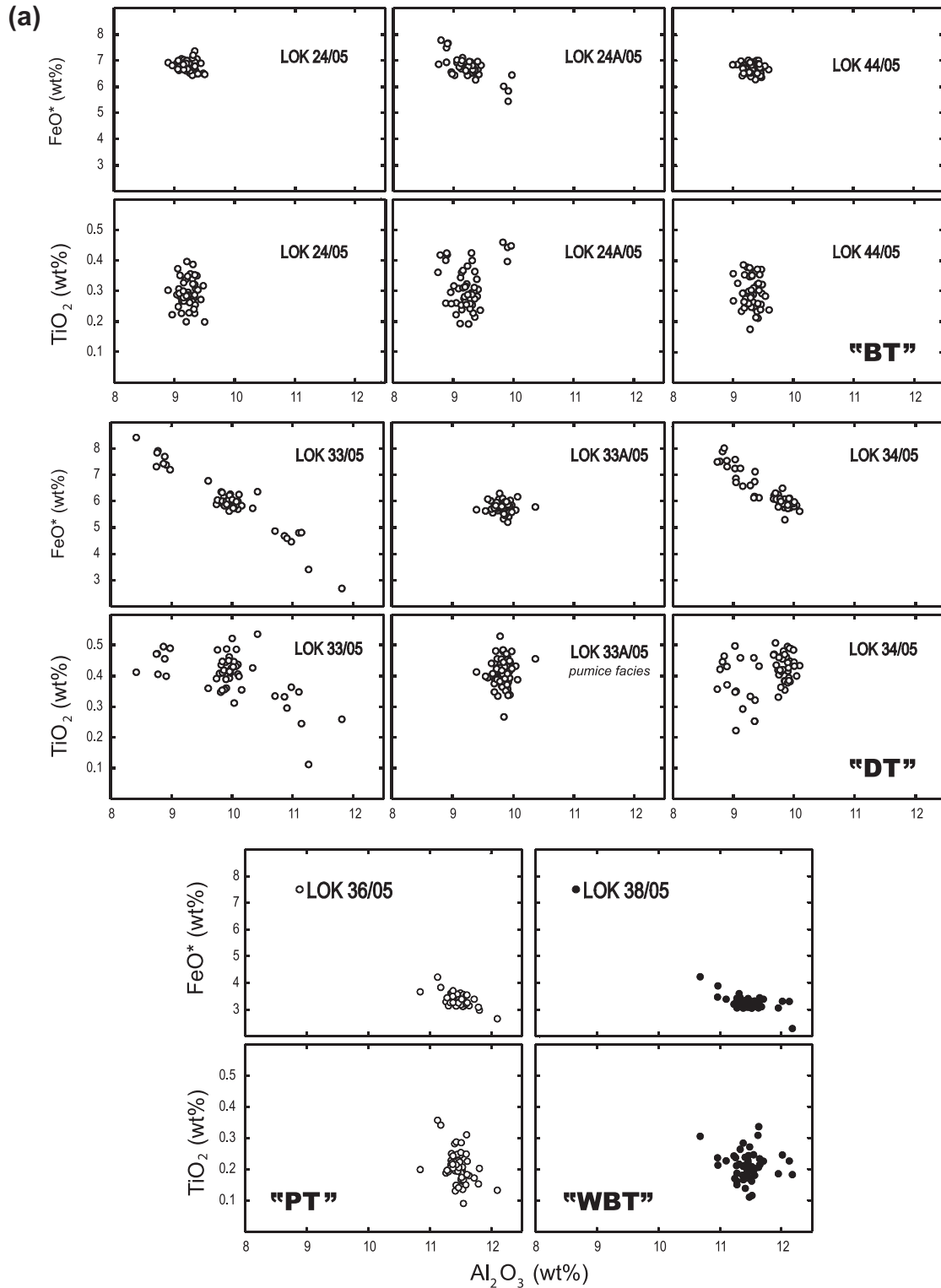


Fig. 12. Chemical discrimination diagrams (FeO total versus Al_2O_3 and TiO_2 versus Al_2O_3). (a) For the tuffs identified in the Lokalelei area. (b) For the tuffs associated to the LA1 archaeological site.

3.2.5. Geochemical correlations

Tentative geochemical correlations supported with sedimentological data can be made between the different tuff layers identified in our lithological sections and tephra originally described in the Kalochoro Member by Harris et al. (1988) (Fig. 3; Tables 2 and 3). The “lower tuff” in the LOK S1 section (LOK 02/04 and 04/04 samples) has been geochemically identified as corresponding

to the Ekalalei Tuff (Prat et al., 2005; this work) (Fig. 12b). In the Kalochoro area (Fig. 2c), at 8 m above the Kalochoro Tuff, Harris et al. (1988; p. 10) describe the K84-1849 Tuff (Fig. 3b), and cite for this tuff a possible correlate in the Lokalelei area. The sedimentological characteristics presented by Harris et al. (1988) for the K84-1849 Tuff – thickness varying between 0 and 5.5 m, lenticular shape, small scale cross-laminations, abundant root casts – look

Table 2

Electron microprobe major-element data of glass shards from tuff layers identified in the Lokalalei archaeological site complex area, Nachukui Formation.

