

## Lecture 5

### Nomenclature for Trace Element Classification

We have already grouped elements into two classes, major elements and trace elements (Figure 1). In addition, there are many ways of classifying trace elements.

Examples are:

**1) Siderophile elements:** elements that concentrate in metallic iron such as Ni,

Co, Os, Ir

**Chalcophile elements:** elements that concentrate in sulfides, such as Se, As,

Zn, Cd

**Lithophile elements:** elements that concentrate in silicate phases, such as Rb,

Sr, Ba, Nb, Ta, Th, U, REE

**Atmophile elements:** naturally occurring gaseous elements such as N and rare gases

These definitions are useful when considering formation of major earth reservoirs, i.e., core, mantle, crust and atmosphere.

**2) Compatible and Incompatible elements:** In an equilibrium system composed of minerals and coexisting silicate melt, compatible elements are preferentially partitioned into the solid phases and incompatible elements are preferentially partitioned into the melt. This terminology is commonly used in context of partial melting of mantle rocks to form basaltic magma. Upper mantle rocks are rich in olivine and pyroxenes and the elements Sc, Cr, Co and Ni are compatible (enriched) in these phases relative to a silicate melt. However, a key aspect of this definition is to specify what mineral phases are

being considered, e.g. Sc is compatible in clinopyroxene but not in olivine, Zr is compatible in zircon and P in apatite but neither is compatible in olivine or pyroxene.

Incompatible elements are preferentially partitioned into silicate melts rather than coexisting minerals. Incompatible elements can be sub-divided based on the ratio of charge/ionic radius ( $Z/r$ ) (see Figure 10).

**3) Large Ion Lithophile** – the term large-ion lithophile element (or LILE) is frequently used, but poorly defined in the geochemical literature. Some authors use LILE as a synonym for incompatible trace elements, whereas others use LILE to refer to a specific subset of incompatible trace elements characterized by large ionic radius to ionic charge ratio (or low "field strength" elements). The term was first used by Gast (1972) to encompass the cations K, Rb, Sr, Cs, Ba, REE, Th and U. Gast also included Li as a LILE, since it has a large radius to charge ratio, even though it is small ( $IR = 0.82$ ). Because of the confusion in the literature regarding usage of LILE, it is recommended that the term be restricted to lithophile trace elements having a large ionic radius to charge ratio that have ionic radii greater than those of  $Ca^{2+}$  and  $Na^{1+}$ , the largest cations common to rock forming minerals. By this definition, LILE are K, Rb, Cs, Sr, Ba, Pb and  $Eu^{+2}$  (Figure 10).

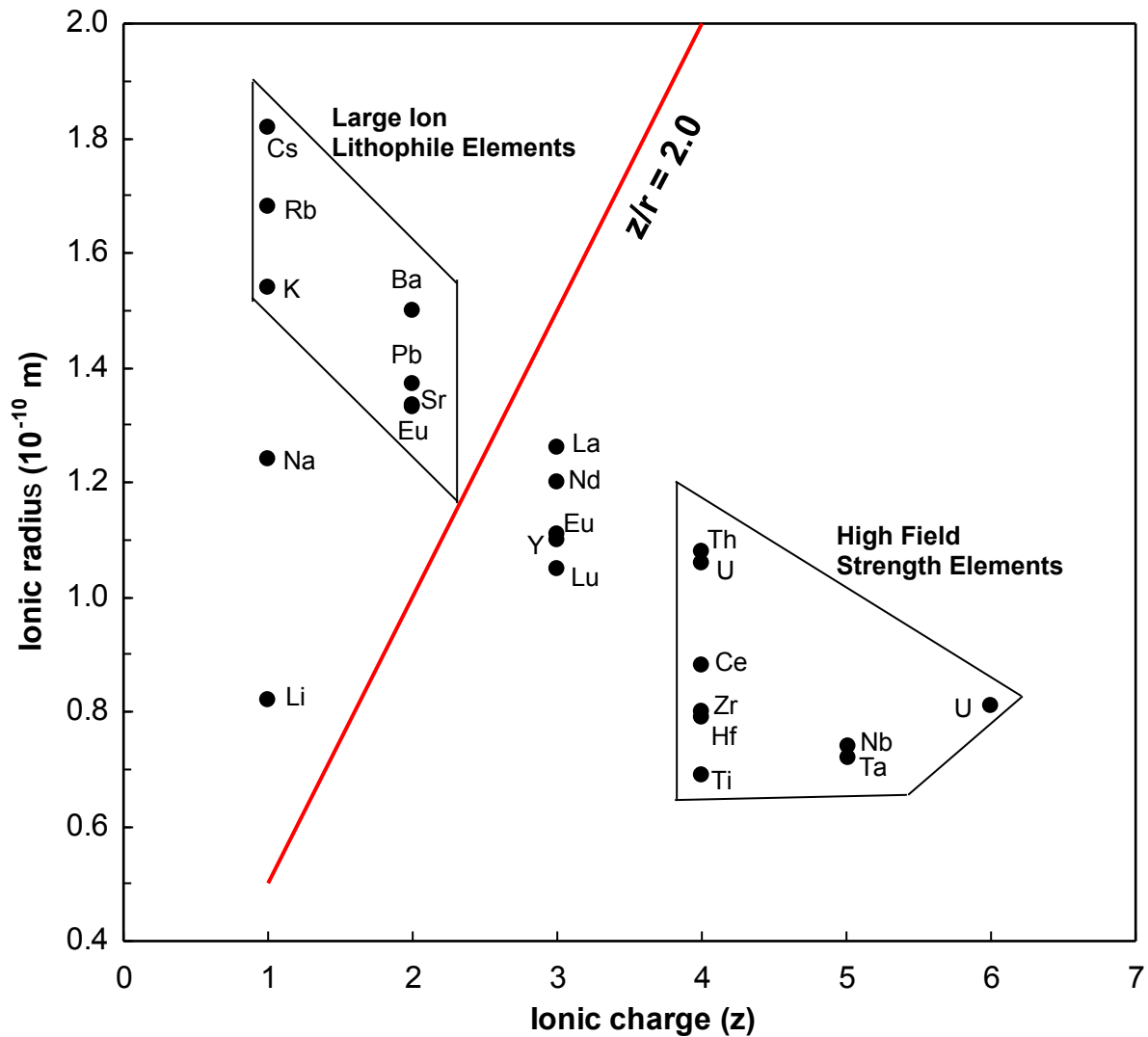


Figure 10. Ionic radii versus ionic charge for elements that are incompatible in mafic minerals. Elements with  $Z/r > 2$  are classed as **high field strength elements**; they are incompatible because of the difficulty in achieving charge balance when these ions with  $Z = +3$  to  $6$  substitute for major element cations with  $Z = 2$ . In contrast, elements with relatively high ionic ratios, hence low  $Z/r$ , are classed as **large-ion lithophile elements**. Ionic radii are for CN6 (for Li and ions with  $+4$ ,  $+5$ ,  $+6$  charge) and CN8 (for all other alkalic metals, and ions with  $+2$  and  $+3$  charge) are from Whittaker and Muntus (1970).

#### **4) High Field Strength Elements**

Although these elements do not have large IR, because of their high charge and the consequent difficulty in achieving charge balance, they are typically incompatible. Usually HFSE is used to designate Ti, Zr, Hf, Nb and Ta all with  $Z/r > 2$  (Figure 10); however, it is important to realize that these elements do not always partition in a similar manner.