Introduction to GEOLOGICAL MAPS AND STRUCTURES

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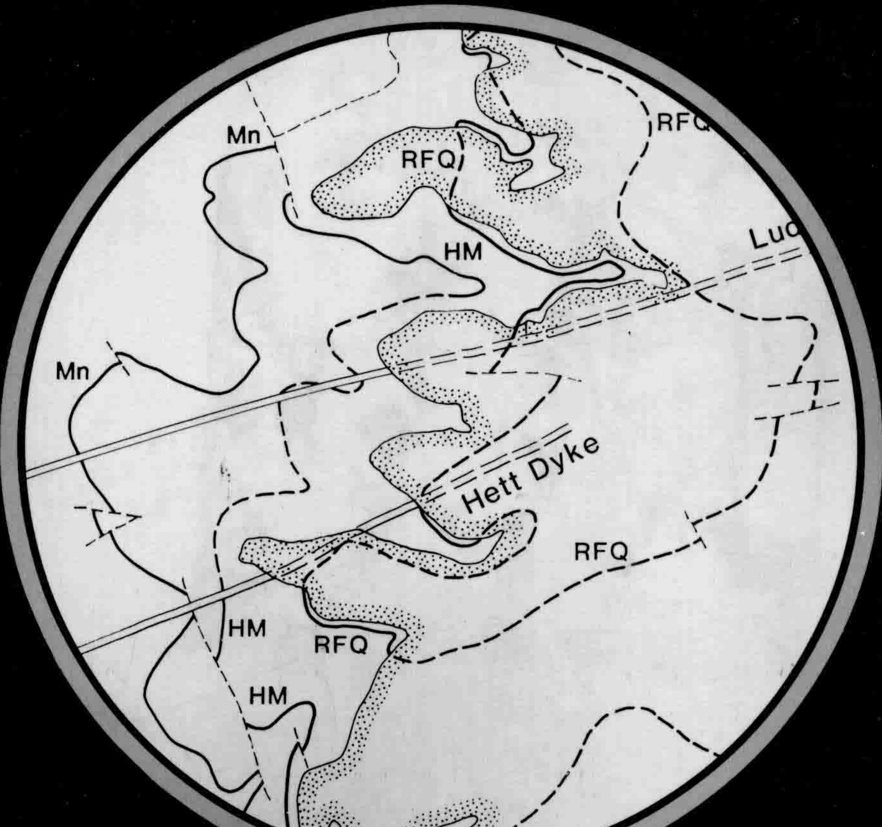

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Preface

THE elementary student of geology may well first encounter the basic elements of structural geology through the study and interpretation of geological maps. However, there are few if any textbooks on structural geology which concentrate on showing how the forms of geological structures can be determined from the evidence presented by a geological map, even although such an analysis is fundamental to their interpretation. Admittedly, there are several laboratory manuals on the British market which offer a very elementary introduction to the basic methods used in the interpretation of geological maps. These manuals are mostly based on so-called "problem maps", often of a rather artificial nature and usually based on a very simplistic view of the complexity shown by geological structures.

By way of contrast, the present book attempts a reasonably comprehensive account of geological structures and how they may be recognised through the study of geological maps, starting from first principles. It therefore provides an introduction to the basic methods used in the interpretation of geological maps, while it also attempts to cover the backround knowledge needed for a full understanding of geological maps. Any discussion of the mechanical principles involved in the formation of geological structures is kept to a minimum, since this aspect of the subject is covered adequately by the standard textbooks on structural geology.

The bulk of the text was written during the tenure of a Leverhulme Trust Fellowship which I acknowledge with much gratitude. I should also like to thank Christine Cochrane, who prepared all the illustrations from my very rough drafts, Elizabeth Walton and Sandra Elcock, who provided secretarial help at many stages in the preparation of the manuscript, and my colleagues in the Department of Geology at Newcastle who took an interest in the progress of the book from its inception, particularly Colin Scrutton who provided useful advice on stratigraphic principles and nomenclature.