| Tephra name (this work) | SiO ₂ | TiO ₂ | Al ₂ O ₃ | FeO | MnO | MgO | CaO | Na ₂ O | K ₂ O | P ₂ O ₅ | Cr ₂ O ₃ | Total |
|-----------------------------------|------------------|------------------|--------------------------------|------|------|------|------|-------------------|------------------|-------------------------------|--------------------------------|-------|
| <i>Big Tuff</i> (LOK 24/05) | 72.32 | 0.26 | 8.09 | 5.96 | 0.30 | 0.03 | 0.11 | 0.28 | 0.33 | 0.01 | 0.01 | 87.70 |
| <i>Big Tuff</i> (LOK 24A/05) | 72.57 | 0.28 | 8.14 | 5.94 | 0.29 | 0.04 | 0.13 | 0.27 | 0.38 | 0.02 | 0.01 | 88.06 |
| <i>Big Tuff</i> (LOK 44/05) | 71.98 | 0.26 | 8.22 | 5.80 | 0.29 | 0.03 | 0.12 | 0.28 | 0.43 | 0.02 | 0.01 | 87.43 |
| <i>Double Tuff</i> (LOK 33/05) | 72.04 | 0.40 | 7.75 | 6.74 | 0.35 | 0.09 | 0.22 | 0.19 | 0.32 | 0.02 | 0.02 | 88.12 |
| <i>Double Tuff</i> (LOK 33/05) | 72.99 | 0.37 | 8.85 | 5.31 | 0.27 | 0.10 | 0.17 | 0.32 | 0.52 | 0.01 | 0.02 | 88.93 |
| <i>Double Tuff</i> (LOK 34/05) | 72.97 | 0.37 | 8.52 | 5.60 | 0.27 | 0.09 | 0.17 | 0.25 | 0.48 | 0.02 | 0.02 | 88.75 |
| <i>Double Tuff</i> (LOK33A/05) | 73.63 | 0.37 | 8.86 | 5.22 | 0.24 | 0.10 | 0.19 | 0.41 | 1.03 | 0.02 | 0.02 | 90.10 |
| <i>Pinched Tuff</i> (LOK 36/05) | 74.95 | 0.18 | 10.36 | 3.04 | 0.11 | 0.03 | 0.15 | 0.50 | 0.95 | 0.01 | 0.01 | 90.29 |
| <i>W & B Tuff</i> (LOK 38/05) | 74.18 | 0.20 | 10.35 | 2.90 | 0.16 | 0.06 | 0.12 | 0.59 | 1.13 | 0.01 | 0.01 | 89.72 |
| <i>LOKS2 Tuff</i> (LOK 02/10) | 72.13 | 0.36 | 8.07 | 6.26 | 0.33 | 0.09 | 0.18 | 0.22 | 0.34 | 0.01 | 0.00 | 87.98 |
| <i>LOKS2 Tuff</i> (LOK 02/10) | 72.72 | 0.27 | 9.70 | 4.17 | 0.19 | 0.08 | 0.17 | 0.35 | 0.65 | 0.02 | 0.01 | 88.33 |
| <i>LOKS1 upper T.</i> (LOK 05/04) | 74.13 | 0.17 | 10.42 | 2.73 | 0.10 | 0.03 | 0.13 | 1.10 | 1.56 | 0.01 | 0.01 | 90.40 |
| <i>LOKS1 upper T.</i> (LOK 05/04) | 72.22 | 0.28 | 9.41 | 4.30 | 0.20 | 0.08 | 0.16 | 0.48 | 0.88 | 0.02 | 0.02 | 88.05 |
| <i>LOKS1 upper T.</i> (LOK 05/04) | 72.05 | 0.22 | 7.89 | 6.07 | 0.29 | 0.04 | 0.13 | 0.32 | 0.52 | 0.01 | 0.01 | 87.54 |
| <i>LOKS1 lower T.</i> (LOK 02/04) | 74.33 | 0.15 | 10.36 | 2.80 | 0.10 | 0.03 | 0.13 | 1.03 | 1.63 | 0.02 | 0.01 | 90.58 |
| <i>LOKS1 lower T.</i> (LOK 02/04) | 71.61 | 0.30 | 10.09 | 4.21 | 0.19 | 0.11 | 0.20 | 0.51 | 0.89 | 0.02 | 0.02 | 88.16 |
| <i>LOKS1 lower T.</i> (LOK 04/04) | 73.95 | 0.19 | 10.35 | 2.59 | 0.08 | 0.03 | 0.12 | 1.02 | 1.49 | 0.02 | 0.03 | 89.87 |
| <i>LOKS1 lower T.</i> (LOK 04/04) | 71.48 | 0.30 | 10.12 | 4.19 | 0.20 | 0.10 | 0.18 | 0.51 | 0.83 | 0.02 | 0.04 | 87.97 |

the Lokalalei Member (Fig. 3a). As a consequence, the Kalochoro Tuff, which by definition marks the boundary between the Kalochoro Member and the underlying Lokalalei Member, is not represented in the Lokalalei area (Fig. 3a). In the LOK S8 section, the distinct but geochemically equivalent “*Pinched Tuff*” and “*White and Black Tuff*” correlate with the Lokalalei Tuff that defines the base of the Lokalalei Member (Fig. 3a; Table 3). The Lokalalei Tuff is described by Harris et al. (1988, p. 10) in the Lokalalei area as having been deposited over a dark brown claystone, exactly as it is for the “*White and Black Tuff*” in our LOK S8 section (Fig. 5). This observation fully supports the equivalence of the “*WBT*” with the Lokalalei Tuff. The “*Pinched Tuff*” that lies 2.50 m above the “*WBT*” may represent a reworking phase of the “*WBT*”, or more than likely a second eruptive event of similar nature.

3.3. Facies associations and depositional palaeoenvironments

In the Lokalalei area, the facies associations demonstrate depositional environments ranging from lake shoreline to alluvial environments. In the lower part of the composite section, the fine-grained facies (Facies 3 and 4) and bioclastic facies (Facies 5) demonstrate a freshwater lake coastal environment where foreshore, swash zone and backshore zones can be distinguished (Fig. 13). Bioclastic beds are the result of the accumulation by waves (possibly storm-related). Lakeward oriented low-angle cross-bedding reflect successive episodes of accumulation along the lake strand of floated shells (e.g., Renaut and Owen, 1991), and the preferential orientation of the shells may reflect the swash and backwash action of waves (e.g., Nagle, 1967). These shell accumulations characterize a high-energy shoreface environment. They also relate to high biogenic productivity and rich molluscan fauna diversity in this lake, contrasting with present-day conditions in Lake Turkana (Van Damme and Gautier, 1972; Williamson, 1981). Thin shell beds with preserved grazing tracks on fine sandstone reflect more calm environments such as shallow backshore ponds.

The smectite-rich mudstone and siltstone facies may relate to a low-energy backshore lagoon or embayment environment. This interpretation is more convincing than a flood plain of fluvial origin since lake deposits are represented in the stratigraphic record and no typical fluvial deposits have been observed in relation with this facies. Ripple cross-laminations in fine sand with some local mud-drapes can develop in such an environment. Coarser clastics may

result from fluvial inputs or, when they are mollusc-rich, from wash-over dynamics as suggested by cross-bedded sands prograding landward. Rhizoliths, slikenides and prismatic structures indicate that at least part of these lagoon or embayment deposits are temporarily overgrown by vegetation and affected by pedogenesis as also shown by the presence of kaolinite during periods of lowering lake level (Yuretich, 1979). Temporary drying is very locally indicated by desiccation cracks. Emergence or real terrestrial conditions are also demonstrated by the presence of bioconstructions, notably termite and ant nests that develop in fine sandstone. However, the original depositional conditions of this fine sandstone are more difficult to interpret since it is almost structureless. This sandstone is a lateral equivalent of the rippled to cross-bedded sand as well as of a very fine and loose sand where only faint ripple laminations (without mud-drapes) have been observed. For this last facies, modern terrestrial environments along the western coast of Lake Turkana suggest that an eolian accumulation could be considered, even if no conclusive sedimentary structure has been observed in this particular outcrop.

Finely laminated beige and light brown mudstone (*Sub-facies 5b* in section LOK S7A; Fig. 5) may relate to a short-lived lacustrine episode, also suggested by the planktonic diatom found in the stratigraphically close “*DT*” tephra layer (=Kokiselei Tuff). The hyaloclastic facies possibly identified in the “*Big Tuff*” and Ekalalei Tuff suggests deposition in an open water body. Silica dissolution features that are visible on glass shards and diatom frustules may relate to contact with chemically aggressive water (high pH or very low pH) (Yuretich and Cerling, 1983). Two scenarios could be proposed: either early dissolution immediately after deposition in the lake bottom, or later dissolution by lake water during the Holocene highstands of Lake Turkana (+65–75 m above present lake level), as a consequence of the major erosive phase dated 0.5 Ma (Feibel, 1997) which brought the Nachukui Formation deposits to new surface conditions.

