He-Ne-Ar-CO_2-N_2 isotope and relative abundance characteristics of the East Africa Rift System (EARS)

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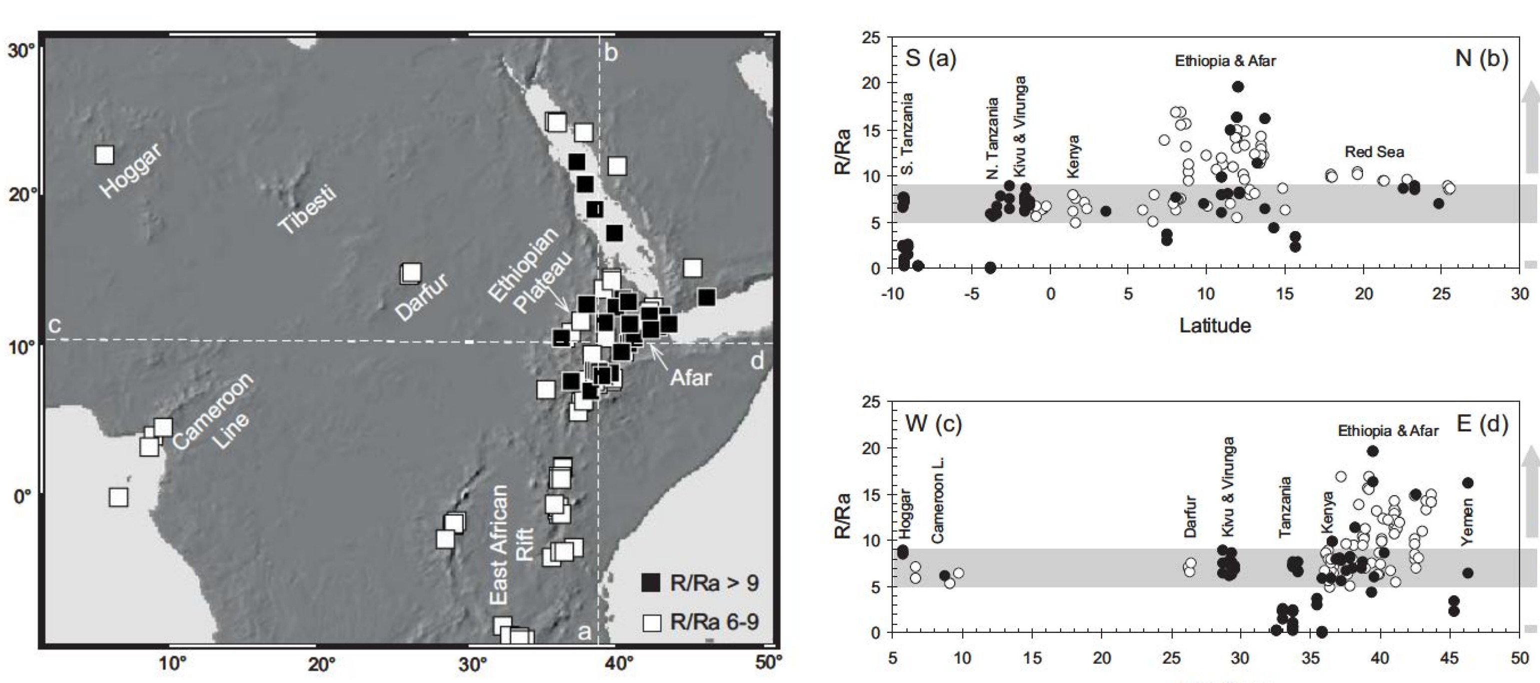
1. Introduction

We present an overview of the volatile systematics of the East Africa Rift System through an integrated approach utilizing geothermal fluids, groundwaters, phenocryst-bearing lavas and scoria, and xenoliths. The tracers of prime interest are the noble gases (He, Ne and Ar), taking advantage of their chemical inertness and sensitivity to volatile provenance (crust and mantle, including SCLM and plume/MORB-like mantle), and other volatiles such as CO_2, which represents the major non-aqueous volatile phase escaping at the surface, as well as N_2.

