Illinois Academy of Science Transactions, Vol. 43, 1950

ATOMIC MODELS OF THE SILICATES AS AN ESSENTIAL AID IN THE TEACHING OF ELEMENTARY MINERALOGY

DONALD M. HENDERSON
University of Illinois, Urbana

Most present-day courses in elementary mineralogy are actually impediments to the progress of mineralogy and geology, and are not even introductions to a *science*. The most serious defect is the lack of logical development and presentation of fundamental unifying principles. A dogmatic approach results in the emphasis falling almost entirely upon the memorization of a vast amount of miscellaneous and apparently unrelated information concerning minerals—much of it erroneous. Heretofore, such a state of affairs may have been somewhat excusable because of insufficient fundamental information. Today, however, there is sufficient information about the behaviour and arrangement of atoms in crystals so that an attempt can be made to present some of the controlling principles necessary for an understanding of miner-

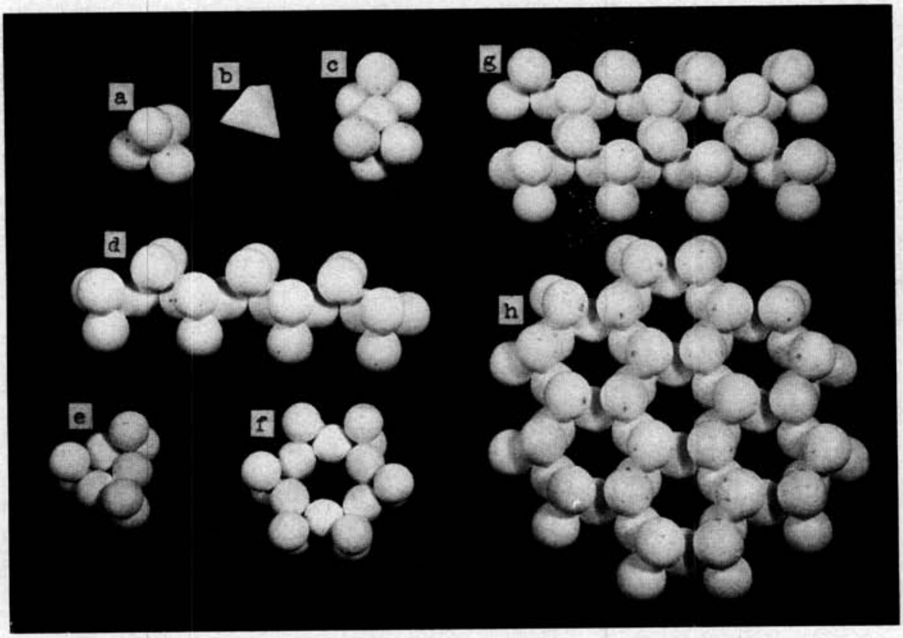

FIG. 1.—Common arrangements of silicate tetrahedra: a = independent tetrahedron characteristic of olivine; b = geometric tetrahedron for comparison with *a*; c = double tetrahedra characteristic of the melilite group; d = tetrahedral chain characteristic of pyroxene; e = three-membered tetrahedral ring characteristic of wollastonite and rhodonite; f = six-membered tetrahedral ring; g = double tetrahedral chain characteristic of amphibole; h = tetrahedral sheet characteristic of the micas. Tetrahedral three-dimensional framework characteristic of the silica minerals and feldspars not shown.

