GEOLOGICAL STRUCTURES AND MAPS

A Practical Guide

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Pergamon Press

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A PRACTICAL GUIDE

by

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Front cover photograph shows Folded Cretaceous limestones around Aliaga, Province of Teruel, Spain. The scale of the structure is indicated by the Moorish Castle in the foreground.

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Preface

GEOLOGICAL maps represent the expression on the earth's surface of the underlying geological structure. For this reason the ability to correctly interpret the relationships displayed on a geological map relies heavily on a knowledge of the basic principles of structural geology.

This book discusses, from first principles up to and including first-year undergraduate level, the morphology of the most important types of geological structures, and relates them to their manifestation on geological maps.

Although the treatment of structures is at an elementary level, care has been taken to define terms rigorously and in a way that is in keeping with current professional usage. All too often concepts such as 'asymmetrical fold', 'fold axis' and 'cylindrical fold' explained in first textbooks have to be re-learned 'correctly' at university level.

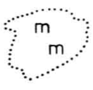
Photographs of structures in the field are included to emphasize the similarities between structures at outcrop scale and on the scale of the map. Ideally, actual fieldwork experience should be gained in parallel with this course.

The book is designed, as far as possible, to be read without tutorial help. Worked examples are given to assist with the solution of the exercises. Emphasis is placed throughout on developing the skill of three-dimensional visualization so important to the geologist.

In the choice of the maps for the exercises, an attempt has been made to steer a middle course between the artificial-looking idealized type of 'problem map' and real survey maps. The latter can initially overwhelm the student with the sheer amount of data presented. Many of the exercises are based closely on selected 'extracts' from actual maps.

I am grateful to Professor T. R. Owen who realized the need for a book with this scope and encouraged me to write it. Peter Henn and Catherine Shephard of Pergamon Books are thanked for their help and patience. Thanks are also due to Vivienne Jenkins and Wendy Johnson for providing secretarial help, and to my wife Ann for her support.

Geological Map Symbols

	inclined strata, dip in degrees
	horizontal strata
	vertical strata
	axial surface trace of antiform
	axial surface trace of synform
	fold hinge line, fold axis or other linear structure, plunge in degrees
	inclined cleavage, dip in degrees
	horizontal cleavage
	vertical cleavage
	geological boundary
	fault line, mark on downthrow side
	younging direction of beds
	metamorphic aureole

Contents

1

Geological Maps

1.1 What are geological maps?

A geological map shows the distribution of various types of bedrock in an area. It usually consists of a topographic map (a map giving information about the form of the earth's surface) which is shaded or coloured to show where different rock units occur at or just below the ground surface. Figure 1.1 shows a geological map of an area in the Cotswolds. It tells us for instance that clays form the bedrock at Childswickham and Broadway but if we move eastwards up the Cotswold escarpment to Broadway Hill we can find oolitic limestones. Lines on the map are drawn to show the boundaries between each of the rock units.

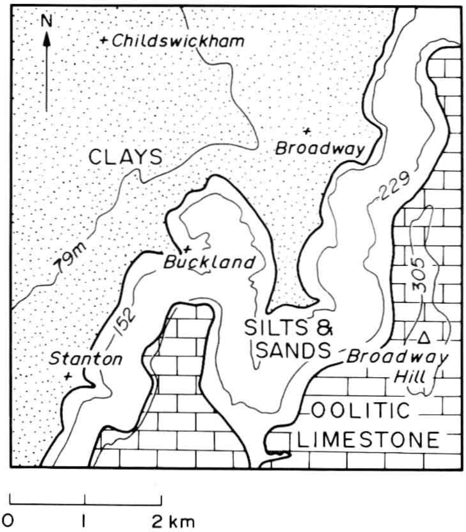


FIG. 1.1 A geological map of the Broadway area in the Cotswolds.

