Electrical Properties of Rocks

E. I. Parkhomenko
Institute of Physics of the Earth
Academy of Sciences of the USSR, Moscow

Translated from Russian and edited by
George V. Keller
Colorado School of Mines
Golden, Colorado

PLENUM PRESS · NEW YORK · 1967

Eleonora Ivanovna Parkhomenko, a senior scientist in the department of physical properties of rocks at the Institute of Physics of the Earth of the Academy of Sciences of the USSR in Moscow, graduated from the Mining Institute in Irkutsk in 1943. From 1943 to 1950 she worked in an industrial laboratory and joined the Institute of Physics of the Earth in 1950. In 1957, she was awarded the degree of Candidate in the Physical and Mathematical Sciences. She has published 34 papers and at present she is studying the electrical properties of rocks at high pressures and temperatures.

The Russian text has been corrected by the author for the present edition. It was originally published for the O. Yu. Shmidt Institute of Physics of the Earth of the Academy of Sciences of the USSR by Nauka Press in Moscow under the following title:

Электрические свойства горных пород

ELEKTRICHESKIE SVOISTVA GORNYKH POROD

ELECTRICAL PROPERTIES OF ROCKS

Э. И. Пархоменко

Library of Congress Catalog Card Number 67-10311

Printed in the United States of America

Electrical Properties of Rocks

Monographs in Geoscience

General Editor: Rhodes W. Fairbridge

Department of Geology, Columbia University, New York City

B. B. Zvyagin
Electron-Diffraction Analysis of Clay Mineral Structures–1967

E. I. Parkhomenko
Electrical Properties of Rocks–1967

In preparation

A. I. Perel'man
The Geochemistry of Epigenesis

Foreword

Recently there has been growing interest in the physical properties of rocks. To interpret data on the geophysical fields observed near the Earth's surface, we must know the physical properties of the materials composing the interior. Moreover, the development of geophysical methods (in particular, electrical methods) is necessitating a multiple approach to the study of the physical properties of rocks and minerals.

In connection with problems now appearing, the physical properties of rocks must be studied in the laboratory under various thermodynamic conditions. Electrical methods of geophysical exploration often may require only data obtained at atmospheric pressure and room temperature, or at temperatures below 100°C. If, however, we have in mind geophysical field observations on the composition and state of matter deep in the Earth's crust and mantle, we must conduct laboratory experiments at high pressures and temperatures. For example, in interpreting data from geomagnetic soundings of the mantle, we may need experimental results on the electrical properties of rocks at pressures of tens of kilobars and temperatures of the order of 1000°C. In this connection, we must remember that pressure has relatively little effect on the electrical properties of rocks, whereas, temperature affects them very strongly.

At present, while research into the mechanical properties of rocks (relating to the problems of geophysics, geochemistry, geology, and mining) is pressing forward on a wide front, much less work is being done with electrical properties. Nevertheless, the electrical characteristics of rocks and minerals are of interest for a number of practical purposes.

Until recently, the electrical properties of rocks were studied mainly in connection with the requirements of well logging. The resultant data, however, have much wider uses in geophysics. In addition, the electrical properties of rocks are now being used in mining; there are promising prospects for the use of electrophysical rock-breaking methods in mining. For this purpose, we shall need to know how the electrical properties of rocks and minerals vary with various factors—in particular, temperature and pressure.

In recent years there have been extensive developments of various types of electrical prospecting, including electrical sounding and electrical profiling with direct current, the method of telluric currents, the induction, radio-wave transmission and electromagnetic frequency-sounding methods, and the piezoelectric method for prospecting for quartz and pegmatite veins. The use of these methods demands a knowledge of various characteristics of sedimentary, metamorphic, and igneous rocks. É. I. Parkhomenko's book therefore contains chapters giving detailed discussions of the methods and results of investigations of electrical resistivity, dielectric constant, and dielectric loss in rocks and minerals.

Rocks and rock-forming minerals are quite varied and complex in their electrical properties. For example, their resistivities vary from 10^{-2} to 10^{16} ohm · cm. Most of them are dielectrics, but some are semiconductors. Their electrical properties depend on their chemical and mineral contents, genesis and petrographic characteristics, structure, texture, porosity, water content, etc. The first chapter therefore gives a short summary of the petrography of rocks. In addition, later chapters include sections on the electrical properties of dielectrics and semiconductors.

