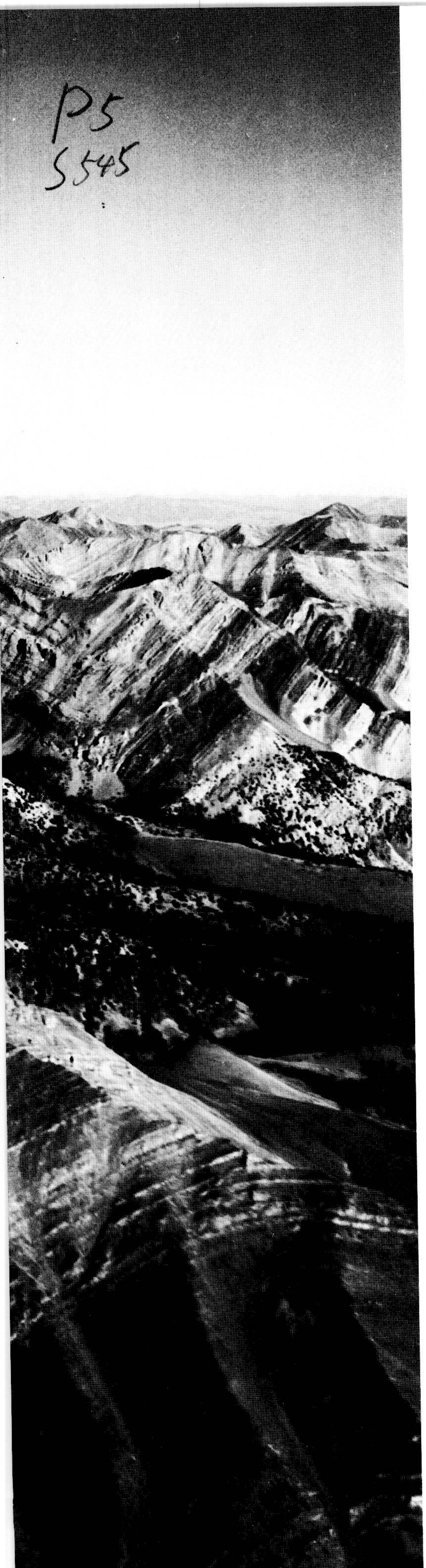
Geology Illustrated



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Geology Illustrated

Drawings by HAL SHELTON

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Preface

This book is addressed to thoughtful and observant people who enjoy the outdoors: especially to those with some curiosity about the origins and meanings of familiar rocks and landscapes. It presupposes no particular acquaintance with science and will, I hope, be intelligible to readers of many different ages and backgrounds.

Most elementary geological truths are best discovered and explored where geology is—in the field—while looking at the evidence. On the pages that follow we take a step toward this ideal by using photographs of localities that might be visited and, so far as practicable, treating these scenes as prime sources of information. No photograph can replace reality, but what is lost is partly offset by the freedom to examine areas that would be out of reach in any reasonable program of field trips.

The photographs are arranged in sequences that develop, through this observational approach, some of the main principles of geology. The majority of the illustrations are drawn from the American West and Southwest both because many geological features are grandly displayed there, relatively unobscured by vegetation, and because this is the region I know best.

As a means of communicating geological concepts, the pictures are fully as important as the words that accompany them. On most pages the photographs represent the facts, the words supply the interpretation. Many of the illustrations will, therefore, repay a little of the kind of attention that would be accorded the real feature in the field. In keeping with this, almost no identifying marks have been placed on the photographs and very few on the drawings. The text (which almost invariably concerns an illustration on the same or a facing page) serves as an expanded legend for the picture; if, while reading it, it is necessary to look more than once to identify some feature with certainty, this is no more than Nature asks of those who contemplate her unlabelled cliffs and hills.