Left: Travertine hot springs at Songwe, Rungwe Volcanic Province, southern Tanzania. Right: Peridotite xenoliths from the MER (Main Ethiopia Rift). Both types of sampling media capture, preserve and transfer volatiles to the surface.

2. Helium isotope variations in Africa

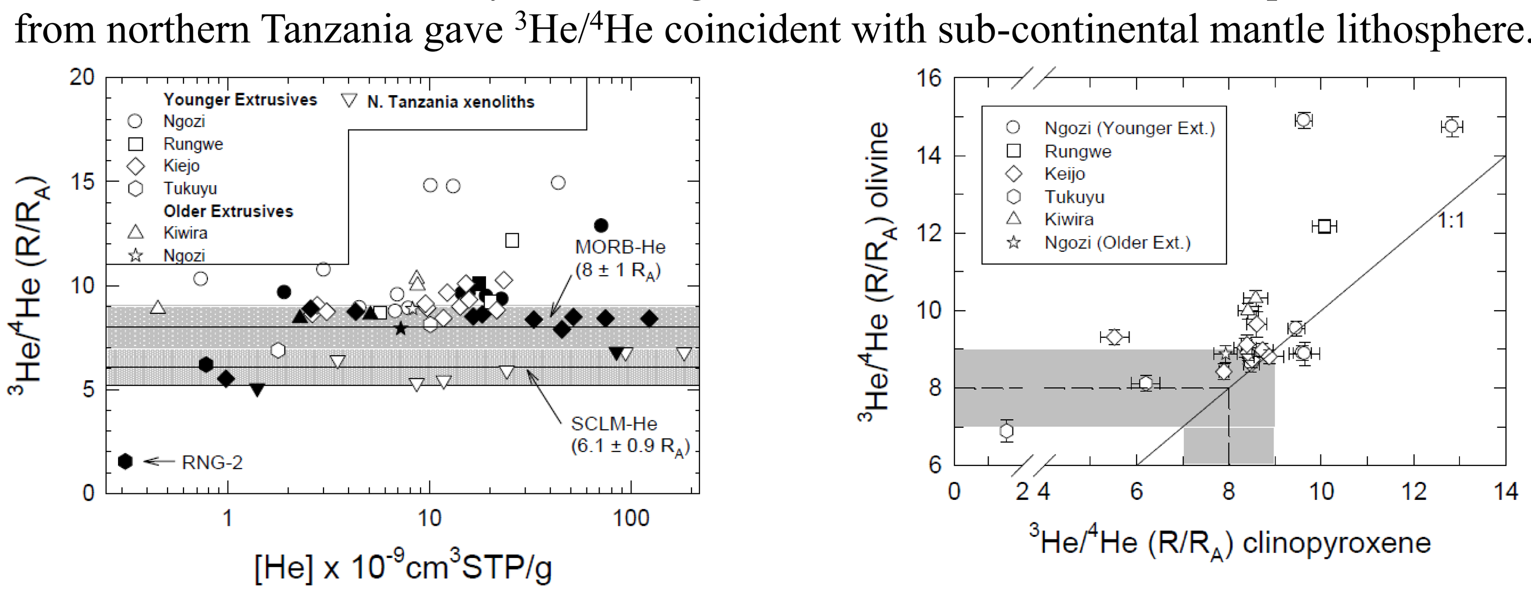


A summary of the helium isotope ($^3He/^4He$) distribution in Africa and along the Red Sea Rift (from Pik, Marty and Hilton, 2006). Note: He-isotopes are given in the R/R_A notation where R = sample $^3He/^4He$ and R_A = air $^3He/^4He$. All results are corrected for air-derived He contamination.

