Palaeomagnetism and geochronology of Oligocene and Miocene volcanic sections from Ethiopia: geomagnetic variability in the Afro-Arabian region over the past 30 Myr

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2018 Fall Meeting
Session GP43A
Poster 0758

Abstract: We report palaeomagnetic and K-Ar geochronologic results from two volcanic sections from Ethiopia. One section near Belessa, dated around 29–30 Ma and spanning ca. 1 km in thickness, is related to the Oligocene Afro-Arabian traps. The second ca. 700-m-thick section near Debre Sina was emplaced during the Miocene in two periods around 10–11 and 14–15 Ma. We sampled 67 flows (550 cores) of predominently basaltic rocks near Belessa and 59 rhyolitic to trachybasaltic flows (500 cores) near Debre Sina. We combined our results with other palaeomagnetic studies for the Early Oligocene, Middle Miocene and Plio-Pleistocene to better understand how palaeosecular variation (PSV) changed through time in the Afro-Arabian region. Recentred directional distributions for all three periods are elongated in the meridional plane, in coherence with field models for a dipole-dominated field. The angular dispersion *S* of the virtual geomagnetic poles, which quantifies PSV, was 50% higher during the Early Oligocene and Middle Miocene than during the Plio-Pleistocene. As the reversal frequency *f* during the Early Oligocene is twice lower during the Early Oligocene than during the Plio-Pleistocene, it appears that *S* and *f* are uncorrelated in this near-equatorial region.

Résumé : Nous rapportons les résultats paléomagnétiques et géochronologiques (K-Ar) de deux sections volcaniques en Éthiopie. Une première section près de Belessa, datée vers 29–30 Ma et d'une épaisseur d'environ 1 km, est associée aux traps d'Ethiopie et du Yémen. La deuxième section près de Debre Sina, d'une épaisseur d'environ 700 m, a été mise en place pendant le Miocène durant deux périodes distinctes vers 10–11 Ma et 14–15 Ma. Nous avons échantillonné 67 coulées (550 carottes) de roches principalement basaltiques près de Belessa, et 59 coulées (500 carottes) d'ignimbrites et trachybasaltes près de Debre Sina. Nous avons combiné nos résultats avec ceux d'autres études paléomagnétiques pour l'Oligocène inférieur, le Miocène moyen et le Plio-Pléistocène pour mieux comprendre comment la paléovariation séculaire (PVS) a évolué pendant les 30 derniers millions d'années dans la région des traps d'Ethiopie et du Yémen. La dispersion angulaire *S* des poles géomagnétiques virtuels, utilisée pour quantifier la PVS, est 50% plus élevée pendant l'Oligocène inférieur et le Miocène moyen que pendant le Plio-Pléistocène. Comme la fréquence des inversions est deux fois plus faible pendant l'Oligocène inférieur que pendant le Plio-Pléistocène, il apparaît que *S* et *f* sont décorrélés dans cette région proche de l'équateur.

I– Motivations :

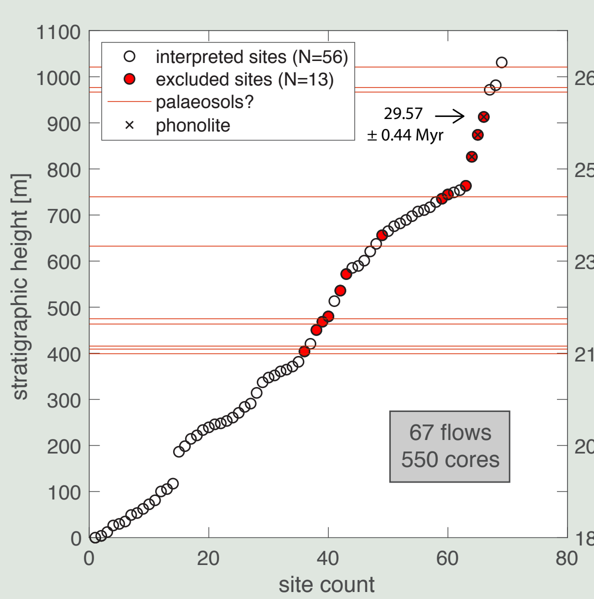
The rate of change of the Earth's magnetic field during stable periods, called palaeosecular variation (PSV), is usually quantified by the angular dispersion *S* of the virtual geomagnetic poles[1] (VGP scatter) and thought to reflect the geodynamo's activity[2].

