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Rift deflection, migration, and propagation: Linkage of the Ethiopian and Eastern rifts, Africa

Stratigraphy

Below we provide additional information on stratigraphic relations within the broadly rifted zone of southwestern Ethiopia, including the results of Ar/Ar step heating for sample 305F (Figure A1).

Northern Transect

The oldest date obtained for a volcanic rock along this transect is that of a NE-striking dike (97 Ma, 319V, Table 1) that intrudes metamorphic basement along the western Beto basin escarpment (Fig. 3). This Cretaceous date may result from excess Ar from basement. However, a second sample from the southern transect also yields a Cretaceous date (see below).

The lowest stratigraphic unit above metamorphic basement is commonly a red sandstone with kaolinitised feldspars that formed at low elevation in an arid climate (Davidson, 1983; Ebinger et al., 1993). Olivine and aphyric basalt flows conformably overlie the ~8 m-thick regolith. The thickness of the oldest basalt unit ranges from a few meters to over 600 m in the northeastern part of the study area, although strata locally have been eroded (Davidson, 1983). Laterites and soil horizons are rare or absent within this parallel-bedded basaltic unit. Within the eastern Mago basin aphyric basalts within this sequence are dated at 36.9 ± 1.5 Ma (316M, Table 1). Highly altered or brecciated porphyritic trachytes with local interbedded cliff-forming basalt flows overlie the basal flows (e.g., Fig. 5a). The trachytes probably emanated from the Mago volcanic edifices (Fig. 3). Olivine basalts overlying basement along the Tolta range separating the Mago and Ashkare basins yielded 39.9 ± 1.6 Ma K-Ar dates (318C, Table 1). Basalts at the bottom and near the top of the 600 m-thick basal unit along the Gamo-Gidole horst were dated at 42.7 ± 2 Ma (Davidson and Rex, 1980) and at 38.3 ±1.5 Ma (326L, Table 1; Fig. 4). Minor rhyolites occur within the sequence on both the western and eastern side of the Gamo-Gidole horst (Figs. 3, 4). A flow from a much thinner sequence of petrographically similar aphyric basalts overlying basement along the Weyto horst was dated at 35.6 ± 1.4 Ma (321Z, Table 1). Based on compositional similarity and stratigraphic relationships, we correlate these predominantly basalt flows with the upper Eocene to lower Oligocene Gamo-Amaro basalts in the southern MER that are capped by the widespread Amaro rhyolitic tuff dated at 36.90 ± 0.05 Ma using the SCLF method (Fig. 4).

Overlying the often laterized upper surface of the Gamo-Amaro basalts across the Weyto region and along the southern Gamo-Gidole horst are trachy-basalts and tephrites dated at 18.8 ± 0.7 Ma and 12.7 ± 0.5 Ma (326D, 329F, Tables 1, 2; Fig. 4). Eruptive centers for some of these flows lie along faults bounding the Gamo-Gidole horst, and ignimbrites and altered ash horizons are common. These basalts are chronostratigraphic with the Miocene Getra-Kele basalts in the southern MER (18.3-11.1 Ma; Ebinger et al., 1993; George, 1997), but they are absent in basins west of Chew Bahir (Fig. 4).

Phonolite flows from eruptive centers located along faults bounding the Mali, Weyto, Bala-Dancha, and Segen basins were dated at 16.7 ± 0.6, 14.1 ± 0.6, and 12.4 ± 0.4 Ma using both K-Ar and $^{40}Ar/^{39}Ar$ methods (Tables 1, 2). Davidson and Rex (1980) dated flows from small phonolite centers and plugs overlying the Paleogene basalts in the Bala-Dancha basin at 13.0 ± 2.4 and 12.7 ± 1.0 Ma, consistent with our results. Although the trachyte/phonolite flows associated with these centers are of local extent, we collectively refer to these mid-Miocene phonolite/trachytes as the Weyto Trachytes, which are chronostratigraphic with the Mimo Trachytes in the Chamo and Ganjuli basins to the northeast (Fig. 4).