The present-day Ferguson’s Gulf embayment on the central western shore of Lake Turkana, as well as some other smaller comparable coastal systems, provides an interesting analog for this kind of palaeoenvironment. The Ferguson’s Gulf shows an interesting process leading to the construction of a lagoon (Fuchs et al., 1935; Cohen, 1982; Cohen et al., 1986). There, the migration of a sand spit under the influence of the alongshore drift progressively isolates a lagoon from the open lake. A comparable process can be considered for palaeo-lagoons even if available sedimentological

Table 3
Comparative compositional data on tuffs of the Kalocho Member and other tuffs belonging to the Lokalalei Member (Nachukui Formation) (from Harris et al., 1988 and our analyses). The following conversions have been used: TiO_2 (%) \times 5994 = Ti (ppm); $\text{Fe}_2\text{O}_3 \times 0.8998 = \text{FeO}$; Mn (ppm) = $\text{MnO} \times 7745$. In bold letters, correlations between geochemical analyses cited in Harris et al. (1988) and our analyses.

| Tephra name (from Harris et al. (1988)) | FeO | Fe ₂ O ₃ | CaO | K ₂ O | Mn | MnO | Ti | TiO ₂ | Location |
|---|-------------|--------------------------------|-------------|------------------|-------------|-------------|-------------|------------------|------------------|
| <i>Kalocho Member</i> | | | | | | | | | |
| Kangaki Tuff | | | | | | | | | |
| K82-739 | 3.239 | 3.6 | 0.16 | 2.3 | 1523 | 0.19 | 1318 | 0.22 | Kangaki |
| Unnamed Tuff | | | | | | | | | |
| K82-738 | 5.569 | 6.19 | 0.19 | 1.7 | 2512 | 0.32 | 1175 | 0.19 | Kangaki |
| K82-741 | 5.686 | 6.32 | 0.18 | 1.1 | 1805 | 0.23 | 1116 | 0.19 | Kokiselei |
| Unnamed Tuff | | | | | | | | | |
| K82-740 | 4.274 | 4.75 | 0.2 | 1.5 | 1736 | 0.22 | 1796 | 0.30 | Kokiselei |
| K82-737 | 4.229 | 4.7 | 0.21 | 2.1 | 1681 | 0.22 | 1858 | 0.31 | Kokiselei |
| Unnamed Tuff | | | | | | | | | |
| K84-1849 | 5.560 | 6.18 | 0.22 | 1.4 | 2260 | 0.29 | 1446 | 0.24 | Kalocho |
| Ekalalei Tuff | | | | | | | | | |
| K85-2614 | 4.274 | 4.75 | 0.21 | 1.2 | 1772 | 0.23 | 1807 | 0.30 | Lokalalei |
| Kalocho Tuff | | | | | | | | | |
| K34-1848 | 4.112 | 4.57 | 0.19 | 1.6 | 1517 | 0.19 | 1781 | 0.30 | Kalocho |
| <i>Lokalalei Member</i> | | | | | | | | | |
| Unnamed Tuff | | | | | | | | | |
| K82-780 | 2.12 | 2.36 | 0.29 | 2.4 | 1290 | 0.17 | 1913 | 0.32 | Kaitio |
| Nalukuwoi Tuff | | | | | | | | | |
| K82-779 | 3.87 | 4.30 | 0.19 | 2.0 | 1447 | 0.19 | 1504 | 0.25 | Kaitio |
| Unnamed Tuff | | | | | | | | | |
| K82-777 | 4.45 | 4.95 | 0.19 | 2.0 | 1706 | 0.22 | 2145 | 0.36 | Kaitio |
| <i>Kokiselei Tuff</i> | | | | | | | | | |
| K85-2615 | 5.50 | 6.10 | 0.22 | 1.2 | 2406 | 0.31 | 2249 | 0.37 | Lokalalei |
| ET-45 | 5.50 | 6.11 | 0.20 | 1.5 | 2402 | 0.31 | 2276 | 0.38 | Shungura |
| Unnamed Tuff | | | | | | | | | |
| K82-729 | 5.31 | 5.90 | 0.13 | 1.1 | 2058 | 0.26 | 1368 | 0.23 | Lomekwi |
| Unnamed Tuff | | | | | | | | | |
| K85-2654 | 2.81 | 3.13 | 0.37 | 1.8 | 1559 | 0.20 | 3213 | 0.54 | Lomekwi |
| Lokalalei Tuff | 3.10 | 3.45 | 0.19 | 1.80 | 1337 | 0.17 | 1333 | 0.22 | Lokalalei |
| Lokalalei Tuff | | 2.83 | 0.19 | 1.80 | | 0.15 | | 0.29 | Nachukui Fm. |
| (from Brown et al. (1992)) | | 3.17 | 0.16 | 2.03 | | 0.16 | | 0.22 | Nachukui Fm. |
| | | 3.57 | 0.13 | 1.92 | | 0.17 | | 0.22 | Nachukui Fm. |
| This work | FeO | Fe ₂ O ₃ | CaO | K ₂ O | Mn | MnO | Ti | TiO ₂ | Location |
| <i>LOKS2 Tuff</i> | 6.26 | | 0.18 | 0.34 | | 0.33 | | 0.36 | Lokalalei |
| | 4.17 | | 0.17 | 0.65 | | 0.19 | | 0.27 | |
| <i>LOKS1 upper T.</i> | 4.36 | | 0.14 | 0.98 | | 0.19 | | 0.22 | Lokalalei |
| <i>LOKS1 lower T.</i> | 4.71 | | 0.19 | 0.58 | | 0.23 | | 0.30 | Lokalalei |
| (from Prat et al. (2005)) | 3.80 | | 0.18 | 1.41 | | 0.16 | | 0.26 | |
| <i>“Big Tuff”</i> | | | | | | | | | |
| LOK 24/05 | 5.95 | | 0.11 | 0.32 | | 0.30 | | 0.26 | Lokalalei |
| LOK24A/05 | 5.94 | | 0.13 | 0.37 | | 0.29 | | 0.27 | Lokalalei |
| LOK44/05 | 5.79 | | 0.12 | 0.44 | | 0.29 | | 0.26 | Lokalalei |
| <i>“Double Tuff”</i> | | | | | | | | | |
| LOK33/05 | 5.30 | | 0.18 | 0.52 | | 0.26 | | 0.36 | Lokalalei |
| LOK33A/05 | 5.24 | | 0.18 | 1.03 | | 0.27 | | 0.37 | Lokalalei |
| LOK34/05 | 5.59 | | 0.17 | 0.48 | | 0.28 | | 0.38 | Lokalalei |
| <i>“Pinched Tuff”</i> | | | | | | | | | |
| LOK36/05 | 3.05 | | 0.15 | 0.94 | | 0.11 | | 0.19 | Lokalalei |
| <i>“W & B Tuff”</i> | | | | | | | | | |
| LOK38/05 | 2.90 | | 0.12 | 1.13 | | 0.16 | | 0.19 | Lokalalei |

