Understanding multiple stable and non-radiogenic isotope fractionation processes

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Mass-dependent (equilibrium, kinetic) fractionation (MF) of isotopes of masses i, j, and k of element E between 2 phases/reservoirs A and B (fractionation due a MF process) is described by $\ln \alpha_{B-A}^{j,k} = \theta_{B-A}^{i,j,k} \ln \alpha_{B-A}^{i,k}$ with

$$\alpha_{B-A}^{i,k} = \left(\frac{^iE}{^kE} \right)_B \times \left(\frac{^kE}{^iE} \right)_A \text{ and } \alpha_{B-A}^{j,k} = \left(\frac{^jE}{^kE} \right)_B \times \left(\frac{^kE}{^jE} \right)_A.$$

Quantum mechanics dictates that $\theta_{B-A}^{i,j,k}$ can vary between 0.5 (if $i - j = 1$ and $i - k = 2$) and $\frac{m_k^{-1} - m_j^{-1}}{m_k^{-1} - m_i^{-1}}$. In general, $\theta_{B-A}^{i,j,k} = f(T)$ decreases with T. An example is oxygen: for MF of oxygen $0.5 \leq \theta_{B-A}^{18,17,16} \leq 0.5305$ with $\lim_{T \to \infty} \theta_{B-A}^{18,17,16} = 0.5305$. Hence variations in $\Delta^{17}O$ due to MF alone are expected. It follows for all Elements E with > 2 isotopes: i) rocks, minerals, water, and gases do *not* fall on a common mass fractionation line (the concept of a terrestrial fractionation line is incorrect), ii) $\theta_{B-A}^{i,j,k}(T)$ is a thermometer, and iii) $\theta_{B-A}^{i,j,k}(T)$ is a fractionation process indicator.