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Applied Geothermics

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Summary

This book describes the origin and characteristics of the Earth's thermal field, thermal flow propagation, and some thermal phenomena in the Earth. Description of thermal properties of rocks and methods of thermal field measurements in boreholes, underground, at near-surface conditions enables to understand the principles of temperature field acquisition and geothermal model development. Processing and interpretation of geothermal data are shown on numerous field examples from different regions of the world. The book warps, for instance, such fields as analysis of thermal regime of the Earth's crust, evolution and thermodynamic conditions of the magma-ocean and early Earth atmosphere, thermal properties of permafrost, thermal waters, geysers and mud volcanoes, methods of Curie discontinuity construction, quantitative interpretation of thermal anomalies, examination of some nonlinear effects, and integration of geothermal data with other geophysical methods.

This book is intended for students and researchers in the field of Earth Sciences and Environment studying thermal processes in the Earth and in the subsurface. It will be useful for specialists applying thermal field analysis in petroleum, water and ore geophysics, environmental and ecological studies, archaeological prospection, and climate of the past.

Introduction

Geothermics is an area of geophysics that studies the thermal state and history of the interior of the Earth. Solar heat penetrates only into the topmost layers of the Earth's crust. Diurnal soil temperature variations extend to a depth of 1.2–1.5 m; annual variations, to 10–20 m. The heat associated with solar radiation does not penetrate further, although a regular increase in temperature with increasing depth has been established, indicating the existence of sources of heat inside the Earth. Heat flows continuously from the depths to the surface of the Earth and is scattered into surrounding space. The density of the heat flow is given by the product of the geothermal gradient and the coefficient of thermal conductivity. A considerable part of the heat flow is radiogenic heat—that is, heat involved in the breakdown of radioactive elements present in the Earth.

The temperature of the Earth's interior within the boundaries of dry land is determined directly in shafts and boreholes by means of electric thermometers. Instruments for recording the thermal gradient are used for measurements on the ocean floor. Laboratory measurements are made to determine the thermal conductivity of rocks, and show that the change in temperature with depth at various places varies from 0.006 to 0.15 °/m. The density of heat flow is more constant and is closely connected with the tectonic structure. Very rarely does it extend beyond the limits of 0.025–0.1 W/m^2; individual values attain 0.3 W/m^2. Precambrian crystalline shields are characterized by low values (up to 0.04 W/m^2); platforms, by medium values (0.05–0.06 W/m^2); and technically active regions (midocean ridges, rifts, and regions of modern orogenesis), by high values (0.07–0.1 W/m^2). On average, oceans and continents yield the same values; about 0.05 W/m^2; however, this figure is not very reliable, since most of the Earth's surface has not yet been examined.

The Earth's temperature may be measured directly to a depth of only a few kilometers. Below that, the temperature is estimated indirectly from the temperature of volcanic lavas and from certain geophysical data. At depths of over 400 km, only probable temperature limits can be obtained.

The energy of the total heat flow coming from the Earth is about 2.5×10^{13} W, which is about 30 times greater than that of all the electric power stations in the world but 4,000 times less than the amount of heat the Earth receives from the Sun. Consequently, the heat coming from the Earth's interior does not affect the regional climate.

An explanation of the Earth's thermal history requires data about the original content of radioactive material of the various shells of the Earth, their shifts from one geosphere to another, energies and rates of decomposition, the Earth's age, the amount of heat received by the planet during its formation, and the amount of heat involved and absorbed in the various mechanical, physical, and chemical processes in the Earth's interior. The coefficients of thermal conductivity, the specific heat of the material of the interior, and the temperature and pressure at various depths and on the Earth's surface should also be taken into account.

Geothermic research is of great theoretical significance for various types of Earth studies. Its role is particularly important in constructing and evaluating tectonic hypotheses. For example, geothermic data contradict the thermal contraction hypothesis and other hypotheses that postulate that the Earth's heat loss is much greater than the observed values. Geothermic measurements are also used practically; they assist in prospecting for oil and minerals and in preparation for using the Earth's heat for industrial and domestic purposes.

