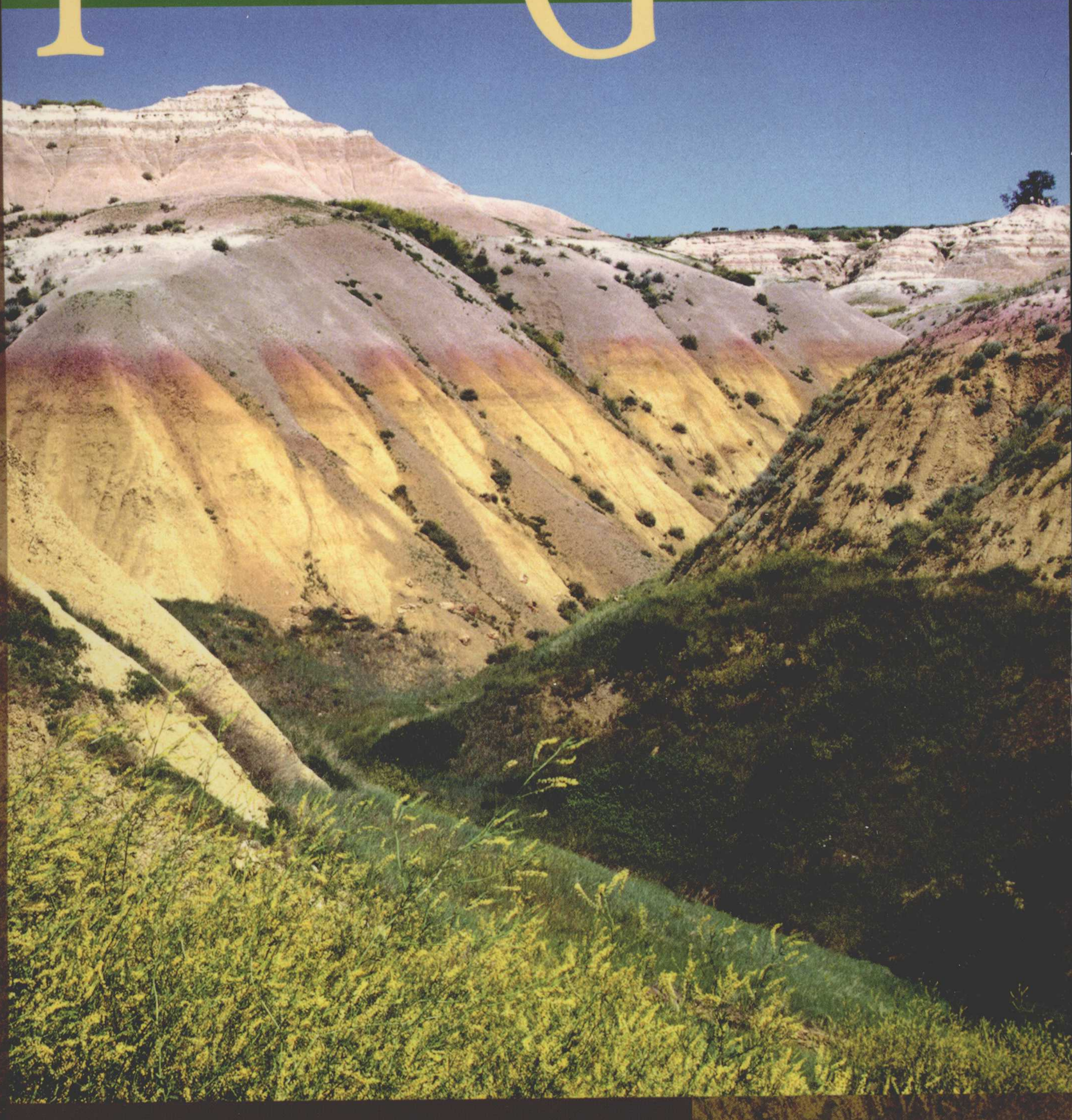
Laboratory Manual for

PHYSICAL GEOLOGY



Fifth Edition

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Laboratory Manual for Physical Geology

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Preface

To the Student

Geology and other sciences are major parts of our lives, and many of the daily decisions we make are affected in some way by science. Because of this, all educated people (scientists or not) should understand, in a general way, how science is done, and should be able to apply the basic ideas of the scientific method. Thus, a principal objective of this laboratory manual is to show you how geologists use the scientific method by having you do it yourselves. You will find that geologists, like other scientists, operate in a very logical and straightforward manner, which differs little from the way you normally do things. You will learn how to gather and use data (for example, making measurements to use in calculations), establish relations based on these data, classify information, develop and test hypotheses or models to explain observations and relations, and use this information to draw conclusions and make predictions. This may sound a bit intimidating, but don't panic; it's not difficult. You'll be surprised at what you'll be able to do.

