



Pleistocene Landscape Variability Recorded in the Homo-Bearing Dandiero Basin (Eritrea)

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Abstract

Plio-Pleistocene fluvio-lacustrine continental successions can provide unique insights into link transformations of terrestrial ecosystems with related landscapes in East Africa. Continental deposits of the Dandiero Basin (Eritrean Rift margin) form a 450–500 m sedimentary succession recording paleoecological and landscape transformations that occurred at the Early-Middle Pleistocene transition in the northernmost sector of the African Rift Valley. The Dandiero Basin is bounded by two main, roughly NNW-SSE trending faults, which were superimposed on the N-S trending faults that delimited the basin at early stage of development. The basin-fill succession consists of alternating fluvial and lacustrine deposits. The quality of magnetostratigraphic data and its comparison with radiometric dating and vertebrate paleontology, constrains deposition between ~1.2 up to 0.75 Ma. Integrated sedimentological, paleopedological and isotopic data suggest that although sedimentation occurred under the dominant control of tectonics repeated shifts from fluvial to lacustrine deposition were also triggered by climate forcings.

Keywords

Pleistocene • Climate • Fluvio-lacustrine deposition • East Africa • Eritrea

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5.1 Introduction

Plio-Pleistocene environmental dynamics played a crucial role in shaping the modern landscapes and in distributing different biota worldwide. In East Africa, ecological and landscape changes, associated with Plio-Pleistocene environmental instability (e.g., de Menocal 2004; Maslin et al. 2014), had considerable impact on mammal dispersal and diversification (Fernández and Vrba 2006; Patterson et al. 2014) and on hominid evolution as well (Potts 2013; Antón et al. 2014). Plio-Pleistocene marine and lacustrine deposits provide continuous, high-resolution proxies, which are widely investigated to understand time and mode of paleoecological transformations. However, fluvio-lacustrine continental successions are no less important and can provide unique insights to link transformations of terrestrial ecosystems with the landscape change (Wolde Gabriel et al. 2005; Aronson et al. 2008). In East Africa, Early to Middle Pleistocene paleoecological and landscape changes are essentially documented in the continental succession of the Olduvai Gorge (Domínguez-Rodrigo et al. 2013) in Tanzania, the Daka Member of the Bouri Formation (Gilbert and Asfaw 2008) in Ethiopia, and the Ologesailie Formation (Owen et al. 2009) in Kenya.

The Early-Middle Pleistocene continental deposits of the Dandiero Basin (Eritrean Rift margin) form a unique sedimentary succession recording paleoecological and landscape transformation during the Early-Middle Pleistocene transition (Abbate et al. 2004) in the northernmost sector of the Red Sea through of the African Rift Valley system. The fluvio-lacustrine deposits filling the basin contain abundant remnants of fossil mammals and artifacts and, over the past 25 years, provided also several human remains, including a complete cranium. This paper summarizes a number of previous multidisciplinary works (Abbate et al. 2004; Delfino et al. 2004, 2018; Ghinassi et al. 2009, 2013, 2015; Papini et al. 2013; Rook et al. 2010, 2013; Sani et al. 2017; Scarciglia et al. 2018) and aims at outlining the major

landscape transformations that have occurred in the Dandiero Basin since its origin during the Middle Pleistocene.

5.2 Geological Settings

The Dandiero Basin is located 35 km south of the Gulf of Zula (Fig. 5.1), along the N-S trending western marginal graben system of the Danakil depression (Abbate et al. 2004). The Danakil depression extends for ca. 300 km in a NNW-SSE direction, and it is bounded by the Eritrean–Ethiopian plateau and by the Danakil block to the west and east, respectively. The alignment of the Quaternary Mahalta-Afrera volcanic centers marks the southern termination of the Danakil depression. The sedimentary infill of the Danakil depression is mainly made of Plio-Pleistocene marine evaporitic deposits, which onlap Palaeozoic–Mesozoic sedimentary units, the Precambrian basement of the Eritrean–Ethiopian plateau and the Danakil horst. Moreover, huge volumes of flood basalts, mainly referred to as the Stratoid Series, were outpoured since the Middle Miocene.

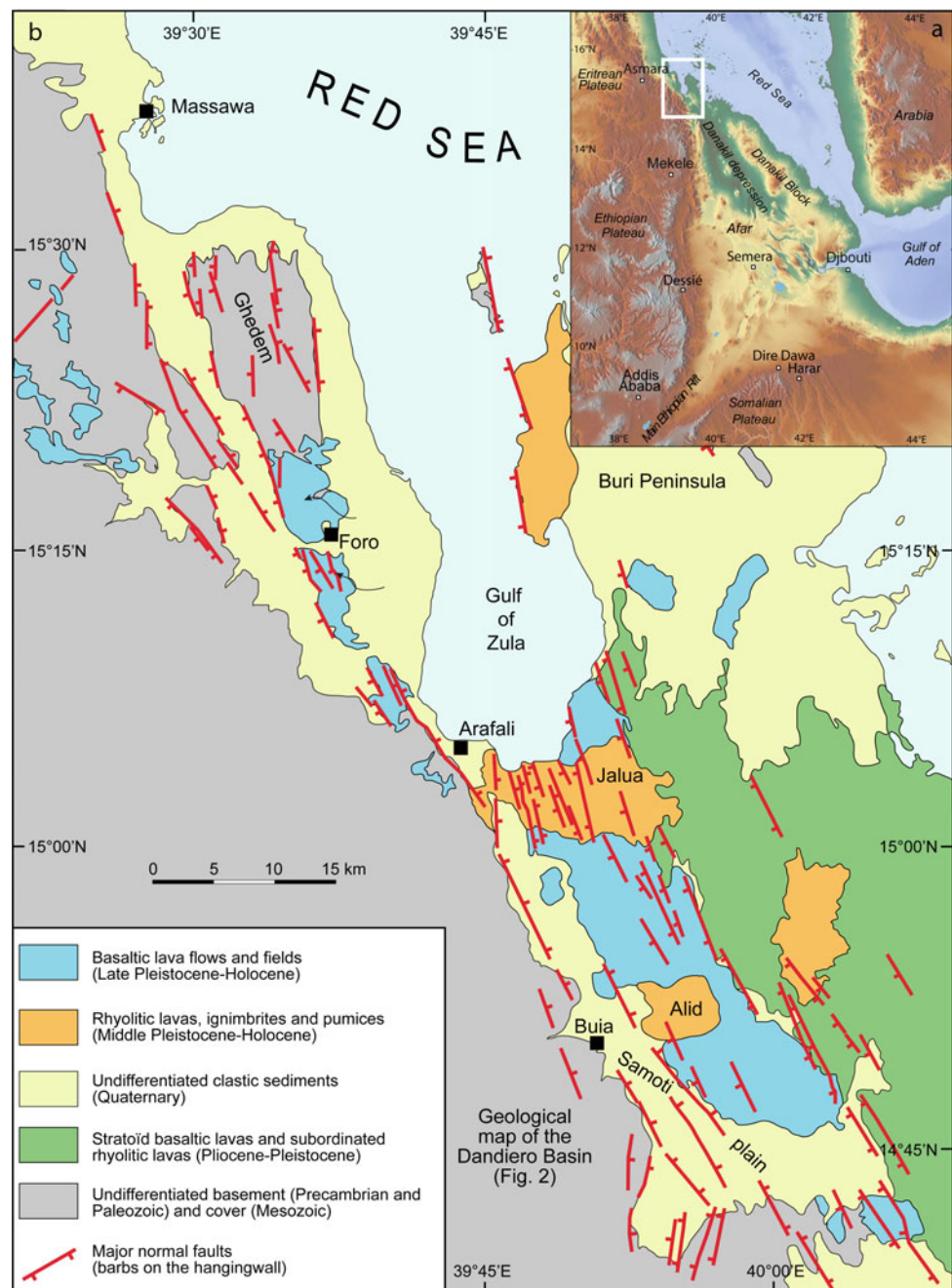
The Dandiero Basin is filled with Early-Middle Pleistocene fluvial and lacustrine deposits (Fig. 5.2), which were mainly fed from the south (Abbate et al. 2004; Ghinassi et al. 2013, 2015). Two major NNW-SSE trending and east-dipping normal faults roughly bound the basin. The westernmost fault delimits the basin from the Eritrean Plateau, whereas the easternmost one marks the boundary between the basin-fill deposits and the Samoti Plain, where fluvio-aeolian sedimentation currently occurs (Fig. 5.2). The age of the basin-fill deposits has been constrained to the Early-Middle Pleistocene transition by means of integrated magnetostratigraphic, geochronological and paleontological data (Abbate et al. 2004; Ghinassi et al. 2015). The sedimentary succession filling the Dandiero Basin (Fig. 5.2) has been referred as the Dandiero Group (Abbate et al. 2004; Ghinassi et al. 2009; Papini et al. 2013), and it has been partitioned into three unconformity-bounded stratigraphic units (Synthems): Maebele Synthem (Early to Middle Pleistocene), Curbelu Synthem (Late Pleistocene) and Samoti Synthem (Late Pleistocene to Holocene). The Maebele Synthem is the focus of the present study and consists of six formations (Abbate et al. 2004; Papini et al. 2013): fluvial Bukra Sand and Gravel (the oldest), fluvio-deltaic Aalat Formation, fluvial Wara Sand and Gravel, lacustrine Goreya Formation, fluvio-deltaic Aro Sand and alluvial Addai Funglomerate (the youngest).

