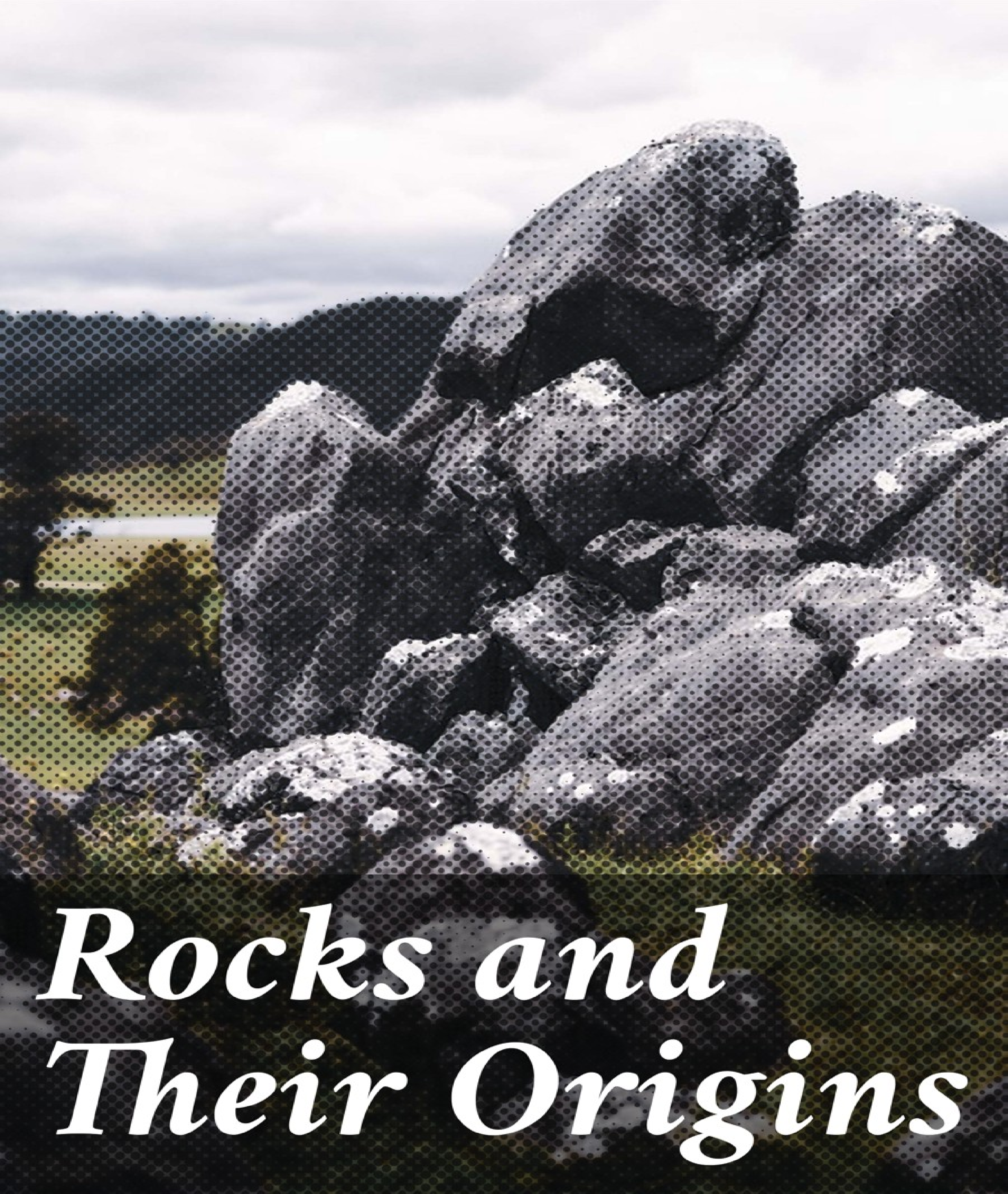
Grenville A. J. Cole



Rocks and Their Origins

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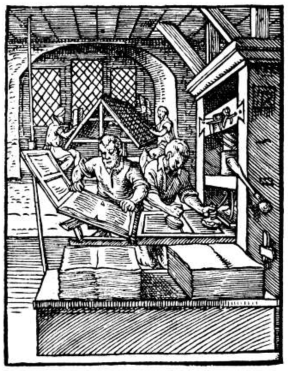

