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DEPARTMENT OF GEOLOGY

B.Sc. SEMESTER-II

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TRACE ELEMENTS AND ITS SIGNIFICANCE IN GEOCHEMISTRY

Trace elements are those which occur in very low concentrations in common rocks (usually < 0.1 % by weight). Their concentrations are therefore commonly expressed in parts per million (ppm) / parts per billion (ppb).

The incorporation of a trace element in the crystal structure of one or more minerals depends largely on its charge and radius, but also on the electro-negativity of this element, and crystal field effects. Accordingly, a trace element will either substitute for a major element in the structure of a crystallizing mineral, or remain in the liquid.

Unlike major elements, trace elements tend to concentrate in fewer minerals, and are therefore more useful in formulating models for magmatic differentiation, and in some cases, in predicting the source of a particular magma.

Trace elements most commonly used for the interpretation of the petrogenesis of igneous rocks include: Ni, Cr, Sc, V, Rb, Ba, Sr, Zr, Y, Nb and the Rare Earth Elements [REE] (La to Lu). The concentration of trace elements will vary with the rock type; whereas Ni and Cr show higher concentrations in mafic and ultramafic rocks, Zr and Rb are more concentrated in acidic rocks. Accordingly, some major or minor elements as K and P, which occur in very low concentrations in basalts (approaching trace levels), are just as useful in petrogenetic interpretations.

Applications of trace elements to Igneous Petrogenesis

1- Testing models of magmatic differentiation using trace elements

Relies on calculating the concentrations of trace elements remaining in the liquid once a certain amount of a particular mineral fractionates. The method can also be utilized to determine how much partial melting is needed to produce a specific magma from a given rock type. It is therefore invaluable for testing models of partial melting vs. fractional crystallization.

2- Determination of the depth of generation of a primary magma

Trace element contents of different types of primary magmas indicate that these can be produced by different degrees of partial melting at different depths in the mantle.

As you are aware, primary basalts are produced by partial melting at different depths in the mantle. At shallow depths, the mantle consists of Plagioclase lherzolite, at depths between 40 and 80 km, it consists of spinel lherzolite, whereas at depths > 80 km, it consists of garnet lherzolite. Because Plagioclase, Spinel and garnet concentrate Sr, V + Cr, and Heavy Rare Earth elements (HREE), respectively, magmas produced by small degrees of partial melting at shallow depths will be depleted in Sr, those from intermediate depths will be depleted in V and Cr, whereas those from depths > 80 km will be depleted in HREE's.

3) Prediction of the phases fractionating from a magma

The same rationale presented in (2) above applies for the identification of the phases which have fractionated from a magma undergoing fractional crystallization.

Separation of:

- (a) Plagioclase depletes the remaining melt in Sr and Eu,
- (b) Olivine depletes it in Ni and Co,
- (c) spinels deplete it in V, Cr and possibly Zn,
- (d) K-feldspar in Ba and Rb etc.

4) REE and REE diagrams

REE are very useful for petrogenetic interpretations. Their concentrations in an igneous rock are usually divided by (i.e. normalized against) their concentrations in standard chondrites or N-MORB (normal mid-oceanic ridge basalt) in order to smooth out large differences in concentration between one REE and the other. These normalized values are then plotted on diagrams similar to that shown on Fig. 1, where the REE are arranged on the X-axis from the lightest element to the heaviest.

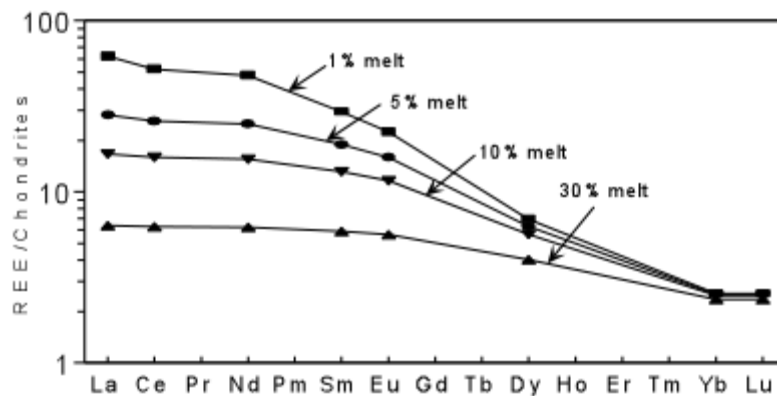


Figure 1- REE Diagram showing change in concentration of trace elements in a melt as percentage of partial melting increases. Light REE's (La-Gd) are less compatible as compared to heavy REE's (Ho-Lu) which are more compatible in garnet. Thus with increase in % of partial melting the incompatible element concentrations will decrease.

5) Discriminant diagrams

Trace elements can also be used to identify the paleotectonic setting of some volcanic rocks (i.e. to determine where they were erupted). In this case, rather than use the absolute concentrations of trace elements (which may have been affected by such post-magmatic processes as weathering, alteration or metamorphism), ratios of relatively immobile trace elements (as these are least affected by post magmatic processes).