Lacustrine mudstones with petrified wood and mudcracks and water-laid felsic tuffs, onlap phonolite intrusive and extrusive trachytes in the Segen basin, indicating that lake basins had formed in the subsiding rift basins by Mid-Miocene time (Fig. 3). These lacustrine strata may represent shoreline deposits. Poorly or unsorted conglomerates and sandstones with interbedded ash and mudstones overlie the Weyto phonolites within the Gofa province (Usno, Beto, Mali, Bala-Dancha basins), and MER (Segen, Chamo, Galana basins)(Fig. 3). The lack of cross-bedding, lack of sorting, and proximity to faults with large throws suggests that they are debris flows and/or alluvial fan deposits. These strata may be chronostratigraphic with the syn-rift Burji-Soyoma Formation at the southern tip of the Segen basin which contains Mid-Miocene fauna (WoldeGabriel et al., 1991).

Along the seismically active Nyalibong fault a 5 m-thick basalt unit dated at 4.0 ± 0.6 Ma (Table 2) overlies Paleogene basalts and trachytes (Fig. 5a). These basalts are correlated with the widespread Mursi basalts previously dated at 4.2 Ma in the north Omo basin where they overlie thin fluvio-lacustrine strata of the Mursi Formation (Brown and Nash, 1976). The Mursi basalts are overlain in areas by lacustrine strata of the Nyalibong Formation and the Usno Formation (Brown and Nash, 1976; Davidson, 1983). Non-fossiliferous lacustrine strata of presumed Quaternary age are exposed along incised rivers and as terraces along the margins of the Weyto and Bala-Dancha basins (Davidson, 1983).

Southern Transects

A sample of one of many aphyric basaltic dikes intruding basement along the western margin of the Chew Bahir basin was dated at 151 Ma using the K-Ar method (Table 1). Step-heating of sample 305F suggests that the rock contained excess radiogenic Ar (Figure A1). On the basis of the minimum age determined from the age spectrum, however, the dike was intruded at ~95 Ma, consistent with the Late Cretaceous dike in the Gofa province.

The Oligocene age tholeiitic Fejej basalts, or Nabwal basalts in Kenya, are exposed along parts of the Hamer range separating the Chew Bahir and Omo basins (e.g., Davidson and Rex, 1980; Asfaw et al., 1991). Chronostratigraphic basalts along the northern margin of the Kibish basin and east of the Ilubabor basin (Gok and Makonnen basalts) are up to 700 m thick in places (Davidson and Rex, 1980; Zanettin et al., 1978; Watkins, 1986; McDougall and Watkins, 1988; Asfaw et al., 1991; Morley et al., 1992) (Figs. 6, 7). At their base, the 100 m-thick Fejej basalts are interbedded with a thin fluvial unit containing silicified wood and calcified root casts (Asfaw et al., 1991; this study). Red grits with silicified wood are also found along the western margin of present day Lake Turkana (Morley et al., 1992).

The lowest volcanic sequence exposed along the eastern side of the Chew Bahir basin is a >400 m thick sequence of parallel-bedded porphyritic and aphyric basalt flows. Thin ash units commonly separate individual flows that are traceable along strike for at least 2 km. An olivine basalt near the base of this unit and a porphyritic basalt near the top were dated at 20.2 ± 0.8 Ma and 19.3 ± 0.6 Ma using conventional K-Ar (304Z, 330A, Table 1, Fig. 5). A sanidine separate from a porphyritic basalt overlying basement yielded 23.0 ± 1.2 Ma SCLF ages (302B, Table 2). We correlate this flood basalt sequence with the Teltele basalts previously dated at 21.2 - 18.7 Ma by the K-Ar method (Davidson and Rex, 1980) (Fig. 6). At least one trachytic plug has been exposed by faulting along the Chew Bahir escarpment, but altered and sheared trachytic tuffs from this center are undatable.

Problematic are the different age determinations for sample 302C (33.0 ± 2.0, Table 1; 13.4 ± 0.4 Ma, Table 2), collected along a tilted fault block near the base of the eastern Chew Bahir escarpment. $^{40}Ar/^{39}Ar$ step heating of feldspar separates from this porphyritic basalt gives a mean plateau age of 33 ± 15 Ma, suggesting that some phenocrysts contain excess radiogenic Ar. Stratigraphic relations indicate that this sample is part of the Teltele basalts (Fig. 7a).