Many of the scenes include examples of geological features or processes other than the one discussed in the text adjacent to them. The index will assist the reader in making fuller use of these examples; under each entry, such as *alluvial fan* or *erosion*, are listed all the figures in which these features or processes may profitably be recognized, whether or not they are mentioned in the accompanying discussion.

Most of what might be considered conventional textbook style and arrangement has been deliberately avoided. There are no summaries or review questions, and few suggested readings. Definitions are woven into the text rather than set apart as phrases to be memorized. The six major parts into which the book has been divided constitute a somewhat unconventional approach that cuts across the customary divisions of physical and historical geology. Yet step by step, largely through examples, the book develops most of the concepts that lie near the heart of traditional geology.

I am more interested in engaging the reader in the quest for better understanding of earth's record in rock than in setting forth the achievements of geology. Accordingly, the geological interpretations outlined herein are presented more as samples of method than as *faits accomplis;* indeed, if the contents of this volume should lead anyone to formulate different explanations, as good or better than those offered here, I would count the book a real success.

As a teaching aid, the book is a point of departure rather than something to lean on. I would urge that wherever possible, teachers and readers expand and supplement the topics introduced here through field trips and analysis of whatever local geology is accessible to them. We learn best from what is real, and teach best from what we know through firsthand experience.

A word about units of measurement: At present the majority of us who live in English-speaking countries prefer to use inches, feet, miles, pounds, and degrees Fahrenheit, although nearly all of our scientists have adopted the metric system and the Centigrade (or, more properly, Celsius) scale of temperature. Recent events indicate that we are almost surely entering a transition period during which most of us will need to be familiar with both systems and no choice of units will please everybody. In writing for a general audience at this time it seems reactionary to ignore the metric system and presumptuous to adopt it completely. My conservative compromise between good communication and good sense has been to use millimeters and Centigrade but keep inches, feet, miles, pounds, and tons, instead of adopting centimeters, meters, kilometers, grams, and kilograms. Simple devices for quick estimation of equivalents will be found at the back of the book, just preceding the index.

It is not often that a geologist and artist can work closely with each other, unhurriedly probing, comparing, and blending their sometimes very different insights about the same scene. The drawings in this book are the product of such a joint effort, during which my brother and I found increased respect for each other's discipline and pleasure in this opportunity to create together. Except as otherwise credited in the legends, the photographs are my own.

Inevitably the author of a work of this kind draws heavily upon the current pool of knowledge in its field. I am acutely aware that I have done this, both consciously and unconsciously, and that I am indebted to many indirect contributors. Specifically, I acknowledge generous assistance on individual subjects from Raymond M. Alf, Edward C. Beaumont, C. Wayne Burnham, Doak C. Cox, J. S. Creager, Bruno D'Argenio, Joseph Ernst, J. H. Feth, Carl Fries, Jr., Mason L. Hill, Carl L. Hubbs, Charles B. Hunt, Douglas L. Inman, Richard H. Jahns, Vincent C. Kelley, Robert L. Kovach, Chester R. Longwell, J. Hoover Mackin, John H. Maxson, Richard Merriam, Jack C. Miller, Thane H. McCulloh, Donald B. McIntyre, Edwin D. McKee, Berlen C. Moneymaker, George E. Neff, Carleton H. Nelson, Antonio Parascandola, Robert P. Sharp, Eugene M. Shoemaker, L. T. Silver, and J. W. Wilt.

Helpful correspondence and discussions have been conducted with John H. Aldrich, Clarence R. Allen, Charles A. Anderson, William S. Cooper, Wakefield Dort, Jr., Richard F. Flint, George M. Stanley, William D. Thornbury, and C. A. Whitten.

Special thanks are due Robert Frampton and Paul Ulmer, upon whose darkroom wizardry I have leaned heavily, and Joan Kemp, who patiently and skillfully adapted her fine calligraphy to a number of special needs. Mrs. Ruth Douglas typed the manuscript with meticulous skill.