Contents

CHAPTER 1

Introduction

Nature of Geological Maps

GEOLOGICAL maps are generally prepared in the field using a topographic map as a base. Such a base map, produced in Great Britain by the Ordance Survey, shows the form or topography of the land surface by means of topographic contours. These are drawn as lines of equal height above a reference plane, such as mean sea-level, which is known as the Ordnance Datum. Topographic contours are usually drawn at a particular interval, so that the contour height is a multiple of the contour interval. The topography of the sea floor can likewise be represented by submarine contours.

It is important to be able to visualise the form of the earth's surface by studying the contour pattern drawn on a topographic map (see Fig. 1.1).

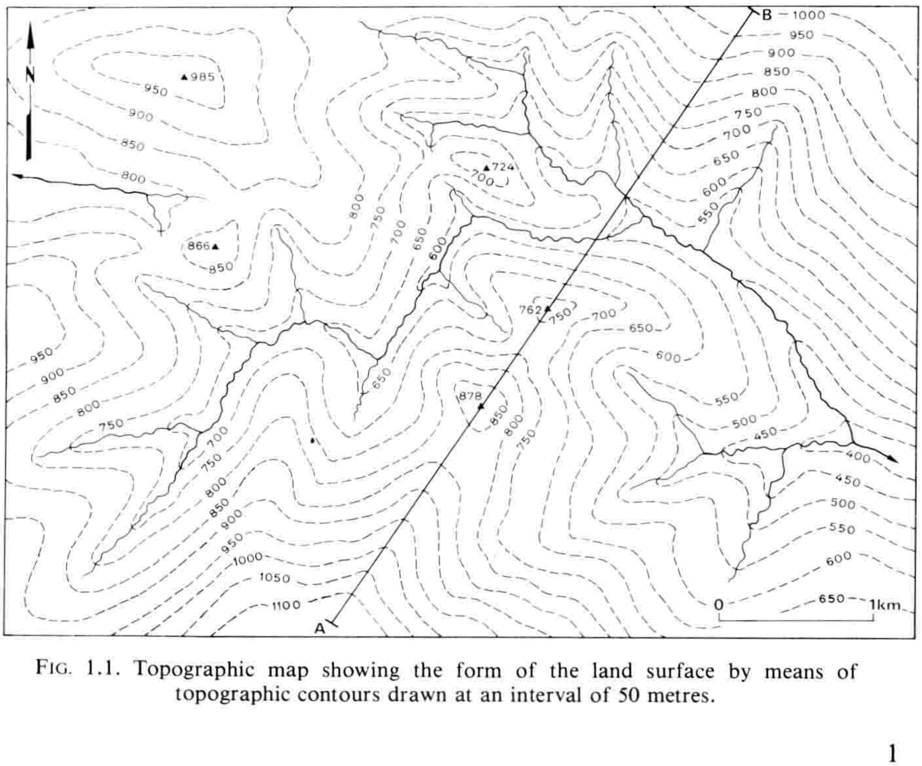

FIG. 1.1. Topographic map showing the form of the land surface by means of topographic contours drawn at an interval of 50 metres.

Particular features can be recognised from the contour pattern, thus allowing a mental picture of the topography to be constructed. Studying the natural features such as rivers, lakes, marshes, screes, cliffs and coasts, which are also shown in topographic maps, helps to identify the hills and valleys which together form the topography of an area.

The topographic map used as a base in geological mapping has a particular scale. This can be given in writing (1 inch equals 1 mile), as a fractional scale (1:63,360), or as a line printed on the map and divided into segments corresponding to certain distances on the ground.