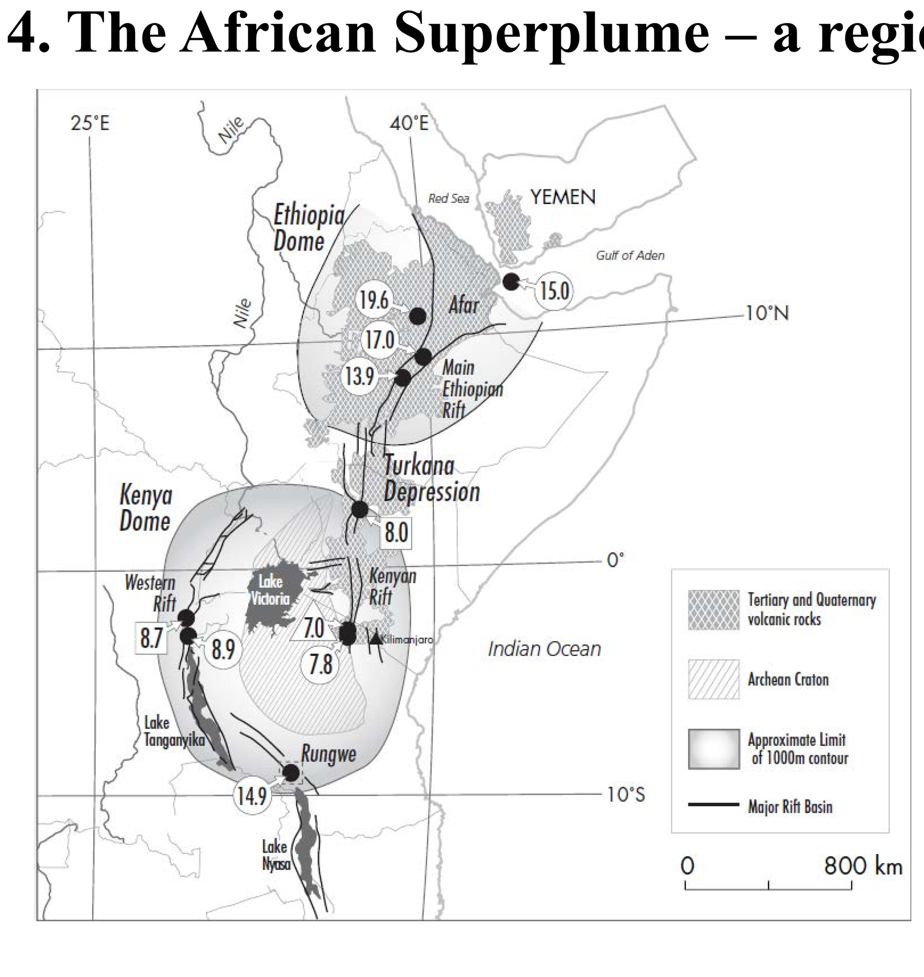
The above study summarizes published He-isotope results up to 2006. The principal point to note is that $^3He/^4He$ ratios significantly greater than values characteristic of ambient upper mantle – as sampled by mid-ocean ridge basalt ($8 \pm 1\ R_A$), and restricted to the Main Ethiopia Rift (MER)/Afar/Red Sea region (maximum = 19.6 R_A). This observation is consistent with a deep (lower) mantle plume origin for convective uplift of the Ethiopia Dome. Notably, Kenya Dome $^3He/^4He$ ratios do not exceed the MORB value: prompting suggestions of a different scale of mantle convection supporting the Kenya Plateau, restricted to the uppermost mantle only.

3. He-isotope studies in Rungwe, Tanzania

We targeted 31 lava and tephra samples from Rungwe Volcanic Province (RVP) for He-isotopes with a total of 52 individual analyses of olivine and/or clinopyroxene separates (Hilton et al., 2011). He isotope ratios as high as 14.9 R_A are the first observation of $^3He/^4He$ ratios >>MORB in the Kenya Dome region, i.e., south of the Turkana Depression. Xenoliths from northern Tanzania gave $^3He/^4He$ coincident with sub-continental mantle lithosphere.