Parts of the manuscript have been read and helpfully commented upon by members of my family and by Frederic W. Dundas, Chester R. Longwell, Howard E. Norris, and Robert M. Walker and family.

Most of all, I am indebted to Professor Alfred O. Woodford, who as teacher, colleague, and friend has supplied inspiration and encouragement during more than thirty years of stimulating and happy association, and to Chester R. Longwell for memorable times in both classroom and field and for generous permission to include some unpublished data.

The ideas expressed on the pages that follow do not necessarily have the approval of all these good people; any weaknesses and errors reflect my ignorance and stubbornness in the face of good counsel.

Claremont, California
December, 1965

Introduction

Geology is the science of the earth. It is based primarily on the study of rocks exposed at the earth's surface and is therefore an outdoor science in the sense that most of its fundamental data must be gathered in the open and most of the information acquired in the laboratory must ultimately be evaluated in the field.

But a major goal of geology is knowledge of conditions, relations, processes, and events that in large part cannot be directly observed, either because they are out of sight beneath the earth's surface or because they belong to times that predate human history. Much of geology is therefore concerned with indirect evidence and with working out possible combinations of processes and events which, taking place in and on the crust during past eons of time, might reasonably have produced the present scene. In short, geology probes downward to depths far below what we can see and backward to times long before there was anyone to look.

Speculation about what is out of sight underfoot must be as old as thinking man; it certainly is a principal part of the motivation of geologists, all of whom have continuing interest in such questions as: What is the earth's crust? How thick is it? What lies beneath it? What causes such phenomena as volcanism and earthquakes that occur within it? Furthermore, what is out of sight underfoot is often of considerable economic importance. Modern geology was hardly fifty years old when, in 1856, R. A. C. Godwin-Austen predicted that coal could be found in the Weald lowlands, southeast of London, more than a hundred miles from the nearest place where coal was visible at the surface. Such a notion must have seemed almost incredible to most of his contemporaries, but his reasoning was beautiful in its simplicity; he knew the sequence and thickness of the layers overlying the coal north and west of London and recognized that they were also present, very gently domed, in the Weald. If coal occurred beneath them in one place, it was probable that it also did in another. In 1890 a borehole proved him correct and a mine was established there. Today our industrial civilization depends in part on the ability of trained geologists to predict where such hidden wealth as petroleum and uranium and nearly all the ores that sustain the machine age can be found. The examples and analyses on the pages that follow should lead to increased understanding of the relations between what we see at the surface and what lies beneath.

The unending effort to reconstruct conditions of the distant past that is such an important part of geological research may also have economic as well as scientific value. For example, the search for uranium deposits in the Colorado Plateaus region in the late 1940's developed into a problem in reconstructing the details not only of the paths but even the flow-patterns of rivers that existed about 150 million years ago—because the patterns of sand they deposited had obviously been factors that influenced the localization of the ore. Much of the world's petroleum is associated with shallow-water marine sediments whose delineation involves the location of ancient shorelines now deeply buried under younger deposits. The more accurately the position of these ancient features can be determined, the more effectively the uranium and oil can be located and recovered.

Very often, however, the geologist is driven by plain curiosity. How old are the various rocks of the earth's crust? If they are continuously disintegrating in high places and being washed down to low places, why are there any mountains left? Where and how are rocks like granite produced? What keeps rivers flowing during long seasons of no rain? How do we know there was an Ice Age? Have the continents always had their present sizes, shapes, and positions? Can we accurately locate prehistoric mountains and seas? What was happening in Pennsylvania when any particular layer in the Grand Canyon was being deposited? Indeed, the same curiosity can be aroused simply by pausing over the view from any hilltop and asking: Has it *always* looked like this?

The geological answer will always be no, and the logical next question, What *was* it like?, can be asked again and again for the successive chapters of earth history in any given place. Numerous examples of how the search for the answers to this question is conducted will be found throughout this book.