Laboratory sessions will be most efficient if your **read the entire chapter before coming to class.** If allowed by the instructor, students may work in groups. In a group setting, it soon becomes apparent who has prepared and can contribute to the group. As a courtesy to others, and for your own benefit, *prepare for class!* Make sure you bring those things to class that are needed for the lab, as indicated in the **Materials Needed** section. Don't depend on your classmates.

You will find that geology is relevant to our daily lives. Look around you. Most of the manufactured items you see are made of earth materials—minerals, rocks, or petroleum. We live along rivers that flood, drink water pumped from underground, and dispose of our garbage in the ground. We and our politicians have to understand the consequences of our actions. So pay attention, ask questions, and learn to think critically about these geological issues. Make sure that science-related issues are based on good science; don't let charlatans determine our public policy.

To the Instructor

This lab manual is for a college-level, introductory course in physical geology. It is based on the following assumptions: (1) A typical student is a freshman or sophomore concurrently in a physical geology class. He or she has little background in science and math. The student may have had a unit on Earth science in seventh, eighth, or ninth grade, but most likely has had little or no exposure to geology. (2) The course has no prerequisites. (3) Although a few students taking the class plan to major in geology, and more will decide to major once they learn how interesting geology is, most students are taking the class to satisfy a general requirement and will not major in geology or other sciences.

Each chapter contains more exercises than your students may have time to do, so you will have to be selective as to which problems you assign. The sequence of topics is a traditional one, but the instructor is free to choose which topics to cover as well as the order in which they are covered. The text in each chapter is intentionally brief. It is meant to serve as background for the problems rather than a "complete" treatment of the subject. An Instructor's Manual is available as PDF and Word files on-line *(www.mhhe.com/jones5e)* and is accessible with a password obtained from the publisher. We strongly recommend you take a look at it.

The first edition of this manual, by NWJ, was the outgrowth of twenty-five years of teaching physical geology and using many different lab exercises. NWJ first wrote a physical geology lab manual in 1975 for use in these classes. That manual went through many revisions, and the first edition of this manual, though much more extensive than the original, benefitted much from the comments and criticism of the earlier manual offered by colleagues and students. The second and third editions are essentially refinements of the first edition, with one major exception: new problems based on resources available on the World Wide Web were added to all but one chapter.

With each new edition, we strive to increase clarity in both the text and problems. We also try to meet changing instructional needs by keeping both text and problems as current as is necessary. We are aided in this task by the very helpful comments and suggestions from our reviewers. If you find any errors in the manual or have suggestions for future im-

Prologue: Methods of Science

Science is a systematized body of knowledge derived mostly from observation and logical inference. The ultimate goal of scientists is to discover the basic principles that determine how things behave. Scientists have the following in mind as they work: (1) natural processes are orderly, consistent, and predictable; (2) there is a cause (or set of causes) for every effect; and (3) the best explanations are usually the simplest *(Doctrine of Simplicity or Parsimony).* Geologists and other scientists who study the past assume that physical and chemical laws, such as the law of gravity, are constant and have not varied over time *(Doctrine of Actualism).*

Scientific advances come in different ways. Some are based on theoretical ideas about things not yet observed (for example, Einstein's theory of relativity). Others result from unplanned, fortuitous events (such as the eruption of Mount St. Helens volcano). But most advances result from a painstaking approach known as the *scientific method.*

The **scientific method** generally involves: (1) formulation of a problem or question; (2) observation and measurement to determine characteristics or properties, to measure variation, classify, and establish relations—in other words, to get a basic understanding of the situation; (3) formulation of one or more explanations, models, or **hypotheses** to explain the observations; (4) experimentation and testing to reject or modify hypotheses; and (5) acceptance of a best hypothesis that withstands all tests and the scrutiny of peers as a **theory.**

The scientific method is *not* a rigid series of steps that must always be followed to do science. For example, most scientists already have a tentative hypothesis in mind when making observations. In fact, as philosopher Karl Popper said, successful scientists often are those with the best "imaginative preconception" of the correct hypothesis.