5.3 The Basin-Fill Succession

5.3.1 Sedimentology and Magnetostratigraphy

The Dandiero Basin infill succession is ca. 450–500 m thick and has been investigated in four main sections: Dandiero River, Aro Mt., Aalat well and Aalat Mt. (Fig. 5.3). The Dandiero river section is located to the south, in the upstream reaches of the basin, whereas the Aalat Mt section is in the downstream portion of the basin (Fig. 5.3). These sections include the same stratigraphic units and have been physically correlated through integration of remote sensing analyses and a detailed ground checking. Correlations across these sections allowed one to depict a basin-scale stratigraphy, along with detecting downstream transformations of depositional environments and landscapes. The Bukra Sand and Gravel Fm. is the lowermost stratigraphic unit of the succession and consists entirely of fluvial deposits, which onlap the metamorphic bedrock. This unit is at least 120 m thick and includes 2–6 m thick channelized sandy and gravelly bodies with overbank mud (Fig. 5.4a). Its uppermost part consists of dominant overbank mud that commonly lacks clear evidence of pedogenic processes. Fluvial deposits of the Bukra Sand and Gravel Fm. are abruptly covered by lacustrine sediments, which contain a major calcareous layer bearing peculiar fossil traces (Fig. 5.4b, c; Abbate et al. 2012). This layer originated in shallow water setting, as pointed out by the local occurrence of desiccation cracks and represents a basin-scale key bed (“Donut key bed” in Abbate et al. 2012; Fig. 5.3) which, in the southern part of the basin, directly overlies the metamorphic bedrock. The donut key bed marks the base of the Aalat Fm., which is ca. 70 m thick, although at the Aalat well site (Fig. 5.3) it thins to 35 m. The Aalat Fm. consists of two major fluvial intervals embedded within deltaic and lacustrine deposits (Fig. 5.4d, e). The fluvial deposits occur in the lower and upper part of the Aalat Fm. and mainly consist of amalgamated, channel-like bodies ranging in thickness between 1 and 3 m, whereas deltaic sediments were mainly accumulated by sandy shoal water deltaic systems, which formed coarsening-upward, compensationally stacked lobate units up to a few meters thick. The uppermost part of these deltaic deposits, that commonly host fluvial distributary channels, locally contains centimeter to decimeter-thick, laminated sandy layers cemented with secondary gypsum. Gilbert-type delta deposits occur only in the central part of the Aalat Fm. and consist of clinostratified sands. The Gilbert-type delta system was sourced from the south and reached a maximum

Fig. 5.1 Geographic location of the Dandiero Basin (see Fig. 1 for location)



thickness of ca. 10 m, pointing to a 10 m-deep lake. The lacustrine flooding event, which created accommodation space for the emplacement of this Gilbert-type delta, allowed for the development of a clear stratigraphic surface (i.e., flooding surface) that is the second basin-scale key bed (Fig. 5.3). Lacustrine deposits mainly consist of massive to laminated mud. The major fossiliferous horizon of the basin-fill succession is sited in the fluvial deposits occurring in the upper part of the Aalat Fm. This horizon provided abundant fossil mammal remains and artifacts, along with several human bones, which were mainly accumulated at the

base of channelized sand. Fluvial beds in the upper part of the Aalat Fm. show also paleopedological features, consisting of iron-oxide/hydroxide mottles and coatings approximately conformable to bedding and laterally continuous hardpans up to 50 cm thick.

The overlying Wara Sand and Gravel Fm. is entirely made of fluvial deposits but, unlike the Bukra Sand and Gravel Fm., it mainly consists of isolated fluvial channels embedded within alluvial plain deposits (Fig. 5.5a). The thickness of the Wara Sand and Gravel Fm. is ca. 90 m at the Aalat Mt. section, but it increases to 120 m upstream, in the

Fig. 5.2 Geological map of the Dandiero basin (modified after Sani et al. 2017)