The quest for knowledge about what is out of sight underfoot and backward in time begins with what we can see now. We must reason from what we observe in the present to what we postulate at depth or in the past. This kind of extrapolation, so often dramatized in detective stories, is one of the main sinews of science. Geology provides a rich field for the exercise of this technique. Much of the language it uses is relatively nontechnical. The starting points, the observable data, are relatively easy to grasp. Many good questions can be asked without special knowledge of facts and processes. What was the geography west of Rapid City, South Dakota, before the Black Hills came into existence—or have they always been there? Possible answers readily come to mind as visions of deserts, volcanoes, plains, tropical forests, an ice cap, or a shallow sea. Most people will have less difficulty examining these critically, and deducing the consequences of each, than they would in formulating and choosing among alternative explanations for the properties of electricity, or the atom, or the role of catalysts in chemical reactions. In geology most investigations begin with visible things known by relatively familiar names.

This book will have fulfilled its purpose if it helps anyone to visualize what lies below the earth's surface, and understand some of the changes that have occurred over the vast reaches of geologic time. To discover this added meaning in the land we live on is to attain *geological insight.*

CONTENTS

Part III. Sculpture

I Materials

A brief look at the rocks that compose the accessible part of the earth's crust.

1 A FIRST LOOK

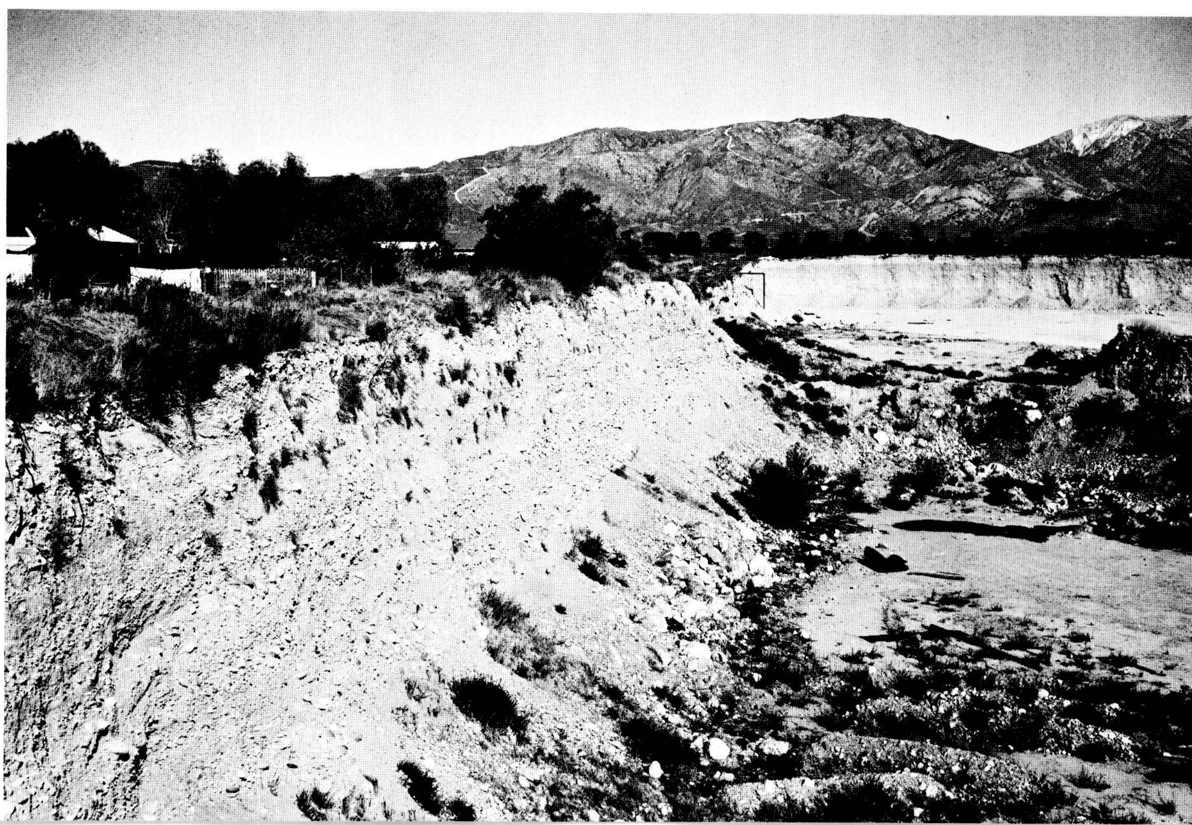
Beneath the Surface