This is the first monograph ever devoted specifically to the electrical properties of rocks. Owing to the increasing practical uses now being made of the electrical properties of rocks in electrical methods for prospecting for minerals, as well as for other purposes in geophysics, geology and mining, this monograph is a timely production. É. I. Parkhomenko's systematization of the accumulated material will undoubtedly be beneficial to the further development of the subject.

In conclusion, the reader will find descriptions of the piezoelectric and seismo-electric effects and certain other electrical phenomena observed in rocks, including high-voltage and induced polarization.

Mikhail P. Volarovich
Director, Department of the
Physical Properties of Rocks
Institute of Physics of the Earth
Academy of Sciences of the USSR

ELECTRICAL PROPERTIES OF ROCKS

Contents

Chapter I

Brief Review of the Petrography of Rocks

The physical properties of a material cannot be studied independently of the structure and chemical composition of the material. Rocks commonly are very complex with respect to textural and chemical properties, consisting of multicomponent aggregates. The texture and composition of aggregates are of primary importance in determining physical properties. Therefore, before considering the reported values for electrical properties of rocks, it is necessary to review briefly the petrographic properties of various rocks. References [1-5] provide the best review of the general subject of petrography.

Mineral Composition of Rocks

Rocks are aggregates of mineral grains bound together by molecular interaction forces. Minerals which are chemical compounds and pure elements differ from one another in chemical composition, internal structure, and physical properties. The properties characterizing a mineral are: crystal form and grain habit, hardness, durability, ductility, cleavage, color, luster, and other secondary properties. The great majority of minerals have a crystal structure; that is, they have some orderly internal molecular structure. Some minerals occur in an amorphous form, as, for example, various forms of chert, volcanic glass, and so on.

At the present time, about 2000 minerals have been classified. Most of these minerals occur but rarely in nature, and only a few tens of these minerals are common rock constituents. These minerals determine the rock type and the rock name that they form; for example, the compounds of granite are feldspar, muscovite, and quartz.

It should be noted that one particular mineral may be essential in one rock type, and occur only as an accessory in another rock type. For example, quartz is an essential mineral in granite, but is an accessory mineral in gabbro. Sometimes, classification is made also on the basis of minor minerals, as, for example, fluorspar in granite or gneiss, galena in sandstone, sphalerite in limestone, topaz in liparite, and so on.

The classification of minerals is based on chemical composition.

Feldspar is the commonest rock-forming mineral group. Minerals in this group comprise about 60% of the earth's crust. The total number of feldspar minerals with different compositions is nearly 800. These are found largely in granite, syenite, diorite, gabbro, basalt, diabase, and so on.

After the aluminosilicates, quartz is the commonest mineral found in the earth's crust. It is the main constituent of quartzite and sandstone. Quartz is also found in large quantities in igneous rocks such as quartz porphyry, granite, granite porphyry, liparite, and so on, as well as in the metamorphic rock, gneiss. Quartz frequently occurs in fine-grained or coarsely crystalline form in veins penetrating other rock types. Iron magnesium silicates and carbonates are less abundant.

Rock may be classified as monomineralic (marble, labradorite, limestone) or as polymineralic (granite, gabbro, peridotite) depending on whether it contains one or more essential minerals. It should be noted that a monomineralic rock usually contains other minerals as accessories.

The mechanical properties of a rock are determined to a large degree by the properties of the minerals comprising the rock. However, the electrical and magnetic properties in a number of cases depend on the properties of accessory minerals; for example, the magnetic properties of basalt, diabase, and granite are determined by the presence of such minerals as magnetite, hematite, and pyrrhotite.

Basic Rock Types

Depending on their origin, rocks may be classified as igneous, sedimentary, or metamorphic.

The first type of rock is formed by the cooling of magma, or molten rock. If the cooling of the magma takes place slowly at great depths, the igneous rock is intrusive and has a coarsely crystalline form. Rocks solidifying at the surface or at shallow depths are termed extrusive. These typically are microcrystalline. Typical examples of such rocks are basalt, trachyte, andesite, and liparite. With very rapid cooling, the texture may be cryptocrystalline or amorphous, as in volcanic rocks.

Igneous rocks at the earth's surface break down as a result of various weathering processes (mechanical, thermal, and chemical) into fragments which differ in chemical composition. The mechanical deposition of these fragments leads to the formation of sedimentary rocks (sandstones). Sedimentary rocks may also be formed by precipitation of salts from solution (rock salt, gypsum). Such rocks are termed evaporites. Finally, shell fragments and debris from dead organisms accumulate into rock masses which are termed organic rocks (organic limestone, coal, oil).