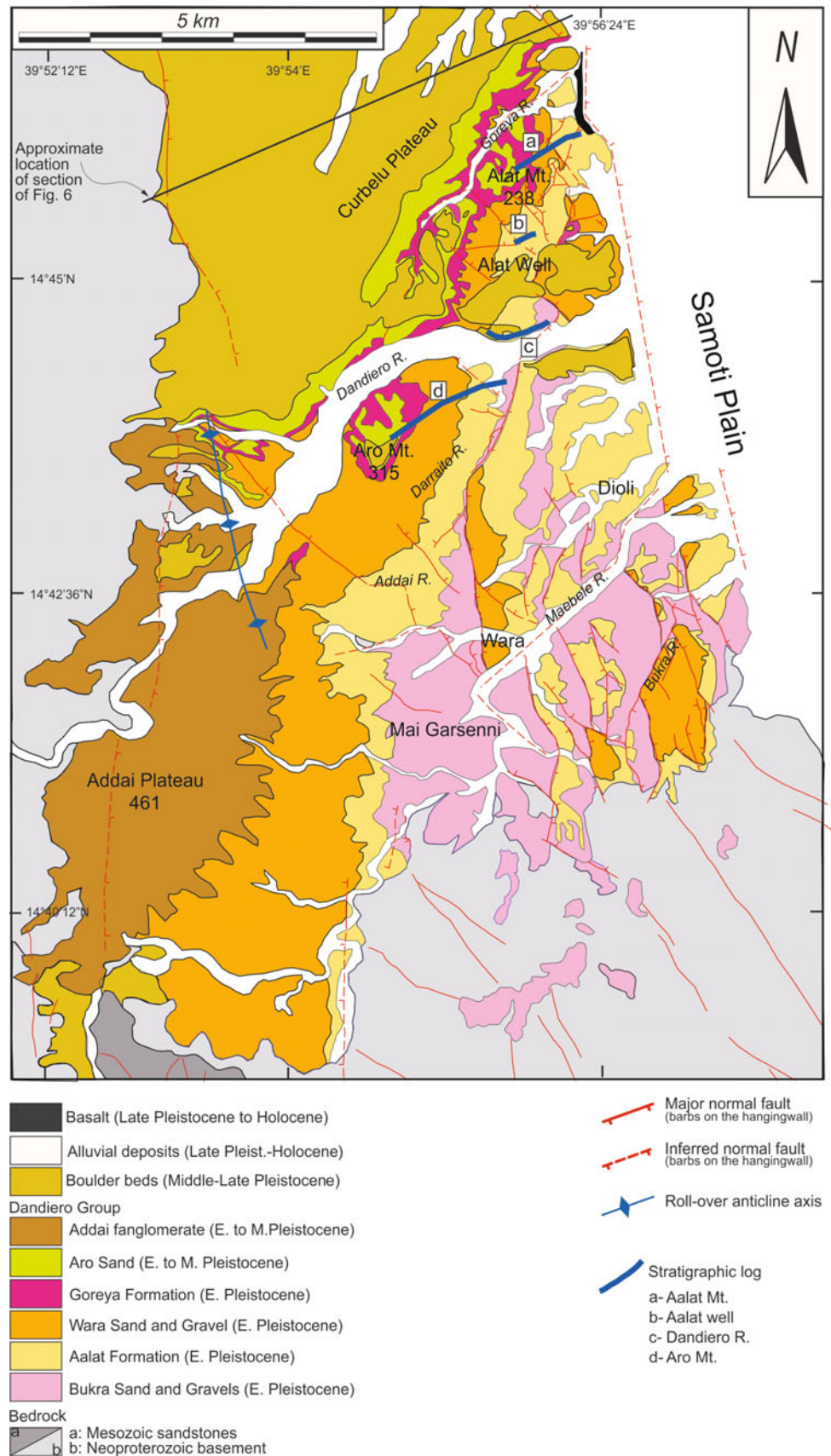
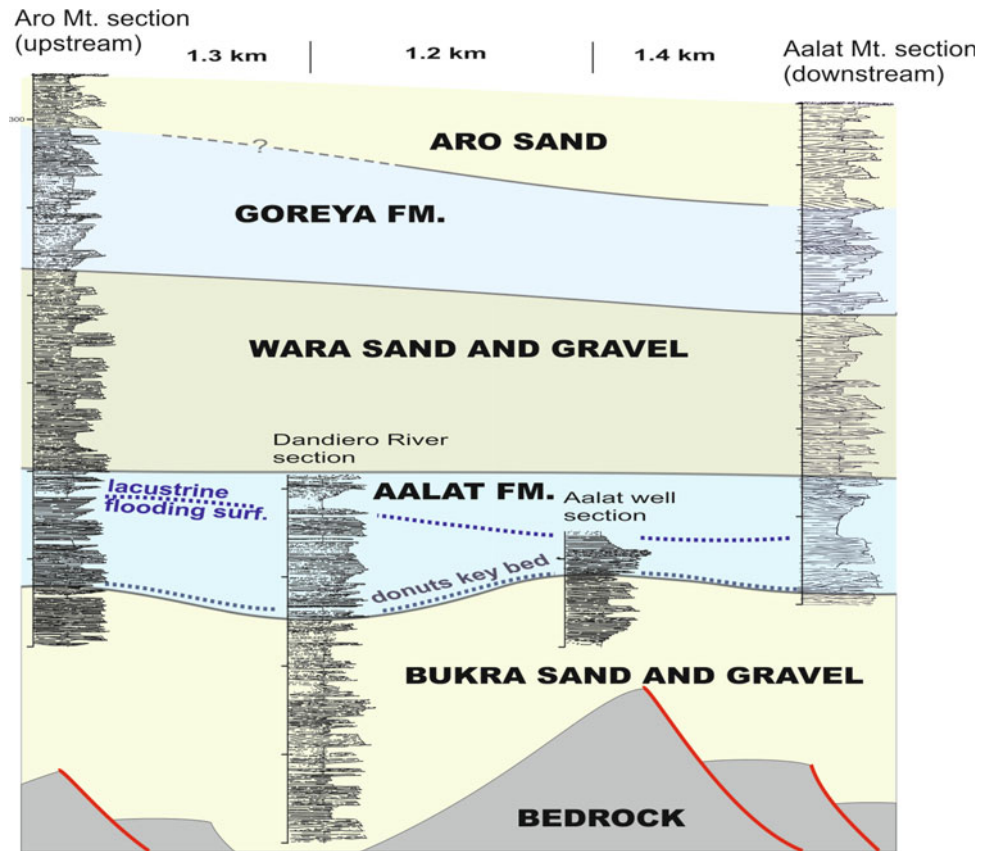


Fig. 5.3 Downdip variability of different formations composing the Dandiero basin-fill succession



Aro Mt. section (Fig. 5.3). Channelized deposits are essentially sandy and tend to increase in thickness from 2–3 m at the base to 7–8 m in the top of the formation. Overbank deposits are mainly made of crevasse sand with subordinate overbank mud, the latter showing local pink to pale brown and reddish yellow iron-oxyhydroxide mottles and sub-vertical to sub-horizontal carbonate-filled veins.

The overlying Goreya Fm. is about 65 m thick and consists of fluvial and lacustrine deposits, though fluvial sediment is dominant in the upstream reaches of the system (Aro Mt. section). In the distal part of the basin, two major lacustrine intervals are separated by a fluvial unit (Fig. 5.5a). The lacustrine deposits are essentially muddy and are characterized by a high content of carbonates and the presence of freshwater shells (Fig. 5.5b). The fluvial sediments are sandy and form amalgamated channelized bodies up to 7 m thick, which, in their upper part, show yellowish iron-oxyhydroxide mottles.

