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A geoarchaeological reassessment of the co-occurrence of the oldest Acheulean and Oldowan in a fluvial ecotone from lower middle Bed II (1.7ma) at Olduvai Gorge (Tanzania)

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ABSTRACT

The coexistence of the oldest Acheulean and Oldowan industries means that the appearance of the former cannot be due to an anagenetic development from the latter. At Olduvai Gorge, Tanzania, both industries are found within the same chronostratigraphic unit, the Lower Augitic Sandstone (LAS; 1.7 Ma), at HWK, HWK-E, HWK-EE (Oldowan) and FLK-W and FLK-N (Acheulean). Recently, McHenry and Stanistreet (2018) and Stanistreet et al. (2018) have argued that the Acheulean site of FLK West is actually located within a more recent stratigraphic unit, the Middle Augitic Sandstone (MAS). If so, the Acheulean could potentially have evolved from the Oldowan anagenetically. We test this hypothesis by reviewing the stratigraphy of the LAS from the HWK area to the FLK-W site. Hay's (1976) previous work stresses the continuity of the LAS from HWK-EE to FLK-NN, and stratigraphic and sedimentological evidence indicates that while the MAS has eroded away, the LAS is continuous throughout the study area. According to Hay (1976), Uribelarrea et al. (2017) and this work, the LAS is present at HWK-EE, HWK-E, HWK, HWK-W, FLK-S, FLK-W, FLK-N and FLK-NN. The emergence of the Acheulean at Olduvai Gorge ca. 1.7Ma and its coexistence with the Oldowan thus demonstrates a cladogenetic, rather than an anagenetic, origin for the Acheulean. This has implications for the behavioral and biological interpretations of the origin and co-existence of both types of industries.

1. Introduction

Two paradigms compete to explain the emergence of the Acheulean stone tool industry. The older, which is inspired by traditional Darwinian gradualism where stone tool industries and hominins co-evolved, presents a linear evolutionary path. This anagenetic conception posits that *Homo habilis* produced the Oldowan technology, which evolved and was replaced by the Acheulean technology associated with *Homo erectus/ergaster* (e.g., Leakey, 1951, De la Torre and Mora, 2014; De la Torre, 2016; Sánchez-Yustos et al., 2016). An alternative cladogenetic view maintains that the Acheulean technology emerged and co-existed with the Oldowan during hundreds of thousands of years and that both technologies reflect different adaptive behaviors rather than just different cognitive skills and, therefore, different hominins (e.g., Leakey, 1971; Heinzelin et al., 2000, Díez-Martín and Eren, 2012; Domínguez-Rodrigo et al., 2014, Diez-Martín et al., 2015; Uribelarrea et al., 2017).

The older anagenetic paradigm has been revised by redefining both industries on technological grounds, whereas the cladogenetic paradigm rests on a typological concept of both industries (Leakey, 1971; Baena et al., 2012). This handicaps tests of either approach because they both abide by different conceptual arguments. The anagenetic conceptual framework is cognitive, whereas the cladogenetic approach is functional. The epistemologically-unwarranted cognitive approach has lead lithic experts to identify some assemblages as Acheulean based simply on the single occurrence of a handaxe or a large format artefact among thousands of small flakes and cores (De la Torre and Mora, 2014). However, typological approaches that use arbitrary frequency

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thresholds of large format tools in any given assemblage to qualify as Acheulean are also heuristically problematic (Leakey, 1971). The fact is that there are assemblages with large numbers of handaxes and other large format tools and others that are dominated by cores and small flakes that most certainly reflect different behaviors. At Olduvai, the former occur in different palaeogeographic settings than the latter (Hay, 1976; Domínguez-Rodrigo et al., 2017; Uribelarrea et al., 2017; Domínguez-Rodrigo, 2018).

Recently, it has been argued that, technologically, the transition of the Oldowan to the Acheulean occurs at Olduvai Gorge (Tanzania) in the middle of middle Bed II in the stratigraphic unit referred to as the Middle Augitic Sandstone (MAS) (McHenry and Stanistreet, 2018; Stanistreet et al., 2018). On the other hand, Diez-Martín et al. (2015) argue that the transition occurs in lower Bed II, in the Lower Augitic Sandstone (LAS), as seen at the FLK West[1] Acheulean site at ca. 1.7 Ma (Diez-Martín et al., 2015). FLK West was inferred to be pene-contemporaneous with HWK, HWK E and, HWK EE (Uribelarrea et al., 2017), all of them classified as Oldowan (Leakey, 1971; De la Torre et al., 2018). This would support a cladogenetic evolution of the Acheulean. However, McHenry and Stanistreet (2018) and Stanistreet et al. (2018) argue that FLK West is located stratigraphically higher due to the erosion of the LAS by the MAS, which, according to these authors, is associated with the overlying Bird Print Tuff (BPT). Should that be true, then the Acheulean industry could potentially have evolved from the Oldowan anagenetically. Here, we test this hypothesis by reviewing the stratigraphy from the HWK area to the FLK West site, especially between the two outcrops where, we will show, the MAS, rather than the LAS, disappears by erosion. This reinforces previous adscription of FLK West to the lower part of the sequence.

2. Methods

This study uses a standard stratigraphic model, which applies classic stratigraphic techniques: a) strata identification, genesis interpretation, and local stratigraphic succession, b) the movement from a local to a regional scale through correlation of different stratigraphic and tectonosedimentary units, c) a detailed stratigraphic interpretation that includes the reconstruction of depositional environments, lateral extension, stratigraphic relationships with other units, and even the reconstruction of paleotopography and paleogeomorphology, and d) the introduction of time as a fourth dimension to describe the basin's evolution. Using precisely these methods, Hay (1976) created an exhaustive geological framework, including palaeolandscape reconstructions, stratigraphical sequences, and petrological and stratigraphic descriptions, which still are the main reference for all later geological studies carried out at Olduvai Gorge. In this present work, we compare the results of Diez-Martín et al. (2015) and Uribelarrea et al. (2017)–which coincide with those of Hay (1976)–with those of McHenry and Stanistreet (2018) and Stanistreet et al. (2018). In addition, we present detailed results for the area between geolocalities 44 and 45d (following Hay, 1976) at the end of the side gorge by the junction with the main gorge (Fig. 1).

Uribelarrea et al. (2017) offered a description of the most important units (Tuff IF, Lemuta-IIA, the LAS, Tuff IIB, and the BPT) for contextualizing the FLK-W site. In the same publication, amongst other evidences, the presence of Tuff IIB at Leakey's Road (geolocality 45d according to Hay, 1976) was indicated. This demonstrates that the surface over which the BPT lies erodes the MAS and part of Tuff IIB, northwards creating a wide disconformity. BPT gets progressively closer to the LAS, until at FLK-W it is located ~25 cm above it (Uribelarrea et al., 2017). The MAS, alongside other minor geological units, were not described in detail when geologically contextualizing FLK-W because these occur above Tuff IIB and are eroded westwards and northwards. Hypotheses formulated by other authors (McHenry and Stanistreet, 2018; Stanistreet et al., 2018) including the idea that FLK-W lies in the MAS are based on the interpretation that the MAS starts to erode Tuff IIB and the LAS in a very precise area: the geological void created by the erosion of the side gorge between geolocalities 44 and 45d. According to this interpretation, the only augitic sandstone from geolocality 45d northwards would be the MAS, which would place FLK-W in middle Bed II. This model is based on the hypothesis that the BPT conformably overlies the MAS without any disconformity between them. This contradicts the stratigraphic framework proposed by Hay (1976) and Stanistreet (2012). However, both stratigraphic models do agree on one thing: the augitic deposits defined at Loc. 45 and Maiko Gully are the same as those present at FLK-W.

