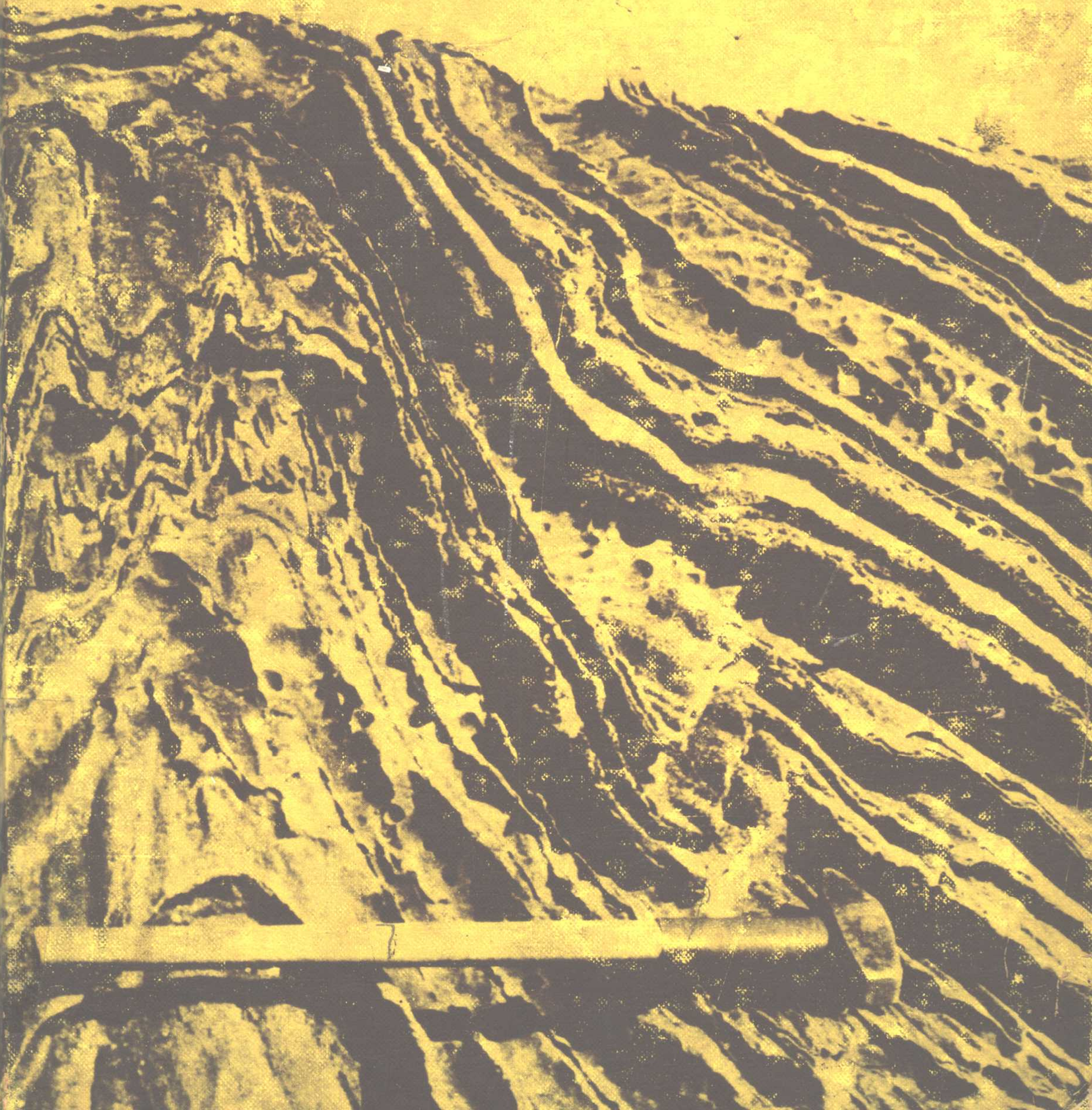
STRUCTURAL GEOLOGY

third edition

Marland P. Billings



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PREFACE

Much new information on structural geology has been published since the last edition of this book. Obviously the more significant new data should be introduced into an elementary text. But in order to keep the length within reasonable bounds it would be necessary to eliminate some of the older material. This is not easy to do. Some might be eliminated completely and some might be shortened, but presumably the original text was as concise as possible.

As in the past, the principal purpose has been to present the basic principles of structural geology. There has never been a pretense to cover global tectonics, such as the evolution of mountain ranges, continents, and ocean basins. In the second edition I said: "Oceanography . . . is discovering many exciting facts about the topography and composition of the floors of the oceans, facts that are already revolutionizing our thinking about the crust of the earth." But little did I anticipate the full magnitude and impact of these discoveries. However, a synthesis of the tectonics of the ocean basins is beyond the scope of this book.