The Goreya Fm. is covered by the fluvial Aro sand (Fig. 5.5c), which thins northward from 80 to 60 m (Fig. 5.3). The Aro sand consists of channelized sand and overbank sandy mud occurring in a similar proportion. Channelized sand deposits form 6–8 m thick bodies, whereas overbank deposits are made of crevasse sand with subordinate overbank mud and levee materials. Overbank

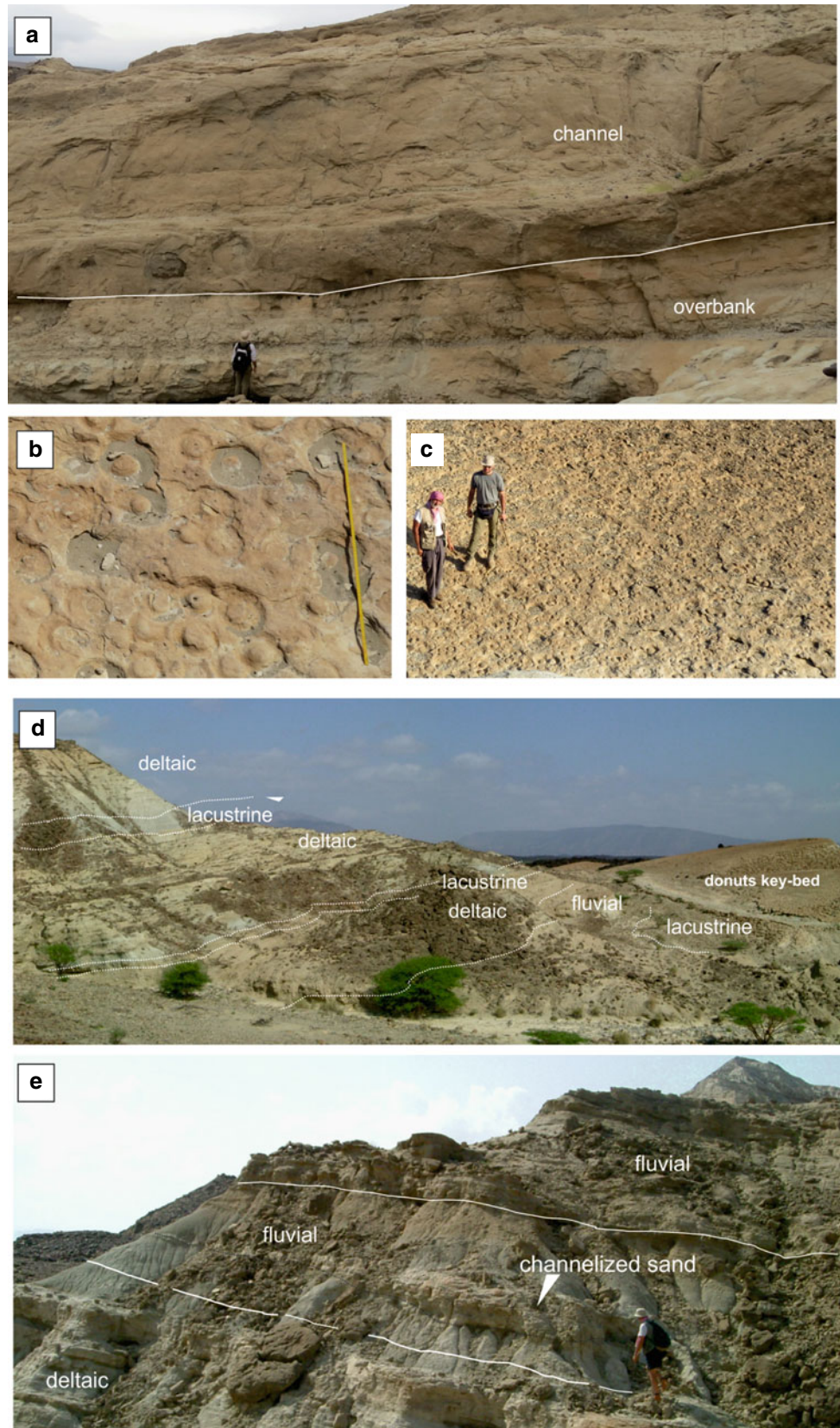
mud also includes secondary carbonate coatings on aggregate surfaces and small nodules.

In the Aalat Mt. area, paleoflow measurements document an overall provenance from the south, whereas close to the Aro Mt. zone flows were mainly sourced from the west (Fig. 5.6), following the gradual transition of the deposits embedded between the Bukra Sand and Gravel Fm. and the Aro Sand into the conglomerates of the Addai Fm. These conglomerates are a few hundred meters thick and consist of poorly organized, channelized gravel emplaced in an alluvial fan setting.

The Dandiero basin-fill succession is erosively overlain by alluvial fan gravels, which contain clasts of ignimbrites emitted by the Alid volcano (Duffield et al. 1997) in their uppermost part.

Detailed magnetostratigraphic analyses through the basin-fill succession were carried out (Ghinassi et al. 2015; Sani et al. 2017), and the results were correlated with the polarity standard scale (Fig. 5.7), observing the constraints provided by fission-track radiometric ages (Bigazzi et al. 2004) and the general age attribution of mammal biochronology (Delfino et al. 2004, 2018; Ferretti et al. 2003; Martínez-Navarro et al. 2004, 2010; Medin et al. 2015; Rook et al. 2010, 2013). Stratigraphic key horizons of the Aalat Fm., represented by the lacustrine flooding surface

Fig. 5.4 Basin-fill deposits—the lower part of the succession. **a** Fluvial facies of the Bukra Sand and Gravel Fm. **b, c** Top surface of the donut key bed at the Aalat Oasi section. **d** Lower part of the fluvio-lacustrine Aalat Fm. **e** Fluvial deposits in the upper part of the Aalat Fm



