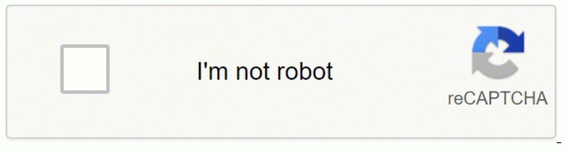

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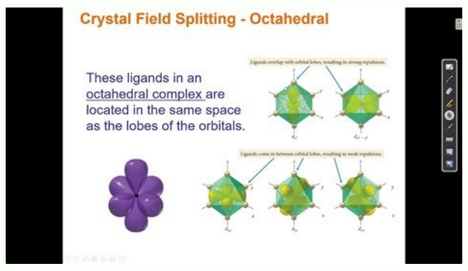

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Trace elements 301

Eight elements dominate the continental and oceanic crustal abundances summarized in Appendix 1. They are oxygen, silicon, aluminium, iron, calcium, magnesium, sodium and potassium, which together constitute almost 96 wt per cent of the oceanic crust and more than 98.5 wt per cent of the continental crust (Appendix 1). Four other elements, titanium, hydrogen, phosphorus and manganese, have crustal abundances exceeding about 0.1 wt per cent. If an arbitrary boundary between major and trace elements is drawn at 0.1 wt per cent or approximately 1,000 parts per million (ppm), only three of the transition elements, iron, titanium and manganese, would be classed as major elements of the oceanic crust. The remaining elements, including scandium (38 ppm), vanadium (250 ppm), chromium (270 ppm), cobalt (47 ppm), nickel (135 ppm) and copper (86 ppm) have crustal abundances below 1,000 ppm and would be classified as trace elements.

If the elements were classified on the basis of their abundances in the Earth as a whole and the boundary between major and trace elements was still maintained at 1,000 ppm, then nickel, chromium and cobalt, together with iron and manganese would rank as major elements, with titanium being relegated to a trace element. In extreme situations of metal concentrations in ore bodies, such as stratiform chromite deposits in layered intrusions or porphyry copper deposits in calc–alkaline igneous rocks, chromium and copper might be regarded as major elements. Since the Earth's continental crust is the most accessible source of samples for measuring and interpreting element distribution patterns during mineral-forming processes, a classification of the elements into major and trace categories is usually based on their relative crustal abundances. Therefore, the majority of the transition elements must be regarded as trace elements in the crust.

8.3 Trace element distribution rules

8.3.1 Background

The historical development of trace element geochemistry has been founded on chemical analyses of minerals and rocks and on theoretical interpretations of the abundance data. In the pioneering stages of geochemistry, considerable analytical data were obtained for the occurrences, distributions and abundances of most of the elements in rocks, minerals and other geologic media principally by F. W. Clarke and co-workers at the US Geological Survey. These data were first published in 1908 as a US Geological Survey bulletin under the title *The Data of Geochemistry* which was revised five times before 1924 (Clarke, 1924). The acquisition of geochemical data was continued by Goldschmidt and co-workers during the 1920's and 1930's, and compiled by

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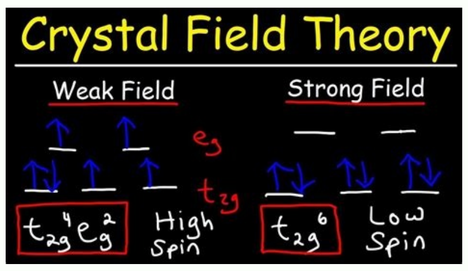

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in the mineral, and the symmetry of the coordination site occupied by the cation. The holder may then be placed in the cell compartment of a double-beam spectrophotometer. For measurements of polarized absorption spectra, various types of polarizers have been used, including calcite Nicol, Glan–Thompson or air-gap prisms, sheets of Polaroid film (e.g., HN42 for the visible and HR for the near-infrared) and stacked AgI plates. This technique, using oriented single crystals and pinhole-size apertures, has provided a plethora of mineral absorption spectra (Rossman, 1988).

Silicate minerals most frequently occur as very small crystals in rock, however, and it is often impossible to prepare polished plates of individual minerals for spectral measurements. Various methods have been devised to obtain absorption spectra for powdered minerals separated from crushed rock by heavy-liquid and magnetic separation techniques (Faye, 1971a). A powdered specimen may be placed between opal scattering discs or embedded in pressed KBr or CsI pellets. A simple but effective method for overcoming light scattering in minerals is to mount between glass slides a finely divided specimen (particle size 10 to 45 microns) as a paste in a transparent oil matching the average refractive index of the mineral. Since powders contain grains mainly in random orientations, measurements made on pulverized samples give average spectra. A few minerals, including amphiboles, micas, gillespite and clay silicates with acicular or platey habits, may give spectrum profiles that closely match polarized spectra of single crystals due to effects of preferred orientation arising from a unidirectional alignment of the crystallites. In diffuse reflectance spectral measurements, powdered mineral samples are used with an integrating sphere accessory, particularly in research to calibrate telescopic remotely sensed spectra of planetary surfaces. Examples of such reflectance spectral measurements are described in chapter 10.

In the development of mineral spectroscopy, microscopes have figured prominently in spectral measurements of small crystals. One early method for measuring polarized spectra of fine-grained minerals contained in rock utilized polarizing microscopes equipped with universal stage attachments (Burns, 1966b). The mineral specimen in the form of a rock thin-section or single crystal mounted in a transparent cement is placed between the glass hemispheres of a three-axis universal stage attached to a polarizing microscope. The microscope is then mounted in the sample chamber of the double-beam spectrophotometer so that radiation from the light-source is transmitted through the polarizer of the microscope before impinging on the specimen and entering the objective. An identical microscope arrangement is placed in the reference beam of the spectrophotometer except that a glass slide containing only the

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