The laboratory exercises and problems at the end of the book are much as they were in the last edition, except that the section on the use of the equal-area net has been expanded from one to three exercises. Serious consideration was given to reducing the coverage and length of the first eleven exercises. In fact, a completely new and shorter draft was prepared. But I became convinced that little of the material could be omitted and that the text was as concise as possible. Also, consideration was given to the preparation of several new exercises, involving the focal mechanisms of earthquakes, radiogenic data, Mohr's circles, and geophysical methods. Problems in the first two of these subjects would necessitate the presentation of much more background material than was possible. Inclusion of exercises on the use of Mohr's circles and geophysical methods would have lengthened the book still more.

A complete discussion of geophysical techniques is obviously beyond the scope of this book. But a discussion of the use of geophysical methods in structural geology is essential. The techniques of both geophysics and structural geology have become more sophisticated in the last two decades. Very few structural geologists are trained to do geophysical field work. Conversely, few geophysicists are able to conduct structural investigations of the type discussed in this book. To understand this relation of geophysics to structural geology, an analogy might be drawn with paleontology. Most structural geologists are not competent to do their own paleontology. But they should understand the basic principles and be prepared to challenge what appear to be incorrect conclusions by the paleontologist.

Although many references are listed at the ends of the chapters, they are of necessity incomplete. In a minor way these references should help emphasize the large number of publications available. In addition, an occasional ambitious student will be encouraged to undertake further reading. The critical reader will also notice that for some of the chapters the references are rather ancient. But very little new can be written on the geometry of faults, methods of measuring the thickness of sediments, and the character of unconformities.

Perhaps the author should have used only the metric system of measurement. But in many English-speaking countries, a dual system will be used for decades.

I want to thank the numerous geologists who have helped develop this book. Foremost among them are my former teaching assistants, who helped especially in the evolution of the laboratory problems: Randolph W. Chapman, Jarvis B. Hadley, Robert P. Sharp, Walter S. White, George E. Moore, Clyde Wahrhaftig, Laurence Nobles, Dallas Peck, and Bruce Reed. Exercises 12 through 14 in the present text are based on material prepared by Dr. James Stout. Mr. Claude Dean prepared the equations used in a discussion of the size of thrust blocks.

I am greatly indebted to Prof. John Haller and the United States Geological Survey for most of the photographs. Prof. Haller supplied many photographs from his own collection, as well as from those in his custody from the Lauge Koch expeditions to East Greenland. The staff of the Photographic Library of the U. S. Geological Survey in Denver, Irvil Shultz, Librarian, was exceedingly courteous and helpful. Other photos were supplied by Kurt Lowe, Bruce Reed, and Charles Doll.

As always, conscientious and efficient secretaries are essential to the preparation of any book. I am especially indebted to Mrs. Mary Maher in the preparation of the manuscript and to Mrs. Susan Williams in the later stages of getting permission to use figures from copyrighted articles and checking the galley proofs.

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Three-Point Problems

The method of working a three-point problem is the opposite of constructing an outcrop pattern. It is possible to calculate the dip and strike of an horizon if the location and altitude of three points on that horizon are known and if the horizon is truly a plane and not a warped surface.

A simple illustration of a three-point problem will be given first. Figure E2-3A is a map giving the location and altitude of three points on an horizon; these points are *A*, *B*, and *C*. Inasmuch as the strike of any plane is a line connecting points of equal altitude on that plane, line *AB* is the strike of the horizon under consideration because *A* and *B* are at the same altitude. The dip is measured at right angles to the strike, and in this case it is toward the southeast. A perpendicular is dropped from *C* to *AB*, the intersection being labeled *D*. To find the value of the dip a vertical triangle is rotated to the surface around *DC* as an axis. *CF* is erected perpendicular to *DC*. The difference in altitude between points *C* and *D*, 600 feet, is set off, on the same scale as the map, along the line *CF*. The angle *CDE* is the dip of the horizon.