Stratigraphical correlations are vital to reaffirm the models proposed by Uribelarrea et al. (2017) and Hay (1976), especially in the gorge's junction (Loc. 45, Leakey's Road and Maiko Gully)(Fig. 1). Correlation is based on facies and lithology descriptions, geometry, and spatial position. This last was calculated with a sub-centimetric GPS and a Digital Elevation Model (DEM) generated with photogrammetry with the use of an unmanned aerial vehicle. Petrological and sedimentological samples have been obtained for further detailed description of facies, synsedimentary, and postsedimentary processes. Miall and Postma, 1997 lithofacies nomenclature was followed for facies description.

While the stratigraphy of the outcrops is relatively clear in this part of the gorge, we opened two geotrenches (3–4 m in depth) to expose the sequence from the waxy claystones at the base of Bed II up to the BPT. The first geotrench was excavated at geolocality 44 in a small gulley named Lava Tongue Korongo (LTK; aka FLKW following Hay, 1996) located on the southern margin of the side gorge (Fig. 1). The second geotrench, at Loc. 45d, is located on the other side of the side gorge, 300 m northwest of the area known as Leakey's Road (LR) next to the location where OH 37 was found (Hay, 1976), although two markers with H-40 are placed in this locality (Fig. 2). These locations were not arbitrarily chosen. In the first place, they follow the commonly used (Leakey, 1971; Hay, 1976, 1996) SE-NW trend of available outcrops in the area, from HWK to FLK. Secondly, these two geotrenches were useful to add intermediate stratigraphic sections in this general SE-NW outcrop area, which would allow a more detailed correlation. Finally, these are the same locations referenced by McHenry and Stanistreet (2018) in their Fig. 9. In this figure, however, while geolocality 45d is clearly identified, it is labeled as "FLK-S/Loc. 46 (OH 40 Marker), which generates some confusion because FLK-S is ~300 m to the west, geolocality 46 is ~500 m to the west and, according to Hay (1976), OH 40 is at geolocality 46a, ~300 m to the southwest (Fig. 1). Nevertheless, there are two OH 40 markers at geolocality 45d. (Fig. 2). For this reason, in order to compare our results, we have considered that two McHenry's sections have been carried out at Loc. 45d. In any case, according to Hay (1976) and our own observations, LAS are also at FLK-S, instead of MAS, as we will show below.

3. Geological framework: Lower to Middle Bed II between HWK and FLK-W, 1.7 ma

Bed II is especially interesting since it displays a wide variety of sedimentary environments, including lacustrine, fluvial, Aeolian, and volcanic facies in a very tectonically active setting that was influenced considerably by the geometry of sedimentary units. Lower Bed II is particularly important since it contains the oldest Acheulean industry at Olduvai Gorge (1.7 ma; Diez-Martín et al., 2015). According to Hay

[1] FLK West was originally assigned as a locality to the spot where OH 26 was found, in association with the artefacts derived from the eponym archaeological site (Leakey, 1971; Hay, 1976; Diez et al., 2015). The recent denomination of FLK West to another site situated across from the original FLK West and in a substantially higher stratigraphic position (De la Torre et al., 2018) induce unnecessary confusion and conflicts with standard protocols of not duplicating site denominations.

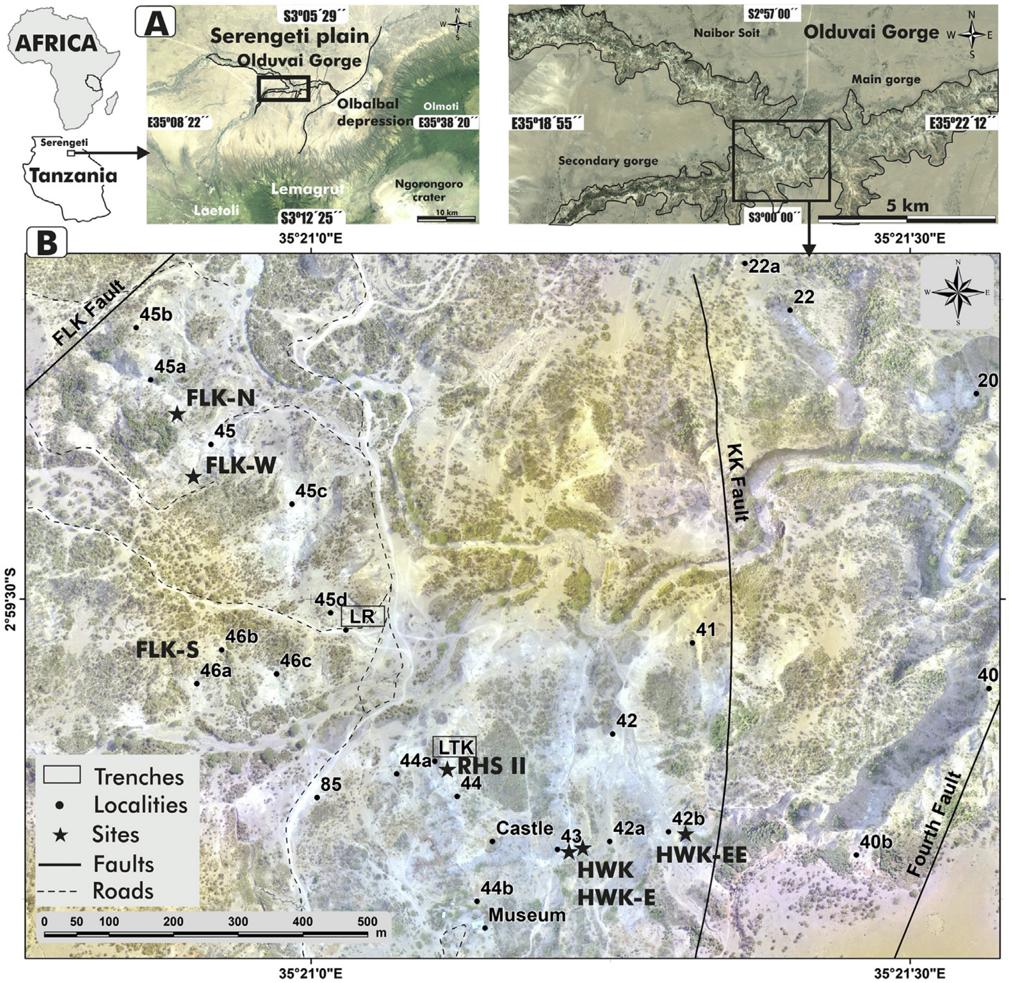


Fig. 1. A, General view of the Olduvai Gorge and the study area. B, Detail of the study area, between the 4th and FLK faults. Orthoimage obtained with an unmanned aerial vehicle.