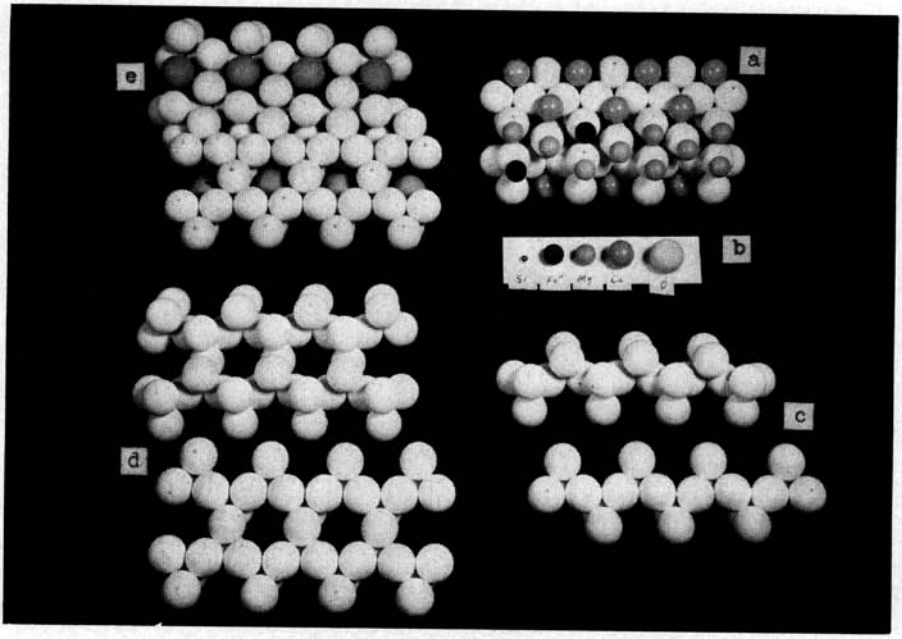

FIG. 2.—Method of assembling models: a = pyroxene showing arrangement of calcium and magnesium-iron atoms in parallel double rows (note isomorphism of magnesium and iron); b = index of atoms in pyroxene model *a*; c = method of assembling tetrahedral chains in model *a*; d = method of assembling tetrahedral double chains in model *e*; e = partly assembled model of amphibole, hydroxyl ions (gray) occupy large holes in double chains, arrangement of cations (not shown) like that in pyroxene model *a*.

als even on an elementary level.

The purpose of this paper is not to present a complete elementary treatment of such principles but simply to call attention to them and to show how readily they may be illustrated by atomic packing models of minerals. The value of this approach is particularly well demonstrated by the insight which it gives into the relations of the extremely complicated silicate group of minerals. However, before describing the atomic packing models, several highly simplified principles will be given first so that the significance and use of the models can be fully appreciated:

(1) The constituent elements occur as spherically shaped ions.

(2) Each kind of ion (Fe^{2+}, O^{2-}, Fe^{3+}, etc.) has a characteristic size (in general anions are larger than cations).

(3) Anions are attracted so as to touch neighboring cations and vice versa.

(4) The number of anions that can surround a cation (and vice versa) is controlled by the relative sizes of the respective ions.

(5) Different kinds of ions that have similar sizes (e.g. Fe^{2+} and Mg^{2+}) can equally well occur in the same kind of position in a crystal structure (isomorphism).

The most important conclusions to be derived from these principles are that most minerals, including silicates, can be considered as composed

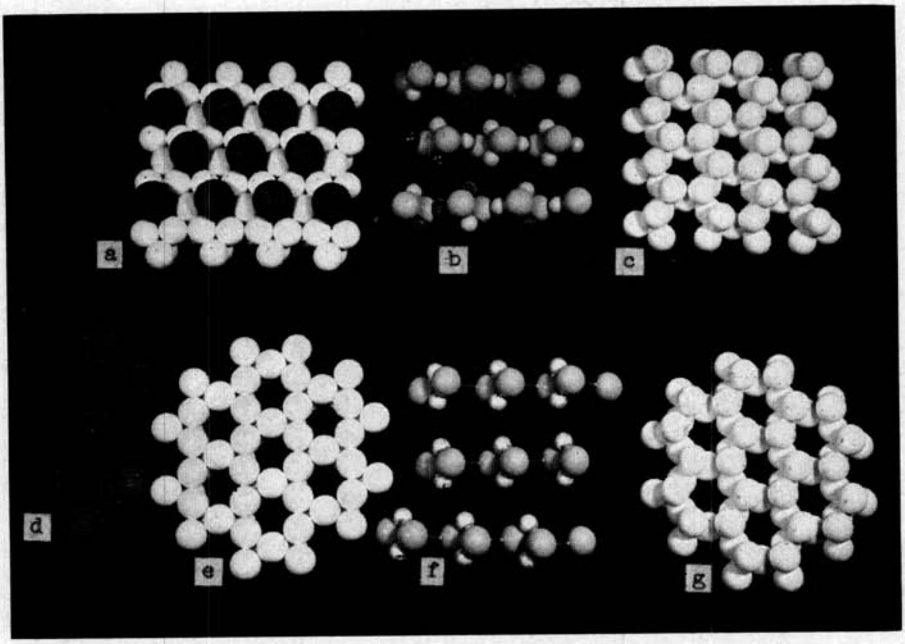

FIG. 3.—Method of making models with interchangeable parts that can be easily assembled and disassembled: a = silicate sheet with large potassium atoms (dark) resting in holes in sheet. b = strings of hydroxyl ions (large gray spheres) and magnesium-iron atoms which form a layer between silicate sheets *a* and *c*. Threefold arrangement of magnesium and/or iron atoms is characteristic of biotite and talc. c = silicate sheet. d = potassium atoms. e = silicate sheet identical to rectangular sheet *a* but with tetrahedra at corners removed in order to show hexagonal symmetry of sheet. f = strings of hydroxyl ions and aluminum atoms (small white spheres) which form a layer between silicate sheets *e* and *g*. Twofold arrangement of aluminum atoms is characteristic of muscovite, pyrophyllite and kaolin. g = silicate sheet identical to *c* but with corner tetrahedra removed in order to show hexagonal symmetry of sheet.

of ion spheres of different sizes, and that many of the properties of minerals depend upon the relatively simple geometric ways in which these spheres can be packed repetitively. An elementary account of these principles can be found in Stillwell (1938). Data on the sizes of ions can be found in Evans (1948).