archives do not allow the identification here of any preserved fossil sand spit system. The water of lagoons that are no longer directly connected to the open lake (e.g., due to topographic depression), may originate through wash-over from the lake, and/or from ephemeral fluvial or rain contribution. The presence of wave-dominated shoreline facies demonstrates the existence of strong wind regimes comparable to the modern ones in the Lake Turkana Basin (Butzer, 1971; Hopson, 1974; Olago and Odada, 1996). In the back of the lagoon, sand accumulation by wind can occur, and vegetation and insects can colonize the area.

In the upper half of the section, the predominant facies are conglomerate and sandstone (Facies 1 and 2), that can be interpreted as representing part of a series of alluvial fans distributed along the faulted basin margin (i.e. the Murua Rith-Lapur Border Fault escarpment), the morphology of which is no longer preserved.

The abundant mm-sized olivine and pyroxene phenocrysts visible in Facies 2 indicate a sediment source within the “Turkana Volcanics”. Detailed petrographic studies conducted on this volcanic formation in the Lapur Range (Clément et al., in preparation) show that only flows forming the lower half of the “Turkana Volcanics” are porphyritic rocks with abundant mm-sized crystals of pyroxene and olivine. This suggests that at the time of deposition of the Kalocho Member, the Murua Rith-Lapur Border Fault escarpment was undergoing erosion and was already deeply incised by streams flowing towards the east.

This abrupt environmental change from backshore/embayment environment to alluvial fan environment could be the result of a progradational alluvial system over the lacustrine shoreline. Alluvial progradation may relate to an increase of fluvial dynamics consecutive to intervals of greater precipitation over the basin

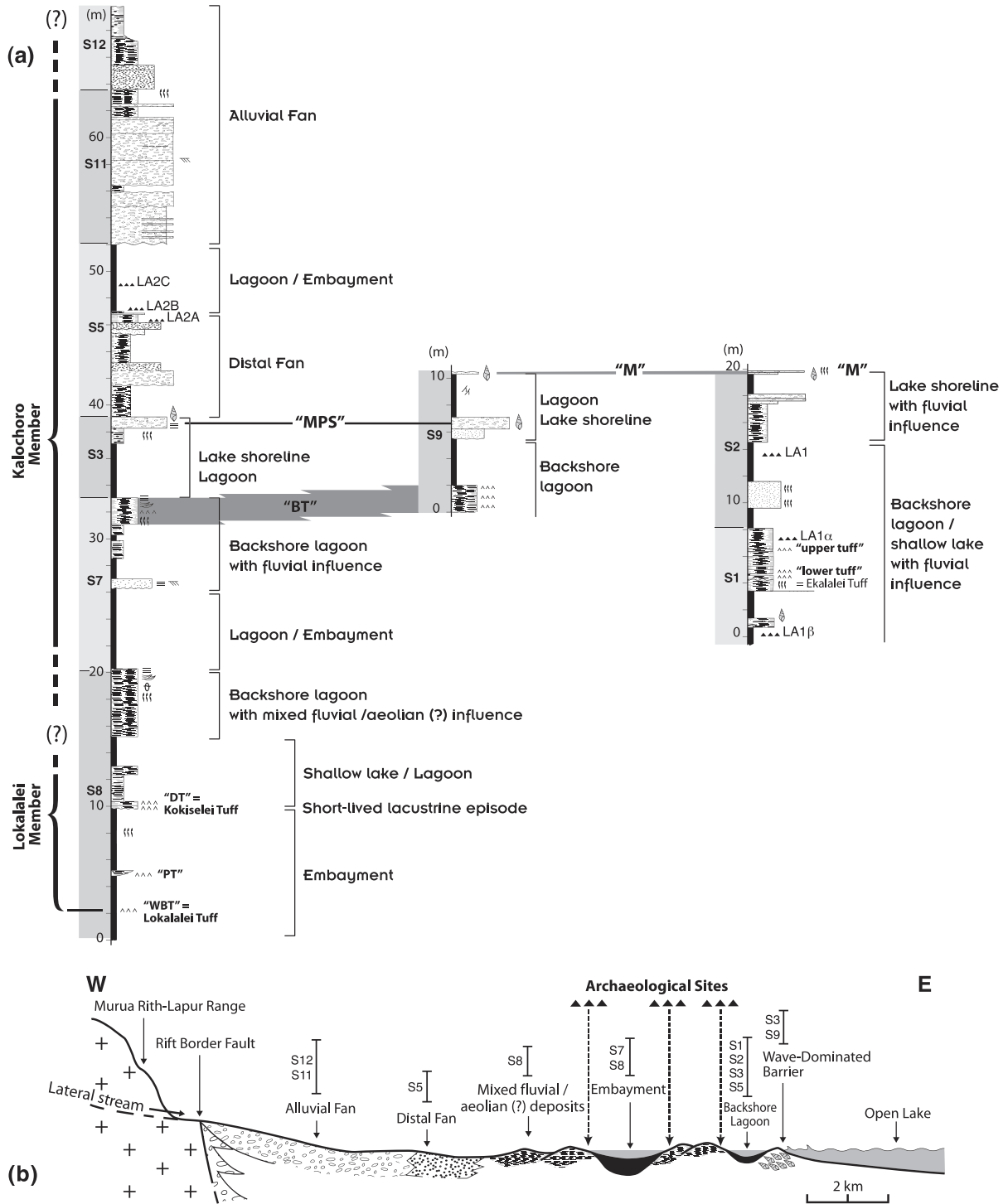


Fig. 13. (a) Composite lithologic log of the sedimentary formations outcropping in the Lokalelei archaeological sites area, showing stratigraphic correlation between the LA1 and LA2C archaeological sites. (b) Morphological/geological cross-section from the edge of the Turkana Basin (Murua Rith-Lapur Range and Border Fault) toward the open lake, showing the succession of environments from west to east: Alluvial fan, proximal then distal, followed by terrestrial systems (possibly mixed fluvial/aeolian deposits), and backshore lagoons or embayments closed by beach-bars built in the swash zone during periods of high wave energy or storms. Location of archaeological sites relate to the shores of lagoons or embayments. Same key as Fig. 5.

catchment. It may also relate to a period of lowered lake level (Vondra and Burggraf, 1978). Clay mineralogy of the conglomerate matrix suggests reworking of mudstone–siltstone facies in the shoreline area. Within this general environmental background ranging from coastal lacustrine to fluvial/alluvial fan system, the LA1 and LA2 archaeological sites appear to be closely associated with a lake shoreline system, and more precisely with a backshore

lagoonal/embayment environment, the LA2 sites lying in a more proximal position adjacent to an alluvial fan environment.