Fig. 2. Field location of two landmarks corresponding to hominid No. 40 (H-40) at locality 45d, next to Leakey's Road (LR), on the left margin of the Gorge.

(1976), during the beginning of Bed II, the Olduvai basin was dominated by the presence of a central lake. Water salinity determined the type of clay deposited, with earthy claystone depositing at low salinity and waxy claystone at high salinity. In areas closer to the basin limits, earthy claystone is more common due to the influence of surface meteoric waters. In this calm depositional environment, the aeolian-volcanic deposits of the Lemuta member were created (marker Tuff IIA and "twiglet"; Leakey, 1971). Tectonic activity triggered the descent of the FLK-5th Fault block, and with it the regional base level, reactivating fluvial systems and forming the Lower Disconformity (LD). From this point on, the geomorphology, sedimentation and even the archaeology changes drastically. In the lowermost areas of the basin, the fluvial unit known as the Lower Augitic Sandstones (LAS) is deposited.

The oldest Acheulean site at Olduvai (Díez-Martín et al., 2015) is found in this unit (Uribelarrea et al., 2017), coexisting with Oldowan sites such as HWK (Leakey, 1971; De la Torre et al., 2018). The LAS unit is situated directly over the LD in our studied area (Main Junction) between HWK-EE and FLK-N (Leakey, 1971; Hay, 1976). Tuff IIB can be found above the LAS, as a mixed aeolian and fluvial (with very characteristic cobbles) deposit. Lake-margin clays and the MAS unit overlie these deposits. After the deposition of these units, the uplift of the southern block of the FLK Fault prompted the erosion of part of this sequence, which is more intense as one travels closer to the fault (in the areas around FLK-Zinj, FLK-N and FLK-NN). For this reason, the sequence is complete at HWK (LD, LAS, Tuff IIB, the MAS, and the BPT), the MAS is slightly eroded at LTK, the MAS is fully eroded along with partial erosion of Tuff IIB at geolocality 45 and Maiko Gully, and at FLK

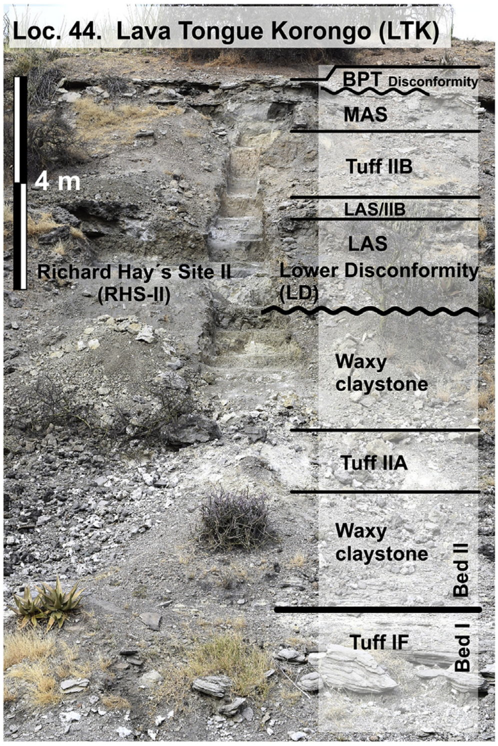


Fig. 3. Geotrench open at location 44, in the Lava Tongue Korongo area (LTK).

only the LAS is present (Uribelarrea et al., 2017). The geometry of the horizontal palaeosurface before the deposition of the BPT is key to understanding how tectonic activity deformed the sequence of LAS, Tuff IIB and MAS and forced the erosion of the latter two units as one progresses northwards. The BPT, in this case, is useful as a marker tuff since it can be easily identified in the field. The BPT lies over a local disconformity more than 3 m above the LAS at HWK and less than 30 cm above the LAS at FLK-W.

4. Results

4.1. LTK section, locality 44

This locality is equivalent to section 11 and HWK-W from Hay (1996) and with HWK-W 16, Loc. 44 from McHenry and Stanistreet (2018). At this locality (Fig. 1), the base of Bed II up to the LD is represented by 3 m of waxy claystone (Hay, 1976). Locally, earthy claystone levels < 1 m in thickness can be found since these deposits are in a transitional facies as defined by Hay (1996). Tuff IIA (< 50 cm) is embedded in the upper half of this clay unit, 1.5–2.0 m above Tuff IF (Fig. 3).

Unit 1 Lowermost Bed II, waxy claystones

At this point, the section includes the last 50 cm of waxy claystones underneath the LD. It is a homogeneous, bioturbated deposit, with no clear laminations or sedimentary structures.

Unit 2 LAS

The LAS are represented by 2 subunits (2a and 2b) that add up to a total thickness of 2 m. Nearly the entire of the section is composed of augitic sand, with the exception of two layers of 30 cm of silts and clays (Fig. 4).

Unit 2a. The first of these units is a 30 cm silty layer of augitic and tuffaceous sediments, with a lag of pebbles, lithic industry and bone fragments in the contact on the LD. It is massive and probably represents the first episode of sedimentation after the erosion caused by the LD. It looks closer to an alluvial environment than a fluvial one.

Unit 2b. This second unit is clearly fluvial, composed of a 1 m fluvial channel with sub-vertical margins eroding Unit 2a, which contains brown chert lithics and bones. In the first 20 cm of the channel, the bedload is composed of cobbles, forming a matrix-supported conglomerate (Gms). Mudclasts are abundant throughout the unit, alongside lithics and bone fragments. Towards the top of the unit, a small < 40 cm channel formed by medium to coarse augitic sand, also containing abundant mudclasts, overlies the unit. These are clearly fluvial facies, of medium energy, with some high energy episodes. Mudclasts indicate the presence of clay banks upstream. Above it, there is a 30 cm massive brown clayey silt, that represents the floodplain facies of the LAS fluvial system, possibly the floodplain of the underlying channels. Finally, the LAS unit is represented by a 65 cm thick medium-to-fine augitic sand, well sorted and bioturbated, with calcium carbonate cemented patches. Despite the intense bioturbation, cross-stratification is observed throughout the unit. These facies are indicative of lower energy, specifically the uppermost 10–20 cm, where laminations are smaller and ripples are common.

Unit 3 LAS-Tuff IIB transition

This unit has features similar to the LAS and Tuff IIB. The base of the unit is composed of 55 cm of reddish brown homogeneous and massive clayey tuffaceous silt similar to Tuff IIB, probably deposited in an aeolian sedimentary environment. This deposit is overlain by 15 cm of a fluvial, fining-upwards stratum of medium to fine augitic sandstone, cemented and with cross-stratification, very similar to the LAS.