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PREFACE

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This little book is intended for those who are not specialists in geology, and it may perhaps be accepted as a contribution for the general reader. To all who are interested in the earth, the study of rocks is an important branch of natural history. If detailed works on petrology are to be consulted later, F. W. Clarke's *Data of Geochemistry* (Bulletin, U.S. Geological Survey, ed. 2, 1911) must on no account be overlooked. Its numerous references to published papers, and the attention given to rock-origins, make it a worthy companion to C. Doelter's *Petrogenesis*. Many things have perforce been omitted from the present essay. It seemed unnecessary to review the Carbonaceous rocks, since the most important of these have been admirably dealt with in E. A. N. Arber's *Natural History of Coal*, published as a volume in this series. I should like to have described occurrences of rock-salt, of massive gypsum, and other products of arid lands, where "black alkali" poisons the surface, and the casual pools are fringed with white and crumbling crusts. Rock-taluses, and all the varied alluvium carried seaward as the outwash of continental land, well deserve a chapter to themselves. But there is really no end to the subject, which embraces all the accumulative processes of the earth. A few vacation-journeys, judiciously planned out, teach us that text-books are merely signposts to set us on what is believed to be the way. When the path enters the great forest, or rises above green lakelets to the crags, we find there those who went before us, pointing to unconquered lands.

G. A. J. C.

ROYAL COLLEGE OF SCIENCE
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CHAPTER I

ON ROCKS IN GENERAL

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The description of rocks has fallen very much into the hands of lovers of analysis and classification, and attention has been diverted, even among geologists, from their fundamental importance as parts of the earth's crust. The geographer or the general traveller may often wish for closer acquaintance with the units that build up the scenery around him. The characters of rocks again and again control the features of the landscape. When studied more nearly, these same characters imply conditions of deposition or solidification, and lead the mind back to still older landscapes, and to the meeting of oceans and continents on long-forgotten shores. Petrology, indeed, involves the understanding of how rocks "come to be where we find them when we try"; but the classification of hand-specimens was from the first easier than field-investigation, and in later times the science was threatened with the description of isolated microscopic slides. Fortunately, a certain amount of feeling for natural history has been imported again into the subject, and evolutionary principles and sequences have been discussed. Experimental work, moreover, has been brought to bear on the question of the origins of rocks, with more success than might have been expected, since it is very difficult to realise in a laboratory, or even in the mind, the conditions that prevail in the lower parts of the earth's crust.

Rocks, we have to remember, are in themselves considerable masses, and have relations with others far away. The coarseness of a sandstone at one point, or even over square miles of country, implies the deposition of finer material somewhere else. The lava-flow implies the existence of mysterious cauldrons in the crust. It is, however, fortunate that the primary classification of rocks was promulgated without regard for theories of rock-origins. The work was done by men who were masters and pioneers in mineralogy. At a time when a powerful school regarded basalt as of sedimentary origin, and when granite was generally believed to be the most ancient component of the crust, rock-masses were taken in hand as aggregates of certain minerals, and were reduced to an orderly scheme for arrangement in the cabinets of the curious. Any system based on ideal relationships would have been fatal at that time to petrology as a science.

Alexandre Brongniart, in 1813, thus saw objections to the classification of rocks that had been proposed by Werner. In his "Essai d'une classification minéralogique des Roches mélangées," he showed the impossibility of determining the age of a rock in relation to others before assigning to it a name, and the absurdity of separating similar rocks on account of differences in their geological age. Brongniart was thus forced to rely, firstly, upon the prevalence of certain mineral constituents, and, secondly, on the structure of the mass. He developed this scheme in 1827, in his "Classification et caractères minéralogiques des Roches homogènes et hétérogènes"; but it is clear that, even in such a system, considerations of natural history and of origin will ultimately predominate. Brongniart was much influenced by Karl von Leonhard's "Charakteristik der Felsarten," published in 1823, and these two authors have been regarded as the founders of petrography.

The difficulty of distinguishing between rocks laid down as true sediments on the earth's surface and those that have consolidated from a state of fusion has been very largely removed. The assistance of the microscope can now be called on to elucidate the minute structure of fine-grained masses, which appeared homogeneous to earlier workers.

The pioneer in microscopic methods was Pierre Louis Antoine Cordier, who knew rocks as a traveller knows them in the field. In 1798, as a young man of twenty-one, he had gone to Egypt with the famous expedition under General Bonaparte. Déodat de Dolomieu had charge of the geological observations, and Cordier went through the hardships of the campaign as his assistant. When Bonaparte abandoned the army and withdrew to Paris, Cordier might well have been lost to Europe.

However, he successfully brought home the knowledge acquired in the field, and set himself, in those agitating years, to solve the problem of the compact groundwork of igneous rocks. He argued that this groundwork probably consisted of minerals, and that these minerals were probably similar to those occurring as visible constituents of the mass. He examined the powder of these larger crystals under the microscope, and made himself familiar with their aspect in a fractured form. He then powdered the compact material of his rocks, washed away the dust, and was able to recognise in the coarser residue the minerals that he had previously studied. He used the magnet to extract the iron ore; he determined the fusibility of the particles with the blowpipe; and he even discovered in volcanic lavas a residual glass associated with the crystalline material[1]. To this day, when a particular mineral has to be determined in a rock, it is often best to follow Cordier's method, and to extract the actual crystals, however small. Various modes of separation, especially those involving the use of dense liquids, have been devised since Cordier's time, and the specific gravity of a single crystal can now be determined, although it may be so small as to require looking for in the dense liquid with a lens[2].

