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# Geochemistry of the Fejej Tuffs (South Omo, Ethiopia), their Tephrostratigraphical Correlation with Plio-Pleistocene Formations in the Omo-Turkana Basin

## *Géochimie des tufs de Fejej (Sud-Omo, Ethiopie) et corrélations téphrostratigraphiques avec les formations plio-pléistocènes du bassin de l'Omo-Turkana*

Cécile Chapon[a,*], Jean-Jacques Bahain[b], Yonas Beyene[c], Jean-Baptiste Bilcot[d], Christophe Guy[d], Michel Jullien[e], Henry de Lumley[f], Olivier Provitina[d]

[a] *Centre européen de recherches préhistoriques, avenue Léon-Jean-Grégory, 66720 Tautavel, France*
[b] *UMR 7194 du CNRS, département de préhistoire, Muséum national d'histoire naturelle, 1, rue René Panhard, 75013 Paris, France*
[c] *Department of Archeology and Anthropology, C.R.C.C.H., Ministry of Information and Culture, P.O. Box 1907, Addis Abeba, Ethiopia*
[d] *Laboratoire d'analyses radiochimique et chimique, commissariat à l'énergie atomique de Cadarache, bâtiment 152, 13108 Saint-Paul lez Durance, France*
[e] *Laboratoire de Modélisation des Transferts dans l'Environnement, centre de Cadarache du commissariat a l'énergie atomique, bâtiment 307, 13108 Saint-Paul lez Durance, France*
[f] *Institut de paléontologie humaine, 1, rue René-Panhard, 75013 Paris, France*

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ABSTRACT

The FJ-1 Tuff and three additional isolated outcrops of volcanic tuffs listed in the Fejej area (South Omo, Ethiopia) are associated with a single volcanic event and correspond to the same ash deposit subsequently truncated by erosion. Data from new chemical analyses given by X-ray fluorescence allow correlation of these tuffs with the Borana Tuff of the Koobi Fora Formation, which is itself correlated with a tuff in the Upper G member or with the H-1 tuff of the Shungura formation. The geochronological assessment of this tephra is in agreement with previous magnetostratigraphical and biostratigraphical studies, attributing the Fejej FJ-1 Tuff to between 1.95 to 1.90 Ma.


RÉSUMÉ

Le tuf volcanique FJ-1 et trois autres affleurements isolés de cendres volcaniques recensés dans la région de Fejej (Sud-Omo, Ethiopie) confirment l'enregistrement d'un seul événement volcanique et d'un unique dépôt de cendres tronqué par l'érosion. D'après la nouvelle composition chimique obtenue par fluorescence X et en concordance avec la

* Corresponding author. UMR 7194, institut de paléontologie humaine, 1, rue René-Panhard, 75013 Paris, France.
*E-mail address:* c.chapon.sao@mnhn.fr (C. Chapon).

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magnétostratigraphie et la biostratigraphie, le tuf FJ-1 de Fejej, d'âge compris entre 1,95 et 1,90 Ma, peut être corrélé avec le tuf Borana de la formation de Koobi Fora, lui-même rapproché d'un tuf situé dans le membre G supérieur de la formation de Shungura, ou avec le tuf H-1 de cette même formation.



## 1. Introduction

In northern Kenya and southern Ethiopia, the fossiliferous sedimentary Plio-Pleistocene formations of the Omo-Turkana basin (the Nachukui, Shungura, Usno, Mursi and Koobi Fora formations, Fig. 1) include several interstratified basaltic lavas and more than 135 individual tephra layers (Feibel, 1999). Most of them were precisely dated by $^{40}Ar/^{39}Ar$ and $^{40}K/^{40}Ar$ methods providing chronological control of the hominid fossil finds and archaeological levels discovered in these formations (Brown et al., 1985; Leakey et al., 1998, 2001; McDougall, 1981, 1985; McDougall and Brown, 2006; McDougall et al., 1985). In addition, more than 120 tephras were geochemically characterized and tephrostratigraphical correlated to determine stratigraphic relations among the various formations of the Omo-Turkana Basin (Cerling and Brown, 1982; Cerling et al., 1979; Feibel, 1999; Haileab, 1994). Because of their widespread and instantaneous dispersion and their specific geochemical signature, the tephra present the advantage of defining local and regional tephrostratigraphical correlations (Brown, 1982; Brown et al., 1992; Haileab and Brown, 1994; Harris et al., 1988; Katoh et al., 2000; De Menocal and Brown, 1999; Pickford et al., 1991). The compilation of all data from the Omo-Turkana Basin contributed to establishing a detailed tephra sequence and to proposing a chronostratigraphical framework for major paleoenvironmental and paleogeographical changes in the region over the last 4 million years (Brown and Feibel, 1991; Feibel, 1997; Rogers et al., 1994).