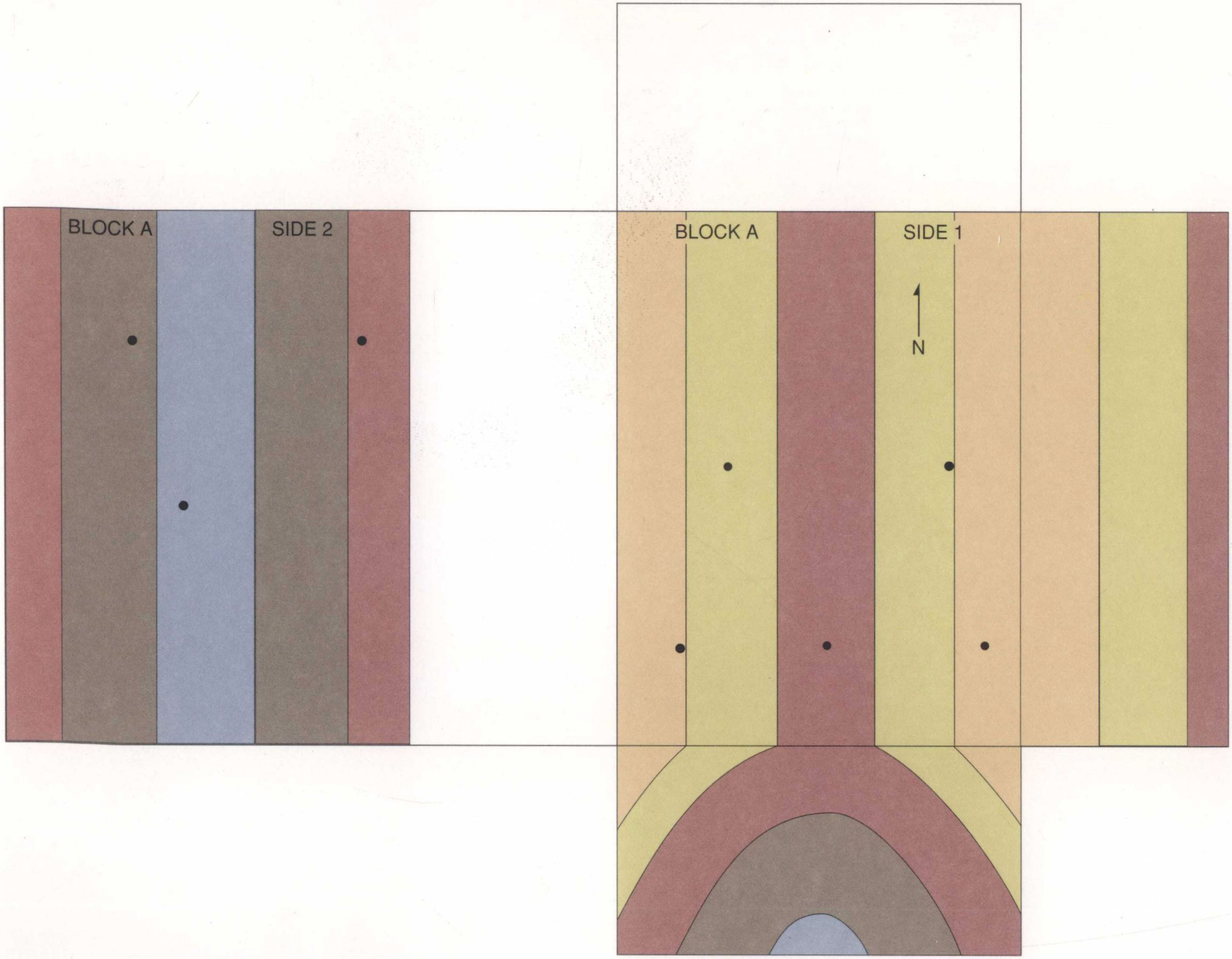
However, to avoid being blinded by such preconception, geologist T.C. Chamberlin recommended maintaining *multiple working hypotheses* until such time as they could be reduced to only one. With this approach, the scientific process involves rejecting those hypotheses that do not withstand testing and experimentation. Commonly, the simplest hypothesis that explains the most observations is the one that survives to become a theory. However, even though a theory is supported by a great deal of evidence and seems to explain all observations, it still is subject to testing, and eventually it may be rejected or modified as a result of new observations. Theories that withstand all testing and are invariable become **scientific laws;** an example is Newton's Law of Gravitation (the law of gravity).