1.2 How is such a geological map made?

The geologist in the field firstly records the nature of rock where it is visible at the surface. Rock outcrops are examined and characteristics such as rock composition, internal structure and fossil content are recorded. By using these details, different units can be distinguished and shown separately on the base map. Of course, rocks are not always exposed at the surface. In fact, over much of the area in Fig. 1.1 rocks are covered by soil and by alluvial deposits laid down by recent rivers. Deducing the rock unit which underlies the areas of unexposed rock involves making use of additional data such as the type of soil, the land's surface forms (geomorphology) and information from boreholes. Geophysical methods allow certain physical properties of rocks (such as their magnetism and density) to be measured remotely, and are therefore useful for mapping rocks in poorly exposed regions. This additional information is taken into account when the geologist decides on the position of the boundaries of rock units to be drawn on the map. Nevertheless, there are always parts of the map where more uncertainty exists about the nature of the bedrock, and it is important for the reader of the map to realize that a good deal of interpretation is used in the map-making process.

1.3 What is a geological map used for?

The most obvious use of a geological map is to indicate the nature of the near-surface bedrock. This is clearly of great importance to civil engineers who, for example, have to advise on the excavation of road cuttings or on the siting of bridges; to geographers studying the use of land and to companies exploiting minerals. The experienced geologist can, however, extract more from the geological map. To the trained observer the features on a geological map reveal vital clues about the geological history of an area. Furthermore, the bands of colour on a geological map are the expression on the ground surface of layers or sheets of rock which extend and slant downwards into the crust of the earth. The often intricate pattern on a map, like the graininess of a polished wooden table top, provides tell-tale evidence of the structure of the layers beneath the surface. To make these deductions first requires knowledge of the characteristic form of common geological structures such as faults and folds.

This book provides a course in geological map reading. It familiarizes students with the important types of geological structures and enables them to recognize these as they would appear on a map or cross-section.

2

Uniformly Dipping Beds

2.1 Introduction

Those who have observed the scenery in Western movies filmed on the Colorado Plateau will have been impressed by the layered nature of the rock displayed in the mountainsides. The layered structure results from the deposition of sediments in sheets or beds which have large areal extent compared to their thickness. When more beds of sediment are laid down on top the structure comes to resemble a sandwich or a pile of pages in a book (Fig. 2.1). This stratified structure is known as bedding.

FIG. 2.1 Horizontal bedding. **A**: Lower Jurassic, near Cardiff.

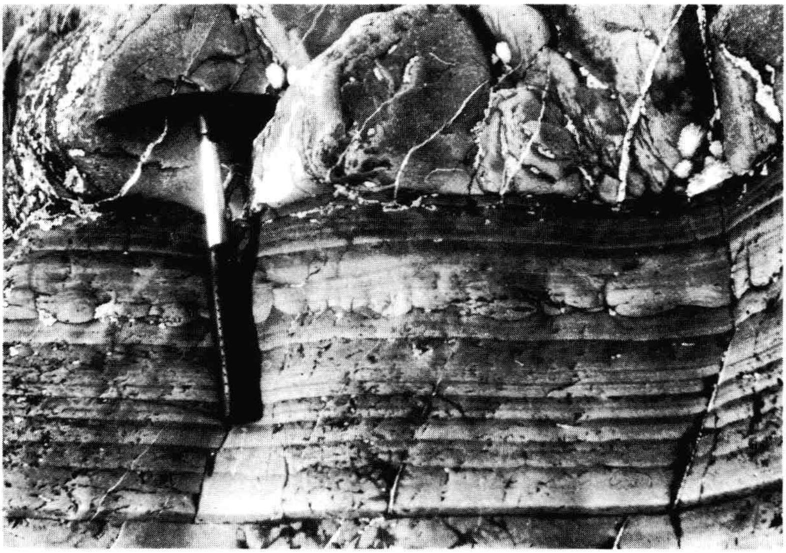


FIG. 2.1 Horizontal bedding. **B**: Upper Carboniferous, Cornwall

In some areas the sediments exposed on the surface of the earth still show their unmodified sedimentary structure; that is, the bedding is still approximately horizontal. In other parts of the world, especially those in ancient mountain belts, the structure of the layering is dominated by the buckling of the strata into corrugations or folds so that the slope of the bedding varies from place to place. Folds, which are these crumples of the crust's layering, together with faults where the beds are broken and shifted, are examples of geological structures to be dealt with in later chapters. In this chapter we consider the structure consisting of planar beds with a uniform slope brought about by the tilting of originally horizontal sedimentary rocks.

