Stratigraphy

An Introduction to Principles

D. T. Donovan

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AN INTRODUCTION TO PRINCIPLES

BY

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PREFACE

I have sought to give an account of the principles of correlation and classification of the sedimentary rocks with brief reference to their history. In describing terminology and classification I have confined myself to practice in English-speaking countries, and have noted some of the chief differences between British and North American usage. Some controversial matters are treated briefly or omitted. It would have been wrong to ignore past and present differences of opinion, but equally inappropriate to give detailed accounts of them in an elementary textbook.

Some countries have codes of stratigraphical practice and others are debating the introduction of codes. Furthermore, past International Geological Congresses have from time to time discussed stratigraphical usage, and the Nineteenth Congress (1952) set up a Subcommission on Stratigraphic Terminology which hopes that an International Code may eventually result. There is a large measure of agreement between recent codes but differences do exist between codes and also between what is laid down in the codes and what is actually done. I have not, therefore, followed any one code rigidly although I have referred to some of them.

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D. T. D.

9th December, 1965

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ESTABLISHING THE SUCCESSION

STRATIGRAPHY is the study of the stratified or sedimentary rocks: their nature, arrangement, and correlation from place to place. It enables geological events, as recorded in the rocks, to be placed in their correct sequence and is thus the key to the history of the earth's crust. Stratification, or arrangement in layers, had been observed by a number of geological pioneers in the eighteenth century, and several of these, notably John Strachey in England (1719) and J. G. Lehmann in Germany (1756), made the further observation that layers of different kinds occurred in the same order within a particular area. With the realization that the sedimentary rocks were laid down layer by layer, it was clear that the upper layers, in an undisturbed section, must be younger than the lower: the principle of *superposition*. From a sequence of rocks could be inferred a sequence of events. This was the theoretical approach developed by James Hutton (1726–1797) who laid the philosophical foundations of modern geology in his famous work, *Theory of the Earth* (1788: 1795). Hutton showed that the rocks recorded events which had occupied an immensely long period of time and established many of the principles by which this record could be interpreted. He saw that there had been periods of upheaval separated by times of denudation and of sedimentation, and that these had alternated not once but many times—his 'succession of former worlds'. He appreciated the significance of unconformities as proving this succession. He lacked only one thing: the means of correlating or identifying his succession of worlds in different parts of the globe. He could recognize the Old Red Sandstone in different parts of Scotland by its characteristic rock-types, but was unable to recognize rocks of the same age in different facies. Thus, although Hutton established the principles of relative dating, he was unable to put them into practice to establish a general history of the earth's crust.

The deficiency was made good by William Smith (1769–1839). Smith discovered the principles of stratigraphy independently while surveying and building the Somerset Coal Canal south-west of Bath from 1793 onwards. As well as understanding stratification and superposition, he began to collect fossils, and by about 1795 had made the discovery for which he is famous, that each group of rocks, or stratum (in modern usage a formation), is characterized by its own distinctive set of fossils. Smith used the principle to trace strata over comparatively short distances. Soon it was extended to correlate strata of the same age which were formed of dissimilar kinds of rock, often over long distances. This is discussed further in Chapter 2.

Smith's criteria for defining a stratum were, then, twofold: a distinctive series of rocks, containing (in most cases) a distinctive fauna. When, in 1799, Smith dictated his first table of strata he was able to list no less than twenty-three distinct strata from the Coal to the Chalk. The original written copy of this document, preserved by the Geological Society of London, is almost illegible. An early printed copy is reproduced opposite. It is a model stratigraphical table, with lithology, thickness, characteristic fossils and typical localities for many of the strata. We can learn an interesting lesson by comparing it with the modern version of the table for southern England. Certain parts of it are very detailed: the strata numbered 8, 9 and 10, are all part of what is now called Upper Fuller's Earth, which is not subdivided today because it is seldom exposed. No doubt the beds were familiar to Smith in excavations. Similarly strata 4, 5 and 6 are now included in undivided Forest Marble. By contrast other prominent formations are absent altogether. Throughout much of its outcrop the predominantly marly and clayey Lias (no. 14) is divided by a highly fossiliferous limestone, the Marlstone, which forms a conspicuous feature in the landscape. Unfortunately for Smith, the Marlstone is absent around Bath, and was therefore omitted from his earlier tables of strata. He first noted it in his published work in 1817. Several Upper Jurassic and Lower Cretaceous strata, which occur between nos. 3 (Oxford Clay), and 2 (Upper Greensand), *Order of the Strata and their imbedded Organic Remains, in the Vicinity of Bath; examined and proved priör to* 1799,

BY WILLIAM SMITH, ENGINEER AND MINERAL SURVEYOR.