The scientific method may seem rather involved, but it is an approach you probably use in many situations without realizing it. Take a very simple example. Let's say you go to geology lab one day and find nobody in the classroom. That *observation* should raise your curiosity. Why is no one there? Several possible explanations, or *hypotheses,* come to mind: (1) the professor is ill and the class was canceled; (2) no class was scheduled for that day; (3) you are there at the wrong time or the wrong day; (4) the class has gone on a field trip that you forgot; (5) the class is hiding in the room, ready to leap out and yell "Happy birthday"; or (6) everyone has been lifted magically from the room. As a good scientist and rational thinker, you rank them in order of which is the most likely, and quickly eliminate those that are impossible or too unlikely. The last one (6) is not testable and is out of the realm of science, because it calls on a supernatural phenomenon for an explanation. A quick check of the time and date allows you to eliminate number 3. It's not your birthday, so you forget about number 5. Three reasonable hypotheses remain to be tested.

One way to test a hypothesis is to assume it is true, make a prediction based on that assumption, then see if the prediction comes true. If the professor is ill (hypothesis number 1), you might predict that a note to that effect would be posted on the door or the blackboard, but there is none. You might also expect to see other curious students about, but there are none. These negative results strongly suggest that hypothesis 1 is incorrect, although they do not necessarily prove it wrong. After all, it is possible that the professor was not able to have a notice put in the classroom, and it is possible that all the other students decided not to come to class that day. Those are pretty complex and improbable explanations, however. Hypotheses 2 and 4 are simpler and more reasonable. An easy way to test these is to look at the syllabus for the class.

Let's assume that no class is scheduled, according to the syllabus. Then you can establish a *theory.* The theory is that the classroom is empty because there is no class that day. Note that this is a **scientific theory** (although theories in science usually require much more time to develop), one that can be tested in many ways, with the same result. For example, you could check with the Geology Department office or look at another student's syllabus. The public tends to use the word *theory* in quite a different sense, almost disdainful, as something that has little basis in fact. As you can see from the example, a *scientific theory* is firmly established and as close to truth as scientifically possible. However, even a scientific theory is always subject to more testing and possible revision in light of new evidence.