4. The African Superplume – a regional influence



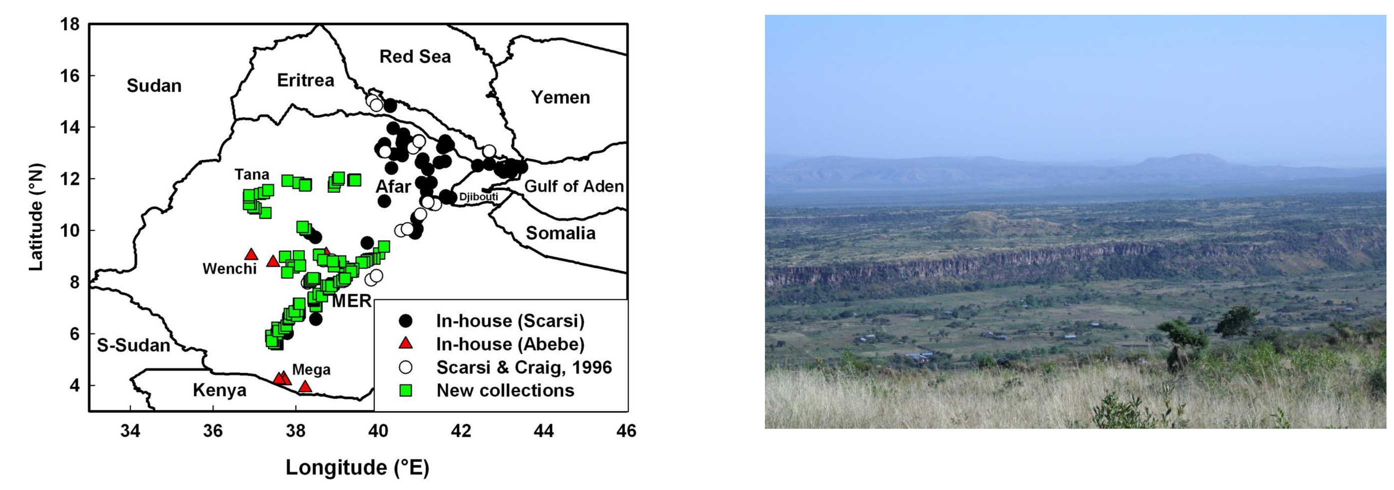
The new He-isotope data provide unambiguous evidence for a deep mantle contribution to magmagenesis at RVP.

The African Superplume - a tilted low-velocity seismic anomaly extending to the core-mantle boundary beneath southern Africa – is the likely source of these high $^3He/^4He$ ratios.

High $^3He/^4He$ ratios at RVP and the MER and Afar provide compelling evidence that the African Superplume extends through the 670-km seismic discontinuity and provides dynamic support – either as a single plume or via multiple upwellings – for the two main topographic features of the East Africa Rift System.

5. New Studies in Ethiopia: the MER and southern Afar

New studies of the volatile systematics of the EARS have focused on Ethiopia – the MER and southern Afar) with extensive field collections undertaken in 2011/12. This expedition supplements in-house samples from Ethiopia and other regions of the EARS.