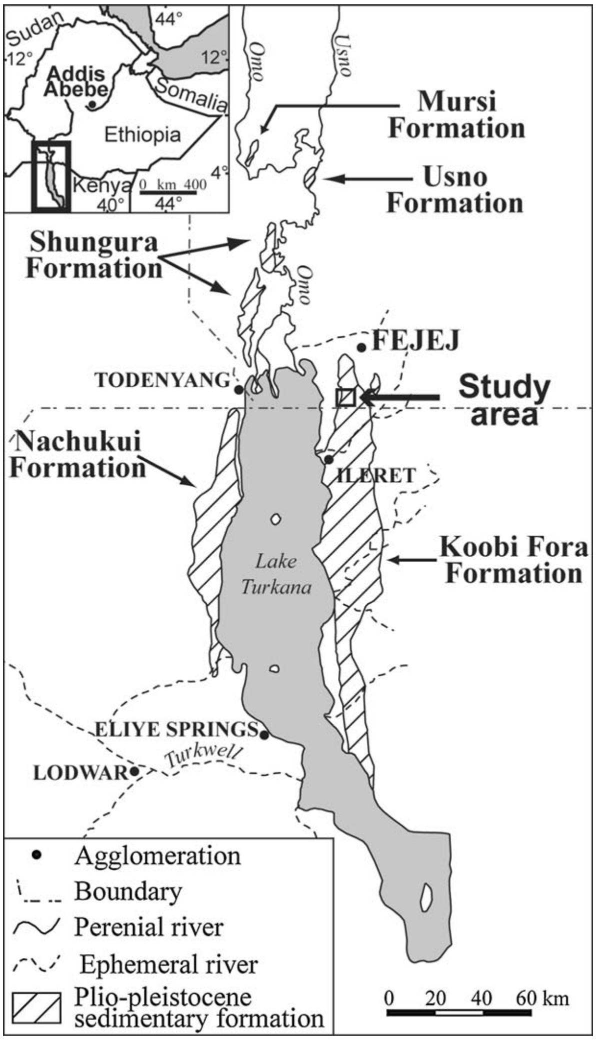


**Fig. 1.** Distribution of the Plio-Pleistocene sedimentary formations of the Omo-Turkana Basin and location of Fejej study area (after Feibel (1997) modified).

**Fig. 1.** Localisation de la zone d'étude de Fejej et répartition des formations sédimentaires plio-pléistocènes du bassin de l'Omo-Turkana.

In the Fejej area, southwestern Ethiopia, several outcrops of grey volcanic ash were observed in deposits corresponding to the northern end of the Koobi Fora Formation during field surveys started in 1989 (Figs. 1 and 2) (Asfaw et al., 1991; de Lumley and Beyene, 2004; de Lumley

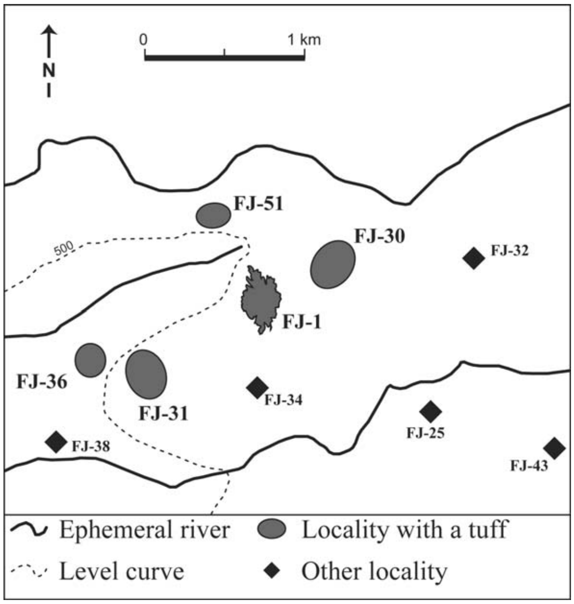


**Fig. 2.** Distribution of the main localities and outcrops of volcanic tuff in the Fejej region.

**Fig. 2.** Répartition des principales localités et des affleurements de tuf volcanique.

et al., 2004b). At the FJ-1 locality, the first tuff recognized in 1989 lies 3 m above a Mode 1 archaeological level, named C1 and excavated from 1992 to 2002 by a French-Ethiopian team from the Museum national d'histoire naturelle, Paris, and from the National Museum of Ethiopia, Addis Ababa (Barsky et al., 2006; de Lumley et al., 2004b). The first geochemical analyses of volcanic glass from the FJ-1 Tuff were then carried out by the Inventory Team members (Asfaw et al., 1991). The geochemical data suggest that the FJ-1 Tuff can be correlated with the H-2 Tuff from the Upper G member of the Shungura Formation (Asfaw et al., 1991), the latter being related to the KBS Tuff of the Koobi Fora Formation (Cerling and Brown, 1982; Cerling et al., 1979) dated to $1.869 \pm 0.021$ Ma (McDougall and Brown, 2006). These results were however criticized by Haileab and Feibel (1993) who proposed instead to correlate FJ-1 Tuff with the H-1 Tuff, whose age, inferred from sedimentation rates, is estimated as $1.90 \pm 0.03$ My (Feibel et al., 1989), in agreement with the paleontological record of the FJ-1 locality (Asfaw et al., 1991, 1993; Echassoux et al., 2004).

