Interim report on loan 855 'How does the Earth's crust grow at divergent plate boundaries? A unique opportunity in Afar, Ethiopia'

We undertook our first field season on this project in January/February 2008, collecting data along a profile crossing the currently active Dabbahu magmatic segment (see loan application). The area is remote and inaccessible, and conditions there are harsh. Most sites were accessed by a commercially hired helicopter (Figure 1). We made very efficient use of this resource by having access to digital SPOT imagery, which enabled us to identify and obtain the coordinates of ~100m diameter sandy patches suitable for MT deployment within the otherwise bare rock rift (Figure 2) at suitable spacings along the profile line.

Figure 1. Commercial helicopter taking off after dropping the MT/TEM field crew and guards at a site

Figure 2. Aerial view of the rift close to the axis of dyking

Despite the difficulty of the terrain and the loss of our sealed gel batteries in customs, we successfully occupied 17 sites along a ~56km profile approximately perpendicular to the axis of dyking (Figure 3). The data quality at a couple of the sites is poor (environmental/equipment problems), and is limited by battery problems to shorter periods at others (Figure 4). We were able to deploy two MT sites simultaneously, each occupied for 1-3 days, using GEF broadband coils, its SPAM III (Ritter et al, 1998), and a recording system loaned from Oliver Ritter (GFZ, Potsdam). (A second instrument loaned from GFZ failed in the field.) TEM data were collected using the GEF PROTEM system at 10 of the sites, using a loop size of 100m square (at site 801 we also collected data with a 50m square loop).

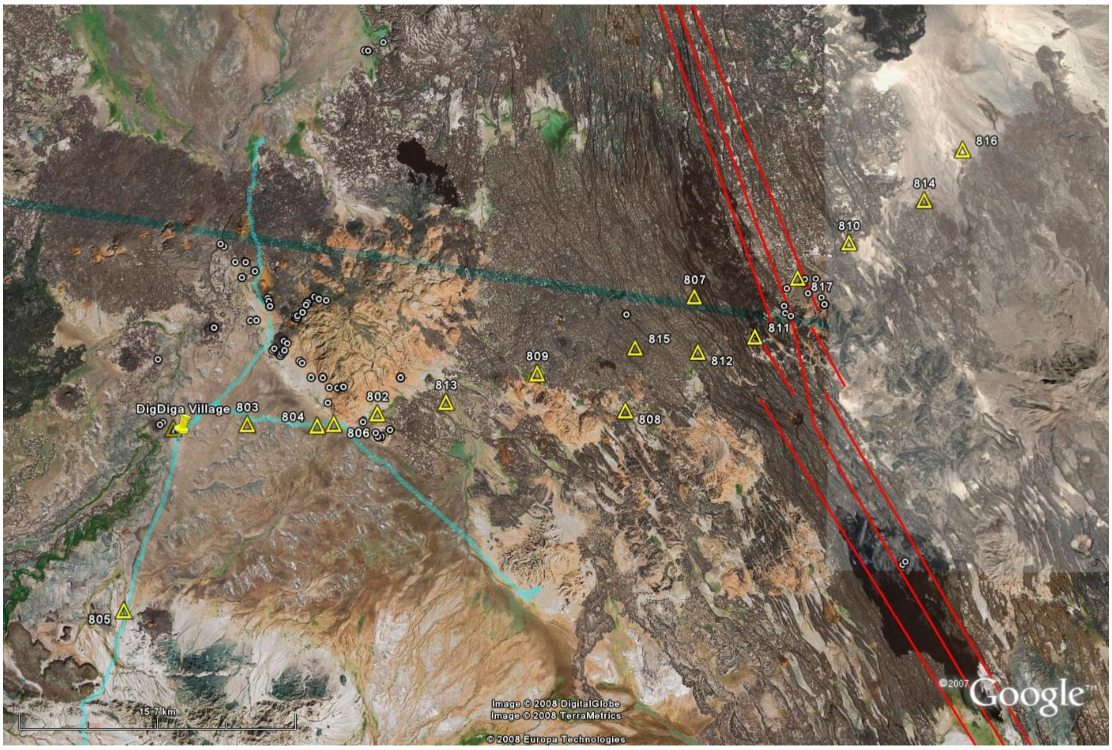

Figure 2. MT sites (yellow triangles) along a profile approximately perpendicular to the axis of dyking (red lines). Small circles are petrological sampling sites. DigDiga village was our field base.