It should be possible, therefore, to show the application of these principles by means of models of minerals constructed with spheres of different sizes representing the different atoms. Spheres of cork probably are the easiest to use. The Armstrong Cork Company makes cork spheres in any size from ⅜ to 3 inches in diameter. Entirely satisfactory models can be made with relatively few sizes. The following sizes have been found to be suitable:

1¼″ = oxygen, hydroxyl, fluorine, and potassium (1¾″ has been found to be more satisfactory for potassium in the micas)
1″ = calcium, sodium
¾″ = magnesium, iron, aluminum (½″ would be more accurate for aluminum)
9/32″ = shot or ball bearings for silicon

The use of different colors for the different kinds of atoms adds to the effectiveness of the models. The spheres can easily be joined together by means of heavy pins or brads from which the heads have been cut off. Models of particular minerals can be constructed from the data in Bragg (1937).

The fundamental unit of construction of the silicates is the so-called silicate tetrahedron which consists of a silicon atom surrounded by four oxygen atoms. This unit well illustrates the control on arrangement of atoms by their relative sizes because the sizes of silicon and oxygen are such that four oxygen atoms can just fit around each silicon atom (figure 1). One of the most important causes of the complexity of the silicate minerals arises from the variety of ways in which the silicate tetrahedra can be arranged (figure 1). In fact, the simplest and probably the most instructive method of making a model of a particular silicate mineral is to assemble several of the tetrahedral groups that compose the major part of that mineral, such as independent tetrahedra for olivine, single chains for pyroxene, or sheets for mica. In general, it will be found that these groups pack together rather snugly and that the other atoms in the crystal fit in the interstices. Large atoms fit in the large interstices and small atoms in the small interstices. Examples are shown by figures 2, 3, and 4.

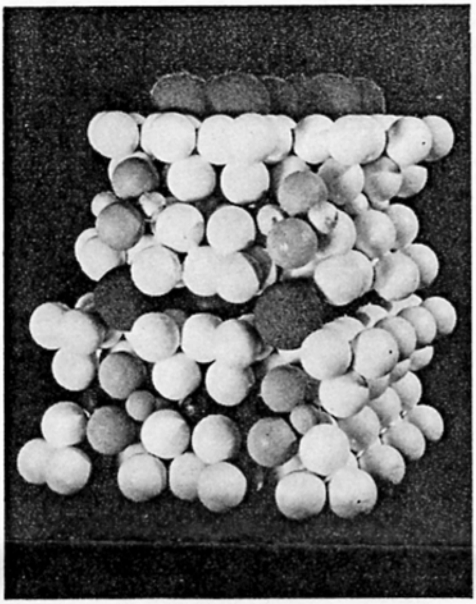

FIG. 4.—Composite model of mica made by assembling units shown in figure 3. Lower half represents biotite assembled from units *a*, *b*, and *c* in figure 3. Upper half represents muscovite assembled from units *d*, *e*, *f*, and *g* in figure 3.

The models are particularly instructive if the groups can easily be disassembled and reassembled by students. Figure 3 shows an example in which the groups are interchangeable and can be assembled in various combinations to illustrate almost all the sheet minerals.

Models such as those that have been briefly described illustrate vividly and fundamentally many of the varied properties of the silicates, such as isomorphism, derivation of the chemical formulae, cleavage, hardness, many of the optical properties; why certain alteration products may be favored; and why melts of certain silicates are viscous whereas others are fluid.

Grateful acknowledgment is made to Dr. Ralph E. Grim of the Department of Geology and the Illinois State Geological Survey, who has long recognized the value of atomic models in his researches on the clay minerals and who called to my attention the convenience of cork spheres. Mr. Merle Williams, a student in the Department of Geology, assembled the excellent models shown in the illustrations.

REFERENCES

Bragg, W. L. (1937), *Atomic structure of minerals*, Cornell University Press.

Evans, R. C. (1948), *An introduction to crystal chemistry*, Cambridge University Press.

Stillwell, C. W. (1938), *Crystal chemistry*, McGraw-Hill.