In the Fejej area, four other localities, listed as FJ-30, FJ-31, FJ-36 and FJ-51 and discovered within a radius of 1.2 km of the FJ-1 locality, also include a volcanic ash level. Characterized by indurations that preserved them from erosion, they correspond to the substructural surface of residual hillocks whose depth could attain several hundred meters. With an altitude reaching around 510 m above sea level, the hillocks dominate the landscape by several meters. For each locality, stratigraphic sequences, sedimentological characteristics, paleontological assemblages and the macroscopic aspect of tephra present similarities with the FJ-1 locality (Chapon, 2007; Chapon et al., 2008). The hypothesis of a single tephra layer later broken up by erosion seems the most probable, but intra-locality stratigraphical correlations are somewhat complex due to truncation caused by faulting, interference from the recent and dense hydrographical system, and lateral variations of facies (de Lumley et al., 2004c).

Because the first geochemical results obtained for FJ-1 Tuff gave conflicting results, the correlation among the FJ-1 Tuff and other tephra known in the Omo-Turkana Basin is not very convincing. We therefore decided to re-evaluate the geochemical composition of the tephra. The two aims of this article are: 1) to verify the pyroclastic accumulation homogeneity over time and space; and 2) to place the Fejej localities within a framework linking the entire Omo-Turkana Basin archaeological and/or paleontological sites on the basis of new tephrostratigraphical correlations inferred from geochemical analyses of glass shards. The FJ-51 Tuff is not affected by the present study.

## 2. Stratigraphical sequence of the Fejej localities

### 2.1. FJ-1 locality and Tuff

Discovered in 1989 (Asfaw et al., 1991), the FJ-1 Tuff crops out on the western edge of the FJ-1 locality where it is relatively well preserved and reaches a maximum thickness of 0.80 m. The FJ-1 Tuff is made up of colourless or clear grey angular glass shards (< 2 mm), with numerous brown, high density, glasseous shards (Chapon, 2007). Following Heiken & Wohletz (1985), the glass shards from the FJ-1 Tuff were classified into four morphological types: 60% are bubble junction, 22% fibrous, 7% bubble-wall fragments, 3% bubbles. No pumice was found. The FJ-1 Tuff is characterized by a laminated structure and ripple marks, indicating a fluvial current from the north (Chapon, 2007; de Lumley et al., 2004a).

The FJ-1 Tuff caps a 12 m thick fluvial sequence, divided into three stratigraphical units (Chapon et al., 2005; de Lumley et al., 2004a) (Fig. 3). The C1 archaeological level, part of unit 3, situated three metres below the FJ-1 Tuff, has yielded "Pre-Oldowan" lithic industry (Barsky et al., 2006; de Lumley et al., 2004b), human teeth attributed to *Homo habilis* (de Lumley and Marchal, 2004) and large mammal fossil remains (Asfaw et al., 1991; Echassoux et al., 2004). The paleontological assemblage suggested that the FJ-1 C1 level can be correlated either with the Upper G member of the Shungura Formation or with the Upper Burgi member of the Koobi Fora Formation (Asfaw et al., 1991; Echassoux et al., 2004).

### 2.2. FJ-30 locality and Tuff

The FJ-30 locality lies about 500 m to east-northeast of FJ-1 (Figs. 2 & 3). The fluvial sequence is composed of fine, light brown silty sands (1.20 m thick), covered by coarser (2 m thick) and then tuffaceous sands (1 m thick). The 1.10 m thick tuff coifs the sedimentary sequence. Characterized by horizontal lamination, it is grey in colour (N73; 2.5 Y 6/0) and rich in tubular and carbonate concretions (Chapon, 2007).

### 2.3. FJ-31 locality and Tuff

The FJ-31 locality was discovered about 1.3 km to southeast of FJ-1 (Fig. 2). The stratigraphic section is composed of a 5 m thick fluvial sequence composed (from the base to the top) of polymictic conglomerate, fine sands and white silts rich in carbonate concretions (figure 3) and overlain by a tuff. The 3 m thick tuff is located on the western flank of the hillhock. It is grey (N73; 2.5 Y 6/0), planar-laminated and ripple-stratified and contains centimetre carbonate concretions (Chapon, 2007).

### 2.4. FJ-36 locality and Tuff

The FJ-36 locality lies around 1.2 km west-southwest of FJ-1 (figure 2). The stratigraphic sequence is composed at the base of a 4-m thick layer of pale yellow (L77; 2.5 Y 8/4) sandy silts rich in carbonate concretions, overlain by a 0.4-m thick layer of coarse calcified sands interstratified with fine sandstone. The tuff, slightly dipping 3° to the north-northeast, completes the sequence. Grey in colour (M31; 7.5 R 7/0), it is over 0.40 m thick and characterized by laminated structures and millimetric tubular carbonate concretions (Chapon, 2007).