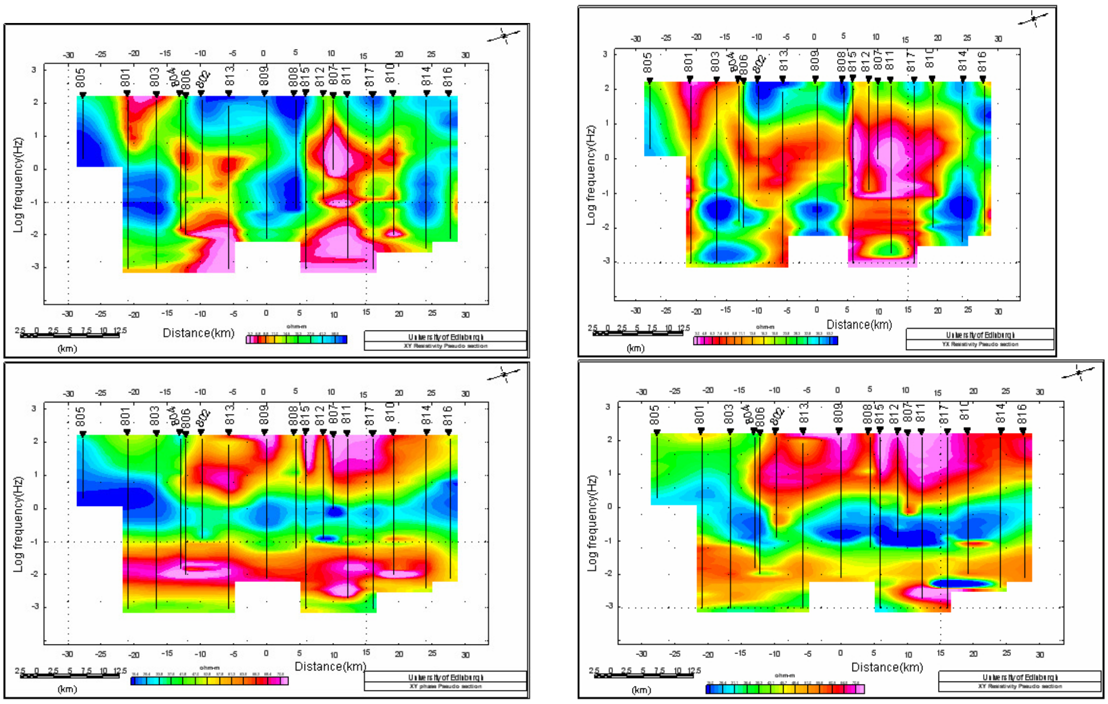

Figure 4. MT data pseudo-sections after robust processing (Chave and Thomson, 19?89). xy-component on the left; yx-component on the right. Upper panels are apparent resistivity; lower panels phase (legend incorrect). The rift axis is around site 11, where very high apparent resistivities are recorded at most periods.

Phase tensors (Caldwell et al., 2004), which are unaffected by galvanic distortion (static shift), calculated from the robustly processed data are shown in Figure 5. These indicate regions of high conductivity, and strong 3D effects at depth directly beneath the rift axes (where the phase tensors are highly elliptical).