Between 1836 and 1838, Christian Gottfried Ehrenberg, Professor of Medicine at Berlin, made an immense step forward in the study of rocks. Being keenly interested in microscopic forms of life, he wished to determine their importance as constituents of rocks. Using a microscope magnifying 300 diameters, he showed the presence of organisms in flint and limestone, and found in 1838 that a thin slice of chalk coated over with Canada balsam became practically transparent. In his "Mikrogeologie," published in 1854, he gives drawings of thin sections of several flints, seen by transmitted light, which are thus rock-sections in the modern petrological sense. His method could not have been generally known until his book appeared in 1854. Meanwhile, Henry Clifton Sorby, about 1845, found the naturalist W. C. Williamson making thin sections of fossil plants and bones. He promptly perceived the importance of the method as applied to rocks in general, and introduced it to the Geological Society of London in 1850, in a paper on the Calcareous Grit of Scarborough. Seven years later, he read his memorable paper on "The Microscopical Structure of Crystals[3]," in which he made use of slices of granite and of Vesuvian and other lavas. Ferdinand von Zirkel met Sorby by chance at Bonn in 1862, and, learning his methods, proceeded to systematise the examination of rock-specimens with the microscope. Such studies, rapidly appreciated by Michel Lévy, Rosenbusch, Judd, and others, naturally led to advances of the first importance in petrology. They enabled workers to ascertain the relations of the rock-constituents one to another, and the order of consolidation of minerals from an igneous magma. The broad division of rocks into those of sedimentary and those of igneous origin has been further emphasised. The rocks styled metamorphic still afford the greatest difficulty, even after prolonged enquiry in the field.

Seeing that some rocks are merely massive minerals, that is, large masses formed of one mineral species, while others consist of crystals or fragments of a variety of minerals, it may be well to remind ourselves of the distinction between minerals and rocks. We may define a *mineral* as a natural substance formed by inorganic action; its chemical composition is constant; under favourable circumstances, it assumes a characteristic crystalline form.

Like all definitions of natural objects, the above requires some qualification. In many cases the chemical composition of a mineral varies by a well-defined series of atomic replacements, and we cannot feel called upon to establish a new species for every step away from the rigid type. Sodium thus replaces potassium to some extent in orthoclase felspar. The crystalline form, again, may not be specifically characteristic, as, for instance, in the members of the garnet series, which crystallise in the cubic system. The homogeneity of molecular structure throughout the individual may be regarded as the most essential feature of what we style a mineral species; that is to say, the molecules contain the same elements in the same proportions, and are arranged on the same physical plan.

A *rock*, on the other hand, is a mere aggregate of mineral particles, or of molecules that, under proper conditions, would group themselves to form mineral species. It may consist entirely of granules or crystals of one species; but the structures in these have no common orientation, as they would have in a single large continuous crystal. The rock itself has no crystalline form, and any structures that simulate such forms will be found on measurement to have none of the regularity that characterises genuine crystals. A rock, moreover, formed of several mineral species in association will by no means possess a constant chemical composition, and the variations from point to point form a feature of especial interest in the study of igneous masses, of sediments deposited on a shore, or of alluvium in a valley stretching far between the hills.

In the pages that follow we hope, then, to bear in mind the relations of rocks to the earth and to ourselves. Like the ancient Romans, we build our cities with huge blocks and slabs brought from crystalline masses oversea. We now tunnel, for our commercial highways, through the complex cores of mountain-chains. Everywhere rocks are our foundations, throughout our travels or in our settled homes. They rise as obstacles against us, or they spread before us fields of fertile soil. Some knowledge of them is part of the general body of culture that makes us, in the best sense, citizens of the world.

LIST OF THE COMMON MINERALS THAT FORM ROCKS

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Actinolite. See Amphiboles.

Albite. See Felspars.

Amphiboles. A series of silicates with the general formula $RSiO_3$, where R is magnesium, iron or calcium; in many, such as the common species *Hornblende*, molecules occur in addition in which aluminium and triad iron are introduced. Hornblende thus consists of *m* $(Mg, Fe'', Ca)\ SiO_3$. *n* $(Mg, Fe'')\ (Al, Fe''')_2\ SiO_6$. *Actinolite* is a non-aluminous amphibole occurring in needle-like prisms. The amphiboles crystallise in prisms having angles of about 56° and 124°. See Pyroxenes.

Anatase. See Rutile.