2.2 Dip

Bedding and other geological layers and planes which are not horizontal are said to dip. Figure 2.2 shows field examples of dipping beds. The *dip* is the slope of a geological surface. There are two aspects to the dip of a plane:

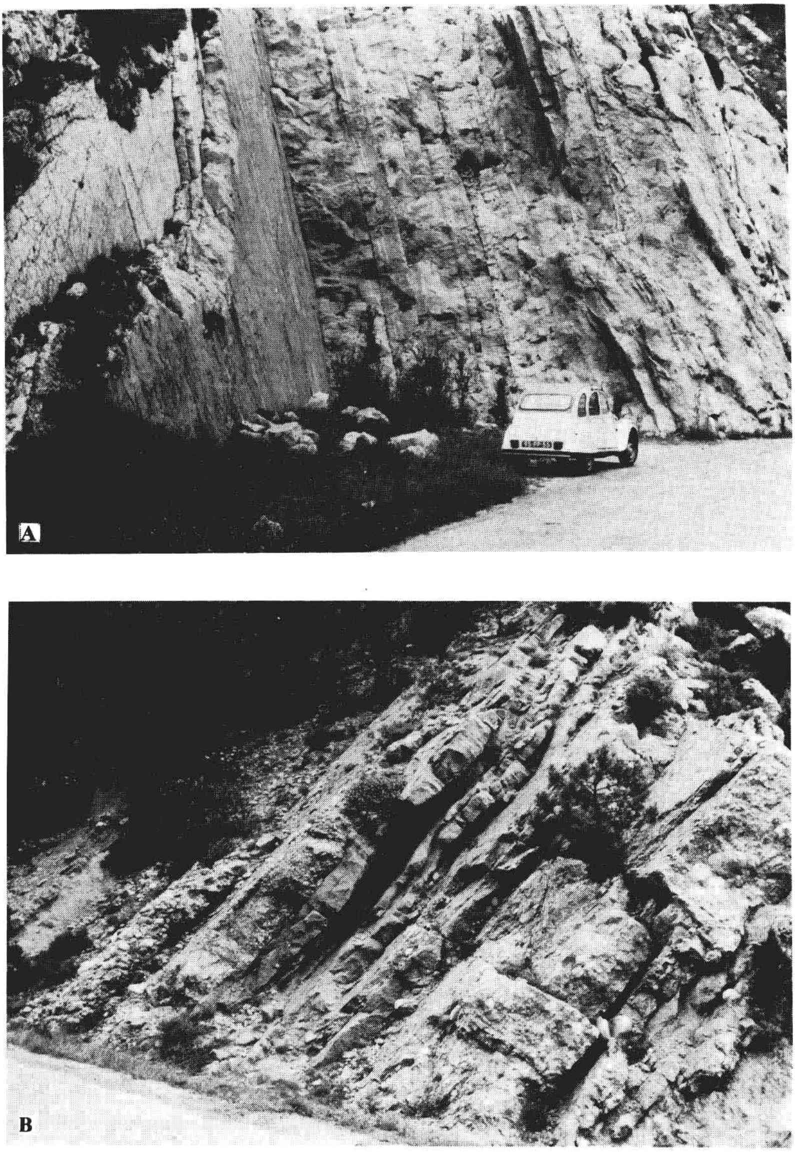


FIG. 2.2 Dipping beds in Teruel Province, Spain. **A**: Cretaceous Limestones dipping at about 80°. **B**: Tertiary conglomerates and sandstones dipping at about 50°.

(a) *the direction of dip*, which is the compass direction towards which the plane slopes; and

(b) the *angle of dip*, which is the angle that the plane makes with a horizontal plane (Fig. 2.3).

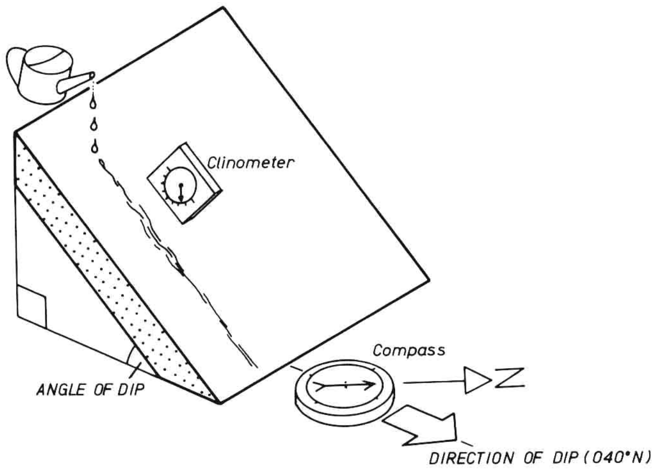


FIG. 2.3 The concepts of direction of dip and angle of dip.