That is how much of science works. There is nothing mysterious about it. It is simply a logical, open-minded approach to a question. Conclusions are not made without considerable thought and testing. It is a rational approach to all kinds of problems or questions, not just scientific ones, and undoubtedly is the approach you have used many times yourself. As you do the exercises in your geology laboratory, you will be using the scientific method as applied by geologists.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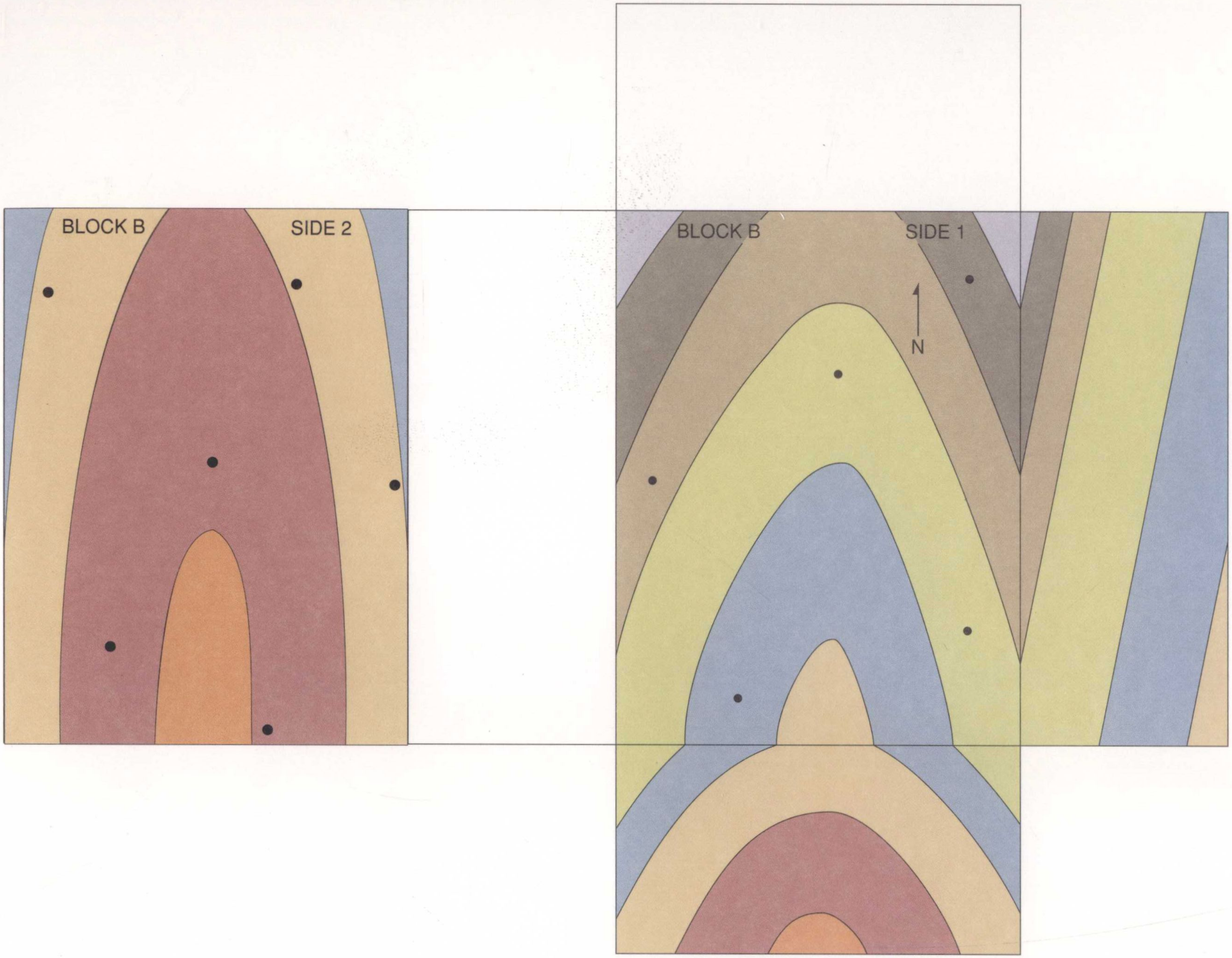