Upon returning home from a long journey we often comment about how good it feels to be on familiar ground again. Yet for most of us this familiarity is at best skin deep. We know the shape of the land surface, the relative positions of many hills and valleys, cliffs and streams, highways and towns. But most of us know very little about what lies beneath these familiar features. Is our town built on old lava flows? River deposits? Glacial deposits? Marine deposits? An old lake bed? An old landslide? Granite? Each of these would mean a drastically different geological story embracing the events of the thousands, or millions, or even hundreds of millions of years, that are recorded in the rocks at and beneath the surface. How can we distinguish between these possibilities—or recognize still others?

A good first step would be to go out and look more closely at the familiar scene. In some areas we might see nothing but *soil*—loose tillable material derived principally from the decomposition of rocks. Except in regions of rugged topography, soil covers most of the land. But our main interest lies in what is underneath, and important though they are, soils conceal more than they reveal regarding the *bedrock*, the underlying solid rock that has not lost its structure and character through decomposition. Our quest leads, therefore, to *outcrops*—places where undisturbed bedrock shows through the blanket of soil or is exposed in stream banks, cliffs, road cuts, or excavations.

Suppose, for example, that our town is on fairly flat ground, a short distance from the base of steep mountains. On the outskirts is the large gravel pit whose walls are shown in the photographs below. There are other such pits between the town and the mountains. Exposed here are pebbles, cobbles, and boulders embedded in fine gravel and sand, the whole exhibiting a crude but unmistakable layering or *stratification*. Each pebble and larger piece is composed

Fig. 1. Wall of gravel pit just outside Claremont, California, looking north toward the San Gabriel Mountains in the background.



