Noble Gas Isotopic Insights into Primordial and Recycled Volatiles in the Cook-Austral HIMU Mantle

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(1) Introduction

HIMU (high-μ, where $\mu = {}^{238}U/{}^{204}Pb$) ocean island basalts (OIB) provide rich information on mantle compositional heterogeneities. Studies suggested that HIMU OIBs sample multiple distinctive mantle geochemical reservoirs, including one that hosts ancient altered oceanic crust recycled to the deep mantle via plate tectonics [1-3] as well as a relatively undegassed component [4].

Noble gas isotopes are powerful tracers for investigating the origin and the evolution of mantle geochemical reservoirs including HIMU: Light noble gases (He and Ne) track the involvement of primordial mantle volatiles and volatile loss through outgassing. Heavy noble gas species (Ar and Xe) provide insights on volatile transport from surface to the mantle via subducting slabs. We present new high precision He-Ne-Ar-Xe abundance and isotope data measured in olivines from HIMU basalts from the islands of Raivavae and Tubuai in the Cook-Austral archipelago. **Results definitively show that a relatively undegassed mantle component with solar-like Ne is sampled by HIMU OIBs, and potentially reflect volatile contributions from altered oceanic slab components (e.g., serpentinites) to the HIMU mantle source.**

(2) Sample Location and Preparation

Geographical location of the Austral Islands:

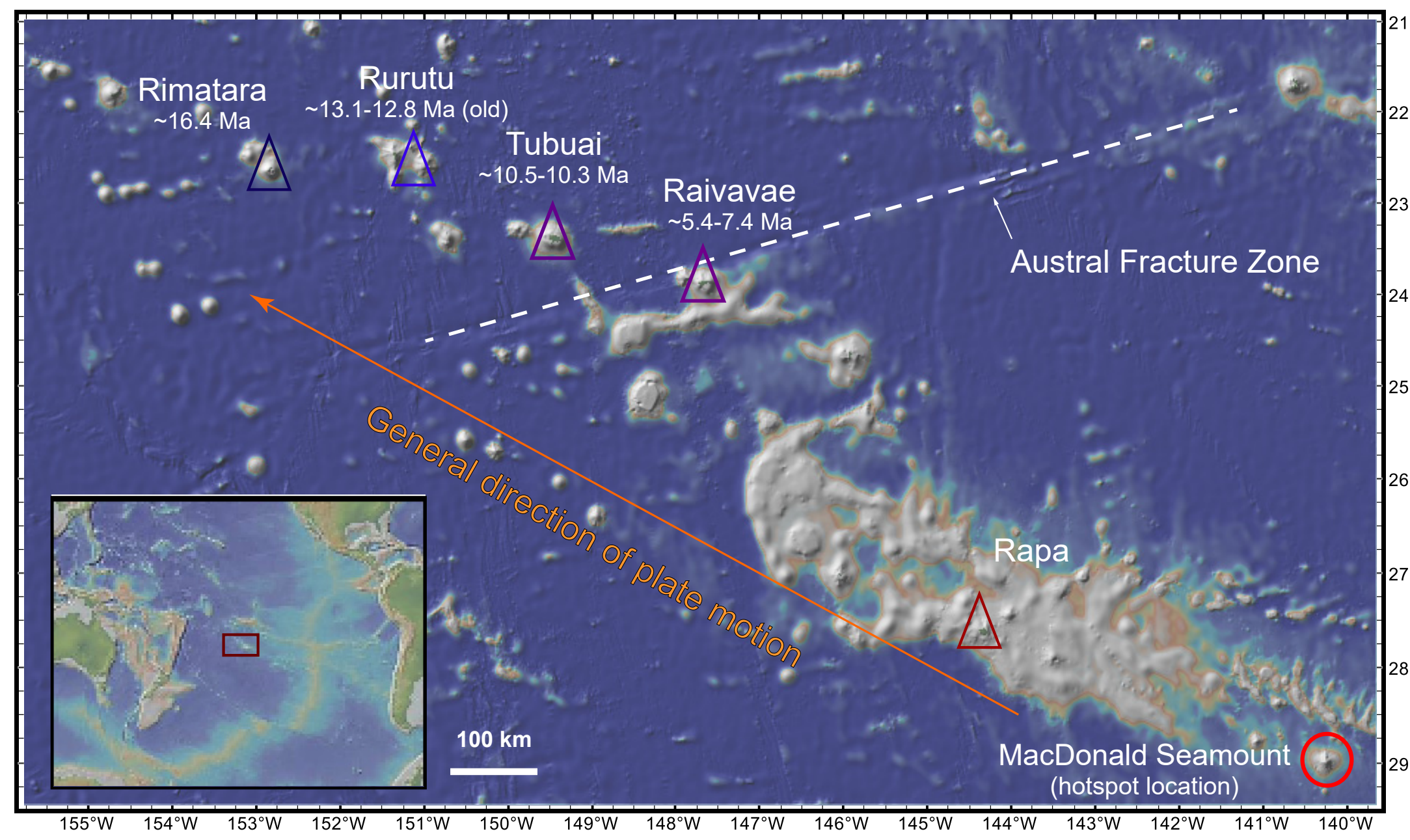
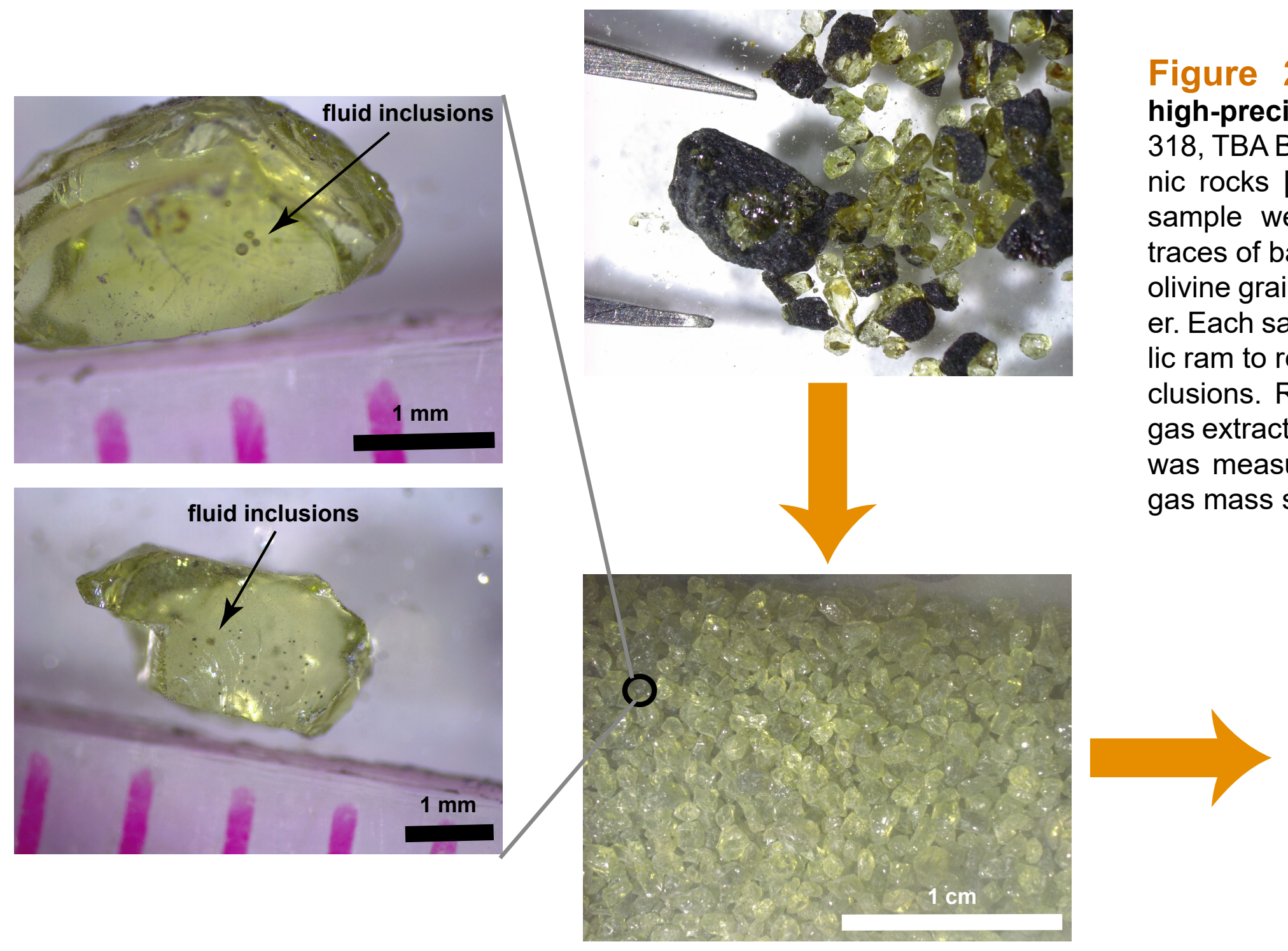


Figure 1. Annotated map showing geographical locations and ages of a selection of the Austral Islands. Labeled islands of the Cook-Austral Island chain exhibit a general age progression [5-6] starting from MacDonald Seamount (where the hotspot is currently located) towards the northwest direction under the Pacific plate motion. Samples for noble gas isotope and elemental analysis are selected from Tubuai (TBA B22) and Raivavae (RVV370, RVV318). Map is made using the GMRT compilation [7].