Strata.	Thickness	Springs.	Fossils, Petrifactions, &c. &c.	Descriptive Characters and Situations.
1 Chalk	300	Intermitting on the Downs	Echinites, Pyrites, Mytilites, Dentalia, funnel-shaped Corals, and Madrepores, Nautilites, Strombites, Cochliæ, Ostreæ, Serpulæ	Strata of Silex, imbedded.
2 Sand	70			The fertile Vales intersecting Salisbury Plain and the Downs.
3 Clay	30	Between the Black Dog and Berkley.		
4 Sand and Stone	30			Imbedded is a thin Stratum of calcareous Grit. The Stones flat, smooth, and rounded at the Edges.
5 Clay	15	Hinton, Norton, Woolverton, Bradford Leigh.		
6 Forest Marble	10		A Mass of Anomiæ and high-waved Cockles, with calcareous Cement	The Cover of the upper Bed of Freestone, or Oolyte.
7 Freestone	60		Scarcely any Fossils besides the Coral	Oolyte, resting on a thin Bed of Coral.—Prior Park, Southstoke, Twinny, Winsley, Farley Castle, Westwood, Berfield, Conkwell, Monkton Farley, Coldhorn, Marshfield, Coldashton.
8 Blue Clay	6	Above Bath.		
9 Yellow Clay	8			
10 Fuller's Earth	6			Visible at a Distance, by the Slips on the Declivities of the Hills round Bath.
11 Bastard ditto, and Sundries	80		Striated Cardia, Mytilites, Anomiæ, Pundibs, and Duck-muscles.	
12 Freestone	80		Top-covering Anomiæ with calcareous Cement, Strombites, Ammonites Nautilites, Cochlæ Hippocephaloides, fibrous Shell resembling Amianth, Cardia, prickly Cockle Mytilites, lower Stratum of Coral, large Scollop, Nidus of the Muscle with its Cables	Lincombe, Devonshire Buildings, Englishcombe, Englishbatch, Wilmerton, Dunkerton, Coomhay, Munkton Coombe, Wellow, Mitford, Stoke, Freshford, Claverton, Bathford, Beaston, and Hampton, Charlcombe, Swainswick, Tadwick, Langridge.
13 Sand	30		Ammonites, Belemnites	Sand Burs.
14 Marl Blue	40	Round Bath	Pectenites, Belemnites, Gryphites, high-waved Cockles	Ochre Balls.—Mineral Springs of Lincombe, Middle-Hill, Cheltenham.
15 Lias Blue	25		Same as the Marl with Nautilites, Ammonites, Dentalia, and Fragments of the Enchrinni	The fertile Marl Lands of Somersetshire. Twerton, Newton, Preston, Clutton, Stanton Prior, Timsbury, Palton, Marksbury, Farmborough, Corston, Hunstreet, Burnet, Keynsham, Whitchurch, Salford, Kelston, Weston, Pucklechurch, Queencharlton, Norton-malreward, Knowle, Charlton, Kilmersdon, Babington.
16 Ditto White	15			

FIG. 1. Part of William Smith's first table of strata. From a copy in the Historical Records Office, British Railways Board.

WILLIAM SMITH'S STRATA AND THEIR MODERN EQUIVALENTS

Present-day subdivisions	*Smith's map, 1815*	*Smith's table, 1799*
London Clay	London Clay	—
Woolwich and Reading Beds, etc. (also East Anglian Crags)	Clay and brickearth Sand and light loam	—
Chalk	Chalk	1. Chalk
Upper Greensand	Green Sand, parallel to the Chalk	2. Sand
Gault	—	—
Lower Greensand	—	—
Wealden Beds	—	—
Purbeck Beds	—	—
Portland Beds	—	—
Kimmeridge Clay	Blue Marl, or Oaktree Soil	—
Corallian Beds (also other formations)	Purbeck Stone, Kentish Rag, and Limestone of the Vale of Pickering	—
Lower Greensand, etc.	Iron Sand or Carstone	—
Oxford Clay	Clunch Clay or Shale	3. Clay
Cornbrash	Cornbrash Limestone	—
Forest Marble	Forest Marble and Clay	4. Sand and Stone 5. Clay 6. Forest Marble
Great Oolite Fuller's Earth	Great Oolyte or Bath Freestone	7. Freestone 8. Blue Clay 9. Yellow Clay 10. Fuller's Earth 11. Bastard ditto and sundries