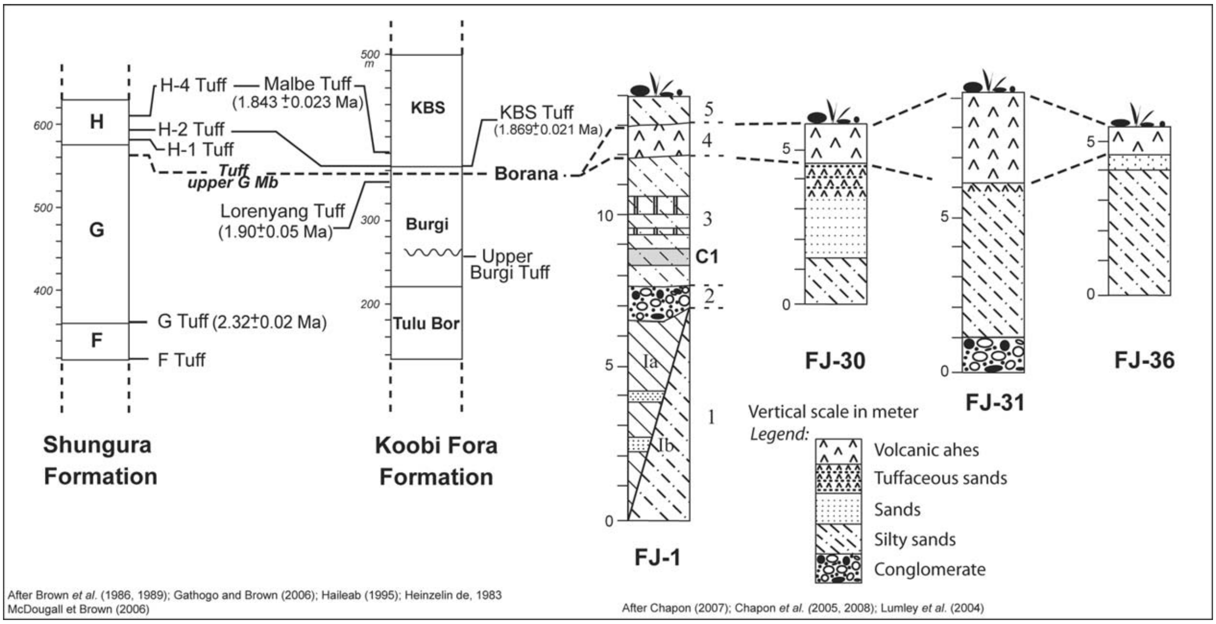


**Fig. 3.** Stratigraphical sequences of the Fejej Tuff localities and tephrostratigraphical relationship among the FJ-1 Tuff, the Borana Tuff, the tuff in the upper G member (noted *Tuff, upper G Mb*) and the H-1 Tuff.
**Fig. 3.** Les séquences stratigraphiques des localités de Fejej et les relations téphrostratigraphiques entre le tuf FJ-1, le tuf H-1, le tuf Borana et le tuf situé dans le membre G supérieur (noté *Tuff, upper G Mb*).

## 3. Analytical procedure

The tuffs of the various Fejej localities were sampled during field surveys organized by the Muséum national d'histoire naturelle and the National Museum of Ethiopia between 1992 and 2002. The FJ-1 Tuff was sampled at regular vertical intervals in order to determine whether the tephra corresponds to several distinct volcanic events based on evidence from the geochemical spectral variation. Three samples provide reference: FJ-1.s1, FJ-1.s2 and FJ-1.s3, respectively sampled from a depth of 65 cm, 40 cm and 25 cm from the top of the tuff layer. Isolated sampling was performed at the other three localities (FJ-30, FJ-31 and FJ-36) to test the probability of a geochemical (and therefore stratigraphical) correlation that would confirm field observations. To establish useful comparisons between the Fejej and Omo-Turkana Basin tuffs, and to minimize analytical errors, we chose the X-ray fluorescence method which has often been applied to analyse tuffs of the Shungura and Koobi Fora formations and of the African distal basin formations. After decarbonation of the material, volcanic glass shards were separated from felsic, mafic and detrital minerals by heavy liquid separation using a mixture of bromoform/ethanol with density of 2.54 g/cc. The quality of separation was verified using a binocular microscope and was improved by manual selection. The purified fraction was pulverized for major element analysis by X-ray fluorescence. The calibration range of the Philips Analytical PW 1404 device was carried out using semi-quantitative analyses of 15 standards at the "Laboratoire d'analyses radiochimiques et chimiques", "Commissariat à l'énergie atomique", Cadarache, France.

The chemical composition of the FJ-1 Tuff was compared with that from other published East African tephra, including the two tephras previously correlated with FJ-1 Tuff, i.e. the KBS Tuff of the Koobi-Fora Formation through two representative samples, the standard tuff KBS 77-17 (Cerling and Brown, 1982; Feibel, 1999) and the KBS Tuff Lothagam (Feibel, 1999), and the H-1 Tuff (Asfaw et al., 1991) located two meters below the H-2 Tuff itself correlated to KBS Tuff. The degree of similarity among the geochemical compositions of the tephra was estimated using the Borchardt's similarity coefficient, which integrates all element contents without carrying out 100% standardization, since this operation does not influence the coefficient's values (Borchardt et al., 1972). The similarity coefficient values (CS) (Table 2) vary from 1, for perfect chemical similarity of the volcanic glass samples, to 0.60, for distinct ash layers (Borchardt et al., 1972). Lastly, the proposed correlation is supported by the magnetostratigraphical and biostratigraphical position of the analyzed tuffs (see p. 10).

