Chapter 2

Basic Principles

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Geochemistry, as originally defined by Goldschmidt and summarized by Mason (1958, p. 2), is concerned with (i) the determination of the relative and absolute abundance of the elements in the earth, and (ii) the study of the distribution and migration of the individual elements in the various parts of the earth with the object of discovering principles governing this distribution and migration. In more recent years, a third concern has been added to these two, namely the application of geochemical principles and information in solving human needs. At present, geochemical exploration and environmental geochemistry are the major fields in which geochemistry is applied.

Although the methods and results of geochemical exploration are largely descriptive, with products usually taking the form of geochemical maps, the optimum planning and interpretation of geochemical surveys must be based on a knowledge of the distribution and abundance of elements, and on the principles that govern the migration of elements. This chapter discusses some of the basic principles and concepts useful in many facets of geochemical exploration.

I. THE GEOCHEMICAL ENVIRONMENT

Geologically and geochemically, the earth is a dynamic system in which materials are moved from place to place and changed in form and composition by a variety of processes, including melting, crystallization, erosion, dissolution, precipitation, vaporization and radioactive decay. Although the detailed behavior of matter in this system is extremely complex, the geochemical environment, as defined by pressure, temperature, and availability of the most abundant chemical components, determines the stability of mineral and fluid phases at any given point. On the basis of gross differences in pressure, temperature, and chemistry, the geochemical environments of the earth can be classified into two major groups: deep-seated and surficial.

The deep-seated environment extends downward from the lowest levels reached by circulating surface water to the deepest level at which normal rocks can be formed. Magmatic and metamorphic processes predominate in this zone. It is an environment of high temperature and pressure, restricted circulation of fluids, and relatively low free-oxygen content. Volcanic phenomena, hot springs, and similar features can generally be included with the deep-seated environment, in view of the temperature and source of material. The terms "hypogene", "primary", and "endogenic" have been used by some workers to refer to phenomena in this environment. However, primary implies a sequence which is not necessarily followed, and hypogene has been more commonly applied to ores than to large-scale geochemical processes. Endogenic, used in the U.S.S.R., is too easily confused with its converse, exogenic. In this book, the term "deep-seated" will be used in referring to environments and locations. Primary will refer to the stage of ore formation, as discussed further below.

The surficial environment is the environment of weathering, erosion, and sedimentation at the surface of the earth. It is characterized by low temperatures, nearly constant low pressure, free movement of solutions, and abundant free oxygen, water, and CO_2. The terms "supergene", secondary", and "exogenic" have also been used to refer to processes in this environment, but surficial seems preferable when considering environments. Secondary is used for processes acting on already formed orebodies, as discussed later.

The movement of earth materials from one environment to another can be conveniently visualized in terms of a closed cycle, as illustrated in Fig. 2.1. Starting on the right-hand side of the diagram and moving clockwise, sedimentary rocks are progressively metamorphosed as they are subjected to increasing temperature, pressure, and increments of new materials from outside the system. They may eventually attain a state of fluidity such that on recrystallization they can differentiate into various kinds of igneous rocks and hydrothermal extracts. When erosion brings the resulting suite of rocks into the surficial environment again, the component elements are redistributed by weathering agencies. A new series of sedimentary rocks is then deposited, and the cycle is closed. Figure 2.1 is, of course, highly simplified, as in reality large parts of the cycle may be missing in any given case, as suggested by the arrows in the center of the diagram. It is quite normal, for example, for sedimentary sandstone and shale to be exposed to weathering and erosion with-