Geological mapping is commonly undertaken at one scale, to be published at a different scale. For example, the Institute of Geological Sciences in Great Britain now undertakes mapping in the field at a scale of 10 centimetres to 1 kilometre (or 1:10,000), which is the metric equivalent of the old 6 inches to 1 mile scale, while it publishes maps on the following scales:

1:10,560	6 inches to 1 mile
1:25,000*	4 centimetres to 1 kilometre
1:50,000*	2 centimetres to 1 kilometre
or	
1:63,360	1 inch to 1 mile
1:100,000*	1 centimetre to 1 kilometre
1:250,000*	1 centimetre to 2.5 kilometres
or	
1:253,440	1 inch to 4 miles
1:625,000*	1 inch to about 10 miles
1:1,584,000	1 inch to 25 miles
1:2,500,000	1 centimetre to 25 kilometres

It is the maps on a metric scale, as marked by asterisks, which are gradually replacing the older maps on a similar scale, which were based on imperial measurements.

Although these maps become less detailed as the scale decreases, they are all based on the same information, as obtained from field mapping. It is the geological maps now being published on a scale of 1:50,000 (previously 1:63,360) which form a series of reasonably detailed maps covering the whole country. On a larger scale, the 1:25,000 maps depict areas of particular geological interest, while some 1:10,560 maps are published for certain areas, mainly coalfields. On a smaller scale, the 1:250,000 maps are intended to provide a complete coverage for the country without showing very much detail, while the geological maps published on the scale of 1:625,000 or 1:1,584,000 are simplified maps covering the whole country as two sheets (1:625,000) or a single sheet (1:1,584,000). The Geologic Quadrangle Maps produced by the United States Geological Survey on a scale of1:24,000 or

1:62,500 are equivalent to the 1:50,000 maps for Great Britain, while geological maps are produced on a scale of 1:2,500,000 as four sheets covering the whole country. Geological maps on various other scales are also published for paticular purposes by the United States Geological Survey and by the corresponding organisations in the individual States.

Solid and Drift Maps.

Geological maps show the distribution of the superficial deposits and the underlying solid rocks at the earth's surface. The superficial deposits include glacial sands and gravels, boulder clay, alluvial sands and gravels, lacustrine silts and clays, screes and landslip deposits, beach sands and conglomerates, and peat. Such deposits form a thin and discontinuous mantle of material, covering the underlying rocks of the earth's crust. This material has been formed during the present cycle of erosion, and the deposits are mostly Pleistocene or Recent in age. This means that they have been formed during the last million years or so.

The geological maps published by the Institute of Geological Sciences for the various parts of Great Britain are produced in two editions. The Solid and Drift Edition shows the distribution of the superficial deposits by means of colouring. The solid rocks are only coloured on these maps where they are not overlain by superficial deposits. The older maps of this type were termed drift maps, simply because most of the superficial deposits in Great Britain are formed by glacial drift. The Solid Edition of the same maps does not show the superficial deposits by means of colouring. Instead, the solid rocks are coloured even where they are overlain by superficial deposits. Symbols printed on the map are used to show the nature of the superficial deposits. However, such maps often show the more widespread areas of river alluvium and wind-blown sand by means of colouring.

The Geologic Quadrangle Maps published by the United States Geological Survey mostly correspond to the Solid and Drift Edition of the geological maps produced by the Institute of Geological Sciences for Great Britain, since the superficial deposits are shown on these maps by means of colouring. However, some maps produced for areas covered by glacial deposits are published in a form similar to the Solid Edition.

Geological Boundaries.

The surface distribution of the solid rocks in a particular region is shown by means of geological boundaries, drawn as lines on the geological map (see Fig. 1.2). These boundaries define the outcrops of geological formations which have been mapped as separate entities in the field. A geological formation is simply defined as any body of rock which is sufficiently distinct that its boundaries can be mapped in this way.