The direction of dip can be visualized as the direction in which water would flow if poured onto the plane. The angle of dip is an angle between 0° (for horizontal planes) and 90° (for vertical planes). To record the dip of a plane all that is needed are two numbers; the direction of dip followed by the angle of dip, e.g. 138/74 is a plane which dips 74° in the direction 138°N (this is a direction which is SE, 138° clockwise from north). In the field the direction of dip is usually measured with a magnetic compass which incorporates a device called a clinometer, based on a plumbline or spirit level principle, for the measurement of dip angles.

2.3 Plunge of lines

With the help of Fig. 2.4 imagine a dipping plane with a number of straight lines drawn on it in different directions. All these lines are said to be contained within the plane and are parallel to the plane. With the exception of line 5 the lines are not horizontal; we say they are plunging lines. Line 5 is non-plunging. *Plunge* is used to describe the tilt of lines, the word dip being reserved for planes. The plunge fully expresses the tilt of a line and has two parts:

(a) the plunge direction, and
(b) the angle of plunge.

Consider the vertical plane which passes through the plunging line in Fig. 2.5. The *plunge direction* is the direction in which this vertical plane runs, and is the direction towards which the line is tilted. The *angle of plunge* is the

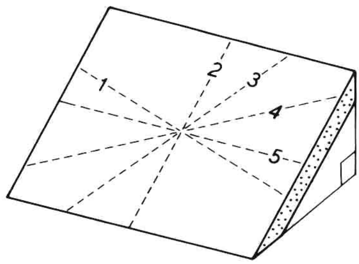


FIG. 2.4 Lines geometrically contained within a dipping plane.

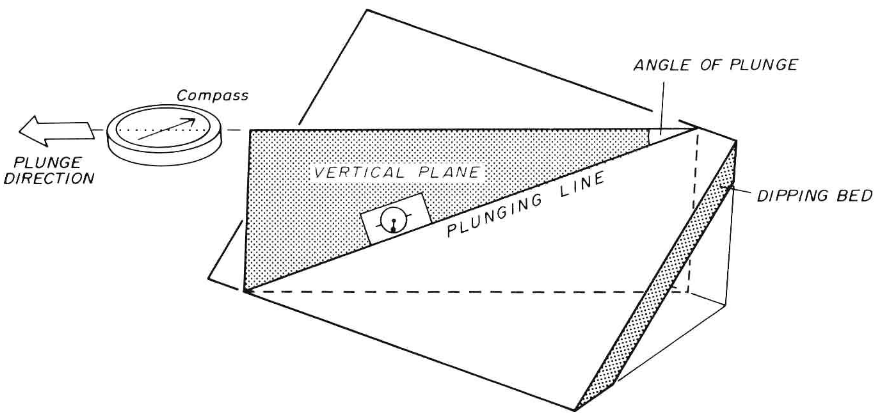


FIG. 2.5 The concepts of direction of plunge and angle of plunge.

amount of tilt; it is the angle, measured in the vertical plane, that the plunging line makes with the horizontal. The angle of plunge of a horizontal line is 0° and the angle of plunge of a vertical line is 90°. The plunge of a line can be written as a single expression, e.g. 325-62 describes a line which plunges 62° towards the direction 325°N. So far we have illustrated the concept of plunge using lines drawn on a dipping plane but, as we shall see later, there are a variety of linear structures in rocks to which the concept of plunge can be applied.

2.4 Strike lines

Any dipping plane can be thought of as containing a large number of lines of varying plunge (Fig. 2.4). The *strike line* is a non-plunging or horizontal line within a dipping plane. The line numbered 5 in Fig. 2.4 is an example of a strike line; it is not the only one but the other strike lines are all parallel to it. If we think of the sloping roof of a house as a dipping plane, the lines of the ridge and the eaves are equivalent to strike lines.