Commonly white, water-deposited volcaniclastic rocks with interbedded grey and pink tuffs overlie the Fejej basalts along the eastern Omo basin margin. A widespread pink pantelleritic tuff dated at 20.7 ± 1.2 Ma lies at the top of this sedimentary sequence (307D, Table 2). From enhanced spectral patterns in Landsat imagery and field descriptions, we correlate the tuffs and shallow lacustrine sedimentary strata with similar strata in Kenya described by Watkins (1986)(Fig. 6). Fitch et al. (1974) reported a date of 22.9 ± 1.9 Ma from ??? separates from the pink tuff, which is correlative within the standard errors of our measurements. Watkins and McDougall (1988) dated feldspar separates at 26.3 ± 0.3 Ma using the K-Ar technique, but we adopt a younger age (~21 Ma) for this unit, based on the $^{40}Ar/^{39}Ar$ data.

The Kumbi rhyolites and rhyolitic tuffs (Hafar tuffs in Kenya), readily identifiable in enhanced Landsat imagery, cap the volcanic succession along the central Chew Bahir escarpment and Teltele plateau, and as landslide deposits along the escarpment (Plate 1). The Kumbi rhyolites and rhyolitic tuffs dated at 14.9 ± 0.6 Ma, 14.6 ± 0.4 Ma and 14.5 ± 0.1 Ma conformably overlie the Teltele basalts along the southern margin of the Chew Bahir basin and between the Chew Bahir and Ririba rifts (302F, 304R1, 304R2, Table 2). A rhyolitic tuff exposed along a horst within the southern Chew Bahir basin was dated at 14.0 ± 1.0 Ma (300E, Table 2; Figs. 6, 8). These rhyolites may have emanated from the syenitic Jibisa ring complex at the Kenya-Ethiopia border which was active at 14.4 ± 0.7 Ma (Key and Watkins, 1988)(Fig. 8).

Along the eastern side of Lake Turkana, a 70 m-thick sequence of columnar basalts flowed to the west and emanated from fissures and small cones along the N-S striking Gulti fault (Fig. 8). Conglomerates and sandstones capped by a basalt flow are in fault contact with a mesa composed of these basalts to the east of the Gulti fault. A sample from the lower part of this mesa sequence was dated at 3.4 ± 0.5 Ma (309F, Table 1), which is within standard errors of earlier K-Ar dates of 4.42 ± 0.07 Ma and 4.2 ± 0.4 Ma for the contact between the basalts and underlying Mid-Pliocene lacustrine strata (Asfaw et al., 1991; Davidson and Rex, 1980). In the southern Chew Bahir basin chronostratigraphic basalts dated at 3.2 ± 0.6 Ma erupted from N-S alignments of small cones (Plate 1), but these flows are of only local extent. We correlate these Pliocene basalts in the Omo and Chew Bahir basins with tholeiitic basalts of the Harr Formation in northern Kenya, and the Pliocene Bulal basalts along the southern Teltele plateau (Davidson, 1983; Key and Watkins, 1988).

The Kuraz (Korath) picrites and ankaramites emanated from a N-S-striking lineament of basaltic eruptive centers that intrude and overlie the Pliocene Shungura Formation in the northern Omo basin (Brown and Carmichael, 1969)(Figs. 2, 5). Lacustrine sediments containing abundant but abraded ostracods, mollusca, and fish fragments unconformably overlie the Fejej basalts or the Harr Formation along the western Hamer plateau (Figs. 6, 7b). This fossil assemblage suggests a nearshore deltaic environment of probable Quaternary age (A. Cohen, pers. comm., 1991), perhaps marking higher lake levels. Alluvial fan and debris flow deposits comprising predominantly basalt clasts overlie these lacustrine sediments along the the eastern lake shore.

Holocene stromatolitic concretions that formed around African river oysters (Etheria elliptica) girdle mesas of Kumbi rhyolites and rhyolitic tuffs and Pliocene eruptive centers in the southern Chew Bahir basin 20 m above the dry lake bed (Fig. 8). Evidence for wave erosion along the margins of these elevated regions and the distribution of the shells indicates a paleolake shoreline 10-20 km south of the early 1900 lake shoreline (Fig. 1).

305F Whole Rock.