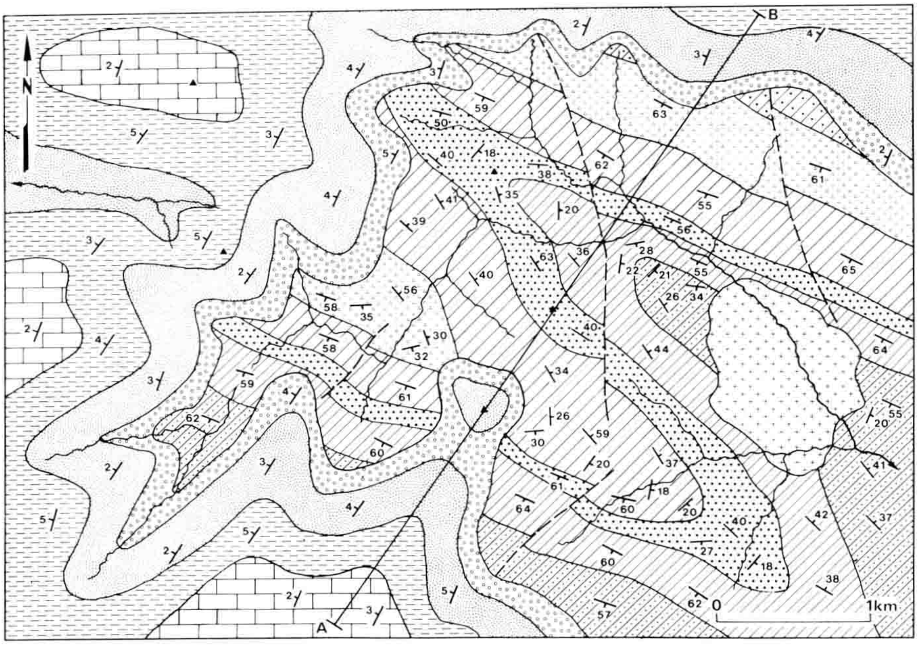

FIG. 1.2. Geological map depicting the outcrop of the geological formations recognised within the area of Figure 1.1. The ornament assigned to each geological formation is shown by the stratigraphic column of Figure 1.3.

The outcrop of a geological formation corresponds to the area which is directly underlain by rocks belonging to the formation. The outcrops of all the formations recognised in a particular region combine to form the outcrop pattern shown by a geological map. Exposures are only found where the underlying rocks are not hidden from view by soil or superficial deposits, so that they can be seen at the earth's surface.

Although the outcrop of a geological formation is mapped at the earth's surface, the formation is itself a three-dimensional body of rock. It has a particular shape, extending to some depth below the earth's surface, as defined by its contacts with the adjacent formations. It is very important to realise that such a formation, now outcropping at the earth's surface, originally extended to some height above the present level of this surface, before it was removed by erosion.

The accuracy of the boundaries shown on a geological map depends on two factors. Firstly, boundaries can only be drawn where there is a sharp contact between adjacent formations. Such boundaries become easier to distinguish as the rocks on either side of the contact become increasingly distinct. A boundary cannot be drawn with any degree of accuracy if it represents a transitional contact across which the rocks change only