Our palaeogeographical reconstruction of the Lokalelei sites area is essentially based on the characterization of major sedimentary facies identified in the nearby environment of the sites. The major difference between our interpretation and the previously published palaeogeographies (e.g., Brown and Feibel, 1986, 1991;

Feibel et al., 1989, 1991) is based on the interpretation of specific lithofacies such as **Facies 5** situated between the LA1 and LA2 sites. In our interpretation, these bioclastic facies give evidence of a lake shoreline subjected to moderate to high-energy waves associated with strong wind episodes and possibly storm events. This also indicates that the associated lake was large enough to generate high-energy waves. Diatoms locally found in the sections also suggest the existence of shallow or deep water bodies. Banks of lagoons or inter-dune deflationary sags forming the nearshore environment of this lake were occupied by hominins and associated faunas. The nearby upstream environment, formed by ephemeral drainage verging into the lake from the range bordering the basin, was the area where cobbles for knapping activities were collected (Harmand, 2007, 2008).

4. Palaeontological associations

Palaeontological sites and localities identified in the Lokalalei area (see Section 1) yielded mammal fossils scattered on the surface or retrieved from excavations. With the exception of remains originating from the two excavated archaeological sites LA1 and LA2C, all the faunal material is from surface collection, and only identifiable specimens were collected. All localities have been carefully located within the sedimentary succession. Taphonomic conditions are more or less similar through the sequence, with most of the material issued from fine-grained (mudstone to siltstone) deposits, with the exception of the LA3 locality where coarse-grained sediments dominate (Fig. 5). Bones and teeth fragmentation is relatively high. Taxonomic identifications were mostly based on isolated teeth.

Within the entire Nachukui Formation, the Kalochoro Member registers a significant change in the faunal composition, with the first occurrence of genus *Equus*, the replacement of several species (*Hipparion ethiopicum*, *Theropithecus oswaldi*), or species appearance (*E. recki shungurensis*, *Hexaprotodon protamphibius*, *Crocota crocuta*, *Canis* cf. *mesomelas*) (Harris et al., 1988). Among antelopes, the Alcelaphine *Menelikia lyrochera* is common. A new form of *Aepyceros* occurs, as well as *Pelorovis* sp. and *Gazella praethomsoni*. Among the Tragelaphine, *Tragelaphus nakuae* is present in the lower part of the Kalochoro Member, and it is replaced by the greater kudu *Tragelaphus strepsiceros* in the upper part. The Alcelaphine and Reduncine are the most well-represented Bovids in the Kalochoro Member. Some new elements (i.e., primates, carnivores, rhinocerotid) have been added to this global faunal list, and site by site comparisons demonstrate the importance of depositional setting in the taxonomical representations (Brugal et al., 2003). The overall species diversity from the entire Kalochoro Member can be estimated around 35 taxa including 29 mammal species (Harris et al., 1988; Brugal et al., 2003): 26 mammal species have been found at locality LA1, and 6, 10 and 3 species at the LA1-2, LA2 and LA3 localities, respectively. Some species such as *Sivatherium* and carnivores (*Crocota*, *Hyaena*, *Canis*, cf. *Lycaon*) recorded in the upper part of the Kalochoro Member are absent in the Lokalalei area. Conversely, other taxa such as *Homotherium*, *Hippotragus* and Primates (*Homo*, *Cercopithecoides*, *Colobine*) are only represented in the underlying Lokalalei Member (Fig. 3a).

The aquatic taxa (Pisces, Reptiles and Chelonids) are always present but never in large proportions. They appear as a background faunal residue deposited with fine-grained sediment, and the remains (vertebrae, teeth, scales, etc.) are often small in size. The exception comes from the LA3 locality where remains of large size may represent large individuals, particularly reptiles such as *Crocodylus* and *Euthecodon*. The genus *Polypterus* is rare and only represented at the LA1 and LA1-2 sites. The habitat of this species is synonymous with thickets of large water plants along river and lake margins. Its low representation could be more of an indication

of running water. Hippopotamids are noticeably frequent at the LA1 and LA2 sites, but they are only represented by few a teeth fragments and rare bones. The palaeoenvironments interpreted from the sedimentary facies such as lacustrine shorelines or back-shore lagoons are in agreement with the habitats proposed for the aquatic fauna.

In contrast, terrestrial mammals, especially ruminants, are common and diversified, and indicate habitats such as floodplain or in the vicinity of channel banks. Among terrestrial species, the Bovids dominated with at least three Alcelaphine species (*Megalotragus*, *Connochaetes*-size, *Menelikia*-size), and two species of Reduncine (large and medium size). The Tragelaphine are rare, as well as the Bovine. The Antilopine and Aepycerotine come essentially from LA1 assemblages. Together with other grazer like *Equus*, present at LA1 and LA3 localities, and the white rhinoceros *Ceratotherium* found at LA2 site, these species compositions suggest a relatively open savannah-like landscape. However, given the presence of mammals requiring a high plant biomass, like the Proboscids (represented by *Deinotherium* at LA1-2 locality) and the Suids (*Notocolobus*, *Kolpochoerus*), another vegetation type can be inferred, such as bushlands and thickets with wooded parts likely developed along streams. The presence of different species of Primates can be pointed out, in particular at site LA1: *Theropithecus*, *Cercopithecoides* and one *Colobine*. Finally, while four carnivore species, two canids and two hyenids, have been documented in the whole Kalochoro Member (Harris et al., 1988), only one carnivore has been found at the LA3 locality. This carnivore is represented by an almost complete and well-preserved mandible of *Homotherium*, a species which was not recorded in the faunal list provided in Harris et al. (1988). The scimitar-toothed machairodont is evidence of cursorial adaptations, and special hunting techniques well adapted to relatively open habitats with moderate cover (Anton et al., 2005). Its presence at the LA3 locality, within an alluvial fan environment connected to a rocky range, suggests adaptation to rough landscape.

According to these faunal associations, the landscape at Lokalalei can be seen as a mosaic of vegetation with the presence of plains associated with more wooded areas, probably developed near stream and/or lake backshore environment. The difference between localities can be linked to sediment lithology and taphonomical biases (e.g., Behrensmeier, 1975) like differential preservation, nature of the outcrops, irregular survey, etc. The LA1 site gives the more diverse association, indicating a mixed nature of bone assemblage like the ones developed in fine-grained deposits near a lake margin (backshore). The LA1 α site shows a more humid component, such as marsh or lagoon conditions. The LA1-2 locality is also close to an open area with bushy and wooded parts. The LA2 (A–D) sites yielded a limited number of species. Alcelaphine are few, and one large rodent (*Hystrix*?) is present. Proboscids, Primates and *Equus* are missing. This mammal association could indicate a restricted habitat with poor and sparse vegetation, more upstream of the lake margin. The LA3 locality is poor in species. The large size of reptiles found at LA3 suggest a well developed humid environment (wide lagoon or lake), providing to such taxons the possibility of an optimal biological development.