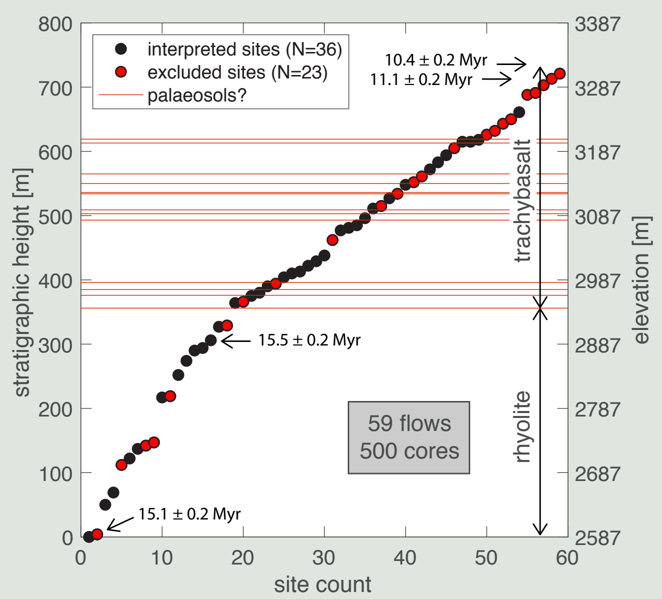
Ethiopia is an ideal location to investigate the PSV evolution over the past 30 Myr due to its rich volcanic activity[3]. It offers the possibility to determine PSV estimates at different time periods (Early Oligocene, Middle Miocene and Plio-Pleistocene) from volcanic sequences emplaced at the same palaeolatitude.

II– Geology and sampling:

Belessa section (Early Oligocene)

Debre Sina (Miocene)