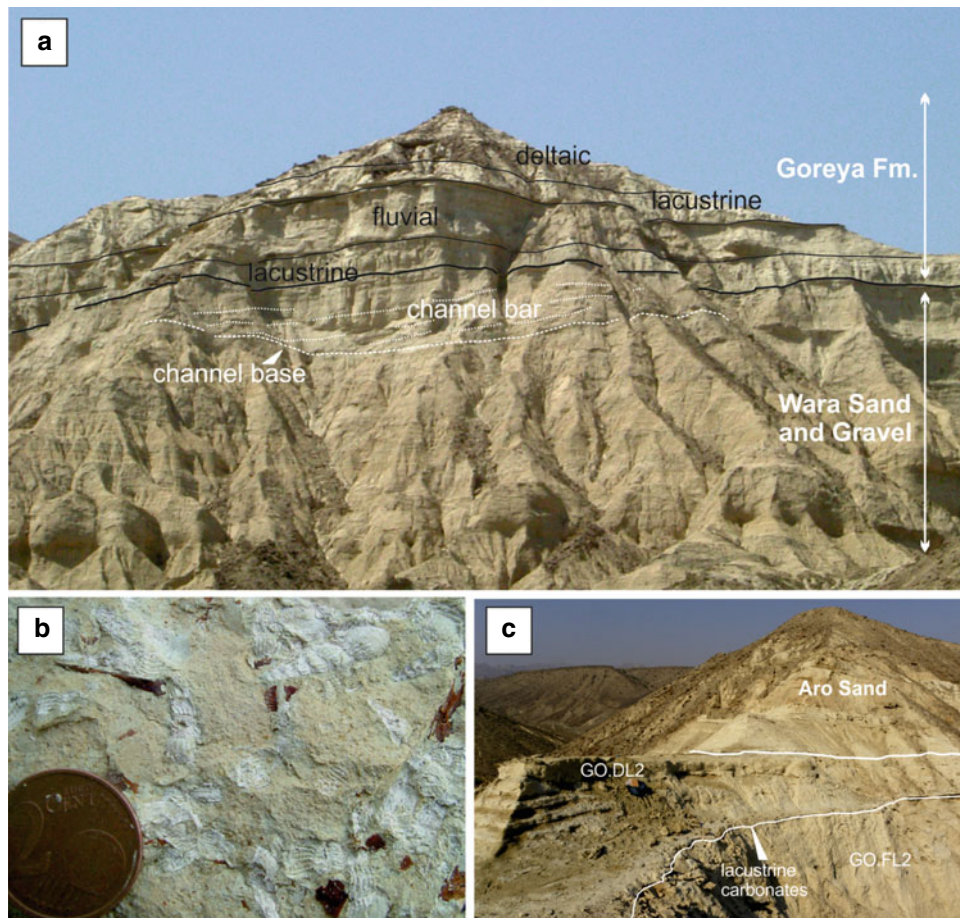


Fig. 5.5 Basin-fill deposits—the upper part of the succession. **a** Fluvial deposits of the Wara Sand and Gravel Fm. covered by fluvio-lacustrine deposits of the Goreya Fm. **b** Shell-rich lacustrine carbonates of the

Goreya Fm. **c** Uppermost part of the Goreya Fm and the overlying fluvial Aro Sand

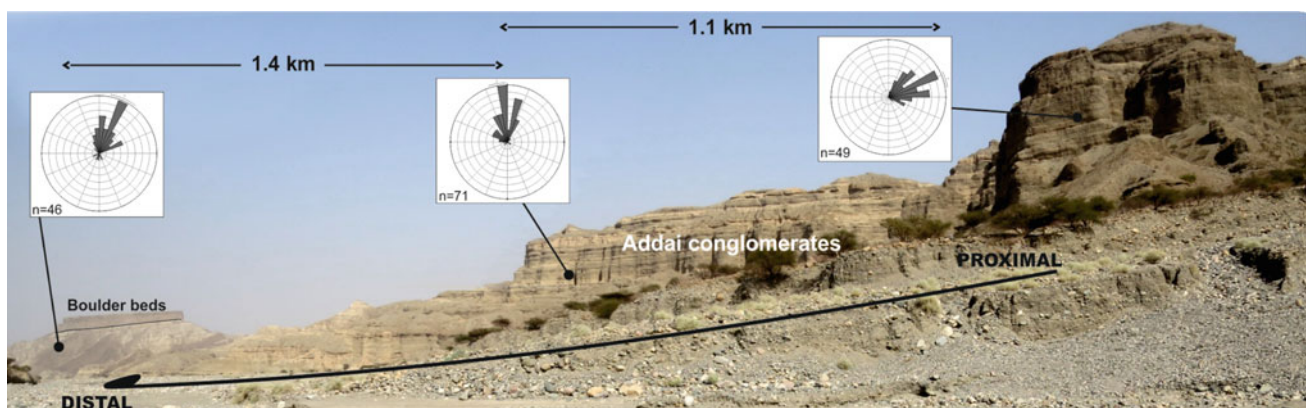
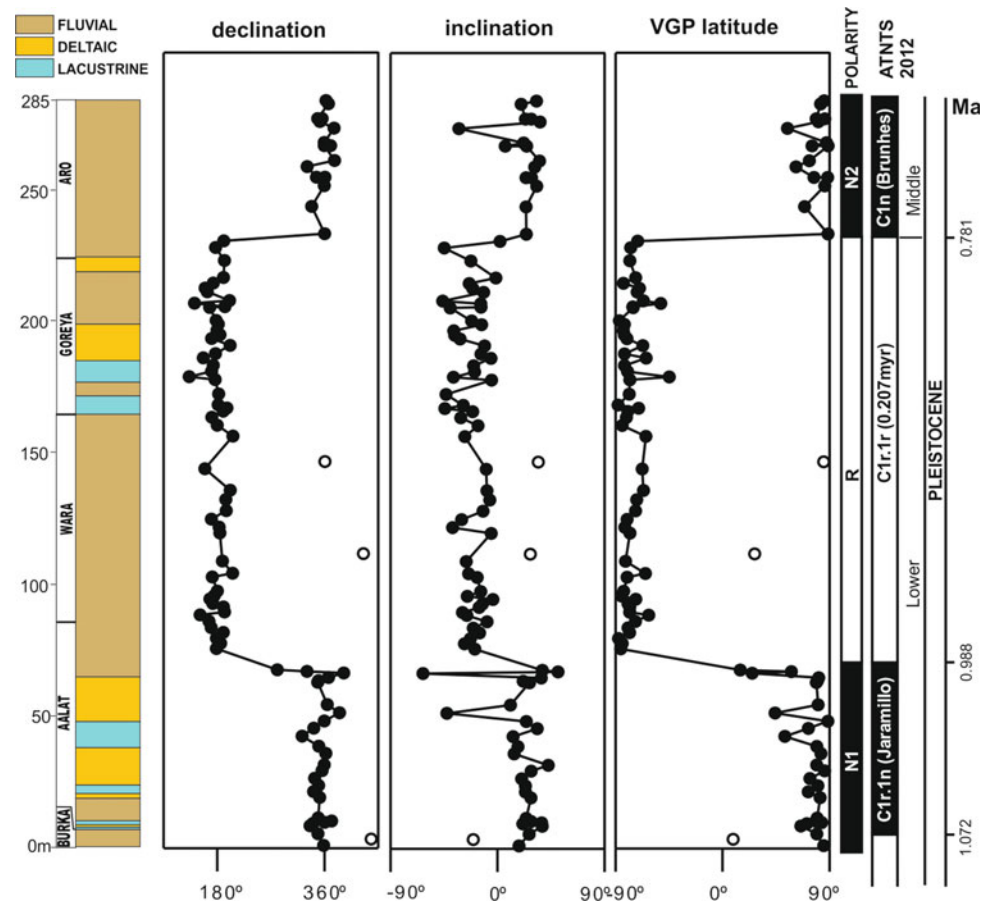


Fig. 5.6 Addai Conglomerates forming the upstream part of the fluvio-lacustrine succession. Note progressive northward shift of flow moving from the proximal to the distal part of the fan

associated with the Gilbert-type delta deposits and the “donut key bed” provide a fully consistent correlation scheme throughout the whole basin. Magnetostratigraphic analyses place the Mathuyama–Brunhes transition at the base of the Aro Sand, and the Jaramillo subchron in

correspondence with the Aalat Fm., with its upper boundary (i.e., 0.988 Ma) sited at the stratigraphic level that provided hominin and artifact remains. These results allow one also to establish that the Aro and Aalat sections were characterized by sedimentation rates of ca 0.95 and 0.70 mm/yr,

Fig. 5.7 Schematic log of the Aalat section and results of paleomagnetic analyses. N and R indicate normal and reverse polarity zones, respectively. Chrons 1r.1n and 1r.1r lasted 0.084 and 0.207 Myr, respectively



respectively. Specifically, fluvio-lacustrine deposits of the Aalat Fm. probably represent the most expanded continental sedimentary record of the Jaramillo subchron up to date.