The faunal associations in the Lokalalei area indicate a range of habitats mixing migratory and water-dependent species with more territorial and habitat-specific species and a global vegetation dominated by bushland and grassland with wooded-canopy elements, likely localized along lake shore as well as river courses. Environmental differences between the LA1 and LA2 archaeological sites have to be enhanced, although of unequal sample size and species diversity. The presence of Primates, Proboscids, Giraffids, with more Suids and Equids at LA1 site would indicate a light-woodland and bushland developed in a floodplain or a lake margin. Most of these taxa are missing at LA2, and the landscape

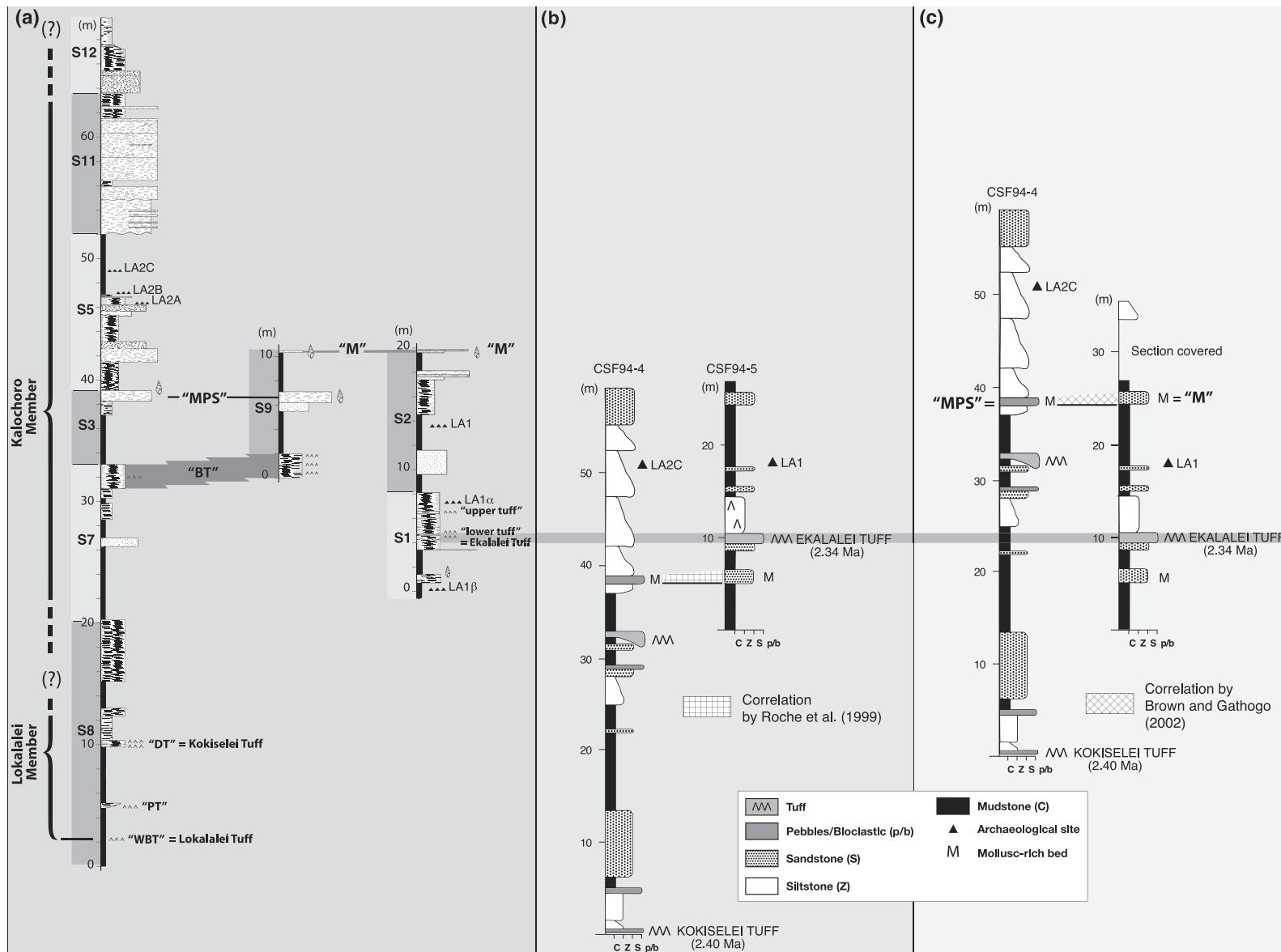


Fig. 14. Chronostratigraphic relation between Lokalelei 1 and Lokalelei 2C archaeological sites. Comparison between: (a) Our correlation. Same key as Fig. 5. (b) Correlation between sections CSF94-4 and CSF 94-5 published by Roche et al. (1999). (c) Alternative correlation proposed by Brown and Gathogo (2002). For a better understanding of the figure, the gastropod-rich bed marked M at about 28 m on the original CSF94-4 section published by Roche et al. (1999) is not labelled.

can tentatively be reported as a grassier and drier component (habitats *sensu* Kovarovic and Andrews, 2007). The difference can also result in the topographic location, with strong influence of a fluvial/alluvial fan environment in a more proximal situation facing a rocky basin watershed, as is the case for the LA2 and LA3 sites located in an ephemeral stream context.

5. Stratigraphic correlation between the LA1 and LA2 archaeological sites. Chronological implications

To determine the stratigraphic relationship between the LA1 and LA2 sites, several key lithostratigraphic sections were used, for which clear marker beds (two mollusc-packed beds, and one tephra bed) have been carefully traced in the field, and correlation was completed by geochemical comparison of tephra layers. Detailed sections are presented in Fig. 5, while Fig. 14 shows our correlation compared to previous works of Roche et al. (1999) and Brown and Gathogo (2002).

From the LA1 site, we used a well-marked 0.10-m thick gastropod-rich pebbly sandstone, that we named “M”, which has been precisely traced between section LOK S2 and section LOK S9 (Figs. 5 and 14a). From the LA2 sites, we identified another prominent marker bed, named “MPS” (as for “Mollusc-Packed Sandstone”), and that we used to correlate the LOK S5 and S6 sections (that contain the LA2A, 2B and 2C sites) to the S4 and S3 sections. This “MPS” bed was perfectly traced in the field between sections LOK S5, S4 and S3 (Figs. 2, 5 and 14a).