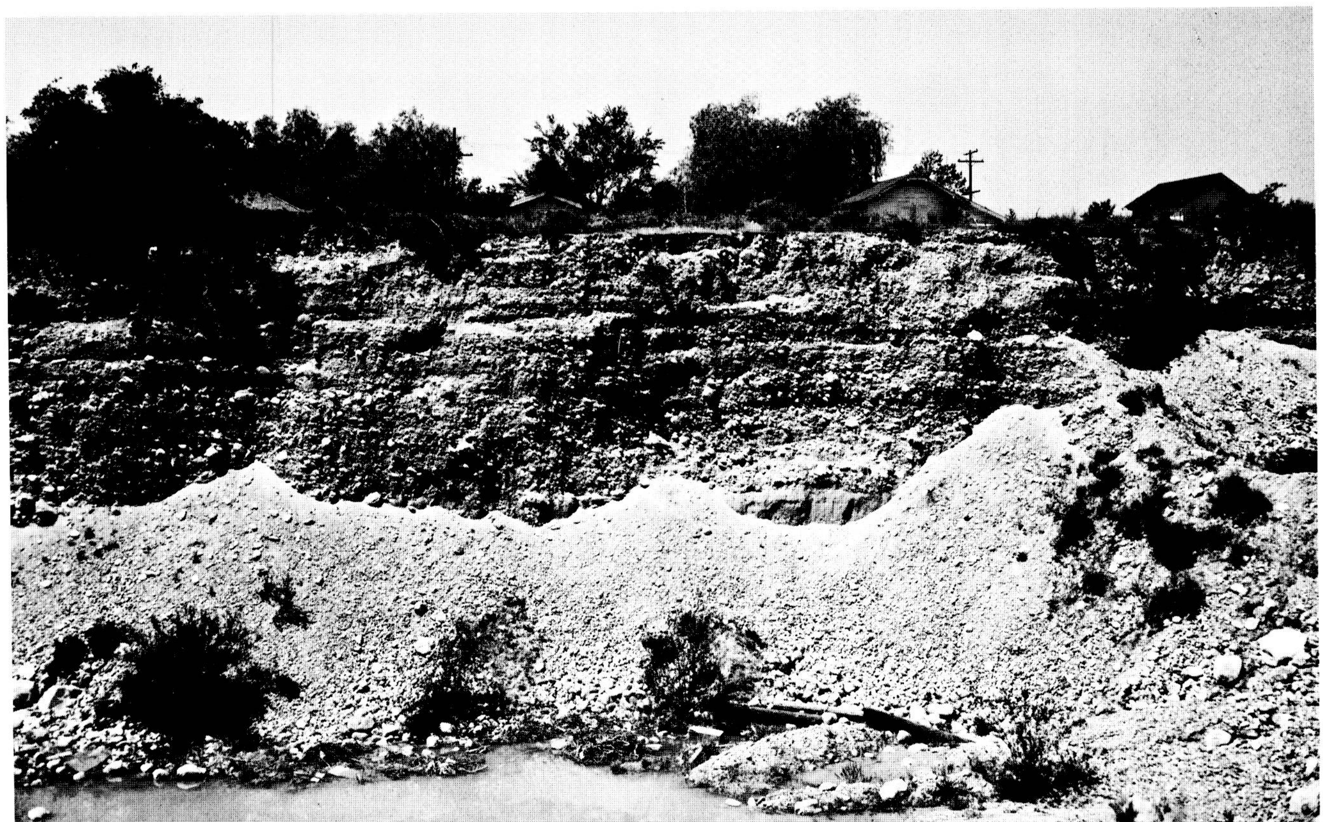
of hard rock, yet the edges and corners of all are smoothed and rounded, as though worn by abrasion. (See Figures 3 and 4 for a closer view.) Abrasion and wear indicate movement; how far have these rock fragments travelled? In what direction? Were they moved by waves, by streams, or in some other way? Where and what was their source? Why are the pebbles and cobbles in crude layers? Do the layers extend under the mountains, or lap up against them? Already the simplest observations have led us to a series of specific queries. Can such questions be answered? To find out we need more facts.

Every few decades heavy rains, sometimes aided by melting snow, create torrents in the mountain canyons that are visible in the background of Figure 1, a little more than two miles away. Flood waters pour out of the canyon mouths, carrying mud and sand and rolling cobbles and boulders from the canyons onto the adjacent flatter ground. As the flood subsides it leaves an irregular and thin deposit of this material. Historical records show that three or four such floods have occurred in the past 100 years. From Figures 1 and 2 it is clear that the surface of the ground, and therefore all such new layers, are exactly parallel to the stratification below. The ground surface and the gravel layers slope away from the mountains, at an angle of less than 2 degrees near the gravel pits, increasing to more than 3 degrees at the mountain front. The size and proportion of boulders also increases toward the mountains, both in the surface material and the layers in the pits.

It is highly improbable that the newest layers of gravel would so exactly parallel and resemble the material beneath them, and that both would be parallel to the present land surface, unless all were products of the same continuing process. Indeed, the most conspicuous variation in the walls of the pits is the change from fresh gray gravels near the top to rust-stained and slightly decomposed ones near the base—just what would be expected if they are progressively older downward.

For these reasons we will tentatively conclude that all of the visible gravels were washed out of the mountains, that the whole lowland region is underlain by gravel and sand, and that the top of each deeper gravel layer is a buried former land surface.

Fig. 2. Looking west at the gravel pit wall shown in the foreground of Figure 1. Loose material at the bottom has fallen from the pit wall.