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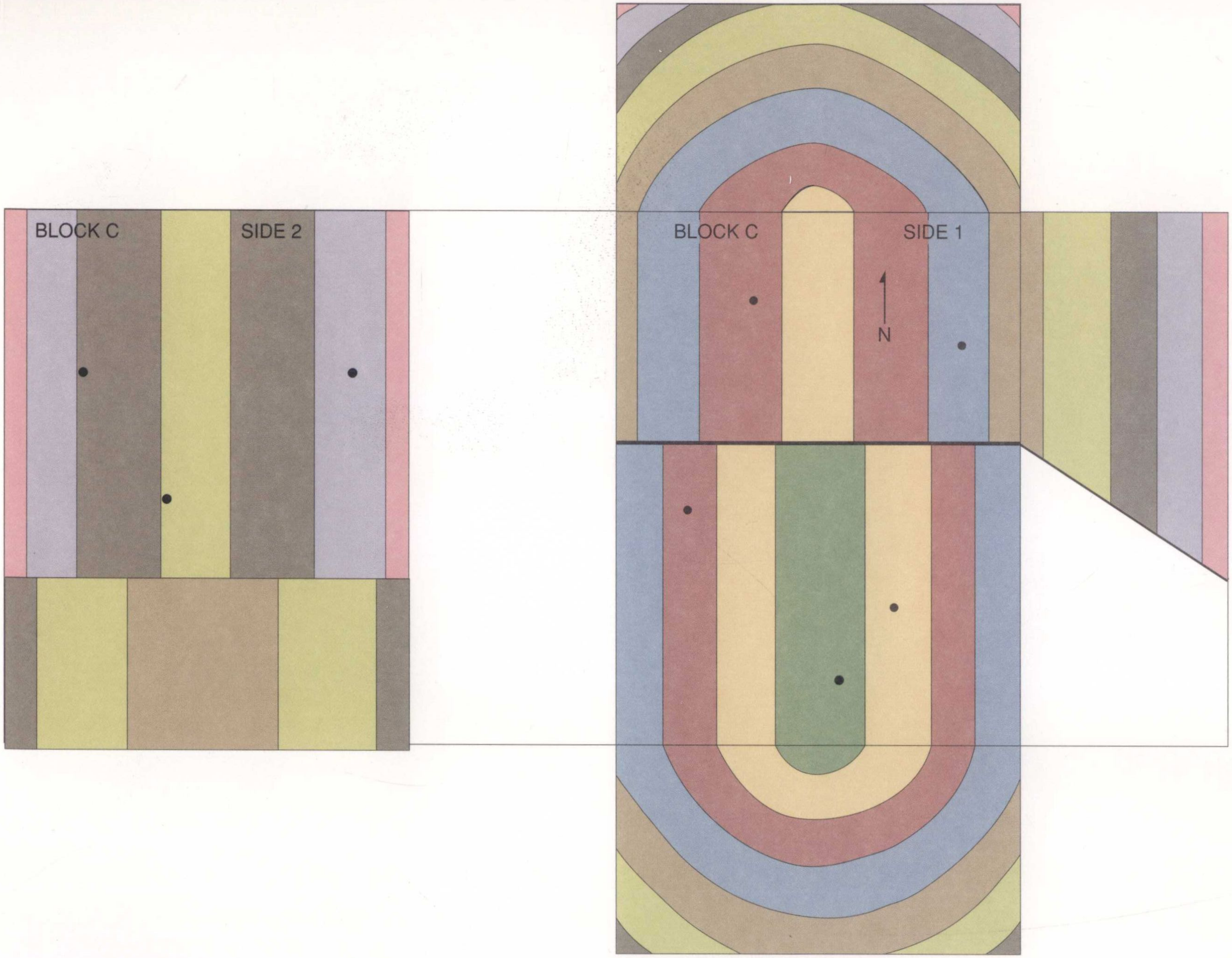
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