## 4. Results and discussion

### 4.1. Chemistry of volcanic glass shards

Using the "Le Maître" variation diagram, the Fejej tuffs have a rhyolitic to dacitic composition (Le Maître, 2002). The major element composition of the volcanic glasses analysed by XRF are presented in Table 1, alongside data previously obtained for the FJ-1 Tuff using electron microprobe and DCP methods (Asfaw et al., 1991). All data were plotted using variation diagrams of $Fe_2O_3$ versus major oxides as shown in Fig. 4. Relatively high CaO and $TiO_2$ contents characterize these tuffs as compared with the gen-

**Table 1**
Major elements contents (wt %) in Fejej tuffs analysed by XRF (with 1σ) (in grey), by electron microprobe (89.Tuff FJ-1(a)) and by DCP (89.Tuff FJ-1(b)) (Asfaw et al., 1991), in H-1 Tuff (Haileab, 1994), in Borana Tuff (Gathogo and Brown, 2006), in KBS tuff (Feibel, 1999) and in the tuff in the upper G member (Haileab, 1994).
**Tableau 1**
Compositions en éléments majeurs des tufs de Fejej dosés par fluorescence X (données à 1σ), par microsonde (89.Tuff FJ-1(a)), et par DCP (89.Tuff FJ-1(b)) (Asfaw et al., 1991), du tuf H-1 (Haileab, 1994), du tuf Borana (Gathogo et Brown, 2006) et du tuf KBS (Feibel, 1999) et d'un tuf intercalé dans le membre G supérieur (Haileab, 1994).

| Sample | Major elements (weight %) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | MgO | $Fe_2O_3$ | MnO | CaO | $Na_2O$ | $K_2O$ | Total |
| FJ-1.s1 (XRF) | 70.90 ± 3.5 | 0.70 ± 0.03 | 13.70 ± 1.5 | 0.20 ± 0.1 | 5.05 ± 0.55 | 0.17 ± 0.01 | 2.10 ± 0.18 | 3.77 ± 0.8 | 2.80 ± 0.3 | 99.39 |
| FJ-1.s2 (XRF) | 70.50 ± 3.5 | 0.41 ± 0.03 | 13.90 ± 1.5 | 0.37 ± 0.1 | 5.27 ± 0.55 | 0.17 ± 0.01 | 2.23 ± 0.18 | 3.87 ± 0.8 | 2.89 ± 0.3 | 99.61 |
| FJ-1.s3 (XRF) | 73.10 ± 3.5 | 0.41 ± 0.03 | 12.50 ± 1.5 | 0.15 ± 0.1 | 5.11 ± 0.55 | 0.18 ± 0.01 | 1.96 ± 0.18 | 3.27 ± 0.8 | 2.80 ± 0.39 | 99.48 |
| FJ-30 (XRF) | 72 ± 3.5 | 0.34 ± 0.03 | 13.90 ± 1.5 | 0.22 ± 0.1 | 5.49 ± 0.55 | 0.10 ± 0.01 | 1.79 ± 0.18 | 3.08 ± 0.8 | 2.60 ± 0.36 | 99.52 |
| FJ-31 (XRF) | 70.90 ± 3.5 | 0.59 ± 0.03 | 13.60 ± 1.5 | 0.27 ± 0.1 | 5.70 ± 0.55 | 0.15 ± 0.01 | 2.62 ± 0.18 | 3.12 ± 0.8 | 2.70 ± 0.33 | 99.65 |
| FJ-36 (XRF) | 70.90 ± 3.5 | 0.45 ± 0.03 | 13.80 ± 1.5 | 0.21 ± 0.1 | 4.93 ± 0.55 | 0.13 ± 0.01 | 2.57 ± 0.18 | 3.90 ± 0.8 | 2.60 ± 0.39 | 99.49 |
| 89.Tuff FJ-1(a) | 72.23 | 0.36 | 14.24 | 0.09 | 4.36 | 0.13 | 1.45 | 3.75 | 3.28 | 99.89 |
| 89.Tuff FJ-1(b) | 73.58 | 0.23 | 14.06 | 0.05 | 3.5 | 0.09 | 1.22 | 3.26 | 4.01 | 100 |
| H-1 Tuff | – | 0.14 | – | – | 4.39 | 0.13 | 1.84 | – | 2.3 | 8.80 |
| KBS Tuff type 77-17 | 72.98 | 0.2 | 10.79 | 0.03 | 3.17 | 0.11 | 0.18 | 3.23 | 3.92 | 94.61 |
| KBS Tuff Lothagam | 73.34 | 0.17 | 10.9 | 0.04 | 3.03 | 0.11 | 0.18 | 1.25 | 1.77 | 90.79 |
| Borana Tuff | 67.78 | 0.40 | 13.59 | 0.19 | 4.13 | 0.17 | 1.47 | 3.82 | 2.80 | 94.35 |
| *Tuff of the Upper G member* | 69.4 | 0.54 | 14.17 | 0.4 | 5.57 | 0.18 | 2 | 3.56 | 4.18 | 100 |

