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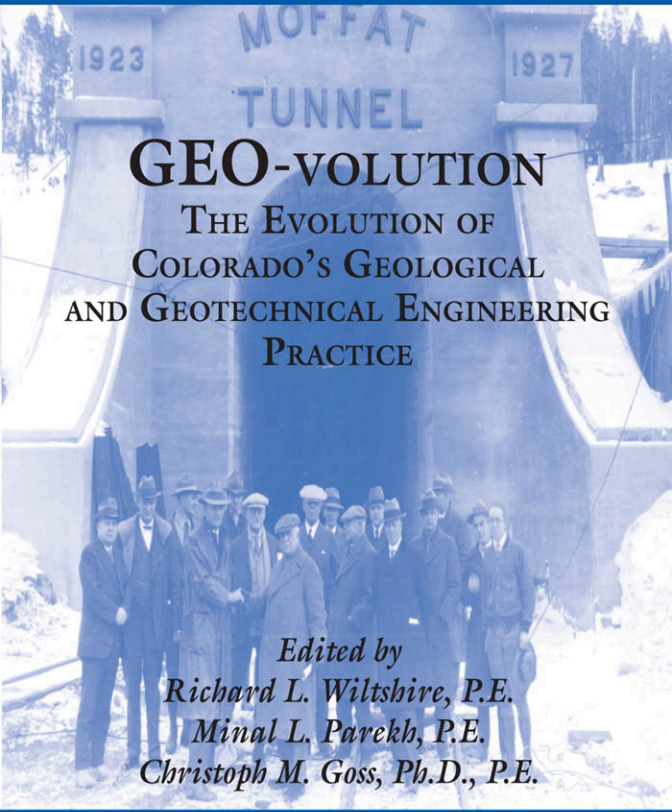

GEO-VOLUTION

THE EVOLUTION OF COLORADO'S GEOLOGICAL AND GEOTECHNICAL ENGINEERING PRACTICE

Edited by
Richard L. Wiltshire, P.E.
Minal L. Parekh, P.E.
Christoph M. Goss, Ph.D., P.E.

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PROCEEDINGS OF THE 2006 BIENNIAL GEOTECHNICAL SEMINAR

November 10, 2006
Denver, Colorado

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Preface

A civil engineering historian would suggest that geotechnical and geological engineering in Colorado began about 1,250 years ago, during the development of the first of Mesa Verde's prehistoric reservoirs. The theme for the 2006 Biennial Geotechnical Seminar is "GEO-volution: The Evolution of Colorado's Geological and Geotechnical Engineering Practice." The theme was chosen to focus on Colorado's storied past, the difficult engineering challenges overcome by its early population, the current state of local geotechnical and geological engineering practice, and ideas that will carry our practice into the future. The seminar papers presented in this publication provide perspectives on Colorado's unique geology, on geotechnical and geological engineering for the challenging ground conditions present in Colorado, on emerging trends in the local engineering practice, and on current solutions to Colorado's diverse geo-problems.

Since 1984, the Geotechnical Group of ASCE's Colorado Section has organized a biennial series of seminars, in collaboration with the Rocky Mountain Section of the Association of Environmental and Engineering Geologists and the Colorado Association of Geotechnical Engineers. The seminars have been attended by as many as 270 civil/geotechnical engineers, engineering geologists, geologists, and other geo-professionals in the Colorado region. The seminars have been held at area universities or hotels and offer the opportunity for sharing ideas and experiences among Colorado's diverse geo-disciplines. We look forward to participating in Geo-Denver 2007.

The GEO-volution Steering Committee has been working to organize the 2006 Biennial Geotechnical Seminar and this accompanying publication since February 2005. The Steering Committee members included Lois Boxill, Mark Brooks, Tom Chapel, Dr. Christoph Goss, Tom Holben, Leslie Jansen, Dr. Bill McCarron, Minal Parekh, Rebecca Roland, Mark Vessely, Chris Wienecke, and Richard Wiltshire.

Richard L. Wiltshire, Minal L. Parekh, and Christoph M. Goss

Acknowledgments

The GEO-volution Steering Committee wishes to thank all of the authors and reviewers of the papers presented herein as Geotechnical Practice Publication No. 4. The authors have spent many hours preparing and revising the papers which will be presented at the 2006 Biennial Colorado Geotechnical Seminar on November 10, 2006. These papers have been reviewed by geo-professionals in the Denver area who volunteered their time in order to improve the quality of this publication as a representation of our local practice. Their thoughtful and timely reviews are greatly appreciated. The GEO-volution Steering Committee also thanks the Geo-Institute's Committee on Technical Publications for working within the constraints of our schedule. Thanks also to Donna Dickert of ASCE's Book Production Department for her assistance in the production of this publication.

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Geology of Colorado and Major Prehistoric Events

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Abstract

Colorado embraces five physiographic provinces, which include the Great Plains, Southern Rocky Mountains, Middle Rocky Mountains, the Wyoming Basin, and the Colorado Plateau. All three major rock types--igneous, sedimentary, and metamorphic-- are widely spread throughout the state. Most of the major structural features, including mountain uplifts and intervening basins, developed during the Laramide Orogeny about 50 to 70 m.y. ago. Colorado is dominated by the Southern Rocky Mountains which include 14 mountain ranges. Most of these ranges are cored by Precambrian igneous and metamorphic rocks with sections of Paleozoic rocks exposed along their flanks.

Structural basins, filled largely with Tertiary clastic rocks, are downwarped features that include North, Middle, and South Park; Raton Basin; Wyoming Basin; Peceance Basin; and the San Juan Basin. During the following Tertiary period, about 40 to 25 m.y. ago, the crust was subjected to major east-west extension, forming the Rio Grande Rift Zone now occupied by the Arkansas River Valley and the San Luis Valley.