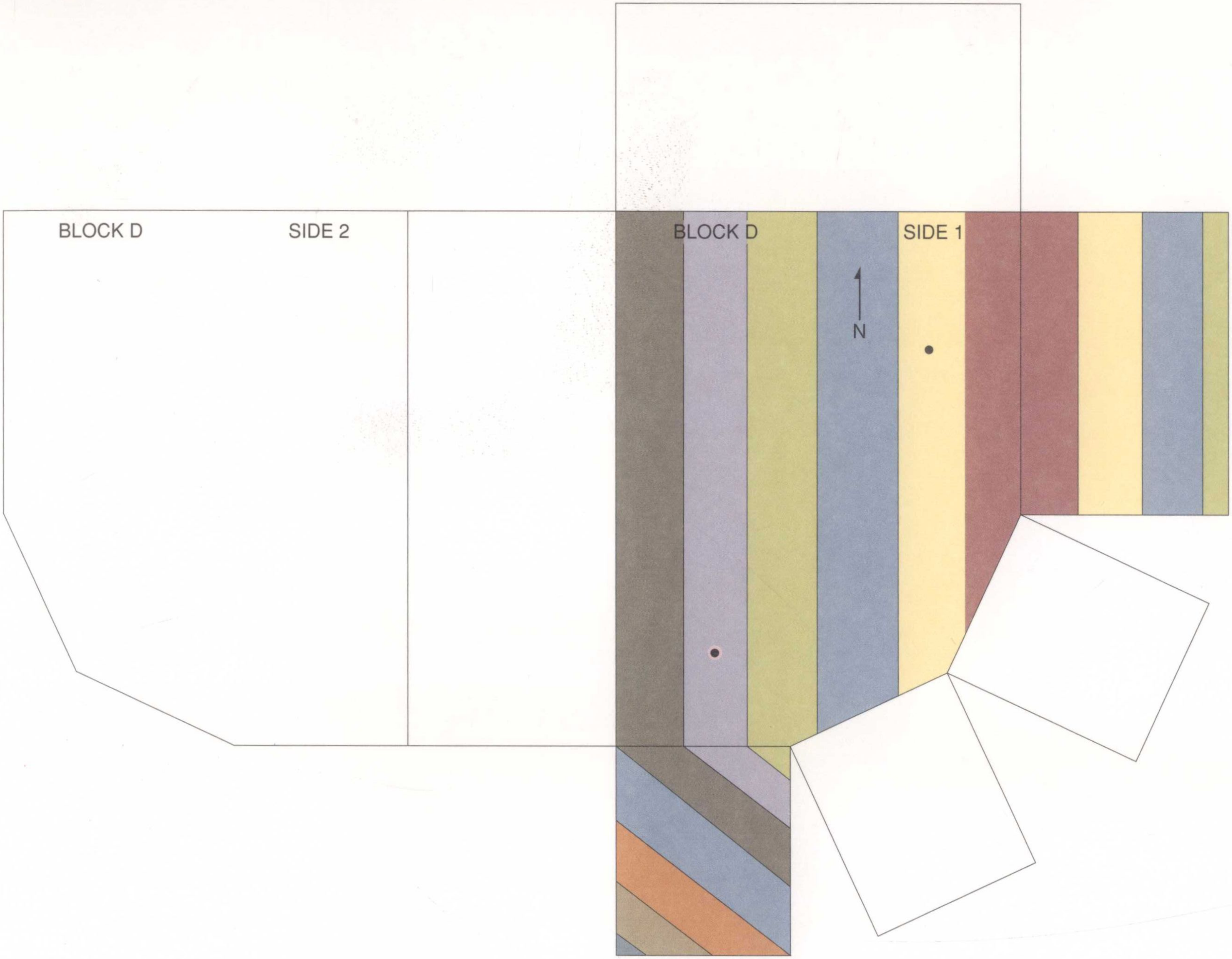
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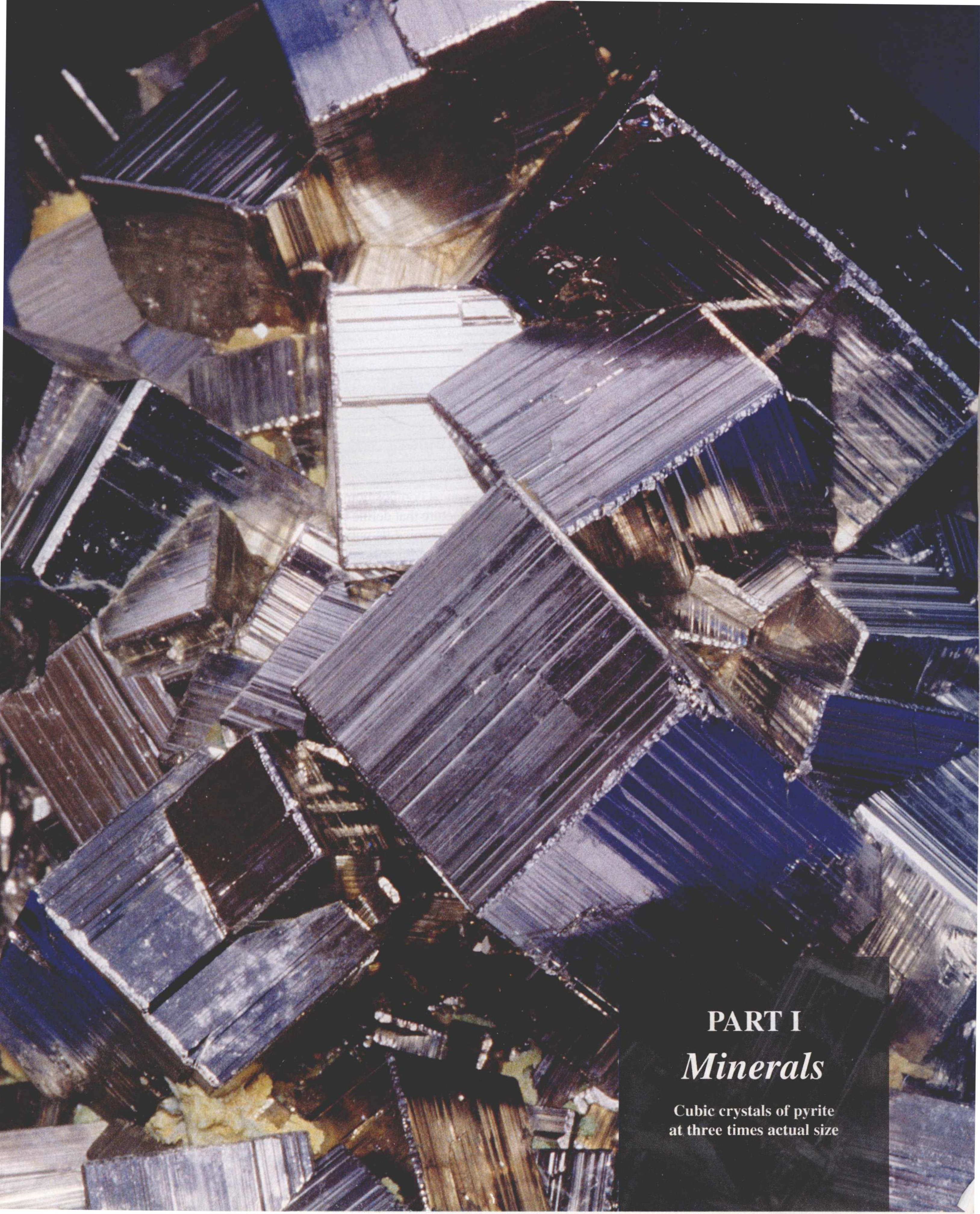