Unit 4 Tuff IIB

Tuff IIB in this section is represented by 1.2 m of massive reddish brown compacted tuffaceous silt. Here, Tuff IIB does not contain the characteristic cobbles of basalt and andesite, although they are seen a few meters away in the same unit. Tuff IIB is a reworked tuff, deposited in several sedimentary environments and possibly over a long period of time. However, Tuff IIB is easily recognizable, and led Hay (1976) to use it as a Bed II marker tuff.

Unit 5 MAS

The 1.1 m thick, MAS are divided into four decimetric levels of augitic sand with a high content in tuff fragments. The first of these sublevels is a 30 cm medium to fine sand with abundant tuffaceous mudclasts. The second sublevel is a 23 cm-thick fining upwards sequence of very coarse to very fine sand with abundant mafic minerals, tuff clasts, and mudclasts is found overlying the first. Above it lies a 22 cm-thick massive fine sand with abundant bioturbation and tuff fragments. The last subunit is a 30 cm-thick fine sand cemented with calcium carbonate. Despite the intense bioturbation, typical lacustrine structures like wave-ripple cross-lamination, can be observed (Fig. 5). Although the granulometry is apparently coarser than in the LAS, sedimentary structures clearly indicate they were deposited in a less energetic environment, especially when compared to the most basal LAS subunit 2a.

Unit 6 BPT

The BPT is comprised of 2 subunits: a sandy basal unit and a tuffaceous unit overlying it. Ripples and small laminations are common in the sandy basal unit, alongside mudcracks and annelid bioturbation, which are diagnostic characteristics of this unit. The overlying tuffaceous unit has a distinctive yellow color and abundant bird ichnofossils (Fig. 6). The inferred sedimentary environment is a shallow lake-

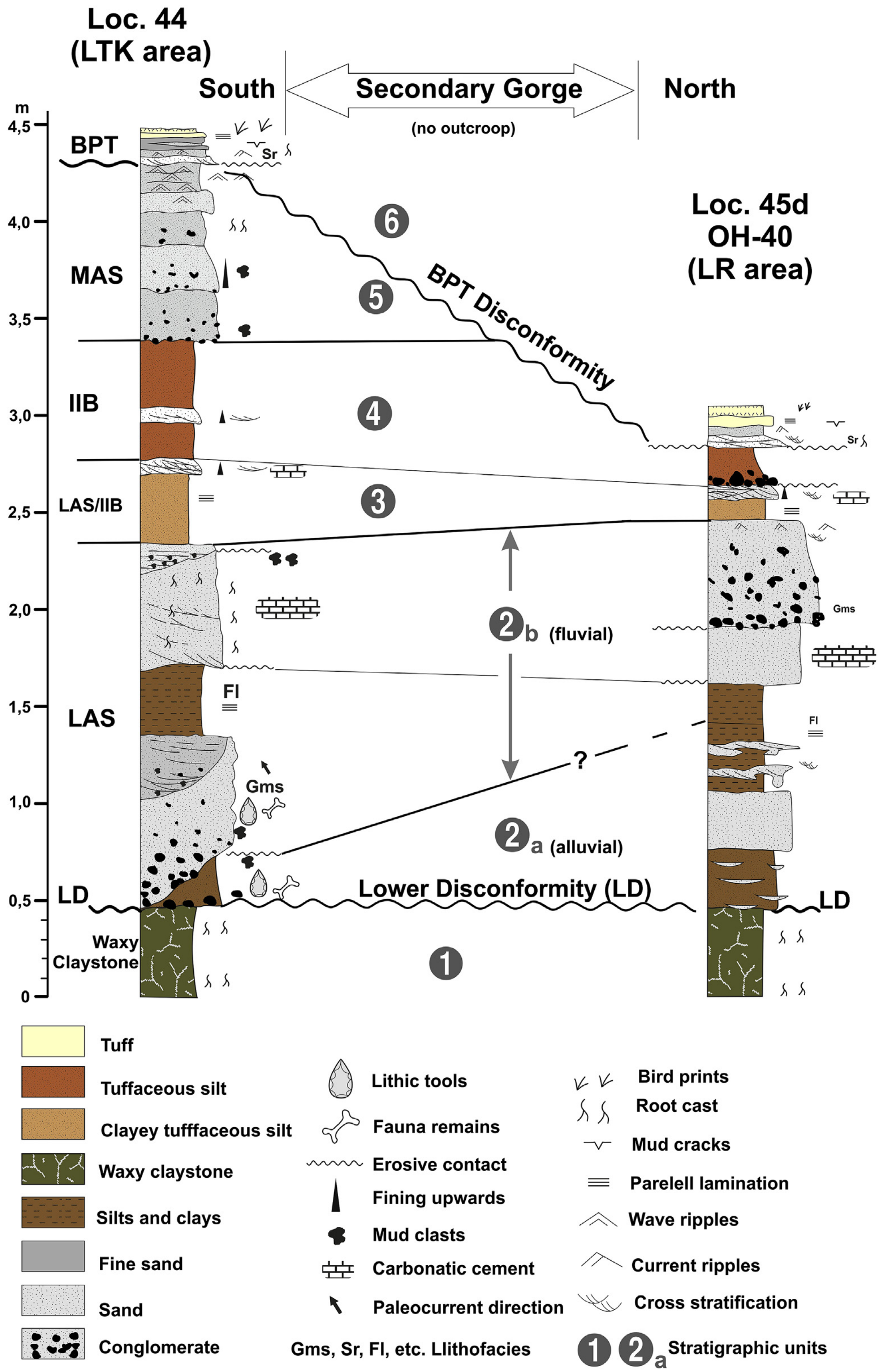


Fig. 4. Stratigraphic sections and their correlation corresponding to locations 44 and 45d.

margin, deposited on a local disconformity (Hay, 1976), called in this work as BPT disconformity.

4.2. Locality 45d

A stratigraphic section was studied at Loc. 45d (Fig. 1), next to OH37 (Hay, 1976). As previously explained, this is also the same location as that marked in Fig. 9 in McHenry and Stanistreet (2018).

Unit 1 lowermost Bed II, waxy claystones

The geotrench was excavated from 1 m below the LD, exposing 1 m of waxy claystone with abundant roots, exactly the same as observed in LTK (Fig. 7).

Fig. 5. Detail of wave ripples in the Middle Augitic Sandstones unit (MAS), which indicate a typical lacustrine sedimentation.

Fig. 6. Detail of bird tracks on the surface of the Bird Print Tuff.