**Table 2**
Similarity coefficients among chemical data of glass shards from Fejej tuffs (FJ-1, FJ-30, FJ-31 and FJ-36) analysed by XRF (in grey), by electron microprobe (89.Tuff FJ-1(a)) and DCP (89.Tuff FJ-1(b)), from H-1 Tuff and a Tuff of the Upper G member of the Shungura Formation and from KBS Tuff and Borana Tuff of the Koobi Fora Formation.
**Tableau 2**
Les coefficients de similarité entre les compositions chimiques des verres volcaniques des tufs FJ-1, FJ-30, FJ-31 et FJ-36 de Fejej analysés par fluorescence X (en grisé), par microsonde (89Tuf FJ-1(a)) et par DCP (89Tuf FJ-1(b)), du tuf H-1 et d'un tuf du membre G supérieur de la formation de Shungura, du tuf KBS et du tuf Borana de la formation de Koobi Fora.

| Sample | FJ-1.s1 | FJ-1.s2 | FJ-1.s3 | FJ-30 | FJ-31 | FJ-36 | 89.Tuff FJ-1(a) | 89.Tuff FJ-1(b) | H-1 Tuff | KBS Tuff type 77-17 | KBS Tuff Lothagam | Borana Tuff | *Tuff of the Upper G member* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FJ-1.s1 | 1 | 0.88 | 0.91 | 0.82 | 0.89 | 0.90 | 0.79 | 0.68 | 0.71 | 0.57 | 0.50 | 0.88 | 0.84 |
| FJ-1.s2 | | 1 | 0.83 | 0.83 | 0.87 | 0.89 | 0.80 | 0.67 | 0.71 | 0.58 | 0.50 | 0.87 | 0.90 |
| FJ-1.s3 | | | 1 | 0.81 | 0.84 | 0.82 | 0.78 | 0.70 | 0.70 | 0.60 | 0.52 | 0.83 | 0.83 |
| FJ-30 | | | | 1 | 0.81 | 0.90 | 0.82 | 0.76 | 0.77 | 0.64 | 0.57 | 0.84 | 0.79 |
| FJ-31 | | | | | 1 | 0.90 | 0.75 | 0.66 | 0.68 | 0.58 | 0.51 | 0.81 | 0.85 |
| FJ-36 | | | | | | 1 | 0.82 | 0.70 | 0.75 | 0.60 | 0.54 | 0.87 | 0.81 |
| 89.Tuff FJ-1(a) | | | | | | | 1 | 0.66 | 0.67 | 0.67 | 0.76 | 0.87 | 0.76 |
| 89.Tuff FJ-1(b) | | | | | | | | 1 | 0.75 | 0.58 | 0.62 | 0.72 | 0.68 |
| H-1 Tuff | | | | | | | | | 1 | 0.59 | 0.65 | 0.41 | 0.36 |
| KBS Tuff type 77-17 | | | | | | | | | | 1 | 0.82 | 0.61 | 0.59 |
| KBS Tuff Lothagam | | | | | | | | | | | 1 | 0.54 | 0.46 |
| Borana Tuff | | | | | | | | | | | | 1 | 0.80 |
| *Tuff of the Upper G member* | | | | | | | | | | | | | 1 |