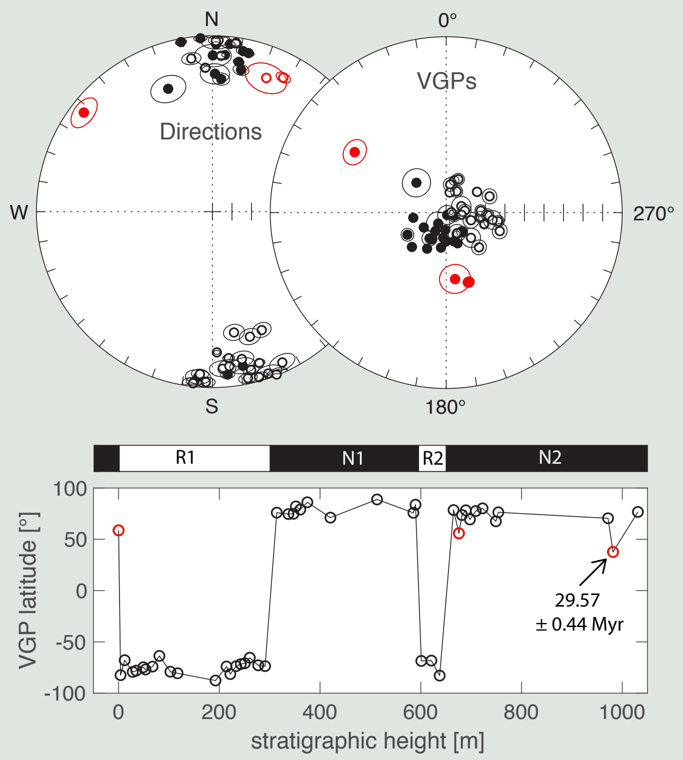




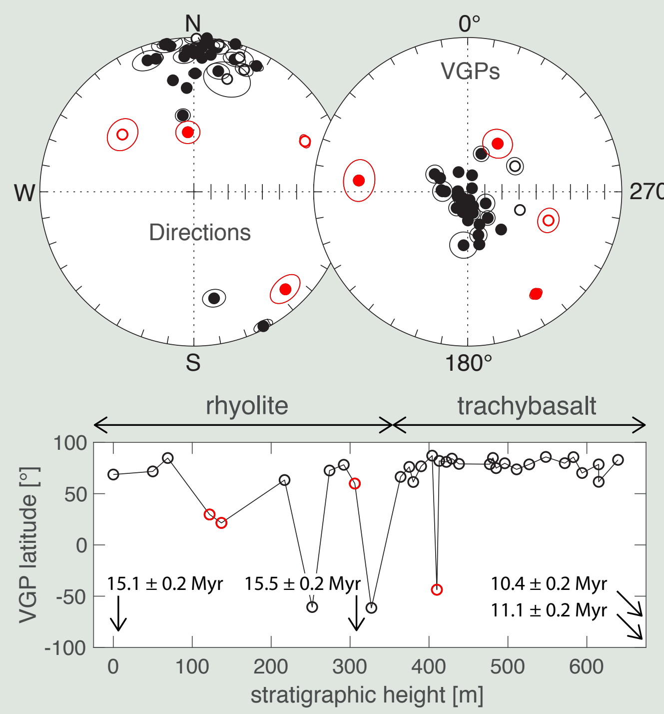
[1] Cox, A. (1970), Latitude Dependence of the Angular Dispersion of the Geomagnetic Field, *Geophys. J. Int.*, 20(3), 253–269.
[2] Lhuillier, F., and S. A. Gilder (2013), Quantifying paleosecular variation: Insights from numerical dynamo simulations, *Earth Planet. Sci. Lett.*, 382, 87–97.
[3] Kieffer, B. et al. (2004), Flood and Shield Basalts from Ethiopia: Magmas from the African Superswell, *Journal of Petrology*, 45(4), 793–834.

III– Palaeomagnetic and geochronologic results:

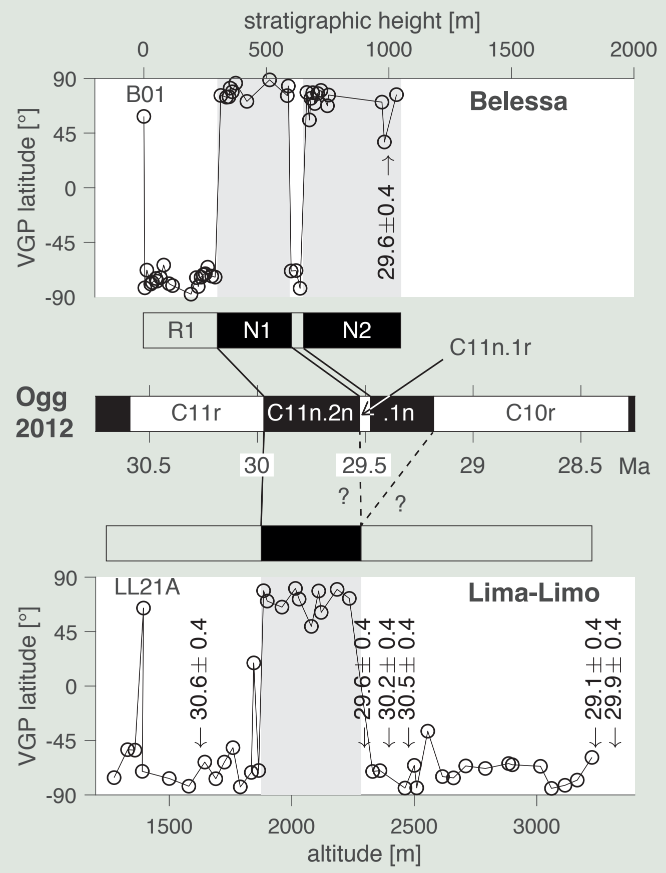
Belessa section (Early Oligocene)



Debre Sina section (Miocene)



IV – Emplacement of the Ethiopian traps:



Belessa section (Early Oligocene)

overlapping of chrons C11n and C11r
duration between 0.59 and 1.40 Ma
minimum emplacement rate of 1 m/kyr

