A SHORT COURSE IN
# GEOLOGY FOR CIVIL ENGINEERS

MARCUS MATTHEWS, NOEL SIMONS AND BRUCE MENZIES

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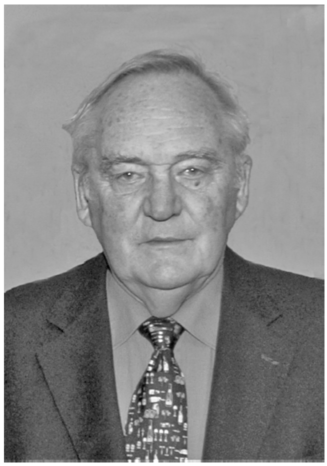
# Dedication



Professor Noel Simons FREng, 1931–2006

Noel Simons, who developed the University of Surrey into one of the UK's leading centres of geotechnical learning and research, and who inspired the Short Course Series of geotechnical books, died on August 10th 2006. He was aged 75.

He was not only a wonderful teacher, mentor, colleague and co-author, but was also a dear friend. This book is dedicated to his memory.

# Preface

This book is based on short courses given at the University of Surrey to undergraduate and postgraduate civil engineering students and at summer schools for civil engineering practitioners.

We believe that civil engineers do not need to be geologists or even engineering geologists as well as civil engineers. But they do need to have a basic knowledge of geology, however, and to know when this knowledge 'runs out' – and so know when they should get the advice of a specialist engineering geologist.

Civil engineers can build almost anything on or in the Earth's crust. Accordingly, they need to know as much as possible about the ground beneath their construction site before carrying out any civil engineering design and works.

We approached writing this book by applying the 'sanity test' of always asking the question, 'How does this information help the civil engineer?'. This immediately cut out a lot of geological science, particularly to do with classification, and much terminology. Our purpose in this book is to explain geology for civil engineers without the major distraction of having to teach the reader the 'foreign language' of geological terminology. This means that our approach relies on tolerance on the part of the reader when geological terms are dropped into the text sometimes without explanation. We do, however, include a glossary of geological terms.

A representation of the layout of this book is shown in Fig. 1. This shows how various chapters fit together. Here we identify a 'core' of particular civil engineering relevance and how it interrelates with geological general knowledge which in turn leads to civil engineering 'deliverables'. In general, this specific knowledge can only fully make sense in terms of a wider understanding of geology. Accordingly, geology is explained in this book, not only as having important civil engineering applications, but also as coherent geological general knowledge. Above all, we explain the mechanisms or 'engineering' of how the ground is made and therefore what it is made of and how the civil engineer can work from a few first principles to decide if the ground is an asset or a hazard.