A more general problem is illustrated by Fig. E2-3B. The location and altitude of three points on the horizon are shown. Some point, to be determined, between points *B* and *C*, will have the same altitude as *A* (1050 feet); a line connecting that point with *A* will be the strike of the horizon. The unknown point can be located by proportion:

$$\frac{\text{Altitude of } A \text{ minus altitude of } B}{\text{Altitude of } C \text{ minus altitude of } B} = \frac{\text{Distance } BD}{\text{Distance } BC}$$

where *D* is the point we wish to find. Solving the equation, we obtain $BC = 1100$ feet. This distance is set off from point *B* using the same scale as the

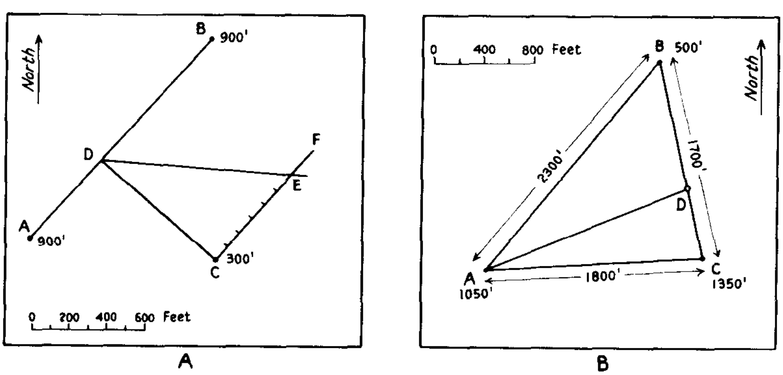

Fig. E2-3. Three-point method. Location and altitude of a plane are given at *A*, *B*, and *C*. Dip and strike of the plane can be determined.

map. *AD* is the strike of the horizon. The dip may be found in the same way as in Fig. E2-3A.

Problems

1. Figure E2-4 is a topographic map in which two geologic horizons are shown, one by a broken line and the other by a dotted line. What is the altitude of the horizons at *a*, *b*, *c*, and *d*?

2. In another area a north-south drainage tunnel 10 feet in diameter is to be driven in bedrock at an altitude of 500 feet above sea level. The tunnel will go directly under a point to be designated *A*. Three vertical drill

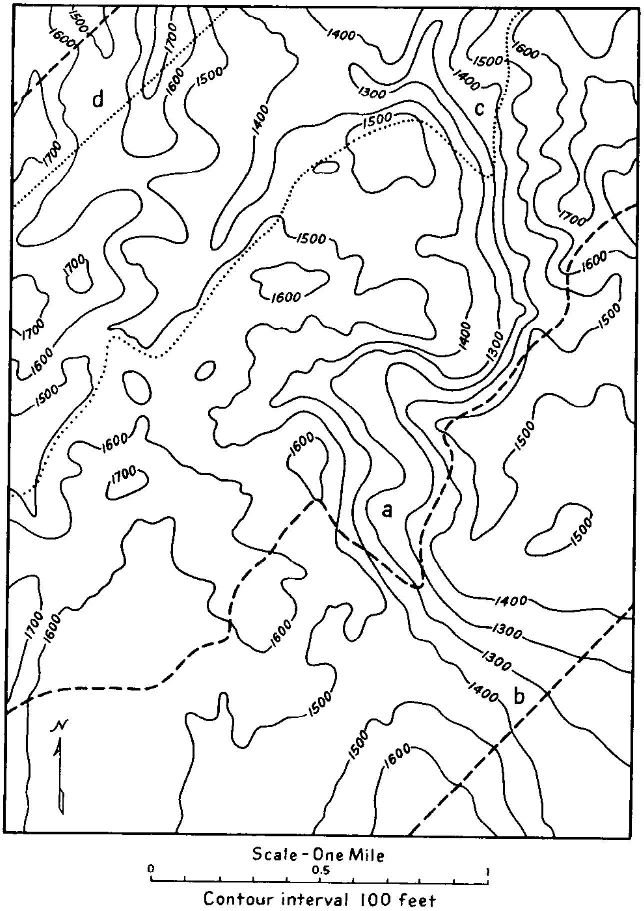

Fig. E2-4. Map for use in Problem 1 in Exercise 2. Topographic contour interval is 100 feet.