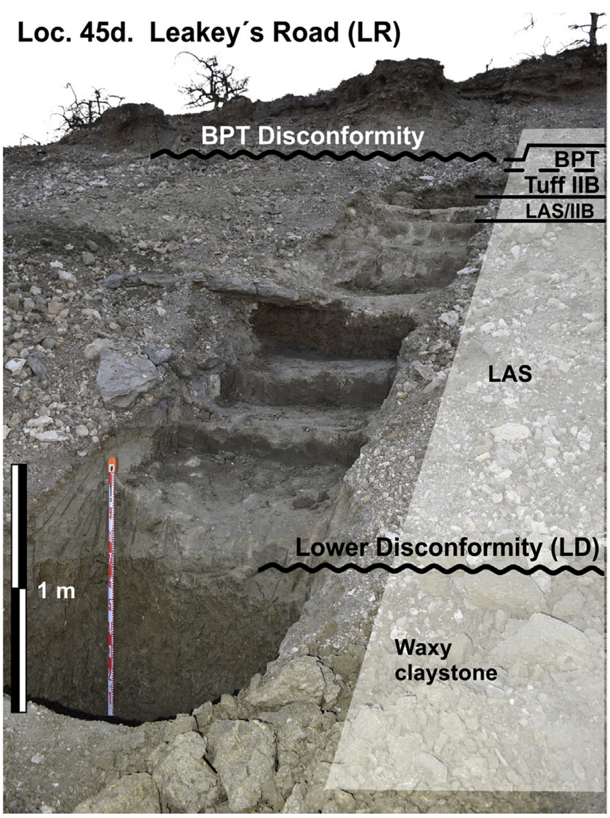


Fig. 7. Geotrench open at location 45d, next to Leakey's Road (LR).

Unit 2 LAS

Above the LD lies 2.0 m of LAS. As discussed in Uribelarrea et al. (2017), fluvial channels from the LAS fluvial system start to merge into single channels, leaving floodplain deposits in between. These floodplain facies are mainly composed of clay and silty-clay, which can contain small troughs of augitic sand. At the same time, large augitic channels with a NW palaeocurrent are present, with the same subunits (2a and 2b) as at Loc. 44.

Unit 2a. The LAS start with 30 cm of massive green silt, with small (< 5 cm) lenses of augitic sandstone. Above it are 28 cm of very fine augitic silty sand without clay content or internal structures. Alluvial to floodplain facies clearly ends with this overbank unit, which could be a continuation of the previous unit, although grain size is much finer. It is represented by 55 cm of reddish brown clayey silt in the bottom half and reddish brown silty waxy clay in the upper half. Towards the base of the unit, two small interbedded laminated augitic sand bodies are present.

Unit 2b. The fluvial unit starts with 32 cm of massive and cemented augitic sand. The rest of the unit (63 cm) is formed by a matrix-supported conglomerate (Gms) with rounded pumice and carbonate clasts, alongside mudclasts and brown chert fragments. The matrix is comprised of silt and very fine sand. Cross-laminations, ripples, and cut and fill structures are observed towards the top of the unit and can be indicative of an energy reduction in the sedimentary environment. Laterally, conglomerates become thinner and finer, to the point where they are 10–20 cm thick levels of augitic sand with abundant laminations over alluvial-floodplain facies.

Unit 3 LAS-Tuff IIB transition

The LAS-Tuff IIB transition is formed by 30 cm of reddish brown massive well sorted clayey silt. In the last 15 cm, a coarse to medium augitic sand with cross-stratification and current ripples (Fig. 8) can be observed.

Unit 4 Tuff IIB

30 cm of Tuff IIB can be found overlying Unit 3. Here, Tuff IIB does contain the diagnostic lava cobble lag (basalt and green, grey, and dark red andesites) and has a well sorted massive orange to reddish brown clayey silt above it (Fig. 8).

Unit 6 BPT

The BPT can be found again over a horizontal erosive surface, which is the BPT disconformity. The basal BPT unit is the same as in the LTK

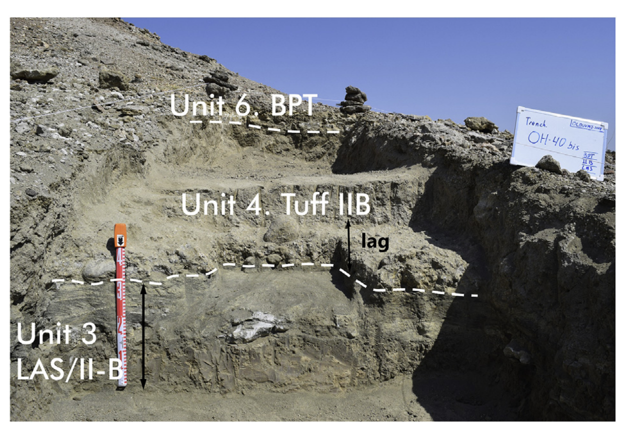
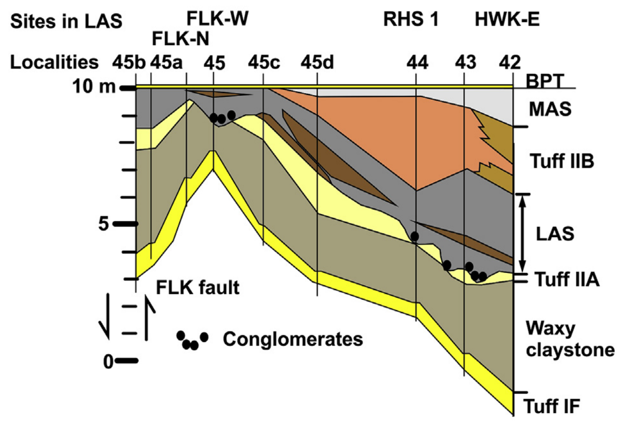


Fig. 8. Detail of the upper part of the section in Loc. 45d. The Bird Print Tuff (BPT) overlay directly on the Tuff IIB.



“Figure 26. Cross-section of the lower part of Bed II up to level of teh bird-print tuff between localities 42, (HWK-E), at right, and 45b (FLK-NN), at left. Bird-print tuff is taken as horizontal datum at top. “ Hay (1976).

Fig. 9. Figure 26 of Hay (1976).

section, with laminations, *hypichnia* bioturbation and small mudcracks. The upper tuffaceous unit is more laminated and has fewer ichnofossils than the equivalent unit at LTK.

5. Stratigraphical correlation

Between LTK and LR, there seem to be no major lithological or facies changes, and the described units are found in the same stratigraphical position in relation to Tuff IF (Fig. 4). The basal deposit of Bed II is a waxy claystone in most places around the junction. According to Hay (1996), in this area, waxy claystones form most of the interval between tuffs IF and IIA in the northern area, whereas they interfinger with earthy claystones in the southern part. The interbedded Lemuta member, including tuffs IIA and “twiglet”, has not been studied in this paper, with the proposed stratigraphic sections beginning on the overlying clay deposits. These waxy claystones (Unit 1) show identical geological properties in both sections. The LD, identified on both sides of the gorge, marks a clear change from lacustrine to fluvial depositional environments.

The LD was formed due to the inclination of the FLK-5th Fault block towards the NW, leading to fluvial incision and widespread erosion throughout the landscape. The fluvial system pene-contemporaneous with this erosion is represented by the LAS fluviosedimentary unit. The Lemuta member was partially eroded in some areas, as was the case at HWK or south of the Castle. In the studied area, the LD was formed over waxy claystones (Unit 1) and, directly above them, LAS (Unit 2) was deposited. The LAS unit, first exhibits an alluvial facies (Unit 2a), at least between LTK and LR.