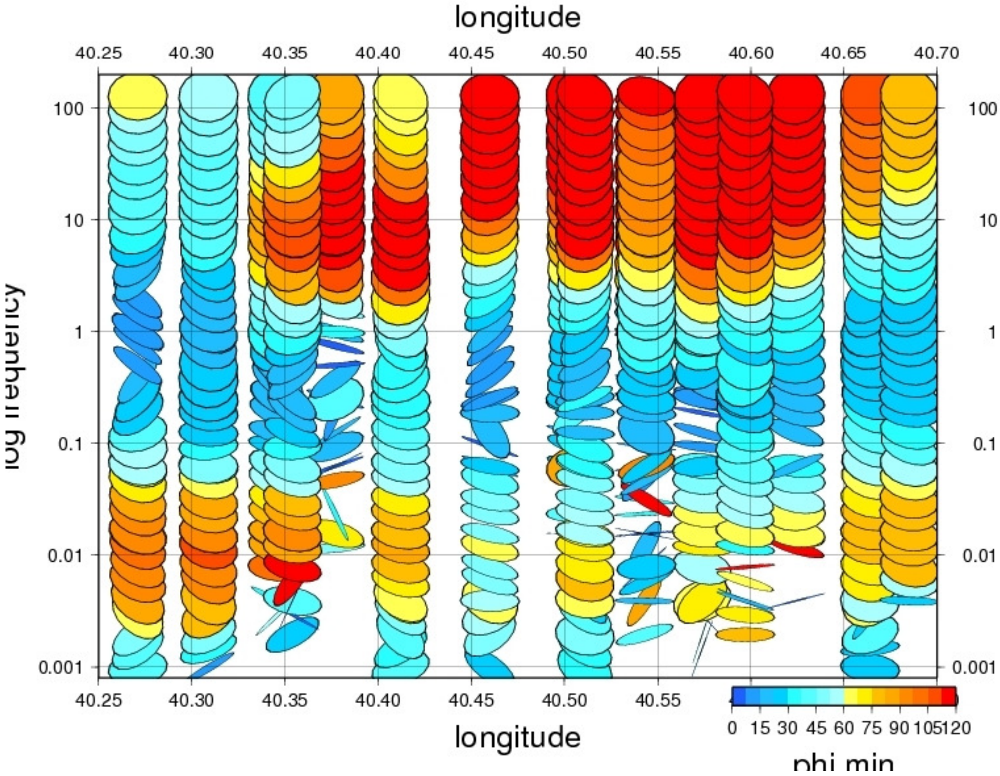

Figure 5. Phase tensors calculated from the robustly processed MT data.

The TEM data have been used to estimate MT static shift, using the method of Sternburg et al. (1988). An example is shown in Figure 6, and Table 1 summarised the results. There is about half a decade of overlap between the MT and TEM data, just about sufficient to estimate reliably the static shift. Since the two MT apparent resistivity curves coincide at short periods for site 801 (Table 1), independent data such as TEM are required to identify the existence of a static shift.

The best compromise geoelectrical strike direction (most sites and frequencies) is an angle of around 20°W, consistent with the rift axis (Figure 3). The next stage is to correct the MT data using the TEM static shift estimate, rotate into the geoelectrical strike direction, defining the TE and TM components, and perform 2D inversion using the REBOCC algorithm (Siripunvaraporn and Egbert, 2000). Independently, 3D inversion (Hautot et al., 1996) is being undertaken. The data phase tensors (Figure 5) and those predicted by the 3D model will be compared; this was found to be a useful interpretational tool in the Omo Valley (SW Ethiopia) 3D MT survey (loan 801). Joint interpretation of the two models should allow a good definition of the sub-surface resistivity structure.