Sample Preparation:



Gas extraction
Gas purification
Noble gas analysis by mass spectrometry

Figure 2. Olivine phenocrysts sample preparation for high-precision noble gas analysis. Samples (RVV 370, RVV 318, TBA B22) are geochemically well-characterized HIMU volcanic rocks [3, 8]. 3 to 7 grams of olivine phenocrysts for each sample were hand-picked under microscope to remove any traces of basaltic matrix and surface alteration. Clean, processed olivine grains were then loaded into a stainless steel piston crusher. Each sample was step-crushed under vacuum using a hydraulic ram to release gases trapped in melt inclusions and/or fluid inclusions. Released gases were processed in a highly compact gas extraction and purification line before each noble gas element was measured by Nu Noblesse HR 5F5M multi-collector noble gas mass spectrometer at Washington University.

(3) Results

Relatively undegassed mantle sampled by HIMU OIBs:

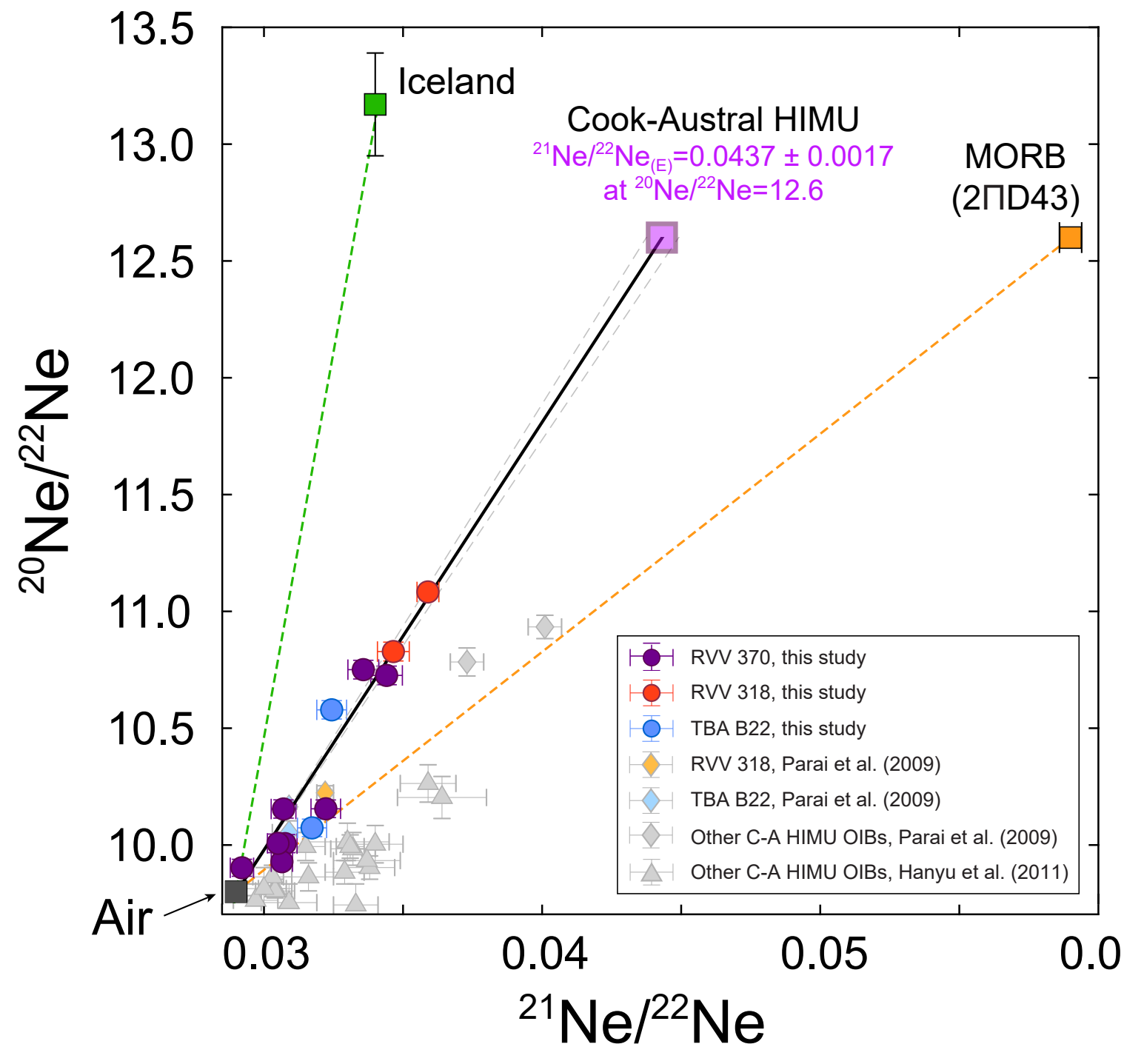


Figure 3. Cook-Austral HIMU $^{20}Ne/^{22}Ne$ vs. $^{21}Ne/^{22}Ne$. Step-crushing data points fall on linear mixing arrays between compositions of the mantle source and the air due to variable degrees of syn- to post-eruptive atmospheric contamination. New step-crushing data agree with the previous study of [4] and define a clear linear compositional mixing array between air and the Cook-Austral HIMU mantle source in the Ne isotopic space. The extrapolated Cook-Austral HIMU mantle source $^{21}Ne/^{22}Ne_{(E)}$ of 0.0437 ± 0.0017 falls between $^{21}Ne/^{22}Ne_{(E)}$ values of Iceland OIB source [9] and MORB (2ΠD43) source [10]. Ne isotopes demonstrate that the Cook-Austral HIMU source taps into a relatively undegassed mantle source compared with the mid-ocean ridge basalt (MORB) source. Errors are 1σ.