The purpose of this book is to present methods of utilizing the data of temperature surveys in deep boreholes as well as the results of field, laboratory, and analytical investigations in geothermics in a clear and concise form to environment science engineers, petroleum reservoir and drilling/production engineers, geophysicists, and geologists. Although some aspects of this book have been discussed in a number of monographs including Lubimova 1968b; Kappelmeyer and Hänel 1974; Cheremensky 1977; Gretener 1981; Jessop 1990; Somerton 1992; Kutasov 1999; Beardsmore and Cull 2001 among others and numerous papers, no comprehensive monographs are available to Earth scientists/petroleum engineers. This volume also incorporates the main results of publications by the authors in the last 20 years.

It is obvious that many geothermal problems (propagation of thermal waves in complex media, glaciation cycles, dangerous geodynamic events at a depth, etc.) are nonlinear. Therefore, some attention has been paid to the possible ways of solving these problems.

The objective of this book is to present the state of the art and predictions of downhole and formation temperatures during well drilling, well completion, shut-in, and production. Our intent is to reach drilling engineers (impact of elevated temperatures on well drilling and completion technology, arctic drilling); production engineers (temperature regime of production, injection, geothermal wells, and arctic production); reservoir engineers (temperature field of reservoirs, thermal properties of formations and formation fluids); well logging engineers (interpretation of electrical resistance, mud density, and temperature logs); geophysicists and geologists (interpretation of geophysical data, calculation of the terrestrial heat flow, reconstruction of the past climate). The authors also hope that this volume can be used as a textbook for senior and graduate geologists, geophysics, environmental as well as petroleum engineering students.

The potential applications of the data presented in this book are listed below.

Well drilling and oil/gas production: (1) Prediction and control of downhole mud properties; (2) Designing deep well cementing programs; (3) Evaluation of thermal stresses in casings and around borehole formations; (4) Logging tool design and log interpretation; (5) Determination of the physical properties of reservoir fluids; (6) Prediction of permafrost thaw and refreezing around the wellbore; (7) Determination of the gas hydrate prone zone; (8) Hole enlargement control in permafrost areas; and (9) Well planning in arctic areas (determination of the surface casing shoe depth, selection of low-temperature cements, design of safe casing strings to avoid pipes buckling during the freezeback).

This book will be useful for geophysicists interested in: (1) Searching hydrocarbon, ore and other economic deposits by the use of thermal methods; (2) Calculation of the terrestrial heat flow; (3) Extrapolation of temperatures to greater depths in the crust and the upper mantle; (4) Determination of the dynamics of the permafrost zone by comparing the values of heat flow in the frozen and unfrozen zones; (5) Forecasting of possible dangerous geodynamic events at a depth by the use of thermal monitoring in subsurface and deep wells; and (6) Integrated analysis of thermal and other geophysical fields.

This book will be useful for geologists interested in: (1) Calculation of the regional heat flow for various tectonic structures; (2) Preparation of regional temperature gradient maps; (3) Evaluation of geothermal energy resources; (4) Evaluation of the rates of erosion and sedimentation from temperature profiles; and (5) Studying underground water movement using the difference in vertical heat in water recharge and discharge areas.

This book will be useful for experts in geodynamics and tectonics interested in: (1) Formation and evolution of the magma-ocean; (2) Early Earth atmosphere; (3) Dynamic interactions of the asthenosphere and lithosphere; and (4) Interrelationship between the thermal regime and tectonic processes.

This book will be useful for specialists in environmental sciences interested in: (1) Reconstruction of the past climate from the temperature profiles; (2) Localization of archaeological targets by near-surface temperature survey; (3) Revealing karst terranes and other dangerous environmental features by temperature field analysis; and (4) Computation of water flow geodynamics in stratified liquids.

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