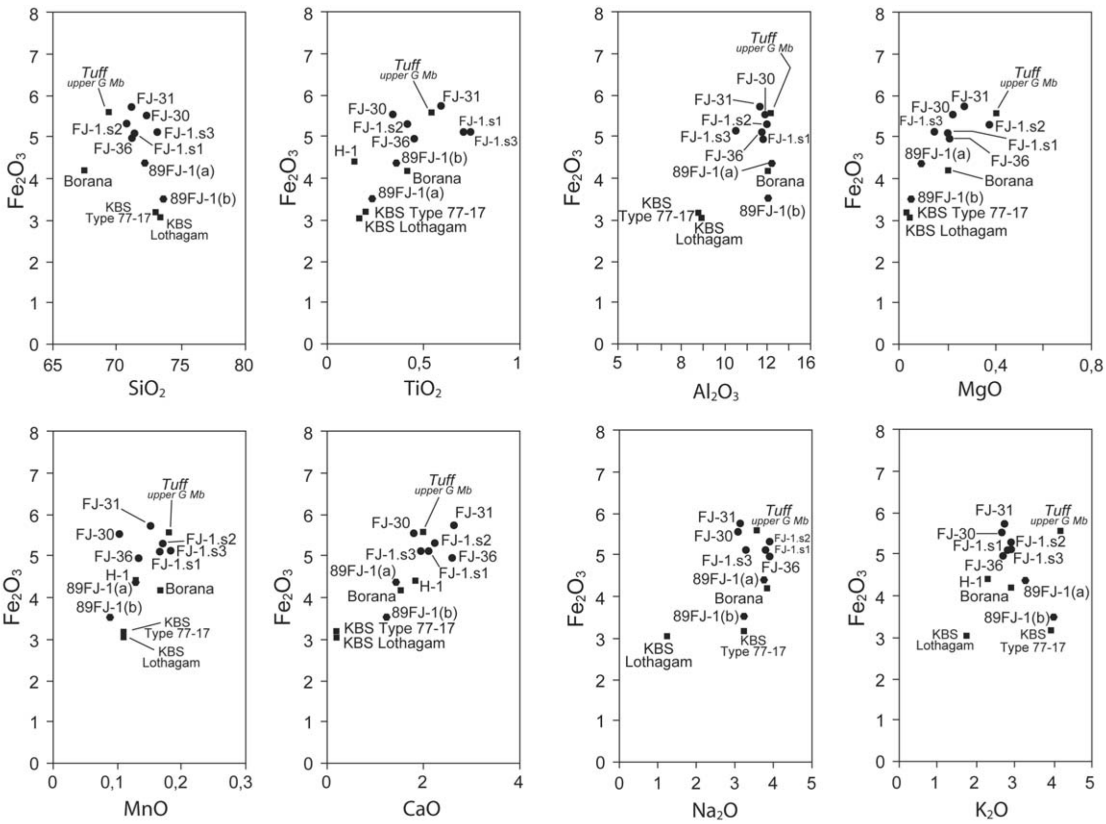


**Fig. 4.** Chemical data in major elements (weight %) of glass shards from Fejej FJ-1, FJ-30, FJ-31 and FJ-36 localities, analysed by XRF, electron microprobe (a) and DCP (Asfaw et al., 1991), from H-1 and Tuff Upper G member (Shungura Formation) (Haileab, 1994) and KBS Tuff (Koobi Fora Formation) (Feibel, 1999).

**Fig. 4.** Compositions chimiques en éléments majeurs (en %) des verres volcaniques des tufs des localités de Fejej FJ-1, FJ-30, FJ-31 et FJ-36 analysés par fluorescence X, microsonde (a) et DCP (b) (Asfaw et al., 1991), du tuf H-1 et du tuf non indexé du membre G supérieur (Tuff upper G Mb) (Formation de Shungura) (Haileab, 1994) et du Tuf KBS (Formation de Koobi Fora) (Feibel, 1999).

erally known chemical composition of tephras known from other Plio-Pleistocene sedimentary formations in the Omo-Turkana Basin, whose ratios are generally lower (Cerling and Brown, 1982; Cerling et al., 1979; Gathogo and Brown, 2006; Haileab, 1994; Harris et al., 1988) indicating probably a geochemical particularity.

### 4.1.1. FJ-1 Tuff

The $SiO_2$ $Na_2O$, $K_2O$, CaO and MnO contents of the various FJ-1 Tuff samples (FJ-1.s1, FJ-1.s2 et FJ-1.s3) are very similar (Fig. 4) and their Borchardt coefficient values are high (CS = de 0.83 to 0.91) (Table 2), suggesting a vertically homogeneous chemical composition. In addition, the chemical composition of the FJ-1 Tuff glass inferred from XRF is similar to that obtained using electron microprobe (89FJ-1(a)) or DCP methods (89FJ-1(b)) (Asfaw et al., 1991), as indicated by the Borchardt coefficient values (CS = de 0.67 to 0.79).

### 4.1.2. Tuffs from the other Fejej localities

The other Fejej tuffs analyzed present the lowest values of oxides ($Al_2O_3$, $TiO_2$, CaO and $Fe_2O_3$), but the data are globally similar to those obtained for FJ-1 Tuff, except for $TiO_2$ and MgO contents which are more dispersed. On the other hand and, rather surprisingly, $K_2O$ and $Na_2O$, considered as very mobile elements, show similar values from one sample to another. Overall, the corresponding groups of plots are compatible and the Borchardt coefficient values are high (CS = de 0.73 to 0.91). Considering lithostratigraphic description, stratigraphic position of the tuffs and paleontological assemblages, the tuffs of the various Fejej localities (FJ-1, FJ-30, FJ-31 and FJ-36 tuffs) appear to correspond to a single volcanic event, which was then parcelled out by erosion.