The key to our stratigraphic correlation between the Lokalelei 1 and 2 sites is represented by section LOK S9. The base of this section shows a 2-m thick blue-grey tephra that has been traced in the field and then correlated with the “Big Tuff” (BT) at top of section LOK S7 (Figs. 5 and 14a). This field correlation has been subsequently confirmed by geochemical analyses (see Section 3.2.1; Fig. 12a). At LOK S7, the top of the “Big Tuff” is characterized by a beige, finely laminated tuffaceous layer that was carefully traced through the LOK S10 section up to LOK S3, where it correlates to a 0.60-m thick beige tuffaceous mudstone showing fine laminations and crumpling (Fig. 5). This stratigraphic link between sections LOK S7 and S3 strengthens the correlation between LOK S3 and LOK S9. Thus, the “MPS” bed at the top of LOK S3 is estimated to correlate with the 0.90-m thick gastropod-rich microconglomerate (shells of *Melanoides* sp. and small *Bellamya* sp.) situated at ~6.20 m on LOK S9 section (Figs. 5 and 14a). However, due to poor outcrop conditions, bed-to-bed correlation between the “MPS” bed at section S3 and its equivalent at section S9 was unsuccessful. This correlation was at last proven using the “Big Tuff” as intermediate marker bed (Fig. 14a).

Our correlation work shows clear differences with both of the previously proposed correlations. The main difference between our work and the correlation proposed by Roche et al. (1999) is based on a disagreement concerning the stratigraphic position of the mollusc-rich bed (named M) used as marker bed to link the CSF94-5 section (associated to LA1 site) with the CSF94-4 section (associated to the LA2C site) (Fig. 14b). The same disagreement was expressed by Brown and Gathogo (2002). The M marker bed used by Roche et al. (1999) to support their correlation model is situated below the Ekalalei Tuff (Fig. 14b). Our correlation is based on the “M” bed which is situated well above the Ekalalei Tuff (Fig. 14a; sections S2 and S9). Our field work demonstrates that the “M” marker bed corresponds (despite a significant difference in thickness) to the mollusc-rich bed M located at ~24 m in the CSF94-5 section (Fig. 14b), used by Brown and Gathogo (2002) for their correlation (Fig. 14c). The other difference between our correlation and the one proposed by Brown and Gathogo is that our “MPS” marker bed corresponds to the mollusc-rich bed (also

named M) located at ~38 m in the CSF94-4 section (Fig. 14a and c), but clearly does not correlate with the “M” bed (as suggested by those authors) which lies 3.20 m above the “MPS” bed (Fig. 14c; section S9). This observation totally disagrees with Brown and Gathogo’s correlation presented on Fig. 14b.

Numerical values for the relative positions of the archaeological and palaeontological sites cited in this work have been calculated using these correlations. The top of the Ekalalei Tuff at section LOK S1 has been used as reference level. Results are presented in Fig. 15. Thus, our section measurements indicate an interval of sediment of 11.20 m from the LA1 archaeological site to the LA2C site, whereas Brown and Gathogo (2002; p. 700) were proposing an interval of 16 m. Considering a sedimentation rate (SR) of 152 mm/ka, they suggested (Brown and Gathogo, 2002, pp. 700–701) that the LA2C archaeological site would be approximately 100,000 years younger than the LA1 site. In this work, using the same SR value of 152 mm/ka, we propose an age difference between the LA1 and LA2C archaeological sites close to 74,000 years.

Sedimentation rate is a reliable tool for time estimation within environments where low-energy and regular fine-grained sedimentation dominates, like deep lacustrine or marine environments. In a continental rift setting, the reliability in using SR values for time estimation can be criticized considering the large variety of sedimentary facies. This particularly applies to the Nachukui Formation and Kalocho Member, where various types of sediment ranging from mudstone to conglomerate co-exist, as well as erosion/gap/deposition episodes. The ~11 m sediment interval that separates the LA1 and LA2C archaeological sites essentially shows medium to coarse clastics (pebbly sandstone and some conglomerate constituting about 30% of the sediment interval), alternating with mudstone, silty mudstone or siltstone (forming 70% of the interval). In this part of the section, the pebbly sandstone

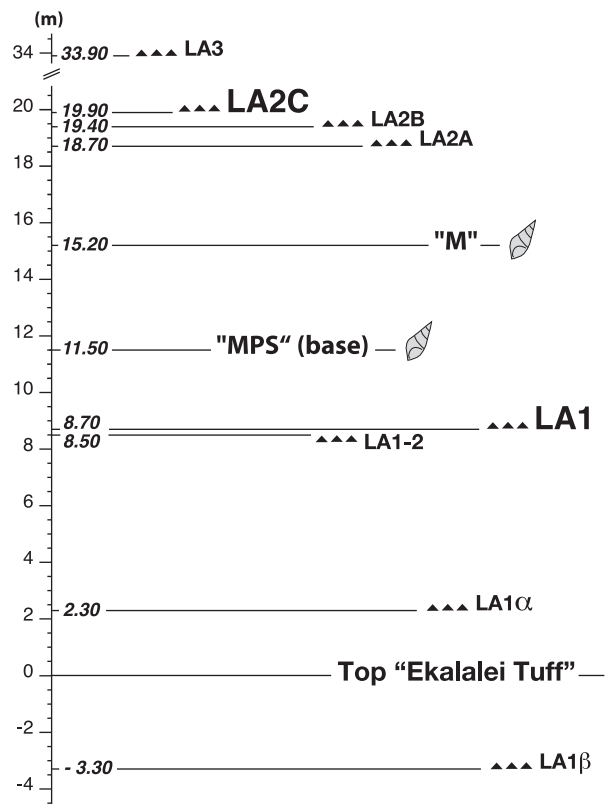


Fig. 15. Intervals in metres calculated on the basis of our stratigraphic correlations between the Lokalelei 1, Lokalelei 2C archaeological sites and other archaeological and palaeontological localities.

Table 4

Average sedimentation rates deduced from various sedimentary environments of the Nachukui Formation (cited from Brown and Gathogo (2002)*, Wynn (2004)**, and Feibel et al. (1989***) used for calculation of the time interval (year) between the LA1 and LA2C archaeological sites.