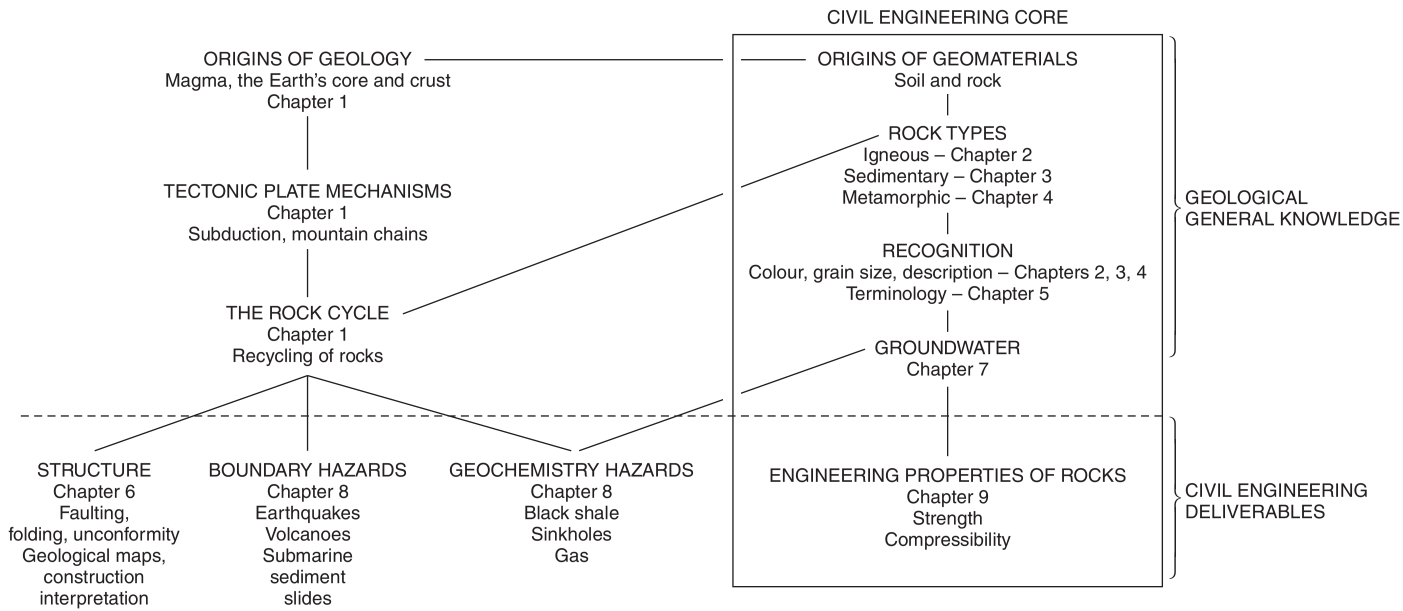



*Fig. 1 Layout of this book*

The book begins with an explanation of what is now the common knowledge of plate tectonics, which most people have acquired from newspaper and television reporting on disasters such as volcanic eruptions, earthquakes and tsunamis. The plate tectonic mechanisms described in the book explain the causes of these hazards. They also explain why we get contorted layering of strata called 'folds' and discontinuous strata called 'faults', as well as apparently illogical or missing layering called 'unconformities'.

From this appreciation of the 'geological engine' creating the geological exposures and landforms we see on the Earth's surface, we go on to consider those aspects of geology of crucial importance to the civil engineer. These include the major geological hazard of earthquakes that the civil engineer can design and build for and so we devote a large section to geological and geotechnical aspects of earthquake engineering. Also included are the formation and chemistry and hence properties of rocks that the civil engineer uses and builds on and so we devote several chapters to rock types, identification, and their engineering properties of strength and compressibility. We also consider groundwater, particularly as a resource to be protected. In order to give a sub-surface picture of the ground, we explain how to interpret geological maps of surface exposures of geological formations and materials.

During the writing of this book, our co-author, Noel Simons, died after a short illness. Noel was that rare combination: not only an outstanding research scholar but also a practical civil engineer and noted geotechnical consultant. We celebrate his life and many achievements – and that some of his vast knowledge is on record in the Short Course Series of books that he inspired and that we have had the privilege to co-write with him.

Marcus Matthews, Bruce Menzies
University of Surrey
Guildford 2007

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# Contents

# CHAPTER ONE

# Ground origins: plate tectonics and the rock cycle

## Plate tectonics: the unifying theory

### Overview

Plate tectonics is fundamental to understanding geology and how the Earth's surface works. Before taking this argument any further it is necessary to gain some appreciation of geological time. It is difficult to comprehend this concept since it is natural to judge time spans in terms of the length of human experience which is usually expressed in decades. However, when researching their ancestors, most people begin to comprehend time in terms of centuries. Furthermore, periods measured in millions of years are almost impossible for people to comprehend. Geologists describing events such as the collision of the Indian Continent with the Eurasian Continent and the resultant formation of the Himalayan mountain chain make it sound as if this happened almost instantaneously. Although it appears that they are shrinking time; in reality they are not. For example, it took about 2 million years for the Himalayas to form, which is certainly a long time. However, when put in the context of the age of the Earth (4500 million years) this event is equivalent to happening overnight in human experience.

The formation and wearing down of mountain chains has been going on for 100's of millions of years. The Highlands of Scotland were once a mountain chain as grand and high as the Himalayas. What is seen today are the remnants or 'roots' of that mountain chain that formed over 400 million years ago. Adjacent points on the San Andreas Fault may have been displaced by about 500 km, but this has occurred over 60 million years. The Grand Canyon was cut some 2 km deep by the Colorado River, but it did so over 30 million years. The chalk, which forms the famous 100 m-high white cliffs of Dover in the UK, represents the accumulation of mainly skeletal remains of micro-organisms (e.g. plankton) over a period of 10 million years. It is important to appreciate how long these things take to happen, as geologists tend to compress time, for obvious reasons, leading the unwary to believe that features such as oceans and mountain chains form relatively quickly.