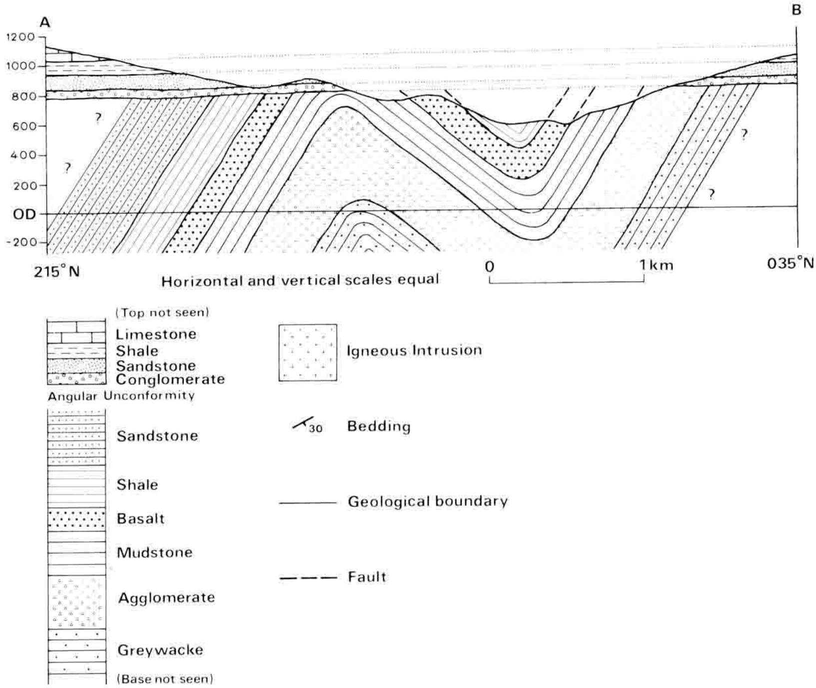

FIG. 1.3. *Above:* a vertical cross-section drawn along the line AB of Figure 1.2 to show the geological structure of the area. *Below:* stratigraphic column showing in chronological order the sequence of geological formations recognised within the area of Figure 1.2, with older rocks arranged below younger rocks.

gradually in character. Secondly, the ability to follow geological boundaries in the field depends on the degree of exposure, according to which the solid rocks tend to be hidden under a cover of soil and superficial deposits. It is common practice to show geological boundaries as solid or dashed lines, depending on whether or not these boundaries have been accurately located in the field.

The detail shown by a geological map depends primarily on the diversity of the rocks which have been mapped, since it is only variations in the nature of the rocks which allow different formations to be mapped. However, it also depends on the scale of the map and the degree of exposure. Geological maps showing areas of economic interest are often very detailed since the information obtained by mapping at the surface is supplemented by subsurface information which has been obtained from bore holes and mine workings.

Sections and Symbols.

Geological maps are generally accompanied by vertical cross-sections, a stratigraphic column, a legend or key showing the structural symbols, ornament and colours used on the map, and a brief description of the geology.

Vertical cross-sections are drawn across the map to illustrate the geological structure of the rocks, as shown in Figure 1.3. The lines of section are generally marked on the map. Each cross-section provides a vertical section through the upper levels of the earth's crust to show the geological structure extrapolated from the surface to a depth of a few kilometres. It should also be extended above the earth's surface to show the inferred nature of the geological structures above the present level of erosion. Such a cross-section is usually drawn at the same scale as the geological map. The vertical scale should correspond to the horizontal scale so that there is no vertical exaggeration to distort the form of the geological structures. The cross-section is then known as true-to-scale. It is constructed from the geological observations made at the surface, supplemented by subsurface data from mine workings and bore holes. It is mistakenly termed a horizontal cross-section on the maps published by the Institute of Geological Sciences in Great Britain because it is drawn along a horizontal line.

The stratigraphic column shows a generalised sequence of all the geological formations which have been mapped, arranged in chronological order from the oldest at the bottom to the youngest at the top, as shown in Figure 1.3. It is commonly drawn to scale, so allowing the thickness of each formation to be shown as appropriate. The symbol, ornament and colour assigned to each formation is shown by the stratigraphic column. It is termed a vertical section on the maps published by the Institute of Geological Science in Great Britain, since it corresponds to the sequence of formations which would generally be encountered with increasing depth. The stratigraphic column is often annotated with brief descriptions of the various formations. This annotation may be expanded to provide a short description of the geology, printed on the map. Alternatively, an explanatory memoir may be published seperately.

CHAPTER 2

Sedimentary Rocks and the Outcrop Pattern

Bedding of Sedimentary Rocks

SEDIMENTARY rocks are formed by material, mostly derived from the weathering and erosion of pre-existing rocks, which is deposited as sediment on the earth's surface. There are two main classes of sedimentary rocks, which differ in their mode of origin.

The clastic or detrital sediments are represented by rocks such as conglomerates, sandstones and shales. They are composed of rock fragments, mineral grains and clay minerals, produced by the physical and chemical weathering of older rocks. These particles are transported from their place of origin by the flow of air, water and ice across the earth's surface, accumulating as sedimentary deposits once the flow of the transporting medium so declines that the particles cannot be moved any farther. Deposition occurs progressively since the larger and heavier particles require more energy to be transposed in comparison with the smaller and lighter particles. This results in a sorting of the particles to form deposits of decreasing grain size away from their source.