Andalusite. Aluminium silicate, Al_{2}SiO_{5}, crystallising in the rhombic system. *Sillimanite* consists also of Al_2SiO_5 and is rhombic, but crystallises with different fundamental angles.

Anorthite. See Felspars.

Apatite. Calcium phosphate, with fluorine, or sometimes chlorine, $(CaF)Ca_4(PO_4)_3 = 3Ca_3(PO_4)_2.CaF_2$.

Aragonite. Calcium carbonate, $CaCO_3$, crystallising in the rhombic system, with a specific gravity of 2·93. See Calcite.

Augite. See Pyroxenes.

Biotite. See Micas.

Calcite. Calcium carbonate, $CaCO_3$, crystallising in the trigonal system, with a specific gravity of 2·72. See Aragonite.

Chalcedony. Crystalline silica, SiO_2, in fibrous and often mammillated forms. *Flint* or *Chert* is a concretionary form, in which some interstitial opal may be present.

Chert. See Chalcedony.

Chlorites. Hydrous aluminium magnesium iron silicates, resembling green micas, but softer and with non-elastic plates.

Chromite. Iron chromium oxide, $FeCr_2O_4$. Magnesium may replace part of the dyad iron, and aluminium and triad iron some of the chromium.

Diallage. An altered augite with a shimmery submetallic lustre.

Diopside. See Pyroxenes.

Dolomite. Magnesium calcium carbonate, $MgCa(CO_3)_2$.

Enstatite. See Pyroxenes.

Epidote. Calcium aluminium iron silicate, $Ca_2(AlOH)(Al,Fe''')_2(SiO_4)_3$.

Felspars. A series of silicates of aluminium with potassium or sodium or calcium, or all of these. *Orthoclase*, $KAlSi_3O_8$, and the corresponding sodium form, *Albite*, $NaAlSi_3O_8$, lie at one end of the series, and the calcium felspar *Anorthite*, $CaAl_2(SiO_4)_2$, at the other. While Orthoclase crystallises in the monoclinic system, a triclinic form, *Microcline*, with the same composition, is also common. All the other felspars are triclinic, and, with microcline, are often styled *plagioclases*. The principal felspars between Albite and Anorthite are *Oligoclase*, the "soda-lime felspar," and *Labradorite*, the "lime-soda felspar."

Flint. See Chalcedony.

Garnets. A series of silicates with the general composition of $R_3''R_2'''(SiO_3)_4$, R'' being Ca, Fe'', or Mn, and R''' being Al or Fe'''. The common red garnet in mica-schists is *Almandine*, $Fe_3Al_2(SiO_3)_4$, while that in altered limestones is *Grossularite*, $Ca_3Al_2(SiO_3)_4$.

Glauconite. A hydrous iron potassium silicate, with some aluminium, magnesium, and calcium, formed in marine deposits.

Gypsum. Hydrous calcium sulphate, $CaSO_4 + 2 H_2O$.

Hornblende. See Amphiboles.

Hypersthene. See Pyroxenes.

Ilmenite. Titanium iron oxide, $m\,FeTiO_3 + n\,Fe_2O_3$.

Iron Pyrites. Iron disulphide, FeS_2. A cubic species, *Pyrite*, and a less common rhombic species, *Marcasite*, occur.

Kaolin. Hydrous aluminium silicate, $H_4Al_2Si_2O_9$.

Kyanite. Aluminium silicate, Al_2SiO_5, crystallised in the triclinic system. See Andalusite.

Labradorite. See Felspars.

Leucite. Potassium aluminium silicate, $KAl(SiO_3)_2$.

Limonite. Hydrous iron oxide. $H_6Fe_4O_9$.

Magnetite. Magnetic iron oxide, Fe_3O_4.

Marcasite. See Iron Pyrites.

Micas. A series of aluminium silicates, with potassium, magnesium, or iron, or all of these. Lithium and sodium sometimes occur. The two marked types are *Muscovite*, rich in aluminium and potassium, the common "alkali mica," $H_2KAl_3(SiO_4)_3$, with a silvery aspect, and *Biotite*, the common dark "ferromagnesian" mica, $(H, K)_2(Mg, Fe'')_2(Al, Fe''')_2(SiO_4)_3$.

Microcline. See Felspars.

Muscovite. See Micas.

Nepheline. Sodium aluminium silicate, with some potassium, the pure sodium type being $NaAlSiO_4$; the types with potassium contain slightly more silica.

Oligoclase. See Felspars.

Olivine. Magnesium iron silicate, $(Mg, Fe)_2SiO_4$.

Opal. Uncrystallised silica, SiO_2, with some water.

Orthoclase. See Felspars.

Pyrite. See Iron Pyrites.

Pyroxenes. A series of silicates corresponding in composition to the Amphiboles, but crystallising in prisms which have angles of about 87° and 93°. On