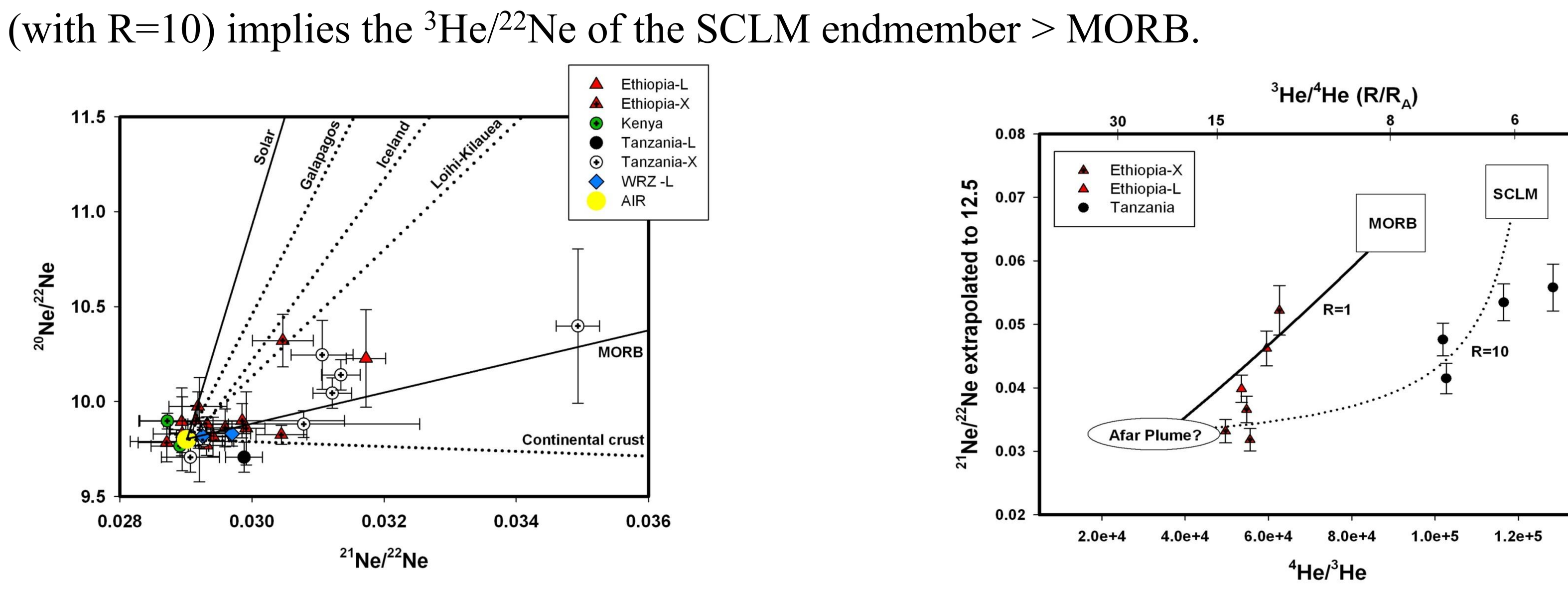


Left: Sample distribution of rocks in Ethiopia. Right: Fault-scarps along the MER – giving access to both outcrops and hot springs and groundwaters.

Our new studies have targeted both (a) hydrothermal fluids and groundwaters, and (b) lavas and xenoliths. The focus of fluid-related studies is the He-CO_2-N_2 isotope systematics of gas and water phase samples together with total gas and water chemistry including stable isotopes (D/H and $\delta^{18}O$). The rocks (see figures above) will allow spatial comparisons with fluids and give temporal controls on He-Ne-Ar-CO_2-N_2 relationships. Some initial results are given below.