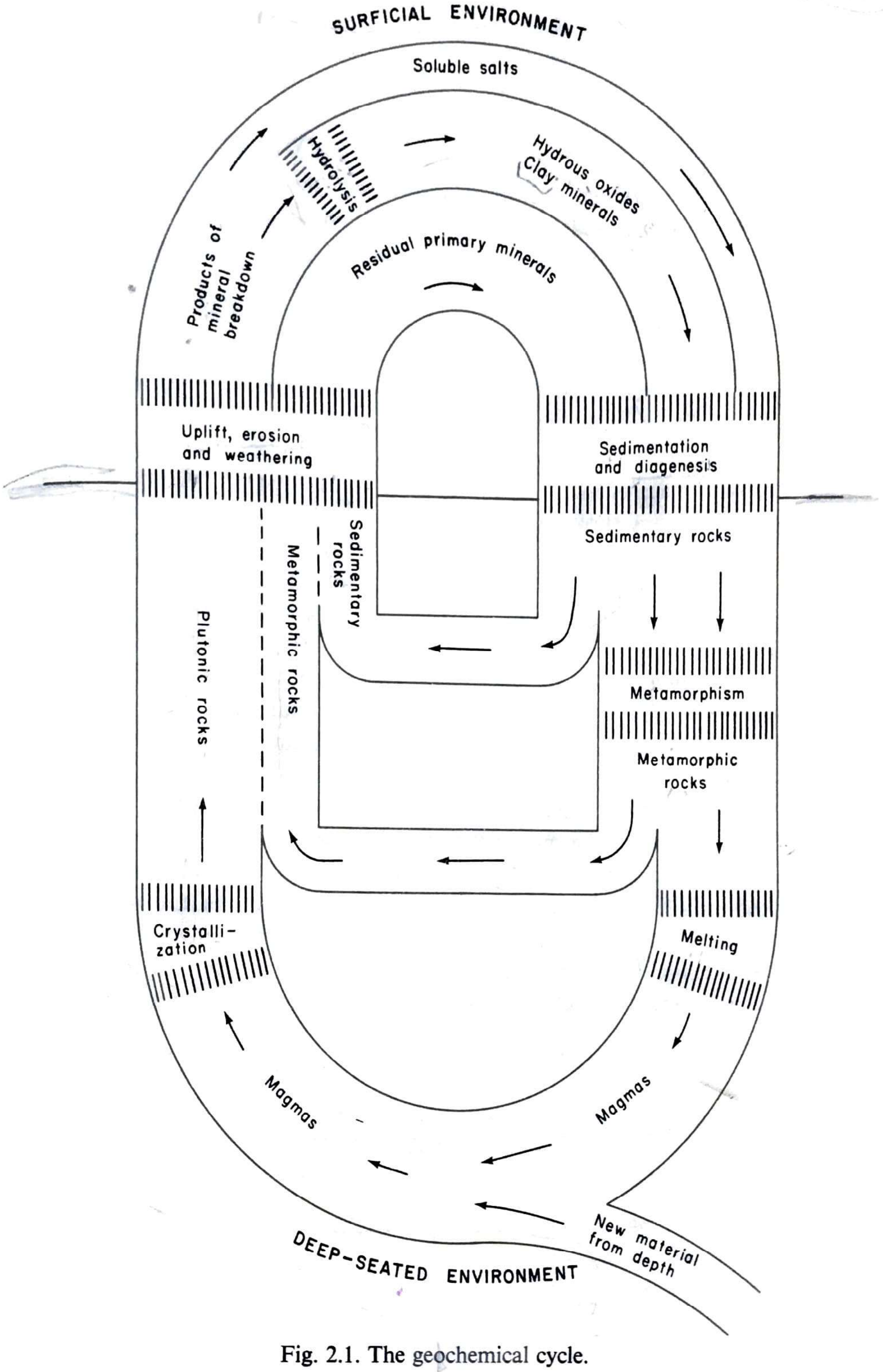

Fig. 2.1. The geochemical cycle.

out remelting or even significant metamorphism. Furthermore, this major cycle incorporates several important minor cycles, such as the circulation of carbon from the air into living plants, animals, organic deposits, and back into the air again.

The major geochemical cycle embraces both the deep-seated processes of metamorphism and igneous differentiation, and the surficial processes of weathering, erosion, transportation, and sedimentation. The horizontal division in Fig. 2.1 indicates the boundary between these two sectors of the geochemical cycle.

II. GEOCHEMICAL DISPERSION

A given small mass of material in the earth normally does not maintain its identity as it passes through the major transformations of a geochemical cycle, but rather tends to be redistributed, fractionated, and mixed with other masses of material (Fig. 2.2). This process, in which atoms and particles move to new locations and geochemical environments, is called geochemical dispersion. Nearly all dispersion occurs in dynamic systems in which earth materials are undergoing changes in chemical environment, temperature, pressure, mechanical strain, or other physical conditions. The rocks or minerals stable in one environment and the grains or atoms contained in them are released to be dispersed by either chemical or mechanical processes.

Dispersion may be the effect of exclusively mechanical agencies, such as the injection of magma or the movement of surficial material by glacial action. Apart from alluvial sorting of clay and sand, purely mechanical processes of dispersion usually involve mixing but not differentiation of the dispersed materials into specialized fractions. In contrast, chemical and biochemical processes commonly create fractions of widely differing chemical composition. The more mobile fractions tend to leave their original host if adequate

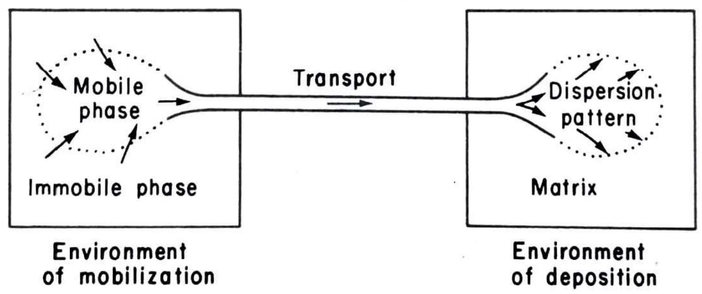

Fig. 2.2. The dispersion process.