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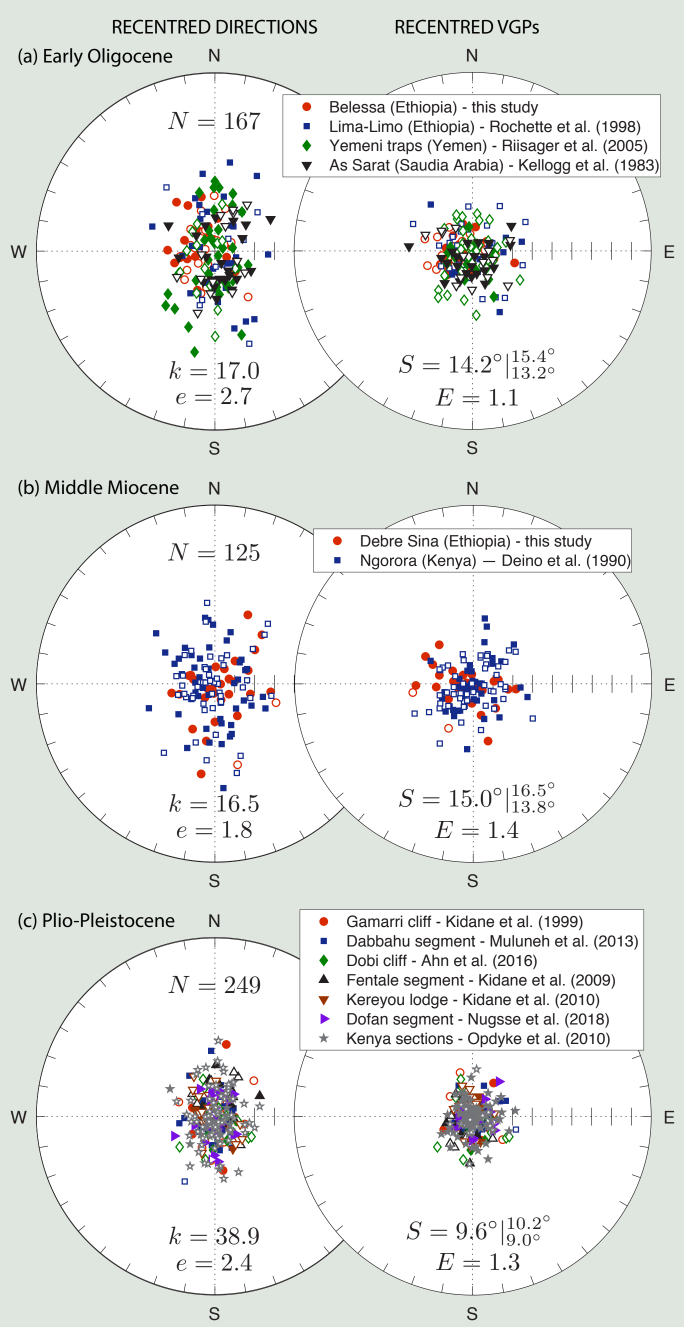
agrees with the timing of the Afro-Arabian traps[4], despite the absence of a one-to-one correspondance with the Lima-Limo section[5,6]