Within the dipping plane the line at right angles to the strike line is the line with the steepest plunge. Verify this for yourself by tilting a book on a flat tabletop as shown in Fig. 2.6. Place a pencil on the book in various orientations. The plunge of the pencil will be steepest when it is at right angles to the spine of the book (a strike line). The angle of plunge of the steepest plunging line in a plane is equal to the angle of dip of that plane.

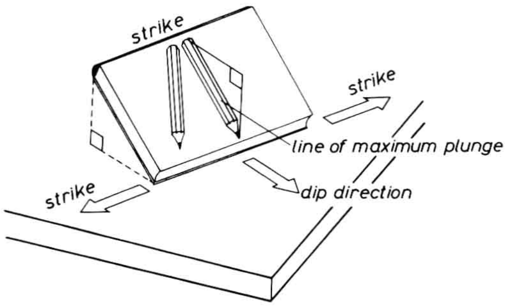


FIG. 2.6 A classroom demonstration of a dipping plane.

When specifying the direction of a strike line we can quote either of two directions which are 180° different (Fig. 2.6). For example, a strike direction of 060° is the same as a strike direction of 240°. The direction of dip is always at right angles to the strike and can therefore be obtained by either adding or subtracting 90° from the strike whichever gives the down-dip direction.

The map symbol used to represent the dip of bedding usually consists of a stripe in the direction of the strike with a short dash on the side towards the dip direction, (see list of symbols at the beginning of the book). Some older maps display dip with an arrow which points to the dip direction.

2.5 Apparent dip

At many outcrops where dipping beds are exposed the bedding planes themselves are not visible as surfaces. Cliffs, quarries and cuttings may provide more or less vertical outcrop surfaces which make an arbitrary angle with the strike of the beds (Fig. 2.7A). When such vertical sections are not perpendicular to the strike (Fig. 2.7B), the beds will appear to dip at a gentler angle than the true dip. This is an *apparent dip*.

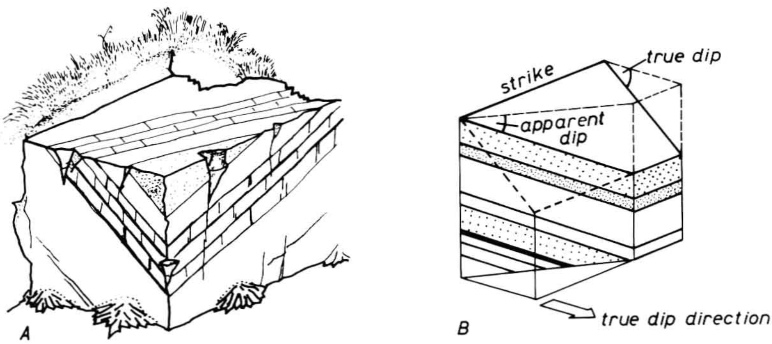


FIG. 2.7 Apparent dip.

It is a simple matter to derive an equation which expresses how the size of the angle of apparent dip depends on the true dip and the direction of the vertical plane on which the apparent dip is observed (the section plane). In Figure 2.8 the obliquity angle is the angle between the trend of the vertical section plane and the dip direction of the beds.

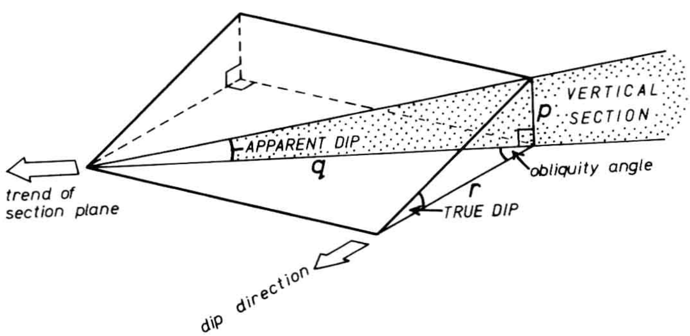


FIG. 2.8 Relation of apparent dip to true dip.

From Fig. 2.8:

Tangent (apparent dip) $= p/q$,

Tangent (true dip) $= p/r$ and

Cosine (obliquity angle) $= r/q$.

Therefore:

Tan (apparent dip) = *Tan* (true dip) × *Cos* (obliquity angle).

It is sometimes necessary to calculate the angle of apparent dip, for instance when we want to draw a cross-section through beds whose dip direction is not parallel to the section line.