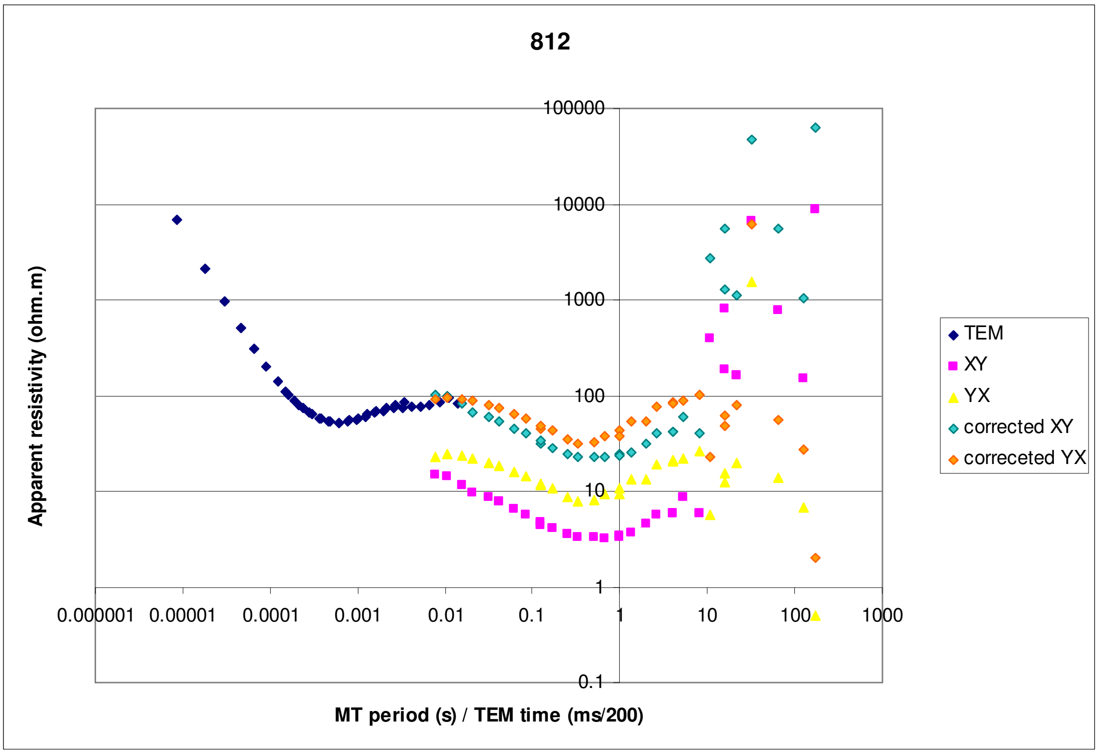

Figure 6. Example of the MT and TEM data plotted together, with TEM times scaled using the formula of Sternberg et al. (1988). This site (812) shows by far the largest static shift of all the sites for which we have TEM data.

Site	Static shift estimation XY (decades)	Static shift estimation YX (decades)
801	0.2	0.2
802	<0.05	<0.05
803	0.18	0.2
804	<0.05	<0.05
806	poor data	poor data
808	0.17	0.13
809	<0.05	0.13
810	0.2	0.15
811	problematic data (probably <0.05 though)	problematic data (probably <0.05 though)
812	0.7	0.4

Table 1. Static shift estimates from TEM data.

Other work planned on the existing dataset is further processing of the high frequency MT data to try to obtain a better overlap between the TEM and MT data for static shift correction. As with other campaigns, the high frequency data are very noisy. A number of geologically logged boreholes to depths of >50m were drilled as part of a campaign to provide well water for the local population in the DigDiga area. The DigDiga site (801) TEM data will be modelled for a resistivity-depth profile and compared with the borehole logs, using standard texts (e.g. Telford et al., 1990) to infer resistivities for the geological units.

The resistivity models will be interpreted in conjunction with other geophysical and geological information from the area, including seismic, gravity and GPS data. Preliminary receiver function analysis estimates of crustal thickness at DigDiga are around 20km, with very high v_P/v_S ratios consistent with partial melt (James Hammond, 2008; pers. comm.). This is in agreement with the high apparent resistivities underlying this site.

As indicated on our original loan application, we intend to acquire data along a profile crossing the currently inactive Hararo segment in our next field season, scheduled for February/March 2009, again using GEF equipment and collecting both MT and TEM data. He logistics of this deployment should be considerably more straightforward since the area is a lot less remote. The contribution electromagnetic methods can make to this multi-disciplinary study of the final stages of continental break-up is recognised by our Consortium partners, following a science meeting last month, and we are also being encouraged to collect data along a profile running approximately NNE from DigDiga towards the Dabbahu volcano on the northern end of the segment. If this were to be feasible (in particular, whether the Consortium can afford it), it would likely be undertaken in October 2009, when other groups will be in the area. Amongst other things, GEF would need to consider whether its equipment could remain in Ethiopia between the two 2009 field seasons. The alternative – shipping the equipment out and back twice in 2009 – would add significantly to the cost of occupying the 3rd profile. We would also need an indication as to whether this could be considered an extension to our existing loan application or whether a new application was required.

References

Caldwell T. G., Bibby H. M., & Brown C., 2004. The magnetotelluric phase tensor. *Geophys. J. Int.,* **158**, 457-469.

Chave, A. D. and Thompson, D. J., 1989. Some comments on magnetotelluric response function estimation, *J. Geophys. Res*., **94**, 14 202-14 215.

Hautot, S., Tarits, P., Whaler, K., Le Gall, B., Tiercelin, J.J and Le Turdu, C., 2000. The deep structure of the Baringo Rift basin (central Kenya) from 3-D magneto-telluric imaging: Implications for rift evolution, *J. Geophys. Res*., **105**, 23493-23518.

Ritter, O., Junge, A., Dawes, G. J. K., 1998. New equipment and processing for magnetotelluric remote reference observations, *Geophys. J. Int.,* **132**, 535–548.

Siripunvaraporn, W. and Egbert, G., 2000. An efficient data-subspace inversion method for 2-D magnetotelluric data, *Geophysics*, **65**, 791-803.

Sternberg B. K., Washburne J. C. and Pellerin L., 1988. Correction for the static shift in magnetotellurics using transient electromagnetic soundings, *Geophysics*, **53**, 1459.

Telford, W. M., Geldart, L. P. and Sheriff, R. E., 1990. *Applied Geophysics, Second Edition*, Cambridge University Press.