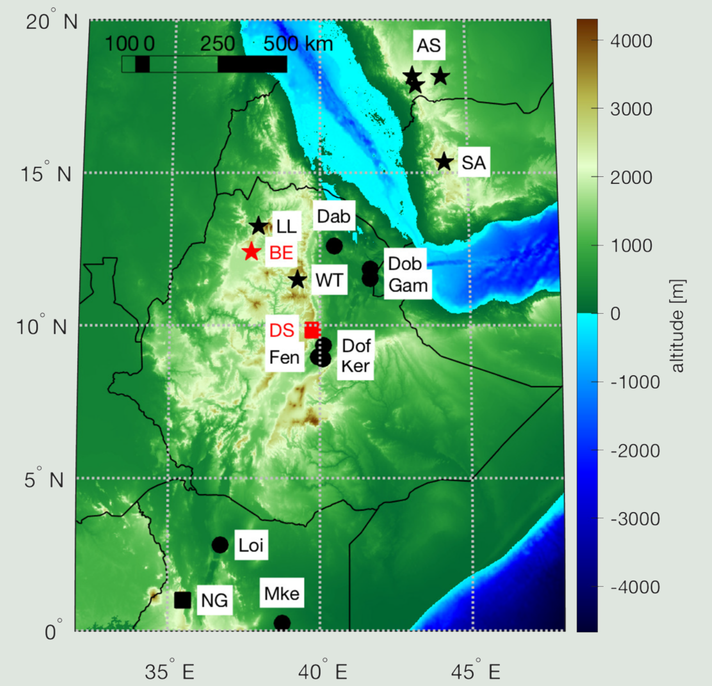
[4] Riisager, P., K. B. Knight, J. A. Baker, I. Ukstins Peate, M. Al-Kadasi, A. Al-Subbary, and P. R. Renne (2005), Paleomagnetism and 40Ar/39Ar Geochronology of Yemeni Oligocene volcanics: Implications for timing and duration of Afro-Arabian traps and geometry of the Oligocene paleomagnetic field, *Earth Planet. Sci. Lett.*, 237(3–4), 647–672.

[5] Hofmann, C., V. Courtillot, G. Féraud, P. Rochette, G. Yirgu, E. Ketefo, and R. Pik (1997), Timing of the Ethiopian flood basalt event and implications for plume birth and global change, *Nature*, 389(6653), 838–841.

[6] Rochette, P., E. Tamrat, G. Féraud, R. Pik, V. Courtillot, E. Ketefo, C. Coulon, C. Hoffmann, D. Vandamme, and G. Yirgu (1998), Magnetostratigraphy and timing of the Oligocene Ethiopian traps, *Earth Planet. Sci. Lett.*, 164(3-4), 497–510.

V – Field behaviour in the Afro-Arabian region:

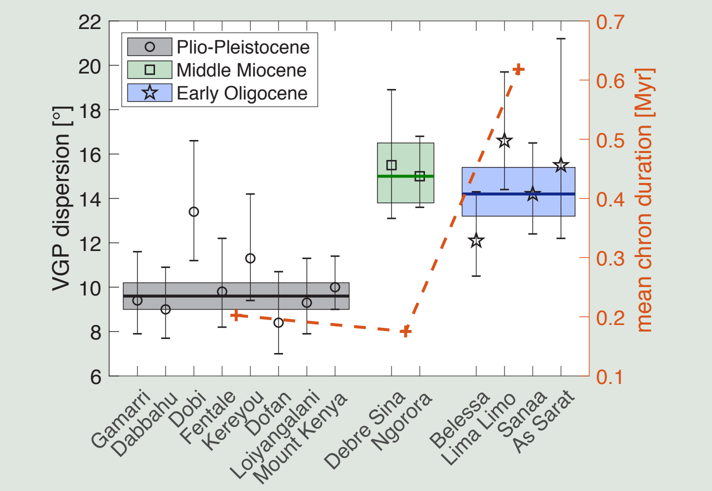




Early Oligocene (stars): LL=Lima Limo; BE=Belessa; WT=Wegel Tena; SA=Sanaa; AS=As Sarat

Middle Miocene (squares): DS=Debre Sina; NG=Ngorora

Plio-Pleistocene (circles): Dab=Dabbahu; Dob=Dobi; Gam=Gamarri; Dof=Dofan; Fen=Fentale; Ker=Kereyou; Loi=Loiyangalani; Mke= Mount Kenya



Take home message

1. The distribution of recentred directions are elongated in the meridional plane, which points to a persistant axial dipolar field over the past 30 Myr
2. The dispersion *S* of the VGPs, which quantifies PSV, is approximately 50% higher during the Early Oligocene and Middle Miocene than during the Plio-Pleistocene
3. As the reversal frequency *f* was more than twice lower during the Early Oligocene than during the Plio-Pleistocene, the two proxies (*f* and *S*) might be, locally or at times, uncorrelated.

More information at: http://dx.doi.org/10.1093/gji/ggy517