Unit 2b is possibly the most characteristic and easily identifiable unit in the studied area, since it is highly cemented and produces great, continuous outcrops. Granulometrically, they vary from being sandy at Loc. 44 to matrix-supported conglomerates at Loc. 45d. Strata thickness, along with typical fluvial features, are maintained (1–2 m) on both sides of the side Gorge.

The LAS-IIB transition (Unit 3) is practically the same in both sections: a reddish brown clayey silt at the base and a layer of cross-laminated augitic sand above it. This unit can be found in outcrops along the road to the museum (VEK) westwards from LTK.

Most of Tuff IIB (Unit 4) has been eroded by the BPT disconformity at LR. However, the deposit does contain the diagnostic basalt and andesite cobble lag. Present day erosion is dismantling part of Tuff IIB at LR, leaving abundant cobbles on the surface.

The presence of the LAS-IIB transition (Unit 3) and Tuff IIB (Unit 4) is fundamental to prove that the MAS unit has been eroded away at Loc. 45d.

Finally, the BPT (Unit 6) has experienced the least amount of changes, since the depositional environment is the same throughout the studied area. The BPT disconformity does not correspond to a high energy event, but instead responds to erosion caused by surface runoff, which does not leave any associated deposits. No erosional surfaces such as channels or troughs have been identified. The erosion was controlled by the uplift of the FLK-5th Fault block, with higher erosion intensity the closer to the FLK Fault. It is important to highlight that this disconformity overlies different materials throughout the junction: MAS at HWK, clays at the Castle, Tuff IIB at Loc. 45d and floodplain clays in Maiko Gully. It is possible that the BPT disconformity has eroded Unit 2c at FLK-W, and that the BPT lies directly on Unit 2b (floodplain facies), with 1.2 m of augitic sands underneath.

6. Discussion

6.1. Richard Hay's (1976) stratigraphy

According to Hay (1976), Middle and Lower Bed II has probably the most complex geology at Olduvai, particularly in the central zone, where the “Eastern fluvial-lacustrine deposits” include a wide variety of sedimentary environments (lacustrine, fluvial, and aeolian) with base level changes and tectonic activity. Hay (1976) pays special attention to the interval between the LD and the BPT, describing five evolutionary stages, summarized below (Pages 87–91 and Figs. 26, 27 and 28 in Hay, 1976).

“Stage 1. The earliest stage is represented in the Main gorge by the lower part of the lower augitic sandstone (LAS), and in the Side Gorge by the main chert unit […]. Sediments of this age apparently do not extent east of the HWK area (Loc. 42). […] the lake extended as far northeast as FLK-NN (Loc. 45b). […] During a drop in the lake level, nodules were slightly reworked and exposed […]. During this time, the lake never fully withdrew from a small embayment to the east (loc. 88a). Equivalent deposits farther east are lake-margin sediments (locs. 45, 45a and 45c), weathered clays of paleosols (locs. 45d and 46c), and conglomeratic sandstones of fluviatile origin (locs. 42, 42a, 42b, 43 and 44). The conglomeratic sandstones is in the form of an elongate body orientated east-west, which appears to represent the cannel deposits of streams which flowed westward into the lake.”

The equivalence of the LAS with the exposed palaeosurface containing chert nodules explains the presence of this material throughout the LAS, with higher concentrations at the archaeological sites (FLK-W and HWK surroundings). In the MAS, this type of chert has not been documented. As described by Uribelarrea et al. (2017), the conglomeratic braided channels transition into more sinuous single channels in a silty and clayey floodplain. Floodplains become more dominant over fluvial channels towards the NE.

“Stage 2. It is represented by the upper part of the lower augitic sandstone. It was deposited as the lake spread eastward, and augite-rich lacustrine sanstone and limestones are found between FLK-NN (loc. 45b) and Castle Rock (loc. 44). In the Main Gorge these lacustrine sediments are bordered on the east by dominantly fluvial sandstones, which thins eastward and include sandy claystones that are either floodplain or mudflat deposits. […].” (Pag. 90 in Hay, 1976).

“Stage 3. It is represented by Tuff IIB, which in most places marks an abrupt change from lacustrine and lake-margin to fluviatile and eolian sedimentation. […].” (Pag. 90 in Hay, 1976).

“Stage 4. The fourth stage is represented by the middle augitic sandstone (MAS), a sheetlike body of lacustrine sandstone which occupies a large eastern embayment in the same general area as that of the preceding stage. **The sandstone pinches out to the west, in the vicinity of localities 85 and 45d, and does not appear to be represented by sediments in the area of FLK and most of the Side Gorge.** (We make emphasis on this sentence). […]. This sandstone sheet provides an ideal example of sedimentation in shallow, waveagitated water. […]" (Pag. 90 in Hay, 1976).

"Stage 5. The last stage of this paleogegraphic development is represented by the bird-print-tuff (BPT), which was deposited in a small, shallow pond or lacustrine embayment roughly 700 m across in a northwest-southeast direction. It is reworked and contaminated by claystone pellets around the margin of the embayment (locs. 42, 45, 45a, 45b). In the central area it is laminated and graded, and although it shows no evidence of reworking, bird prints of plovers (?) are locally abundant (for example, loc. 44), indicating either very shallow water or temporary exposure. The tuff was very likely deposited at nearly the same level everywhere, and if it is taken as a horizontal datum (Figure 26), a cross-section of the undelaying part of Bed II shows the extent to which this area was deformed flowing erosion of the disconformity at the base of the facies. The disconformity is 6.8 m higher at FLK-N (loc. 45a) in this reconstruction than it is at HWK (loc. 43), and lacustrine limestones of the upper part of the lower augitic sandstones (locs. 45, 45c) are topographically 3–6 m higher than equivalent sandstones of fluvial origin to the east (locs. 42, 43). This deformation probably also accounts for the pinching out of Tuff IIB and the MAS in the vicinity of FLK. This stratigraphic relationships suggests anticlinal folding, with a north-east-southwest axis passing through FLK (loc. 45), about 200 m from a major fault. […]." (Pag. 90 in Hay, 1976).

Hay's Figure 26 (Hay, 1976) shows clearly the lateral continuity of the LAS between HWK-E and FLK-NN (Fig. 9). Tectonic deformation triggers the erosion of Tuff IIB and the MAS, creating a horizontal surface over which the BPT deposits.

Hay (1976) references the presence of the LAS and the absence of the MAS in this area on several occasions, such as when describing each unit separately (Page 60). He does not make any reference to the MAS being present at Loc. 45d nor towards the north:

"*Lower Augitic Sandstone*. This deposits, chiefly of augite-rich sandstones, disconformably overlies the Lemuta Member on the south side of the Main gorge, between FLK (loc. 45) and WK (loc. 36). It is highly lenticular and as much as 4 m thick. A basal layer, found in the vicinity of HWK (locs. 42–44) and VEK (loc. 85), is a bed of conglomerate sandstone rich in chert artefacts, the *sandy conglomerate* of M-D. Leakey (1971a, p. 96)."