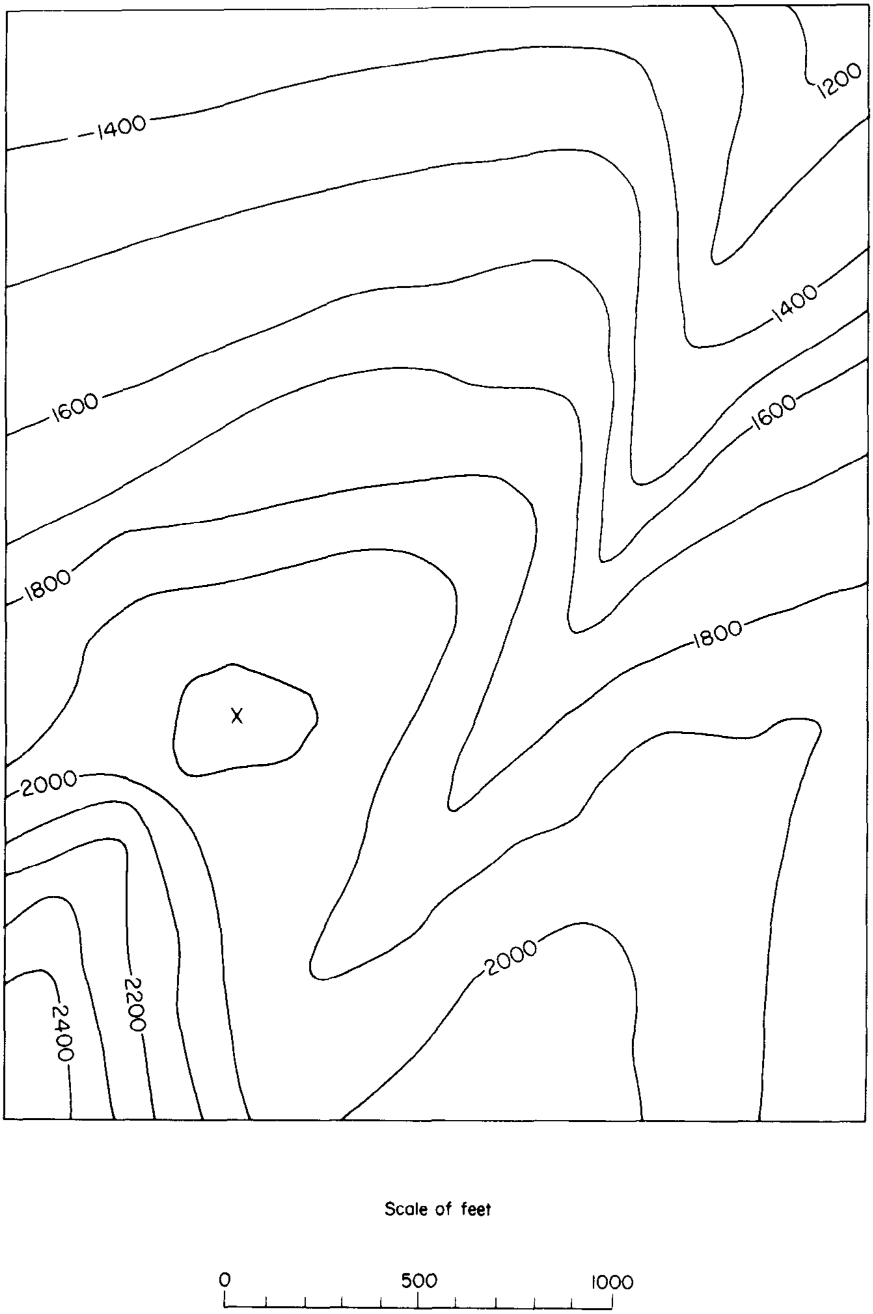

Fig. E2-5. Topographic map to be used in Problem 4.

holes were driven to locate a probable fault. The location of the drill holes and altitude of the fault is as follows.

Drill Hole	Location	Altitude of Fault above Sea Level
B	1000 feet east of *A*	900 feet
C	1000 feet north of *A*	100 feet
D	1200 feet N.60°W. of *A*	700 feet

a. What is the attitude of the fault?
b. Where will the tunnel cross the fault?

3. It is proposed to construct an east-west water supply tunnel in bedrock at an altitude of 1800 feet above sea level. The surface is level and at an altitude of 2000 feet. The proposed tunnel is to be 1000 feet north of a point that may be designated *A*, which is located on a very weak shale. But a few hundred feet south of it there is a well-consolidated conglomerate. Three drill holes were made; the data are as follows. In each case conglomerate is found beneath the shale.

Location	Altitude of Contact of Shale and Conglomerate Relative to Sea Level
A Reference point	1800 feet
B 700 feet N.50°W. of *A*	1400 feet
C 2000 feet N.10°E. of *A*	0 feet

a. What is the attitude of the contact of the conglomerate and shale?
b. In what rock would the proposed tunnel be located?
c. Where would you suggest locating the tunnel?

4. On Fig. E2-5 a thin bed of limestone, striking N.90°E. and dipping 20° north, crops out at the *X*. Show the trace of the limestone on the map on an overlay of tracing paper; altitude of *X* is 2050 feet.

5. Figure E2-6 is an area of limited outcrop. The actual outcrops are surrounded by dotted lines. Four formations are exposed: conglomerate, marble, quartzite, and amphibolite.

a. The base of the conglomerate is well exposed at *A*, *B*, and *C*. Assuming that the base of the conglomerate can be treated as a plane, calculate the attitude of this contact.

b. The trace of the contact of the marble and quartzite is shown in two of the southerly outcrops. Assuming a planar contact, calculate the attitude of this contact.