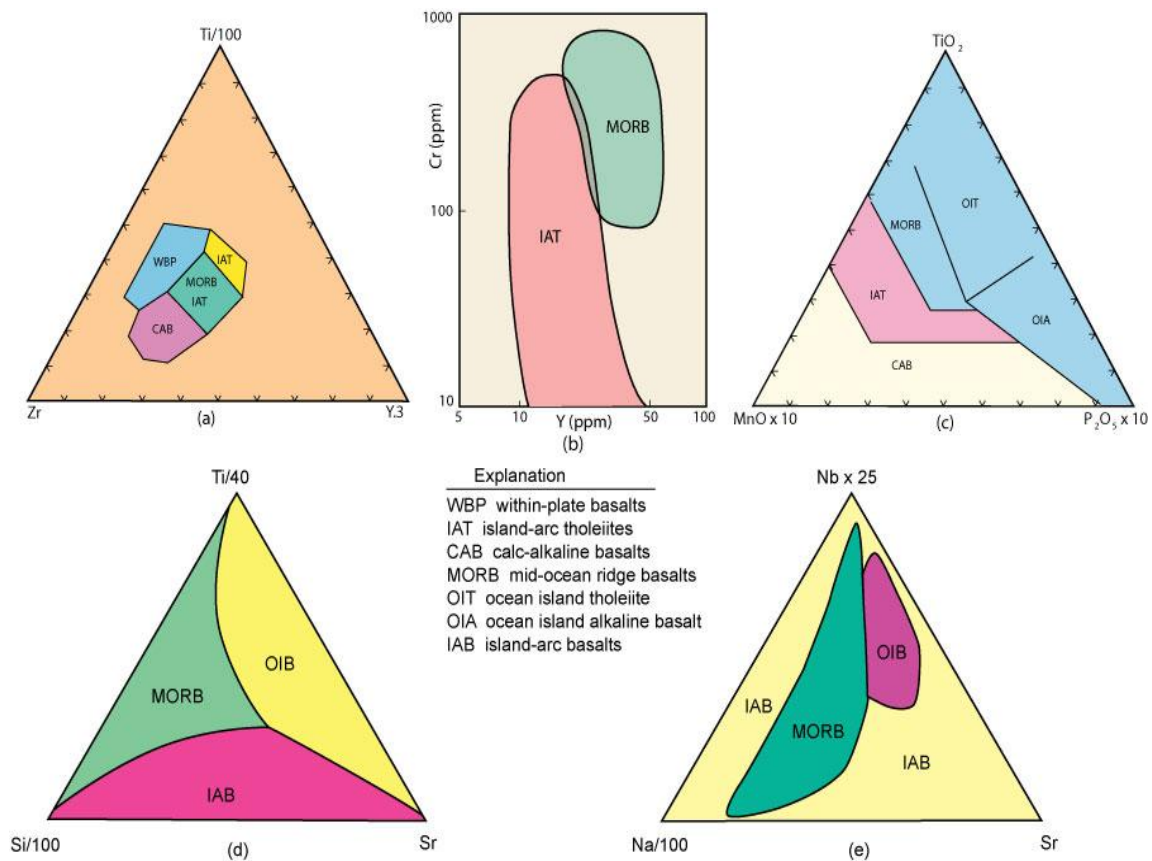


Figure 3 - Examples of discrimination diagrams used to infer tectonic setting of ancient (meta)volcanics. **(a)** after Pearce and Cann (1973), **(b)** after Pearce (1982), Coish et al. (1986). **(c)** after Mullen (1983) **(d)** and **(e)** after Vermeesch (2005).

**A SUMMARY OF SOME PARTICULARLY USEFUL TRACE ELEMENTS IN IGNEOUS
PETROLOGY (after Green, 1980).**

ELEMENT	USE AS A PETROGENETIC INDICATOR
Ni, Co, Cr	Highly compatible elements. Ni and Co are concentrated in olivine, and Cr in spinel and clinopyroxene. High concentrations indicate a mantle source, limited fractionation, or crystal accumulation.
Zr, Hf	Very incompatible elements that do not substitute into major silicate phases (although they may replace Ti in titanite or rutile). High concentrations imply an enriched source or extensive liquid evolution.
Nb, Ta	High field-strength elements that partition into Ti-rich phases (titanite, Ti-amphibole, Fe-Ti oxides). Typically low concentrations in subduction-related melts.
Ru, Rh, Pd, Re, Os, Ir, Pd	Platinum group elements (PGE's) are siderophile and used mostly to study melting and crystallization in mafic-ultramafic systems in which PGEs are typically hosted by sulfides. The Re/Os isotopic system is controlled by initial PGE differentiation and is applied to mantle evolution and mafic melt processes.
Sc	Concentrates in pyroxenes and may be used as an indicator of pyroxene fractionation.
Sr	Substitutes for Ca in plagioclase (but not in pyroxene), and, to a lesser extent, for K in K-feldspar. Behaves as a compatible element at low pressure where plagioclase forms early, but as an incompatible element at higher pressure where plagioclase is no longer stable.
Y	Commonly incompatible. Strongly partitioned into garnet and amphibole. Titanite and apatite also concentrate Y, so the presence of these as accessories could have a significant effect.