PART I
Minerals

Cubic crystals of pyrite
at three times actual size

CHAPTER 1

Properties of Minerals

Materials Needed

- Pencil
- Hand lens
- Calculator
- Set of mineral samples
- Equipment for determination of mineral properties: streak plate, copper penny, glass plate or steel knife, magnet, dilute hydrochloric acid, contact goniometer (optional)

Introduction

To understand most geologic processes, we must understand rocks. And to understand rocks we must first understand minerals, which are the components of rocks. Minerals differ from each other in chemical composition and atomic arrangement, and these factors produce distinctive physical properties that enable minerals to be identified. The most useful physical properties for identifying minerals are examined in this chapter. In Chapter 2, these properties are used to identify minerals.

What is a Mineral?

A **mineral** is a naturally occurring compound or chemical element made of atoms arranged in an orderly, repetitive pattern. Its chemical composition is expressed with a chemical formula **(symbols for important elements are given on the back endsheet).** Both chemical composition *and* atomic arrangement characterize a mineral and determine its physical properties. Most minerals form by inorganic processes, but some, identical in all respects to inorganically formed minerals, are produced by organic processes (for example, the calcium carbonate in clam shells). A few naturally occurring substances called **mineraloids** have characteristic chemical compositions, but are amorphous; that is, atoms are *not* arranged in regular patterns. Opal is an example.

The precise chemical composition and internal atomic architecture that define each mineral also directly determine its outward appearance and physical properties. Thus, in most cases, general appearance and a few easily determined physical properties are sufficient to identify the mineral.

Physical Properties

Color, luster, streak, hardness, cleavage, fracture, and crystal form are the most useful physical properties for identifying most minerals. Other properties—such as reaction with acid, magnetism, specific gravity or density, tenacity, taste, odor, feel, and presence of striations—are helpful in identifying certain minerals.

Color

Color is the most readily apparent property of a mineral, but BE CAREFUL. Slight impurities or defects within the crystal structure determine the color of many minerals. For example, quartz can be colorless, white, pink, purple, green, gray, or black (Fig. 1.1). Color generally is diagnostic for minerals with a metallic luster (defined in next section) but may vary quite a bit in minerals with a nonmetallic luster. **Check the other properties before making an identification.**

Luster

Luster describes the appearance of a mineral when light is reflected from its surface. Is it shiny or dull; does it look like a metal or like glass? Most minerals have either a **metallic** or **nonmetallic** luster. As you will see, the first thing you must determine before a mineral can be identified using the tables in Chapter 2 is whether its luster is metallic or nonmetallic.

Minerals with a metallic luster look like a metal, such as steel or copper (Fig. 1.2A, B). They are opaque, even when looking at a thin edge. Many metallic minerals become dull looking when they are

× 0.2

FIGURE 1.1
Color is NOT a reliable criterion for the identification of many minerals, as illustrated here by three varieties of the mineral quartz: amethyst (purple), rock crystal (clear), and smoky (black). The × 0.2 below the picture is a shorthand notation to indicate the actual size of the mineral samples. It means that the samples are 0.2 times the size in the picture; that is, the picture shows them one-fifth (0.2) their actual size. This notation will be used throughout this lab manual.