"Middle Augitic Sandstone. This is a deposit, dominantly of sandstone, it is generally 60 cm to 1.5 m thick and extends from locality 35a to VEK (loc. 85), a distance of 2.5 km, on the south side of the Main Gorge, and from JK (loc. 14) to locality 20, a distance of 1.4 km, on the north." (Pag. 60 in Hay, 1976).

In addition, the precise and brief descriptions in "Appendix B, archaeological sites in Beds I and II" (Hay, 1976: 193–196) are very significant, since the presence of the LAS is referred to in the following localities, ordered upstream (SE) to downstream (NW):

"43 (HWK-E). Numerous artefacts and faunal remains in 1.2 m of conglomeratic sandstones forming lower part of lower augitic sandstone. Facies: Eastern fluvial-lacustrine."

"46c. FLK-S. "Artefacts and faunal remains in sandstone representing lower augitic sandstones". Facies: Eastern fluvial-lacustrine."

"45d. Several artefacts on paleosol overlying Tuff IIA; may represent paleosol beneath lower augitic sandstone". Facies: Eastern fluvial-lacustrine".

"45 (FLK). Artefacts and faunal remains in conglomeratic sandstone of lower part of lower augitic sandstone, 1,5 m above base of Bed II. Facies: Eastern fluvial-lacustrine".

"45a (FLK-N). Artefacts in 30 cm of clayey sandstones forming lower unit of lower augitic sandstones. Facies: Eastern fluvial-lacustrine".

Lastly, in Table 18 (Hay, 1976: Page 112) sites 45(a) or FLK-W, 45d (OH-37?), 46a (OH-40?) and 46c or FLK-S alongside other six sites are contextualized in the LAS stratigraphic interval or equivalent.

Stanistreet et al. (2018) and McHenry and Stanistreet (2018) hypothesize that the oldest Acheulean site at Olduvai Gorge, FLK-W (Diez-Martín et al., 2015), is not embedded in the LAS, but in the MAS unit. To test this hypothesis, they stratigraphically correlate Loc. 44 and Loc. 45d (Figure 11; McHenry and Stanistreet, 2018), which is referred to in their text: "Diez-Martín et al. (2015) *and* Uribelarrea et al. (2017) *report the presence of Acheulean artefacts, at a level that they attribute to the LAS of Middle Bed II. However, our stratigraphic correlations between the HWK W (Loc 44) and FLK (Loc 45) areas (Figure 11) suggest that the LAS and Tuff IIB intervals, along with much of the Lemuta Member, are lost to incision as one moves northward and approaches the FLK Fault (Figure 11), due to the major disconformity recorded by* Hay (1976) *below the Augitic Sandstones*". In this figure, it is inferred that the MAS erode the LAS between Loc. 44 and Loc. 45d, in the void created by the Secondary Gorge incision. Furthermore, this same MAS unit can be followed continuously from Loc. 45d to FLK-W lying conformably over the LD (Stanistreet et al., 2018; McHenry and Stanistreet, 2018).

As explained in the present work, Hay (1976) always states the LAS, and never the MAS overlies the LD between HWK and FLK-W. Second, as demostrated in this study, the MAS unit has been eroded at LR, leaving only part of Tuff IIB, the Tuff IIB-LAS transition, and the LAS unit (Fig. 8). Furthermore, the augitic sandstones at Loc. 45d correspond to a fluvial (sometimes fluvio-lacustrine) facies, and not to a typical, purely lacustrine facies such as that from the MAS at Loc. 44.

The hypothesis of Stanistreet et al. (2018) and McHenry and Stanistreet (2018) also contradicts that of Stanistreet (2012), who places a "Lower Augitic Sandstone incision" (in other words, the LD overlain by the LAS) at FLK (Fig. 3, Page 303; Stanistreet, 2012) which was in agreement with that proposed by Hay (1976) and Uribelarrea et al. (2017). This contradiction was not referenced in neither Stanistreet et al. (2018) nor McHenry and Stanistreet (2018).

The only empirical justification of the new stratigraphical correlation can be found in Figure 11 of McHenry and Stanistreet (2018). In this figure, the sections between Tuff IF and the BPT at "HWK-W-16 Loc. 44" (Loc. 44 in this paper) and "FLK-S(S) Loc.46, OH-40" (Loc.45d in this study) are shown. The main differences observed with the sections offered in this paper lie in the interpretation of the section at Loc. 45d. Between the LD and the BPT, the authors only describe one unit, interpreted as the MAS. We believe the 5 m of MAS deposit that they report is due to an error in the figure scale, since the same columns in their previous figure have half the thickness. Applying this scale, the augitic deposit would not be 5 m thick, but around 2.2 m, in agreement with what Hay (1976) and Uribelarrea et al. (2017) describe. It is important to stress that there are more than enough significant differences between the purely lacustrine facies (MAS) and the fluvial facies (LAS) to differentiate one from the other. In addition, from a strictly stratigraphical point of view, it is noteworthy that Stanistreet et al. (2018) and McHenry and Stanistreet (2018) have not identified Tuff IIB at Loc. 45d, which is key to understanding that the MAS have been eroded from this point northwards.

McHenry and Stanistreet (2018) also suggest that the MAS is sitting directly on the LD, recorded by Hay (1976) in Loc. 20, (i.e., immediately across the Main Gorge from the FLK site, according to Stanistreet et al., 2018), although it is 1 km eastwards from the FLK sites and 1.4 km from the FLK Fault and therefore very far away from the tectonic setting which is modifying the stratigraphic sequence between the LD and the BPT. It is important to take into account that during the sedimentary infill of the LD palaeosurface, younger units would form an onlap over the LD itself. This geometry is clearly seen in the surroundings of WK (Locs. 36, 35, and 35a), where MAS was deposited above LAS and forms an onlap over the LD. According to Hay (1976), the LAS are deposited directly on the LD in the following 23 localities: 36, 38, 39, 40, 42, 44, 85 (Figure 19 Hay, 1976), 38, 39, 40, 41, 42, 43, 44, 44a, 85 (Figure 20, Hay, 1976) y 45, 45c, 44, 49, 51, 53, 53a, 53b, 54a, 54, 55, 56, 58, (Figure 22, Hay, 1976). In all of them, the MAS are found above the LAS. On the other hand, the MAS unit lies on top of the LD only at Loc. 20 (Figure 19; Hay, 1976).

Further evidence proposed by McHenry and Stanistreet (2018, p. 9) to suggest that the Acheulean site of FLK-W is within the MAS is a possible genetic relationship between these and the BPT. "The underlying augitic sandstone appears to be conformable with the BPT without an intervening erosion surface, which would (based on Hay, 1976) suggest it to be the Middle Augitic Sandstone (MAS), rather than the LAS, as portrayed by Uribelarrea et al. (2017)". It is obvious that the laminated and low energy lacustrine facies of the BPT resembles that of the MAS, and it is uncertain whether or not they are genetically related. However, other abundant empirical data proposed in the present work suggest that is not the case.