The surface layers of the earth's crust usually are sedimentary rocks. The most common sedimentary rocks are shales, followed by sandstones and limestones.

Sedimentary rocks and extrusive igneous rocks may be submerged to great depths in the earth's crust by tectonic forces, where the temperature and pressure radically alter the properties of the rocks. Such altered rocks are termed metamorphic rocks. Intrusive igneous rocks may also be metamorphosed.

Depending on the degree of metamorphism, metamorphic rocks may be classified in the following series: gneiss, slate, quartzite, and marble.

All of these classes of rocks occur in the earth's crust, which extends to an average depth of 35 to 40 km under the continents, and to an average depth of 10 to 13 km under the oceans.

The greatest thickness of the crust in any region is 70 km. Usually the sequence of rock classes through progressively larger depths in the crust is sedimentary, metamorphic, igneous. It should be mentioned that at greater depths, basic and ultrabasic rocks become more important.

In addition to the classification of rocks on the basis of genesis, rocks are classified according to chemical and mineralogic composition, particularly the silica content. In such a classification, rocks are grouped as silicic, intermediate, basic, ultrabasic, and alkaline. The silicic rocks are rich in silica, usually occuring as quartz, and are represented by such types as granite, granodiorite, liparite, and quartz porphyry. In most rocks, all of the silica is found in combination (diorite, porphyrite, andesite, syenite-porphyry, and trachyte). Basic rocks are characterized by relatively small silica content. Examples of such rocks are gabbro, basalt, and pyroxenite. They contain 35 to 40% silica in chemical combination. The alkaline rocks include nepheline syenite, urthite, and others. Rocks in this group are characterized by a high content of alkaline metals.

Rock Structure

The basic structural characteristics of rocks are: (1) the degree of crystallization or crystallinity; (2) the size of individual crystals; (3) the grain habit; and (4) the interrelation between crystalline and glassy material.

The degree of crystallinity of rock is determined by the conditions under which it crystallized and the viscosity of the melt. If crystallization took place slowly at great depth, a rock consists entirely of well-formed mineral crystals. It has a crystalline grain structure. This type of structure is characteristic of granite, syenite, diorite, gabbro, peridotite, and so on. When a rock solidifies very quickly, it consists of glass (basalt glass, obsidian). Different varieties of basalt provide examples of a rock composed entirely of crystals or glass.

The relative size of individual grains defines two basic types of structures – microcrystalline and macrocrystalline. Grain diameters in a microcrystalline rock range from 0.001 to 0.1 mm. Macrocrystalline rocks are further divided into the following classes: fine-grained, medium-grained, large-grained, and coarse-grained. A fine-grained rock is considered to be one in which the grain size is less than 1 mm. If the grain size falls in the range 1 to 5 mm, the rock is termed medium-grained. A large-grained rock has grain sizes in the range 5 to 10 mm. Coarse-grained rocks have still larger grain diameters. Depending on whether or not the grain sizes are all about the same, a rock may be termed uniformly grained or porphyrytic. A uniformly grained rock is one in which the principal minerals all have about the same grain size.

When there are several distinctly different grain sizes in a rock, it is termed nonuniformly grained. There are two possible variants of such rocks, depending on the relationship between grains of various sizes. The larger crystals may be imbedded in a ground mass consisting of medium- or fine-grained rock or glass. This type of structure is called a porphyry. The opposite to a porphyry structure is a poikilitic structure, in which the finer-grained minerals are distributed between the larger-grained minerals.

Grain sizes and their interrelations have a significant effect on the physical properties of a rock and, therefore, they are a very important structural characteristic.

Another characteristic of structure which should be considered is the crystal form, which is determined by the dimensions of a grain in three directions. An isometric crystal is one which has about equal dimensions in three orthogonal directions. Crystals which are well-developed in only two directions may be platy or flat-faced (mica or some forms of feldspar). Crystals which develop principally along one direction are termed prismatic (amphibole or apatite) or needlelike.

With any of these structures, the individual grains may be arranged randomly and chaotically, so that the resultant rock appears to be isotropic.

Rock Texture

In addition to the rocks which lack any orderly arrangement of mineral grains, there are many rocks in which the grains exhibit some preferred orientation. This orientation of grains constitutes the texture of a rock.