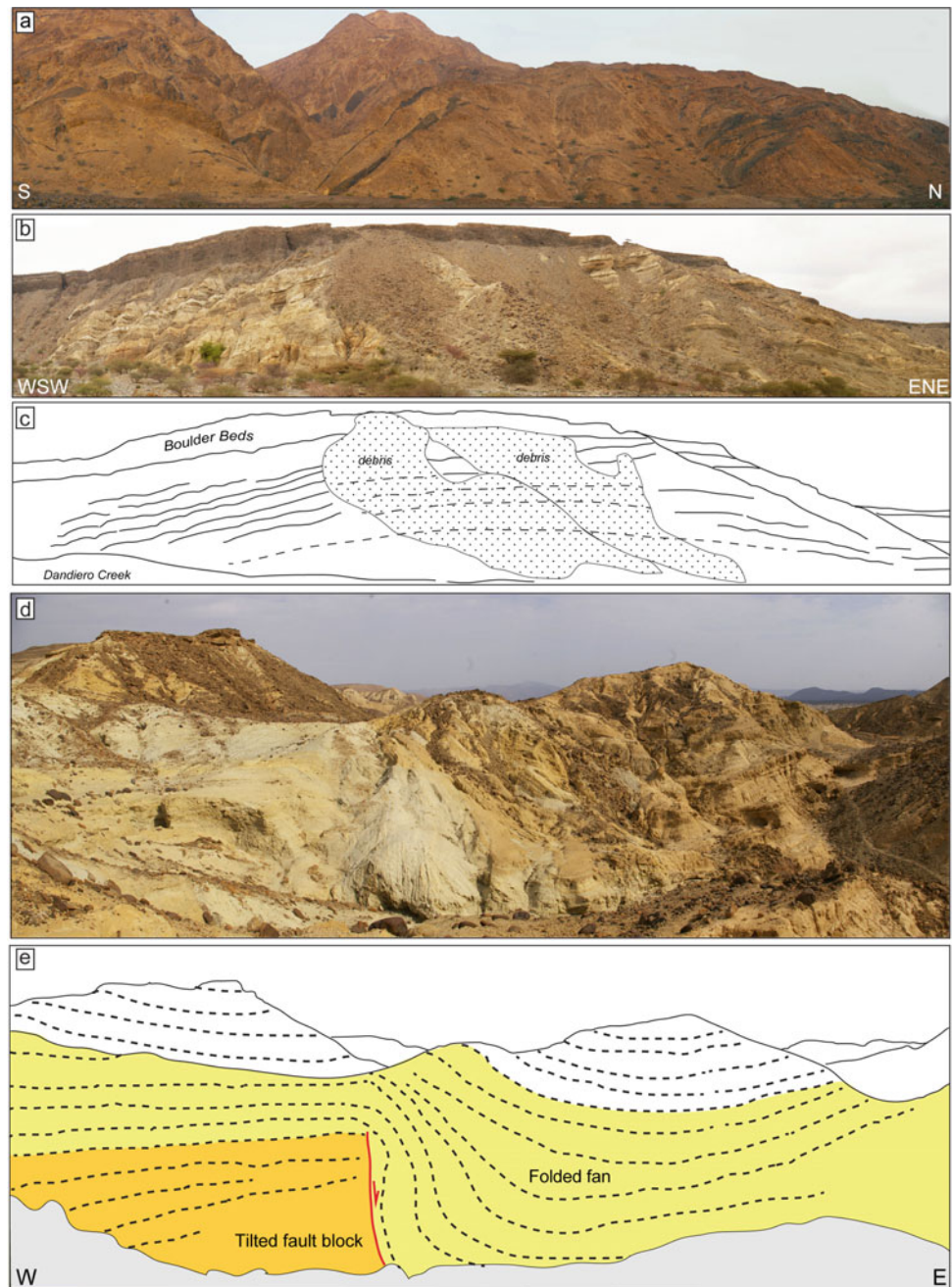
Paleopedological investigations also highlighted geomorphological stability phases within the basin-fill succession (Ghinassi et al. 2015; Scarciglia et al. 2018), along with cyclical alternation of carbonate- or gypsum-cemented horizons with iron-stained, reddish to yellowish paleosols. Stable isotope data from pedogenic carbonate concretions of the upper Aalat Fm. and Wara Sand and Gravel Fm. identify four main negative shifts of $\delta^{18}O$ (Scarciglia et al. 2018), which occurred where wetter conditions are documented by sedimentary facies (e.g., increase in depth of fluvial channels; onset of lacustrine conditions).

5.3.2 Mammal Remains

A number of paleontological studies have documented the occurrence of a faunal assemblage in the Aalat Fm. along the Dandiero succession, including a variety of reptiles and large mammals and, to a lesser extent, of fish, birds and small mammals (Ferretti et al. 2003; Delfino et al. 2004, 2018; Martínez-Navarro et al. 2004, 2010; Rook et al. 2010, 2013;

Medin et al. 2015). The assemblage is known in the literature as the Buia faunal assemblage, and it is world renowned for the occurrence of well-preserved *Homo erectus* remains (Abbate et al. 1998; Macchiarelli et al. 2004; Bondioli et al. 2006; Zanolli et al. 2014; Bruner et al. 2016; Hammond et al. 2018). A preliminary faunal list describing the Buia large vertebrate fossil assemblage was published in 1998 (Abbate et al. 1998). Further discoveries allowed one to expand the faunal list. Overall, the Buia faunal assemblage falls among the typical late Early Pleistocene East African faunas, being characterized by the presence of the latest derived representative forms of *Theropithecus* cf. *T. oswaldi*, *Elephas recki*, *Hippopotamus gorgops*, *Kolpochoerus olduvaiensis*, *Kolpochoerus majus*, *Metridiochoerus* aff. *M. modestus* and *Bos buiaensis*, in association with taxa still living today, such as *Ceratotherium simum*, *Equus* cf. *E. grevyi*, *Tragelaphus* cf. *T. spekei* and *Kobus* cf. *K. ellipsiprymnus*. The indications obtained through mammal biochronology point to the final phases of the Early Pleistocene and such an evidence is in agreement with the geological and sedimentological framework, paleomagnetism and fission-track thermochronology (Ghinassi et al. 2015). Taxa characterized by strong water dependence, such as hippopotamus, waterbuck, sitatunga, *Kolpochoerus*, a