The chemical and organic sediments comprise such rocks as limestones, dolomites, cherts, evaporites and coal. These rocks are mostly formed from material produced in solution by chemical weathering, which accumulates in sea water as the result of evaporation. This material in solution may be abstracted by direct precipitation to form chemical sediment, or it may be removed by organisms to form shells and skeletons, which then accumulate as organic sediment.

Beds and Bedding Planes.

Sedimentary rocks generally occur in the form of layers which were deposited on top of one another to form a stratified sequence as shown in Figure 2.1. Each layer is known as a bed or stratum (pl: strata), while the layered nature of sedimentary rocks which results from such a mode of formation is termed bedding or stratification. Sedimentary beds usually differ from one another in lithology, which is a general term referring to the overall character of a rock, as seen particularly in the field. The lithological

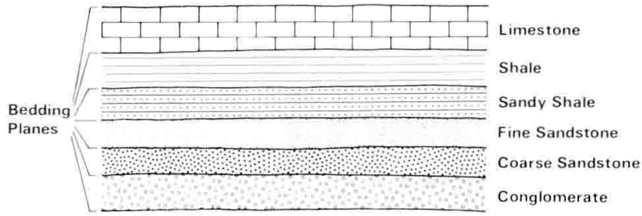

FIG. 2.1. Diagram showing the bedding or stratification of sedimentary rocks with beds of different lithology (conglomerate, sandstone, sandy shale and limestone) separated from one another by bedding planes. Each bed forms a parallel-sided or tabular layer. Such layers often divided internally by bedding planes to form a whole series of beds, differing slightly from one another in lithology.

differences reflected in the bedding of sedimentary rocks are usually defined by differences in mineral composition, grain size, texture, colour, hardness and so on, which allow the individual beds of sedimentary rock to be recognised.

The surfaces separating the individual beds of sedimentary rock from one another are known as bedding planes. They are commonly defined by a more-or-less abrupt change in lithological character which occurs in passing from one bed to the next. However, they may simply be defined by planes of physical discontinuity between beds of otherwise similar lithology, along which the rock will split.

The thickness of individual beds generally varies from several centimetres to a few metres, while their lateral extent may be measured in kilometres. Accordingly, beds of sedimentary rock typically form thin but very widespread layers, which eventually disappear as their thickness decreases to zero. Such beds may retain a lithological identity, or they may show a gradual change in lithological character, as they are traced throughout their outcrop. Some deposits of sedimentary rock show rapid changes in thickness so that they do not have such a parallel-sided form. For example, elongate bodies of sandstone and conglomerate are laid down in river channels and along shore lines, wedge-shaped bodies of breccia and conglomerate are banked against buried hills, volcanoes and coral reefs, while the dome-shaped form of reef knolls and the elongate form of barrier or fringing reefs are the result of organic activity. However, such examples are exceptions to the general rule that most beds of sedimentary rocks occur effectively in a tabular form as parallel-sided layers which extend laterally for a considerable distance before they eventually disappear as their thickness decreases to zero.

A bedding plane generally represents the original surface on which the overlying bed of sedimentary rock was deposited. Such a surface is simply known as a surface of deposition. Since sedimentary rocks are deposited on the earth's surface, such a bedding plane corresponds to this surface just before the overlying rocks were laid down. Commonly, the earth's surface is very close to the horizontal wherever sedimentary rocks are accummulating as the result of deposition at the present day. For example, the alluvial plains and deltas formed by the lower reaches of large rivers, and the shallow seas into which they flow beyond the land, are typically flat-lying areas where considerable thicknesses of sedimentary rocks have just been deposited. However, since a bedding plane is considered to represent such a surface of sedimentary deposition, it can be argued by analogy with the present day that this surface was virtually horizontal when the overlying bed of sedimentary rock was deposited.