In the first place, it is noteworthy that Hay (1976) never suggested that the MAS were found beneath the BPT at FLK. Second, if the MAS "appears to be conformable with the BPT" as suggested by McHenry and Stanistreet (2018), they should commonly be found conformably together, which is not the case. In the studied area, the BPT is also found over clays at the Castle, over Tuff IIB at Loc. 45d, over clayey silt in Maiko Gully and waxy clays at FLK-W. Hay (1976) places the BPT over the LAS at localities 53, 45, 45c, and 44, among others. This relationship is not indicated in the figures presented by McHenry and Stanistreet (2018) or Stanistreet et al. (2018). Moreover, Stanistreet et al. (2018) identify the BPT in 8 sections in Fig. 8, between DK EE and VEK (around 3 km) but the BPT unit is only found overlying the MAS in one (HWK Tembo). In the rest of the sections, the BPT overlies clay, claystone, or sandstone. These same sections are reproduced in Fig. 10 in McHenry and Stanistreet (2018), although the term "sandstone" has been replaced for MAS in 5 of the 8 sections: VEK/Loc. 85, HWK W/Loc. 44, HWK W-16 Loc. 44, HWK-castle Loc. 44 and HWK E Loc. 43. Based on this, it seems arbitrary to justify a possible genetic relationship between the MAS and the BPT. Likewise, the authors place the BPT directly above the MAS even at FLK-W, which is not the case (Fig. 10). Here, the uppermost geological unit of FLK-W (Level 1) is overlain by the local tuff FLK-Wb, dated to 1.66 Ma, and by 30 cm of clays, and finally, the BPT.

Hay's (1976) description of "the lower part of lower augitic sandstones, 1.5 m above the base of Bed II" at Loc. 45 (FLK) is in perfect agreement with the stratigraphic and geographic position of FLK-W.

From a strictly sedimentological and geomorphological point of view, the interpretation posited by McHenry and Stanistreet (2018) is not sustainable, since the inferred sedimentary environments of the MAS (lacustrine), and the fluvial channel at FLK-W are completely antagonistic. The MAS are low energy facies, typically lacustrine, deposited in a horizontal flat surface, whereas FLK-W is a great fluvial channel, erosive with at least two high energy levels (Levels 5 and 6), with very coarse grained fluvial bars and cobble lags. The channel at FLK-W drains towards the central lake in the FLK-5th Fault graben (north), while the depocenter of the MAS is located south. The channel at FLK-W was clearly formed during the LD in a more energetic event, and we provide evidence that this is most likely to have happened during the formation of the LAS unit.

Lastly, regarding the geometry of the stratigraphic units, LAS is commonly parallel to LD from Long Korongo up to FLKN (2 km). McHenry & Stanistreet's (2018) hypothesis assumes that MAS replace LAS between localities 44 and 45d due to a marked erosive process, but after Loc 45d, "MAS" rest upon LD as far as FLKW. Geological proof of this assumption is missing. The only justification of such a model would be a remarkable tectonic deformation just in the area between localities 44 and 45d. This is not documented. As a matter of fact, the underneath marker Tuff IF is not locally folded and can be found on the same stratigraphic position on both localities.

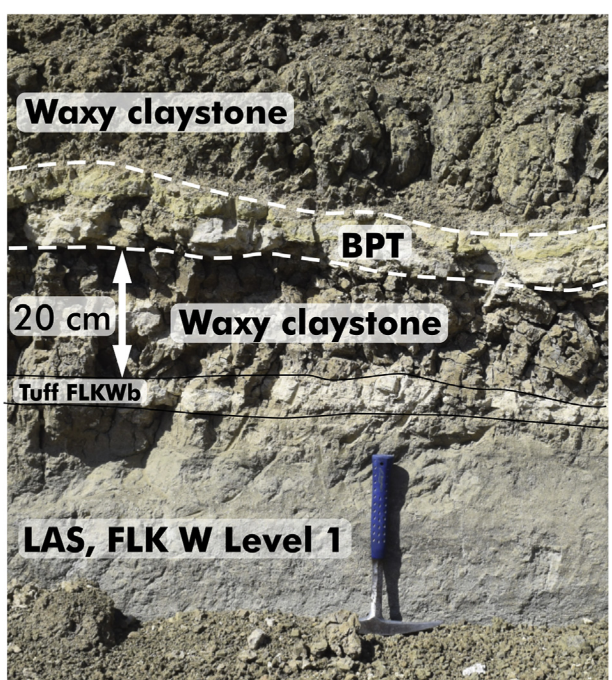


Fig. 10. Location of the Bird Print Tuff (BPT) in the FLK-W deposit, 20 cm above the Tuff FLKWb (1.66 m.y.).

7. Conclusions

According to Hay (1976), the LAS are present at HWK-EE, HWK-E, HWK, HWK-W, FLK-S, FLK-W, FLK-N, and FLK-NN. Between HWK and FLK-W the palaeosurface prior to the BPT erodes the MAS from Loc. 44 northwards and also partially erodes Tuff IIB at Loc. 45d. The MAS unit and Tuff IIB are not present at FLK-W. The MAS unit is typically lacustrine, whereas the LAS unit is fluvial and fluvial-lacustrine and, therefore, they are distinguishable. LAS overlies the LD practically throughout the gorge, while the MAS only does so at Loc. 20 and WK.

At FLK (Loc. 45), the LAS unit is deposited on the LD, very close to the base of Bed II, only 1.5 m above tuff IF (Hay, 1976). Stanistreet (2012) describe a similar situation, as do Díez-Martín et al. (2015) and Uribelarrea et al. (2017).

An evident facies and unit correlation exists between Loc. 44 and Loc. 45d, which proves that the MAS does not replace the LAS in the studied area.

At Loc. 45d, the Tuff IIB-LAS transition, alongside Tuff IIB itself, are identified above the LAS, proving that the MAS unit has been eroded.

The FLK-W site is buried in a fluvial channel, with very coarse-grained fluvial bars and cobble lags. These facies are incompatible with a low energy lacustrine facies such as that attributed to the MAS. This increases the heuristics of the interpretation that FLK West is situated within the LAS unit and that its chronology is 1.7 Ma. It also shows that the Acheulean technology that it contains co-exist with the Oldowan from the HWK complex. Archaeological and palaeoecological studies (Uno et al., 2018; Bibi et al., 2018; De la Torre et al., 2018) based on the stratigraphical interpretation presented by McHenry and Stanistreet (2018) and Stanistreet et al. (2018), should, thus, be revised. The only site that is higher than LAS in the stratigraphic sequence in the FLK West gully is the site being excavated by OGAPP across from the FLK West (Diez-Martín et al., 2015) and which is unfortunately referred to by the same name (De la Torre et al., 2018).

This reassessment of the stratigraphic location of FLK West indicates that the date of the Acheulean in Olduvai Gorge (1.7 m.y.) and the coexistence with Oldowan industries suggests a cladogenetic model for the emergence of this technology.

Declaration of competing interest

The authors declare having no conflict of interest.
We don't have conflict of interest, we make a scientific critique.

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