Rocks Are Not All Alike

The tentative conclusion that all the gravels were washed out of the mountain canyons might be tested by comparing the transported cobbles with the available source rocks in the mountains. If the same kinds of rock occur in both places, and especially if there are some unusual varieties among them, the hypothesis would be greatly strengthened.

If we examine a few dozen stones we discover that there are many different kinds—in fact it is difficult to find two exactly alike. Looking even more closely, as in Figure 4, we see that all the differences of color and texture are caused by differences in the kinds and shapes of particles that make up each rock, and in the way these particles are arranged. The particles are mineral grains and the proportions of the different kinds constitute the mineral composition of the rock. Whether the grains are large or small or variable in size; rounded or irregular or geometric in shape; intergrown, cemented together, randomly distributed, or in a layered arrangement—these determine the *texture* of the rock. It is on the basis of these two fundamental attributes, mineral composition and texture, that almost all rocks are most reliably distinguished.

Among the varieties of rock shown in Figure 4, all of which (and more) are present in larger masses in the mountains, several are distinctive. One (marble, second from left in bottom row) is plentiful in several parts of the mountains but rare as pebbles because, being soft and somewhat soluble, it does not survive much travel. Several others are so rare that pieces could not be found where this picture was taken.

All the facts about the composition of the gravels are consistent with the hypothesis that they are deposits left by repeated outpourings from the mountains, and that the crude stratification reflects successive floods. But might the gravels not have been worked over and modified by the waves of an ancient sea? We know this is not true of those at the present surface, which is more than 1,000 feet above sea level. It is also highly unlikely for the deeper layers, both because they resemble the surface deposits and because a few fossil bones of land animals, but no marine shells, have been found in them. In short, these are land-laid or continental, rather than marine, sediments. Further, to answer the question raised on page 3, they could

Fig. 3. Closer view of the wall of the gravel pit shown in Figure 1: note sorting into layers, finer near the middle, coarser near the top and bottom.

not possibly extend under the mountains because they were derived from them.

But we have taken only the first step. Can it be assumed that these gravels have been accumulating ever since the earth was born? Probably not, for if they had, the mountains might well be eroded away by now. Using a little disciplined imagination, let us undo the one step we are sure of by putting all the pebbles back where they came from. This should more than fill the canyons in the mountains, but poses some new problems: What have we uncovered by removing the gravel deposit; what kind of basin floor was it laid on? (Information from deep wells might be helpful here.) And, to take a further step back in time, what is the origin of the mountains (that shed the stones that made the gravel that buried the floor and built the plain that provided the site for the town that we built)? This is a double problem, for we want to know not only what the mountains are composed of, but how they came to stand so high above their surroundings. If they are old volcanoes, we may solve both problems at once. But what if they are made of rocks that can be formed only on the sea floor, or only deep in the earth's crust?

To make even a small start toward answering these questions we must know how to recognize rocks of different origin. Then we can see whether this second major step back in the geologic history of the area will lead us to a time of volcanic activity, will require us so to reconstruct the geography that the sea could have occupied the region, or will force us to find a means of bringing to view a deeper part of the crust—to name but a few possibilities.

Naturally, the geologist must be able to tell one rock from another, just as the botanist must be able to distinguish different plants and the zoologist different animals. It is a basic skill at which he works all his life, improving with experience. But as the problem of the gravels demonstrates, the geologist's primary interest in rocks is their origin; he wants to know where and how they were originally produced, and how they arrived at the places where we find them. Fortunately, although there are many thousands of varieties of rocks and hundreds of rock names, there are only a few fundamentally different origins. It is far more useful to be able to recognize these origins than to be able to determine the specific name of a rock.

The next fifty pages are therefore devoted to exploring, by means of examples, the origins of some common types of rocks. In Parts II and III we will investigate some of the ways in which they are moved.

Fig. 4. A few pebbles and cobbles from the wall shown at the left, selected to illustrate variety in texture and composition.