Plateaus are found in the western part of the state, and include the Roan and White River Plateaus north of the Colorado River, and the Grand and Uncompahgre Plateaus south of the river. These features are underlain by Tertiary sedimentary rocks, with volcanic rocks locally.

The major historical events that have affected the geologic framework of Colorado include the Laramide Orogeny and the KT Boundary mass extinction. During the close of the Cretaceous Period, the Laramide Orogeny affected the western Cordillera from Alaska to Argentina. In Colorado the movement of mountain blocks was largely vertical, as in the Front Range and elsewhere.

One of the greatest mass extinctions on Earth occurred at the Cretaceous-Tertiary (KT) Boundary, 65 m.y. ago. This boundary is marked by the worldwide occurrence of a 1-cm-thick layer of clay containing anomalous amounts of iridium. At least half the genera living at the time perished, and according to the Alvarez theory, the mass extinction resulted from the impact of a giant asteroid that struck the Yucatan Peninsula, leaving a crater 186 km (110 mi) in diameter.

Introduction

The purpose of this paper is to describe the basic geologic framework for the state of Colorado. In doing so, I will start with the major physiographic provinces, discuss the origin of fundamental rock types, and then proceed to a discussion of the distribution of major rock types and structures.

Physiography

Colorado embraces five physiographic provinces (Figure 1). These include the Great Plains, Southern Rocky Mountains, Middle Rocky Mountains, the Wyoming Basin, and the Colorado Plateau. The Southern Rocky Mountains dominate the central part of the state, and include 14 mountain ranges. The Colorado Plateau underlies the southwestern corner of the state and is composed of flat-lying sedimentary rocks of Paleozoic and Mesozoic age. The Great Plains includes the High Plains of the eastern border, the Colorado Piedmont, and the northern extension of the Raton Basin. The Middle Rocky Mountain Province occupies the northwest corner, and is featured by the Uinta Mountains.

Distribution of Rock Types

Most of the major structural features, including mountain uplifts and intervening basins, developed during the Laramide Orogeny about 50 to 70 m.y. ago. The eastern half of Colorado, not discussed in this presentation, is dominated by the Denver Basin, a major source of petroleum.

Before discussing the distribution of the major rock types, it may be helpful to briefly review how rocks form. You will recall that the Earth's crust is composed of three major rock types: igneous, sedimentary, and metamorphic (Figure 2). Igneous rocks are those that solidify from molten material called magma. When magma cools and solidifies, it forms a wide variety of igneous rocks. Depending upon on the mineralogy and texture of the rock, geologists classify the rock as granite, gabbro, basalt, rhyolite, etc. A coarse-grained igneous rock with feldspar and quartz is called granite, and a coarse-grained igneous rock with calcic plagioclase feldspar and dark-colored accessory minerals is named gabbro. Basalt, the main volcanic rock forming the ocean basins, is the extrusive equivalent of gabbro—black and fine grained, because it cooled rapidly on the surface.

Sedimentary rocks are those that form on the Earth's surface from the weathering and erosion of preexisting rocks. They typically are deposited as sediments in shallow marine water. The sediments are later buried and cemented to form solid rock. They are classified as clastic or chemical. Clastic rocks, such as sandstone, siltstone, and conglomerate, are those that feature mineral grains that are cemented together. Chemical rocks are those that are precipitated from salt or fresh water, and include limestone, rock salt, and gypsum. Coal is also a sedimentary rock, but does not fit into the regular classification, as such, consisting of decomposed plant remains.

Metamorphic rocks are those that have recrystallized from pre-existing rocks, under conditions of elevated temperature and pressure. Under deep burial, temperatures and pressures are elevated, and a sedimentary rock, like shale, is unstable. Therefore, the clay minerals in this shale undergo a change, or metamorphism, whereby, the clay is recrystallized in the solid state to form new minerals of the mica group. The resulting metamorphic rock, called a mica schist, consists of new mineralogy and usually coarser grain size, with oriented mica grains. A fine-grained carbonate rock, like limestone, however, is recrystallized to form marble, consisting of coarse-grained calcite.

Southern Rocky Mountains

There are 14 mountain ranges in Colorado which make up the Southern Rocky Mountain Province. These include the Front Range, Park Range, Gore Range, Rabbit Ears Range, Ten Mile Range, Williams Fork Mountains, Mosquito Range, Sangre de Cristo Range, Wet Mountains, Spanish Peaks, Sawatch Range, San Juan Mountains, Elk Mountains, and West Elk Mountains.

Front Range

The Front Range, extending from Canon City northward into Wyoming where it is known as the Laramie Range, forms the eastern boundary of the Southern Rocky Mountains. It is composed mostly of Precambrian gneiss and other metamorphic rocks that have been intruded by several batholiths of granite. The largest of the batholiths is the Pikes Peak Batholith, which is exposed over an area of 3,400 km^2 (1,300 mi^2) and extends from Pikes Peak north to Conifer.

The range is bordered by steep reverse faults. On the east side, the Golden Fault west of Denver dips about 70 degrees west beneath the range, and has a vertical displacement of about 3,048 m (10,000 ft) near Morrison. Last movement on this fault zone occurred about 500,000 years ago. West of Colorado Springs, segments of this border fault include the Rampart and Ute Pass Faults.

Rocky Mountain National Park is located west of Estes Park, in the northern part of the Front Range. The popular park is carved deeply into Precambrian granites and gneisses. Trail Ridge Road, the highest paved road in North America, climbs westward over the Continental Divide, providing spectacular views of geology across