Fig. 5.8 Tectonic evidence along the basin margin and within the infill succession. **a** Basaltic dikes cutting bedrock strata and striking parallel to major faults bounding the western margin of the basin. **b, c** Roll-over anticline in the Addai Conglomerates along the western margin of the basin. **d, e** Panoramic view of Aalat Well area showing the progressive tilting of a faulted block that generates progressive unconformities and growth folding



Thryonomyid rodent, crocodile, pelomedusid chelonian, Nile monitor lizard and African rock python predominate in this vertebrate assemblage (Martínez-Navarro et al. 2004; Ghinassi et al. 2009). The characteristics derived from the faunal assemblage allow one to reconstruct a paleoenvironment characterized by moist, grassy habitats adjacent to persistent water bodies. The fossil bird taxa identified at Buia (including rare specimens of kori bustard, *Ardeotis kori*, the largest living flying bird native to Africa) suggest the occurrence of both open water with reedbeds and dry areas nearby, with local or distant presence of well-developed savannah with stable grass and scattered trees

(Rook et al. 2013; Delfino et al. 2018), i.e., a much more humid environment compared to the arid desert of today, devoid of almost any kind of vegetation but scattered weeds and bush in the dry beds of ephemeral streams.

5.4 Structural Geology

Sedimentation in the Dandiero Basin has been mostly controlled and conditioned by two major NNW-SSE trending, east-dipping normal faults that roughly delimit the basin. The westernmost major fault system marks the boundary

with the Eritrean Plateau, and it is well exposed along the streams that originate from the plateau. Moreover, it is marked by the occurrence of many basaltic dykes aligned with the major fault planes, evidencing the depth of these structures (Fig. 5.5a). This system is composed of various fault segments, whose trends vary from NNW-SSE to NNE-SSW (Fig. 5.2).

Another regional normal fault marks the eastern limit of the basin and links the basin sediments with the Samoti Plain of the Danakil Depression (Fig. 5.2). This latter fault is not exposed, but the abrupt and straight contact between the sediments of the Dandiero Basin and the alluvial deposits of the Samoti Plain, as well as the occurrence of basaltic dykes aligned for more than 1 km along this margin suggest the presence of an important structure at depth.

Many other minor faults, generally oriented NNE-SSW to NNW-SSE, affect the basin infill (Fig. 5.2). They dip either to the east or to the west and are therefore synthetic or anti-synthetic, respectively, in relation to the two major east-dipping faults. These minor, mesoscopic faults are generally well developed, easily recognizable in the field and show clear kinematic indicators that allowed Sani et al. (2017) to make a complete structural analysis. This intense tectonic activity, expressed by widespread faulting that affected the basin fill, mainly occurred during sedimentation. This is evidenced by throws of faults that reduce up-section, faults sealed by younger sediments, and soft sediment deformations like disaggregation bands (Fossen et al. 2007; Fossen 2010).

However, the best example of interaction between tectonics and sedimentation is the major fault system located along the western margin of the basin. These normal faults show roll-over anticlines with thick wedges of coarse sediments (mainly conglomerates) toward the major fault plane (Fig. 5.8b). Moreover, a westward progressive thickening of Wara and Bukra sand and gravel Fms. can be observed, pointing to a period of major activity of the border fault system during their sedimentation (Fig. 5.9).

Active structures that controlled sedimentation are present at Aalat well area in the north of the basin (Fig. 5.2 for

location). Here, an east-dipping normal fault delimiting a progressively tilted block was active during sedimentation creating the accommodation space for a folded fan of fine sediments in the lowered block (Fig. 5.8c). Above the tilted block, the thickness of the succession is strongly reduced in comparison with the adjacent areas. The oldest tilted sediments are arranged vertically, and they flatten upwards, as a consequence of the progressive deactivation of the fault.

5.5 Discussion: Evolution of the Basin and Forcings on Landscape Transformations

Integration between different proxies, along with the definition of an accurate chronostratigraphic frame, provides insights to discuss the factors controlling the shifts between depositional environments and to make comparisons with the evolution of adjacent areas (Fig. 5.10).

The onset of sedimentation in the Dandiero Basin cannot be established with accuracy, although sedimentation rates estimated for the Aro and Aalat sections can be used to extrapolate back the age of the base of the 130 m thick Bukra Sand and Gravel Fm. at ca 1.2 Ma (Sani et al. 2017). Accumulation of the Bukra Sand and Gravel deposits indicate a well-established fluvial drainage that flowed to the north along the axis of a N-S trending graben, the eastern margin of which is still visible. This basin probably represents the remnant of a marginal graben, which is roughly aligned with other similar basins formed to the south along the Eritrean and Ethiopian margins of the plateau (Zwaan et al. 2020). The inferred 1.2 Ma for the beginning of the Dandiero Basin formation is close to the age of the Stratoid Series located to the east of the Alid volcano (Duffield et al. 1997, Fig. 5.1) and to that of other Stratoid Series in other parts of Afar (Barberi et al. 1972, Zumbo et al. 1995; Stab et al. 2016). Within this framework, the eastern shoulder of the Dandiero Basin, which recently subsided below the Samoti Plain (Fig. 5.1), probably prevented basaltic lava