Inferior Oolite Midford Sand	Under Oolyte	12. Freestone 13. Sand
Upper Lias Clay Marlstone Lower Lias Clay	Blue Marl Pastures	14. Marl Blue
Blue Lias White Lias	Blue and White Lias Limestones	15. Lias Blue 16. Ditto White
Rhaetic Beds		17. Blue Marl
Keuper Marl Bunter Sandstone	Red Marl, Millstone and Breciated Limestone	18. Red-ground 19. Millstone
Magnesian Limestone	Magnesian Limestone	—
Coal Measures	Coal Measures	20. Pennant Stone 21. Grays 22. Cliff 23. Coal
Carboniferous Limestone	Derbyshire Limestone	—
Old Red Sandstone	Red and Dunstone	—
(Various Palaeozoic formations)	Hardstone, Limestone and Slate	—
Upper Palaeozoic slates of S.W. England	Killas and Slate	—
(Various igneous and metamorphic rocks)	Granite, Sienite and Gneiss	—

were likewise omitted because they have been removed by pre-Upper Greensand erosion from the country between Bath and Warminster (Wilts.) where Smith evidently first studied the upper part of his succession (fig. 2, line A-A). If he had gone only a few miles to the north-east (line B-B) he would have seen three more formations, the Corallian Beds, Kimmeridge Clay and Portland Beds, although for the full sequence in the Upper Jurassic and Lower Cretaceous he would have had to go to the south coast and the Weald.

Thus we see that a local succession is liable to be incomplete. To establish the full sequence in an area, one must compare and combine a number of local successions. The method was described by Lyell in his *Elements of Geology* (1838, p. 278):

'In order, therefore, to establish a chronological succession of fossiliferous groups, a geologist must begin with a single section, in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously, as far as possible, from the starting point. As often as he meets with new groups, he must ascertain by superposition their age relatively to those first examined, and thus learn how to intercalate them in a tabular arrangement of the whole.'

The sequence recorded by Smith was not based on direct observation, but on inference. Only a small part of it is actually exposed around Bath In 1793, while levelling along the line of the proposed canal, Smith had discovered that strata which occurred on the hilltops at the western end of his line lay in the valley at the eastern end; in other words, there was an easterly dip. By making the assumption that this dip was general throughout the area, beyond the valleys in which it had been proved by levelling, it was clear that the strata lying further to the east must be the higher, even if sections showing their actual order of superposition were not seen. Thus the Chalk, the easternmost stratum known to Smith at the time, must be the highest. The assumption proved to be justified and the inference correct. It was confirmed by mapping, for by tracing his strata across country Smith found the extension of their outcrops, the strike, to lie roughly north and south, at right angles to the dip. This indirect method of establishing the succession by mapping is, in fact, the usual one in areas where extensive exposures are uncommon.

Where exposed sections are lacking and the order of superposition cannot be established by mapping because of complex tectonics, other criteria may have to be found. If formations are fossiliferous and the faunal sequence is well known from other areas, the succession may be established beyond doubt even though it cannot be observed directly or mapped. Thus in many parts of the world there is little difficulty in deciding upon the relative ages of fossiliferous formations. If fossils are absent difficulties are much greater. Radiometric dating, discussed in Chapter 4, can be used where a series of sediments contains intrusive or interbedded igneous rocks which can be dated, or glauconitic rocks which can be dated by the potassium-argon method.

The phenomenon of *contained fragments* is sometimes useful. If a formation contains pieces of another formation it must be younger than that formation. The method may be applied both to large fragments and, by microscopical study, to the constituent grains of medium and fine grained clastic rocks. It has many limitations, the chief being the difficulty of finding fragments whose source is beyond doubt. It is thus most successful when the fragments are of complex and unusual rock types, most uncertain when they are mineral grains. Contained fragments have figured largely in the attempts to work out the geological succession in the Pre-Cambrian rocks of the Welsh Borderland, and prove that the sedimentary Longmyndian is younger than the highly distinctive Uriconian volcanics, of which it contains pebbles.

In regions of complex tectonics sedimentary sequences may be turned upside down. In piecing together a succession one must know whether beds at individual exposures are the right way up or not. This may be determined in various ways, reviewed in detail by R. R. Shrock (1948).

Improvements to our knowledge of the stratigraphy of well-known areas are coming to depend more and more upon boreholes, as witness the extensive programme of drilling undertaken for research purposes by the British Geological Survey since the war. In areas being studied for economic reasons exploration often includes boreholes at an early stage.