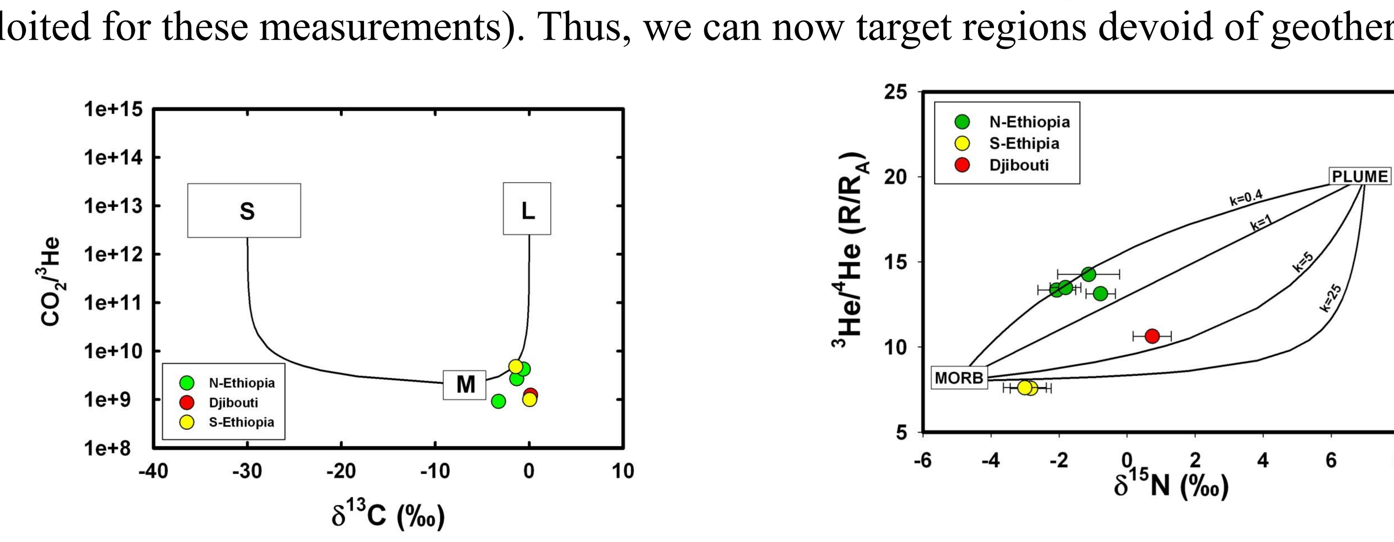
6. He-Ne isotope relationships

In addition to information provided by He-isotopes alone, consideration of coupled He-Ne isotope systematics can be exploited to reveal involvement of different mantle reservoirs throughout the EARS. The procedure involves first identifying non-atmospheric $^{20}Ne/^{22}Ne$ and $^{21}Ne/^{22}Ne$ ratios (left) and then extrapolating measured $^{21}Ne/^{22}Ne$ values to solar, i.e. pure mantle, Ne ($^{20}Ne/^{22}Ne$ = 12.5) and plotting vs. $^3He/^4He$ (right). This plot shows that Ethiopian data can be explained by binary mixing between a MORB-type mantle and an Afar plume component. However, the Tanzania data can only be explained by mixing between plume and sub-continental lithospheric mantle (SCLM) components – effectively ruling out MORB involvement. In this case, what is the significance of MORB-like $^3He/^4He$ ratios measured at RVP (Panel 3) – mixing between SCLM and plume? Note: the hyperbolic mixing line (with R=10) implies the $^3He/^{22}Ne$ of the SCLM endmember > MORB.



7. He-CO_2-N_2 isotope relationships:

Both CO_2 and N_2 are key volatile tracers –of source involvement, extent of mixing, and other petrogenetic processes related to fluxing of volatiles to the surface. The isotopic composition of each volatile phase ($\delta^{13}C$ and $\delta^{15}N$) as well as relative abundance characteristics (particularly to He) provide constraints on EARS volatile provenance. The following plots are the first CO_2 and N_2 isotope data on mafic crystals (olivine and clinopyroxene) from the EARS, opening up the exciting possibility of adding considerably to geothermal fluid CO_2 and N_2 data (the usual media exploited for these measurements). Thus, we can now target regions devoid of geothermal activity.



Carbon and nitrogen data (unpublished) on xenoliths from the Ethiopia/Djibouti region, north EARS. Left: C-isotope and $CO_2/^3He$ relationships plotted vs. possible endmember compositions of MORB mantle (M), and organic (sedimentary) (S) and Limestone (L) – derived C. Binary mixing trajectories between S-M and L-M are shown. Right: He-N isotope relationships for the same xenoliths showing binary mixing between MORB-like and plume endmembers. Note: $K = (He/N)_{MORB}/(He/N)_{Plume}$.

8. Concluding Remarks

Continuing volatile studies (He-Ne-Ar-CO_2-N_2) on the EARS are targeting all regions with the following guiding hypotheses in mind:

(1) The high $^3He/^4He$ provinces of the Main Ethiopian Rift and Afar Depression have unique volatile isotopic characteristics – can they be defined and exploited to map the spatial (and temporal) extent of the Ethiopian plume influence along the EARS.

(2) Provinces of the Kenyan and Western rifts, i.e., south of the Turkana Depression, also have unique volatile isotopic characteristics that can be defined and exploited to test involvement of SCLM and/or a second plume in the petrogenesis of EARS magmas.

(3) Can the volatile record test whether one/two/more plumes exist along the EARS and, if so, help determine if a genetic relationship exists between them.