| Locality or member | Type of sedimentary environment | Sedimentation rate (mm/ka) | Time interval between the LA1 and LA2C archaeological sites (year) |
|-----------------------------------|---|----------------------------|--|
| Lokalalei Member* | (?) | 152 mm/ka | 73,684 |
| Lonyumun** | Lacustrine-fluvial | 250 mm/ka | 44,800 |
| Kataboi** | Fluvial-lacustrine | 89 mm/ka | 125,842 |
| Lomekwi** | Predominantly fluvial, short lake episode | 180 mm/ka | 62,222 |
| Lokalalei** | Fluvial facies | 233 mm/ka | 48,068 |
| Kalochoro** | Fluvial-lacustrine | 174 mm/ka | 64,368 |
| Nariokotome** | Lacustrine to shoreline | 256 mm/ka | 43,750 |
| Kaitio** | Predominantly lacustrine | 586 mm/ka | 19,112 |
| Natoo** | Predominantly lacustrine | 215 mm/ka | 52,093 |
| Moiti Member*** Koobi Fora Fm. | (?) | 100 mm/ka | 112,000 |
| KBS Member*** Koobi Fora Fm. | (?) | 55 mm/ka | 203,636 |

or conglomerate beds are generally characterized by erosional bases of variable prominence (Fig. 5). This coarse sedimentary facies association reflects an ephemeral stream/alluvial fan environment. The mudstone to siltstone facies are interpreted as having been deposited in a backshore lagoon/embayment environment. Erosion processes, mainly associated to coarse-grained facies, are difficult to quantify in terms of duration and corresponding eroded sediment thickness. In lake backshore and fluvial environments, with low to medium energy, sedimentation rates are generally high but may drastically vary from a few hundred mm up to 1000 mm/ka (Smith and Smith, 1980). In this type of environment, the duration of accumulation of the ~11 m thick deposits that separate the LA1 and LA2C sites could be estimated to have been only 11,000 years. Other SR values are available in the literature for the Nachukui Formation (Feibel et al., 1989; Wynn, 2004) (Table 4). Using such values, the duration for the deposition of ~11 m of sediment would have been comprised between 110,000 and 200,000 years.

The 11.20 m sediment interval between the LA1 and LA2C sites has been measured through careful bed-to-bed and cross-checked field correlations between close (maximum distance 0.5 km) lithostratigraphic sections (Figs. 2 and 5). Nevertheless, field observations clearly show that in such types of ancient and modern depositional environments, where river streams, small or large water ponds and lake shore line are often closely associated, lateral facies changes are associated with rapid thickness variations. Thus, the palaeogeographic location of the studied sections has a direct control on thickness of sedimentary beds and, as a consequence, on the cumulative thickness of the whole sediment pile. Therefore, our time estimate based on the ~11 m sediment interval obtained between the two archaeological sites could be re-assessed by measuring when possible other sections at other locations within the Lokalalei area. Our 74,000 years interval time value has been obtained by combining independent field data acquisition (13 new high-resolution lithostratigraphic sections) and a similar age difference estimation method based on sedimentation rates. In such a case, only a direct absolute dating of the sites could bring a conclusive answer to such a question.

6. Conclusions

From the lithostratigraphic sections presented in this work and previous papers (Roche et al., 1999; Brown and Gathogo, 2002; Delagnes and Roche, 2005), the LA1 and LA2 archaeological sites are shown to be stratigraphically distinct. Our high resolution data demonstrates that LA2 is situated ~11 m above LA1, representing a time interval of slightly less than 74,000 years using the sedimentation rate value of 152 mm/ka calculated by Brown and Gathogo (2002). Other valid SR values produce different time intervals ranging from ~44,000 to 200,000 years.

The calculation of the time interval between the sites is of great importance as it may play a major role in interpreting hominin evolution. Such calculation is based on estimated thickness of sediment intervals as discussed above, and of a calculated sedimentation rate value. Determining the accuracy of the sedimentation rate values implies a precise knowledge of the sedimentary facies characteristics of the sediment interval, a comparative analysis with similar environments of different ages, taking into account the confidence interval of the age values used for sedimentation rate calculation (e.g., Cohen et al., 1993). On the other hand, isotopic ages obtained on volcanics now offer a minimal error bar. New ^{40}Ar – ^{39}Ar age measurements now have a precision on the order of 1% (McDougall and Brown, 2006). Stratigraphers therefore must adapt their lithostratigraphic work to a time scale compatible with the error bar in isotopic age measurements. Nevertheless, such measurements remain improvable, and this requires us to still be very cautious in terms of interpretation of hominins behavioural evolution. Expedient patterns of *débitage* in Lokalalei 1 versus organized ones in Lokalalei 2C have been demonstrated, but as stated earlier, these technological differences are not necessarily linked to evolutionary trends due to time, and should not be considered as such.

On the basis of our sedimentological data, the Lokalalei hominin occupation sites are interpreted as being associated with banks of lagoonal ponds or embayments in the backshore environment of a large lake. Modern analogs of these types of environments exist today in the Ferguson's Gulf region in the central western part of Lake Turkana (Fig. 1). The bioclastic shoreline facies described in the Lokalalei sections demonstrates a large and deep freshwater lake with rich molluscan faunas. The wave-dominated shelf and shoreline facies reflect a large and deep water body temporarily affected by strong winds. Ephemeral detrital inputs in the vicinity of the sites indicate the presence of a wide alluvial fan system fed from a deeply incised watershed along the faulted basin margin. Coarse detrital deposits at the top of the section relate to further progradation of the fan system through the lacustrine littoral, consequently to a period of lower lake level. This type of rough, pebbly environmental conditions may have been a less favourable site for hominin occupation than the lagoonal or embayment ones, except as areas from where the knappers collected their raw materials. It has been demonstrated for both sites that the procurement of raw material for knapping activities was made within fluvial channels located close or very close to the sites (Harmand, 2005, 2009). Differences in environmental settings were also shown by the sediments embedding the artefacts: silty mudstone is in favour of the presence of still water for Lokalalei 1 site and, for Lokalalei 2C, a coarse-grained sand lens in erosional contact with silty clay suggests the "peripheral zone of a periodic stream" (Delagnes and Roche, 2005). In addition, the faunal associations found at Lokalalei indicate a range of habitats mixing migratory and water-dependent species living in a mosaic of vegetation with bushland and grassland and wooded-canopy elements, likely localized along lake shore as well as river courses. At the LA1 site, fauna association suggests a lake margin habitat, and at the LA2 sites a

habitat with poor and sparse vegetation along a channeling/alluvial fan system landward of a lake margin.

The basin-wide palaeogeographic reconstruction proposed here for the 2.34 Ma time period during which the Lokalalei sites formed, reflects a landscape dominated by a palaeo-lake that may correspond to the “Lokeridede lake phase” dated 2.5 Ma, as characterized by Williamson (1981) and Feibel (1988). In Eastern Africa, the 2.7–2.4 Ma interval is demonstrated to be a major lake period, suggesting consistency in the moisture history of the Ethiopian, Kenyan and Tanzanian rift basins (Williams et al., 1979; Tiercelin and Lezzar, 2002; Trauth et al., 2005, 2007; Deino et al., 2006). Thus, the presence for the 2.4–2.3 Ma time period in the Turkana region of a large and deep lake did not arise in palaeoclimatic isolation. This humid phase was superimposed on the longer-term aridification trend affecting East Africa since 2.8 Ma (deMenocal, 2004), that may be evidenced in the upper Lokalalei sediment sequence by progradation of a landscape dominated by coarse clastics over the lake shoreline consequently to lake level fall, and by a rising proportion of arid-adapted fauna (Brugal et al., 2003; Hernández Fernández and Vrba, 2006). Such rapid variations between humid and arid episodes in a unique environment such as the East African Rift may have been of major importance in controlling hominin evolution.

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