## 4.2. Correlations between the Fejej tuffs and others tuffs from the Omo-Turkana Basin

The new chemical analyses of the Fejej tuffs allow us to dismiss any initially suggested correlation with the H2/KBS Tuff (Asfaw et al., 1991) because of their very different chemical composition and the low values obtained from the similarity coefficients (CS = 0.50 to 0.64). The chemical composition of FJ-1 Tuff also differs slightly from that of H-1 (Haileab, 1994) with which it has been correlated in the past (Asfaw et al., 1991). The similarity coefficients' values between these two tuffs are low (CS = de 0.68 to 0.77) but remain within the Borchardt's similarity interval

(Brochardt et al., 1972). The use of the tephra database led us to consider a possible correlation between the Fejej Tuffs and the Borana Tuff as defined in the Upper Burgi member of the Koobi Fora Formation (Gathogo and Brown, 2006; Haileab, 1994; Heinzelin, 1983). The similarity of their chemical composition is supported by high values of similarity coefficients (CS = 0.81 to 0.88). On the basis of their geochemical composition, the Borana Tuff may be correlated with the G-29 Tuff located toward the top of the Upper G member (Haileab and Brown, 1994). As this latter tuff was described outside the Upper G member type section, it is preferable to mention that the Borana Tuff is correlated with an unnamed tuff from the Upper G member in contrast to our previous proposal (Chapon et al., 2008). The Borana Tuff lies 5 m below the KBS Tuff, itself correlated with the H-2 Tuff, and has been described in the northern Karari Ridge area and recognized in the Ileret area in Kenya, close to the boundary between Ethiopia and Kenya. Brown in colour, the 0.30 m thick Borana Tuff underlies a lacustrine sequence intercalating sandstone rich in molluscs (Gathogo and Brown, 2006; Heinzelin, 1983).

## 5. Magnetostratigraphical and biostratigraphical correlations

Considering that the FJ-1 Tuff has recorded a normal magnetic polarity (Chapon, 2007, Chapon et al., 2005, de Lumley et al., 2004a), and other available chronostratigraphical data, in particular biostratigraphy (Echassoux et al., 2004), it has previously been suggested that the tuff was deposited during the Olduvai magnetozone (Chapon et al., 2005; de Lumley et al., 2004a), i.e., between 1.77 and 1.95 Ma (Cande et Kent, 1995). In the Upper G member of the Shungura Formation, the base of this magnetozone is recorded within Unit G-27 and it ends in member H, a few meters above the H-4 Tuff which is correlated with the Malbe Tuff of the Koobi Fora Formation and dated to $1.843 \pm 0.023$ Ma (Brown et al., 1978; Cerling and Brown, 1982; Hillhouse et al., 1986; McDougall and Brown, 2006; McDougall et al., 1992). In the latter formation, the Olduvai magnetozone ends about sixty meters above the KBS Tuff (Hillhouse and Cerling, 1986). However the chronostratigraphical position of its base remains unknown because, in the eastern part of the Turkana Basin, a sedimentary hiatus between approximately 2.5 Ma and 2 Ma truncates the Koobi Fora formation; changes to a normal polarity sequence are only observed from 120 m below the KBS Tuff. In this sequence, it is in fact impossible to differentiate the Gauss period from the Olduvai magnetozone (Hillhouse et al., 1986; McDougall et al., 1992). Thus, if the Borana Tuff and one tuff of the Upper G are indeed correlated with the FJ-1 Tuff, their stratigraphical positions confer an age ranging between $1.95 \pm 0.03$ Ma, at the beginning of the Olduvai magnetozone (Cande and Kent, 1995) and $1.869 \pm 0.021$ Ma, age of the KBS Tuff (McDougall and Brown, 2006), in agreement with the biochronological data previously available for the archaeological C1 level (Asfaw et al., 1991, 1993; Echassoux et al., 2004). In the Shungura Formation, the tuff correlated with the Borana Tuff is located a few meters below the H Tuff, whose age was estimated by sedimentation rates as $1.90 \pm 0.03$ Ma (Feibel et al., 1989) and itself located ten meters below the H-1 Tuff (Heinzelin, 1983). Taking these data into account, we suggest that the correlation between the FJ-1 Tuff and the Borana Tuff is therefore acceptable, although a correlation with the H-1 Tuff cannot be completely excluded: the latter was deposited during the same normal polarity interval as the supposed G-29 Tuff, and its chemical composition is quite compatible with that of Fejej Tuffs.

## 6. Conclusions

New geochemical analyses of the Fejej FJ-1 Tuff using XRF give similar results to those of previous studies carried out by DCP and electron microprobe methods (Asfaw et al., 1991). They indicate that tuffs from the four tested Fejej localities correspond to a single volcanic event. Because of the homogeneity of the deposition and the presence of diatoms, the volcanic ash could have been wind-blown into the basin and then rapidly deposited upon a watery surface. Definitively different from the H2 Tuff/KBS Tuff, the Fejej FJ-1 Tuff is chemically similar to the H-1 Tuff, to the Borana Tuff and to a tuff from the Upper G Member. Its chronostratigraphic age, reckoned between the beginning of the Olduvai magnetozone, i.e., 1.95 Ma ago, and the deposition of the KBS/H2 Tuff about $1.869 \pm 0.021$ Ma ago, is consistent with paleontological data provided by excavations of the FJ-1 Mode 1 lithic industry C1 level. We propose that the deposits forming the FJ-1 sequence could be contemporaneous with the Upper Burgi member of the Koobi Fora formation and to the Upper G member or the base of the H member of the Shungura Formation. This new geochemical analyses and the proposed correlation are in accordance with the chronostratigraphical conclusion of Asfaw et al. (1991) which affirms that the FJ-1 Tuff is chronologically older than the KBS Tuff.

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