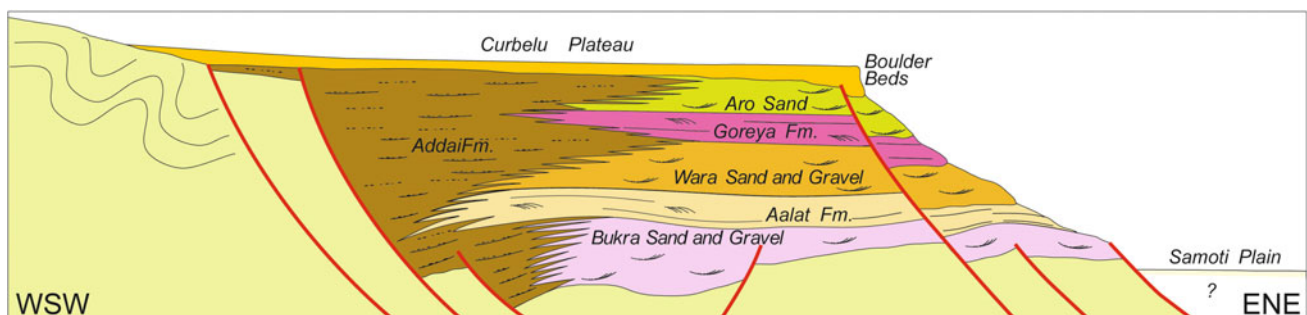
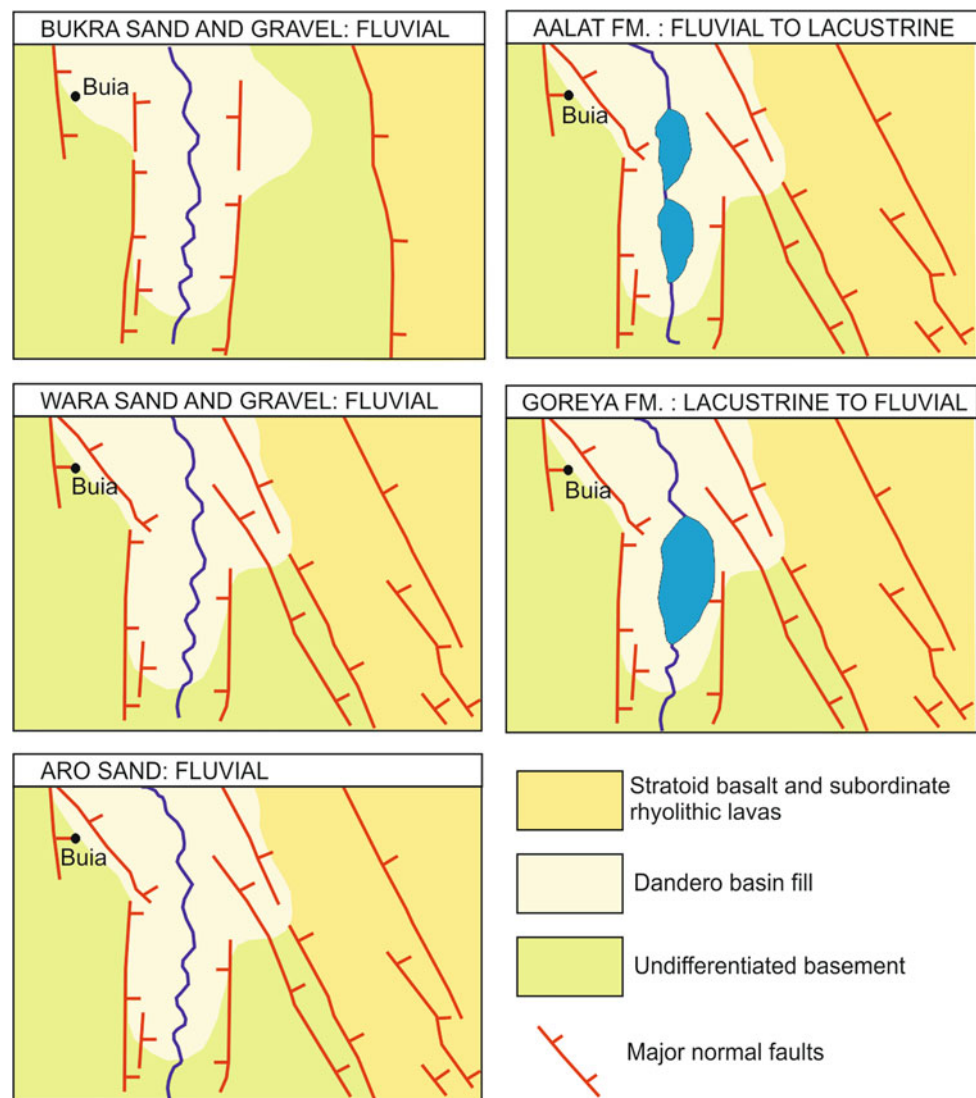


Fig. 5.9 Schematic cross-section through the Dandiero Basin (not to scale). Length of the section is ca 8 km. Thickness of the basin infill is ca. 450–500 m

Fig. 5.10 Chronological scheme of the evolution of the Dandiero Basin within two main extensional tectonic phases. The early phase occurred during deposition of the Burka Sand and Gravel, whereas the second extensional phase started at ca. 1 ma with accumulation of the Aalat Fm



flows to enter the basin, where fluvial deposits of the Bukra Sand and Gravel accumulated. The onset of Aalat Fm. deposition marked a new step in the basin evolution and corresponds to the nucleation and growth of NNW-SSE trending normal faults, which controlled sedimentation of all the units overlaying the Bukra Sand and Gravel. These NNW-SSE faults are consistent with the northern propagation of the Afar branch of the triple junction and are superimposed on the previously formed marginal N-S trending graben, which was dissected and lowered below the modern sediments of the Samoti Plain. Activation of these faults is dated at ca. 1 Ma (i.e., base of Jaramillo subchron), when sediments were sourced from the escarpment to form the Addai alluvial fan and deflected toward the north, along the axis of the basin. This basin configuration persisted until ca. 0.7–0.6 Ma (i.e., lower part of the Brunhes Chron), when, after deposition of the fluvial Aro sand, the

Dandiero Basin was affected by widespread erosion due to lowering of the Samoti Plain and uplift of the fault block corresponding to the basin.

Although a definite structural basin configuration persisted until the onset of this erosional phase, a marked tectonic control on sedimentation is clearly documented during deposition of the Aalat Fm. by the common occurrence of syn-sedimentary faults and growth structures. These localized deformations caused considerable changes in thickness along the basin axis (Fig. 5.3) by developing localized fluvial base levels (cf. Bianchi et al. 2015), but also induced a remarkable downstream variability of depositional landscapes, which varied from alluvial to lacustrine in poorly and highly subsiding zones, respectively. The lack of relevant deformations in deposits accumulated above the Aalat Fm. demonstrates that no significant localized tectonic activities influenced deposition. In the deposits accumulated after the

nucleation and growth of NNW-SSE trending normal faults (i.e., above the Bukra Sand and Gravel Fm.), the cyclical alternation of carbonate- or gypsum-cemented horizons with iron-stained, reddish to yellowish paleosols suggests alternation between dry and wet environmental conditions, in line with major Pleistocene climate oscillations as documented in the oceanic global isotopic record. These pedological data fit with negative shifts of D18O, which tend to occur in correspondence with major increases in water content in the depositional systems. This pattern could support the hypothesis of a cyclic climatic overprint over an overall tectonic-driven sedimentation (Ghinassi et al. 2016).

5.6 Conclusions

The continental Early-Middle Pleistocene Dandiero Basin is filled with approximately 450 m thick fluvial-lacustrine deposits. The Dandiero Basin is bounded by two main roughly NNW-SSE trending faults, which were superimposed to the N-S trending faults that delimited the basin at the time of its inception as a marginal graben of to the Eritrean–Ethiopian plateau. Sedimentation occurred mainly along the basin axis and allowed for accumulation of sand and mud deposits, with subordinate gravels close to the basin margin. Deposition mainly occurred in a fluvial environment, with paleoflow directed toward the north, although alluvial sedimentation was repeatedly replaced by deposition in a shallow lacustrine setting. The quality of magnetostratigraphic data, and its comparison with radiometric dating and vertebrate paleontology, provides a robust correlation of the recorded paleomagnetism and allows to constrain deposition between ~1.2 up to 0.75 Ma. Sedimentation occurred under the dominant control of tectonics, although integrated sedimentological, paleopedological and isotopic data suggest climate forcing on repeated shifts from fluvial to lacustrine deposition. The basin-filling facies association, the faunal assemblage and the paleosol characteristics indicate climatic oscillations between dry and wet environmental conditions, similarly to the major Pleistocene climate alternations documented in the oceanic global isotopic record.

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