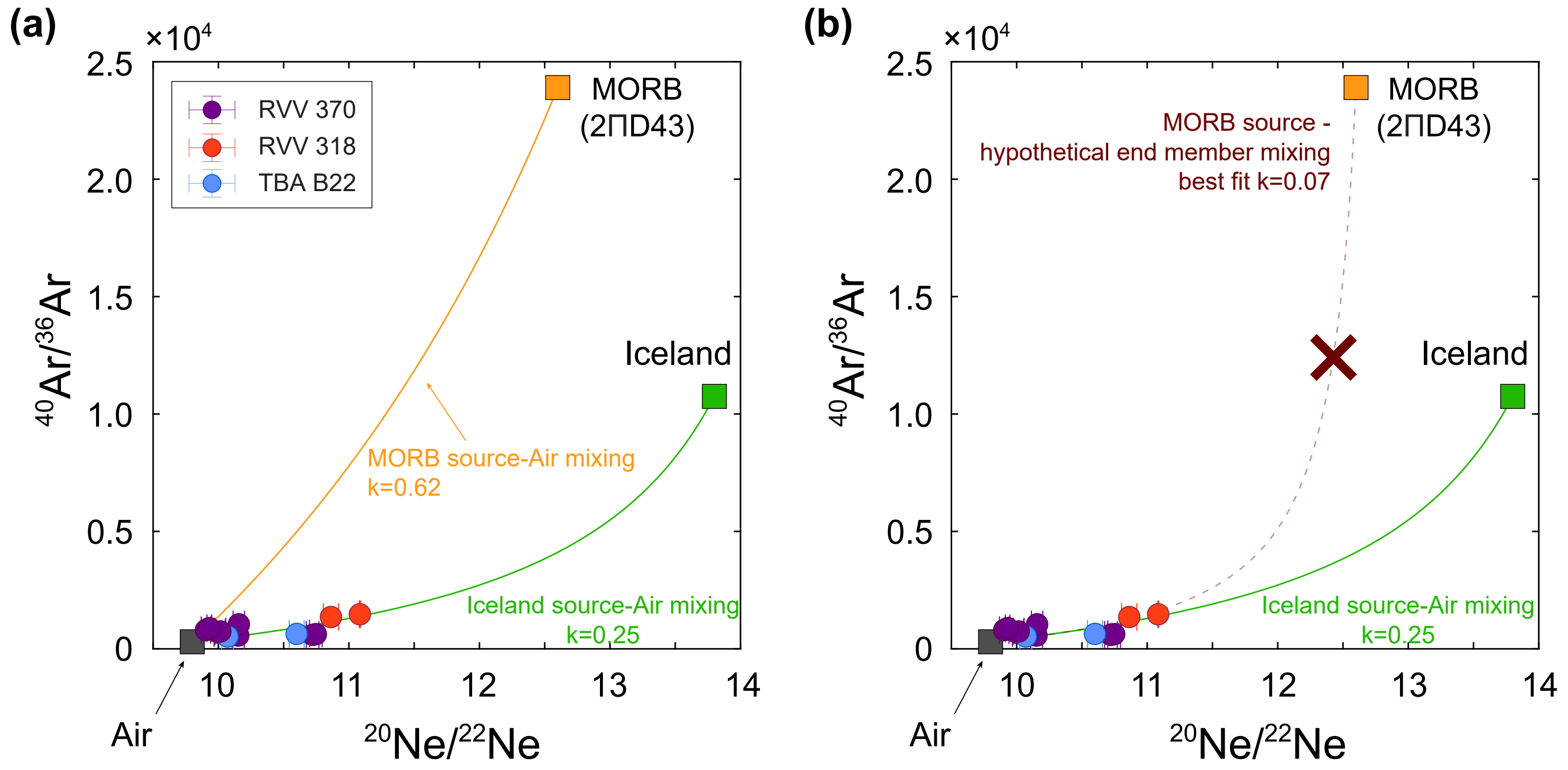


Figure 4. Cook-Austral HIMU $^{40}Ar/^{36}Ar$ vs. $^{20}Ne/^{22}Ne$. Step-crushing data points fall on hyperbolic mixing arrays between compositions of the mantle source and air due to variable degrees of syn- to post-eruptive atmospheric contamination. Curvatures of hyperbolic mixing arrays in Ar-Ne space are determined by the contrast in Ar and Ne elemental abundances of mixing endmembers 1 and 2 (expressed by $k = (Ar/Ne)_1/(Ar/Ne)_2$). Panel (a): Cook-Austral HIMU data fall closely onto the air-Iceland source mixing curve rather than the air-MORB source mixing curve [9, 11], suggesting the involvement of a relatively undegassed plume-like mantle component in the HIMU source. Panel (b): Mixing with the MORB source cannot explain HIMU data. The required hypothetical mixing endmember must have air-like Ar and Ne isotopic compositions and a Ar/Ne ratio of ~165, which is not consistent with fractionated air, seawater, or altered oceanic slab serpentinites [12-13]. Errors are 1σ.

Xe isotopic compositions:

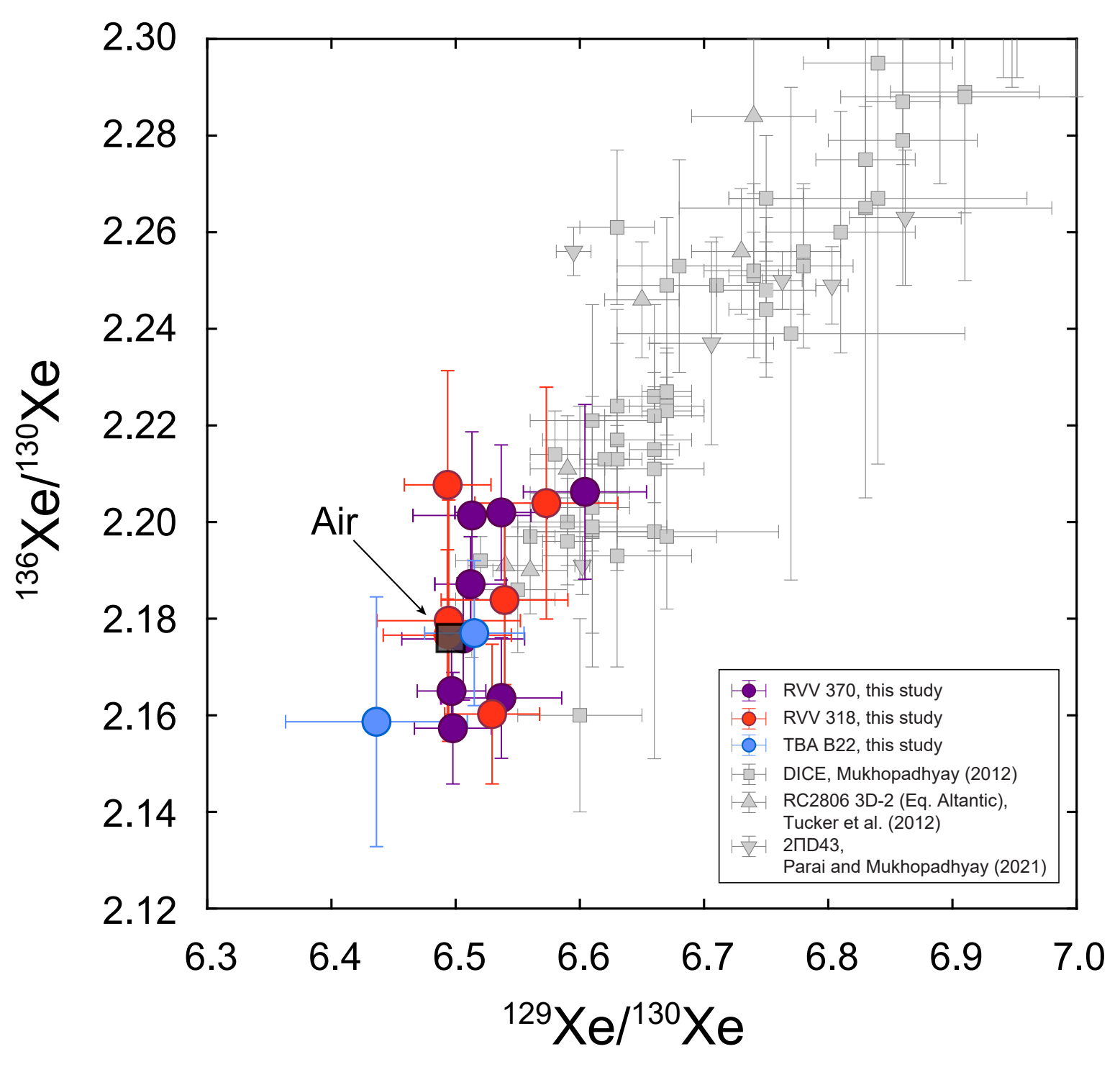


Figure 5. Cook-Austral HIMU $^{136}Xe/^{130}Xe$ vs. $^{129}Xe/^{130}Xe$. Step crushing data points demonstrate the general challenge of resolving compositions of Xe trapped in olivine phenocrysts from air, as a result of widespread atmospheric contamination and low Xe abundances in OIBs erupted on the surface. Nevertheless, Xe from a couple of crush steps are resolved from air and are broadly consistent with air-mantle mixing in other mantle-derived samples [9-10, 14]. Results show that it is possible to resolve Xe isotopic compositions from air in degassed OIBs by increasing Xe signals through high sample masses and by minimizing air contamination through careful sample preparation. Errors are 1σ.

Results (ctd): subduction modifies HIMU

Recycled surface volatiles in the HIMU OIB source:

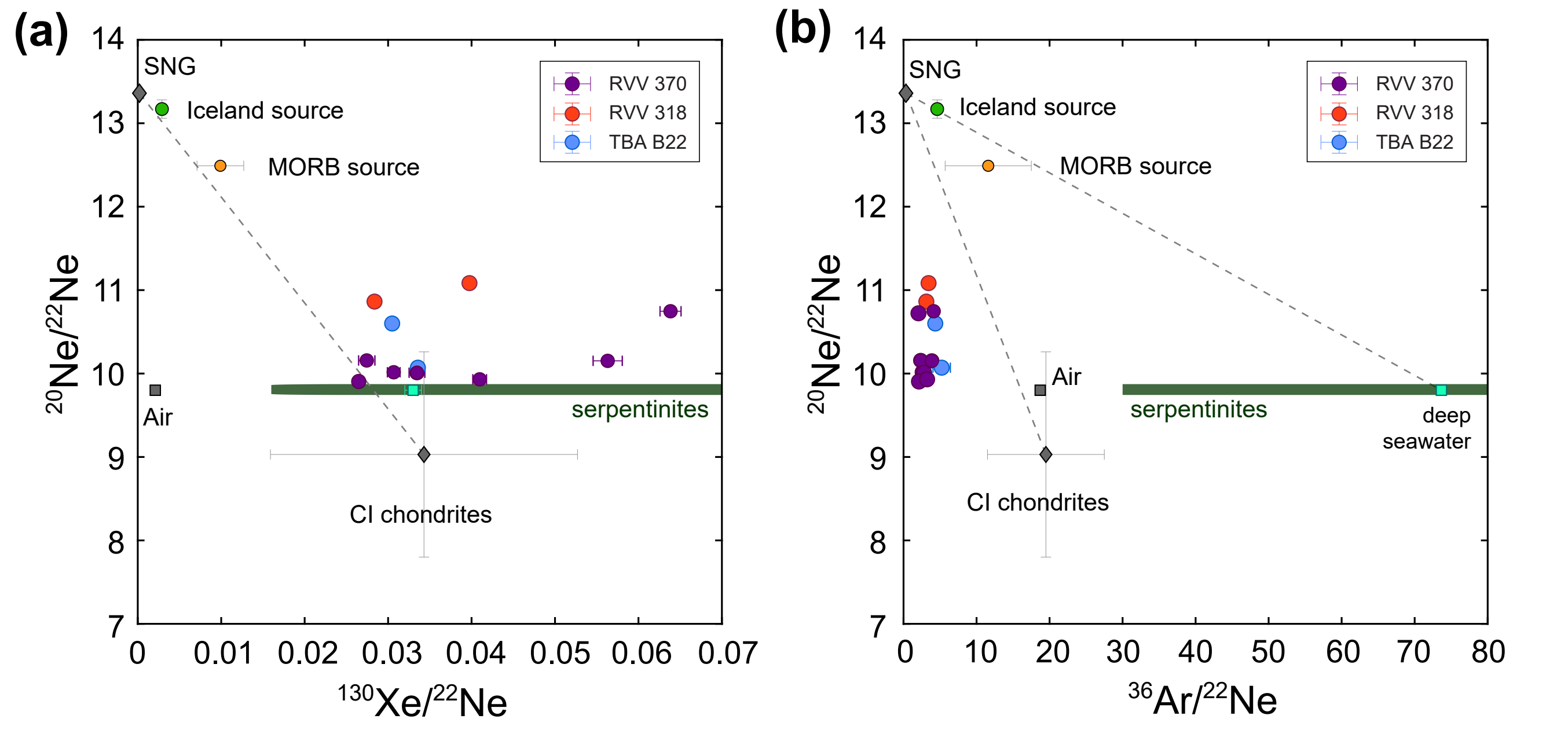


Figure 6. The $^{130}Xe/^{22}Ne$–$^{20}Ne/^{22}Ne$ (panel a) and $^{36}Ar/^{22}Ne$–$^{20}Ne/^{22}Ne$ (panel b) systematics of Cook-Austral HIMU OIBs. Unlike Iceland and MORB sources, HIMU source Xe/Ne and Ar/Ne ratios cannot be explained by mixing solar nebular gas (SNG) [15] with CI chondrites [16] and/or deep seawater [13]. The observed HIMU Xe/Ne and Ar/Ne ratios cannot be simultaneously explained by kinetic degassing of magma. The HIMU mantle source requires a component with a high Xe/Ne ratio, potentially serpentinites in subducted altered oceanic slabs. The much lower HIMU Ar/Ne ratios compared to serpentinites can be caused by Ar loss during subduction, consistent with studies suggesting that the recycling efficiency of Ar into the deep mantle is much lower than that of Xe [17-19]. Errors are 1σ.

Implications for the BSE K/U ratio:

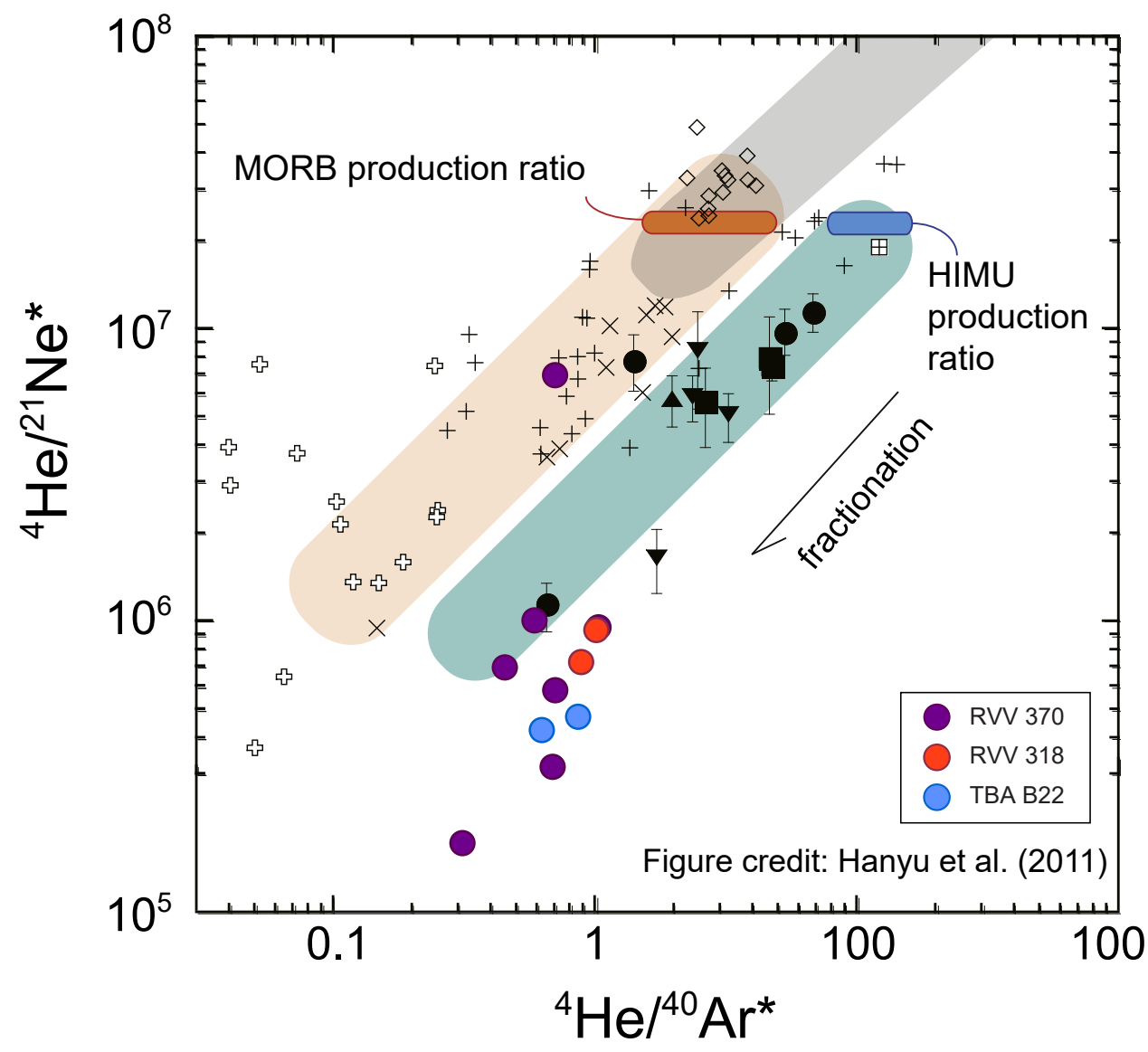


Figure 7. Cook-Austral HIMU radiogenic noble gas production ratio systematics. ^{4}He and ^{21}Ne are both produced by decay of U, while ^{40}Ar is produced by the decay of ^{40}K. A previous study [20] suggested that the HIMU OIB source has higher $^{4}He/^{40}Ar^{*}$ compared to the MORB source due to preferential K loss relative to U from subducted slabs via dehydration. New data are consistent with high HIMU source $^{4}He/^{40}Ar^{*}$ contributed by subducted oceanic slab components with low K/U [3]. However, note that disequilibrium degassing and/or helium loss can complicate the picture. Figure adapted from [20].

(5) Conclusions

Our high-precision He-Ne-Ar-Xe elemental and isotopic measurements on Cook-Austral HIMU OIBs provide insights into the origin and evolution of mantle heterogeneity through long-term mantle degassing and injection of surface volatiles into the mantle via plate tectonics.

HIMU OIBs sample a relatively undegassed mantle reservoir:

Our data confirm for the first time the existence of a solar-like Ne component in samples with strong HIMU lithophile isotope signatures. Depleted MORB source alone cannot account for the Ar-Ne systematics of HIMU OIBs.

HIMU heavy noble gases demonstrate the role of subduction in volatile transports between surface and mantle:

Subducted altered oceanic slab components carry surface volatiles including Xe to the HIMU source. Xe is preferentially regassed compared to Ar and Ne through subducting slabs. Inferred low K/U ratio of the HIMU mantle component is likely generated via slab dehydration, which has implications for the deep Earth argon budget [21].

References:

[1] Chauvel et al., 1992; [2] Hanyu and Kaneoka, 1997; [3] Lassiter et al., 2003; [4] Parai et al., 2009; [5] Rose and Hoppers, 2019; [6] Chauvel et al., 1997; [7] Ryan et al., 2009; [8] Lassiter et al., 2002; [9] Mukhopadhyay, 2012; [10] Parai and Mukhopadhyay, 2021; [11] Holland and Balletine, 2006; [12] Kendrick et al., 2018; [13] Kendrick et al., 2013; [14] Tucker et al., 2012; [15] Heber et al., 2012; [16] Mazor, 1970; [17] Péron and Mukhopadhyay, 2022; [18] Bekaert et al., 2021; [19] Krantz et al., 2019; [20] Hanyu et al., 2011; [21] Lassiter, 2004.