This implies that sedimentary rocks were originally deposited as nearly if not quite horizontal beds. Accordingly, sedimentary rocks are generally deposited with what is known as a low initial dip, unless they were deposited on a sloping surface. Such exceptions are only likely where sedimentary rocks are deposited on the flanks of deltas, coral reefs, volcanoes and hill slopes. The beds rarely have an initial dip greater than 30° from the horizontal, even under these circumstances. They are usually found to flatten out as they are traced away from such prominences, until they eventually become horizontal or nearly so.

Stratigraphic Order and Superposition.

Stratigraphy can be defined as that branch of geology which studies the stratified nature of sedimentary rocks as a basis for interpreting the geological history of the earth's crust. The study of stratigraphy starts with establishing the chronological order in which a sequence of sedimentary rocks was originally deposited at the earth's surface. This is known as the stratigraphic order of the sedimentary rocks. What is known as a stratigraphic sequence can be established by placing the sedimentary rocks in their chronological order.

The stratigraphic order of sedimentary rocks can simply be established according to the Principle of Superposition which states that, while each bed in a stratified sequence is younger than the underlying bed, it is older than the overlying bed. The principle arises simply because sedimentary rocks are laid down as flat-lying beds on top of one another, so that they become progressively younger in an upward direction. In other words, the oldest rocks occur at the base of a stratigraphic sequence, while the youngest beds are found at the top. The stratigraphic order of sedimentary rocks can be shown in this way by means of a stratigraphic column, such as commonly accompanies a geological map (See Fig. 1.3).

Sedimentary rocks are commonly if not invariably found to be affected by earth movements in such a way that the bedding is no longer horizontal. For example, they may become tilted so that the bedding is inclined in a particular direction. This is known as the direction of dip, and the bedding is said to dip at a particular angle from the horizontal in this direction, which corresponds to the dip of the sedimentary rocks. The horizontal direction of right angles to the dip of the bedding is known as the strike. How the dip and strike of a bedding plane can be measured in the field will be described later in this chapter (See Fig. 2.4). The vertical cross-section of Figure 1.3 shows the upper sequence of sedimentary rocks to be very slightly tilted, since the bedding dips at a low angle to the west-north-west. Alternatively, sedimentary rocks may become folded so that the bedding is thrown into a wave-like form, as shown by the lower sequence of sedimentary rocks in the vertical cross-section of Figure 1.3. The bedding shows regular changes in dip as it is traced across these folds in the sedimentary rocks.

Accordingly, earth movements can affect sedimentary rocks in such a way that the bedding becomes increasingly inclined away from the horizontal until it reaches a vertical position, beyond which it may become overturned. The beds are then said to be inverted, even although the bedding may still be inclined away from the horizontal. The Principle of Superposition does not apply to sedimentary rocks which have been so affected by subsequent earth movements that they are now inverted. It is often difficult to determine the stratigraphic order of sedimentary rocks in such regions. However, it may be possible to trace these rocks into areas of less complexity, where the stratigraphic order can be determined according to the Principle of Superposition.

Stratigraphy of Sedimentary Rocks

Sedimentary rocks often contain fossils as the organic remains of plants and animals, which were incorporated into the sediment at the time of its deposition. It was early recognised that the fossils preserved in a sedimentary rock are diagnostic of its geological age, unless they have been derived from the erosion of older rocks. This is simply a consequence of organic evolution whereby certain species change into new and different forms, combined with organic extinction whereby other species die out completely, with the passing of geological time. Thus, each species is only present as a living organism during a particular time span, before which it had not evolved from a pre-existing form and after which it had either become extinct or evolved into a new form. This means that sedimentary rocks can be dated as belonging to a particular interval of geological time, according to the assemblage of fossil species which they contain. This principle allows stratigraphic correlation since it implies that sedimentary rocks containing similar assemblages of fossil species are the same age.

The Stratigraphic Time-scale.

The evolution and extinction of organisms gives a definite and recognisable order to the succession of fossil assemblages which are pre-