*Table 1.1 The stratigraphical column showing the divisions of geological time and the age of certain events (after Blythe and de Freitas, 1984). © Reproduced by permission of Hodder & Stoughton Ltd*

| EON | ERA | PERIOD | EPOCH (here given only for the CENOZOIC ERA) | DURATION and AGE ($10^6$ years) | | MOUNTAIN BUILDING (Orogenies) (EUROPE) | (N. AMERICA) | NOTES |
|---|---|---|---|---|---|---|---|---|
| | | | Holocene | | PRESENT | | | At least 3 major glaciations in N. Hemisphere and changes in sea level from +10 m to −100 m |
| | | Quaternary | (last 10 000 yrs) | 0.01 | | | Coast Ranges | |
| | | | Pleistocene | 1.99 | 2 | (Himalayan) | | |
| | CENOZOIC (= 'recent life') | Tertiary (Neogene) | Pliocene | 23 | | Britain emerges | | |
| | | | Miocene | | 25 | | | ←First record of hominids ←Red Sea opens |
| | | Tertiary (Paleogene) | Oligocene | | | | | Australia separates ←from Antarctica |
| | | | Eocene | 40 | | | | |
| | | | Paleocene | | 65 | Alpine | Laramide | ←Primates appear S. Atlantic opens |
| PHANEROZOIC (= 'evident life') | MESOZOIC (= 'middle life') | Cretaceous | Each of these Periods is divided into numerous Epochs which can be recognized throughout the world | 79 | 144 | | Nevadan | ←Indian and southern oceans open |
| | | Jurassic | | 69 | 213 | | | |
| | | Triassic | | 35 | 248 | | | ←C. Atlantic opens Gondwanaland separates |
| | PALAEOZOIC (= 'ancient life') | Permian ('NEWER') | | 38 | 286 | | | |
| | | Carboniferous | | 74 | 360 | Hercynian | Appalachian | |
| | | Devonian | | 48 | 408 | | | |
| | | | | | | | Acadian | also development in the southern hemisphere of the Samfrau fold belt |
| | | Silurian ('OLDER') | | 30 | 438 | Caledonian | | |
| | | Ordovician | | 67 | 505 | | Taconian | |
| | | Cambrian | | 85 | 590 | Assyntic | | ←First appearance of exoskeletal tissue |
| PROTEROZOIC | SINIAN RIPHEAN | All rocks older than the Palaeozoic can be collectively described as PRECAMBRIAN | Many Precambrian rocks are severely deformed and metamorphosed, but large areas of undisturbed Precambrian strata are known. Epochs that can be correlated throughout the world have not been defined | | | ←2000 First stable crustal plates | | Diamonds, Sn, Cu, NaCl (first appearances) ←Oxygenic atmosphere established, Fe ores ←Great Dyke, Zimbabwe |
| | | | | 1910 | ~2500 | | | |
| ARCHEAN | | | | 2100 | | Numerous orogenies probably not involving plate tectonics prior to the development of stable crustal plates | | Concentration of dispersed elements to form metalliferous accumulations Cr, Au, U, Pt |
| | | | | | 4600 | | | Origin of the Earth |

Geologists divide the Earth's history into time units called *eras* and subdivide it further into *Periods* and *epochs* (Table 1.1). It is customary for geologists to refer to rocks in this way. For example, a rock such as chalk was formed during the Cretaceous period, so it is said to belong to the Cretaceous system. This table also shows periods of mountain chain formation in Europe and North America

**The structure of the Earth**

It has been shown, from the study of how seismic waves produced by earthquakes and nuclear detonations travel through the Earth, that our planet is made up of layers (Grotzinger *et al.*, 2007; Hamblin and Christiansen, 2001). The structure of the Earth is shown in Fig. 1.1. The core of the Earth is believed to comprise mainly iron with some nickel and sulphur. The outer part of the core does not transmit seismic shear waves, suggesting that it is in a liquid state. The core is enveloped by the mantle that is believed to have much the same chemistry throughout but varies in character. Based on small slivers of mantle material that have been brought to the Earth's surface by tectonic activity it is believed that it is composed of peridotite, a rock containing the silicate minerals olivine and pyroxene. The uppermost 100 km of the mantle is considered to be solid since it does not absorb shear waves. This, together with the overlying crust, is known as the lithosphere (Fig. 1.2). At the base of the lithosphere shear wave velocities reduce and the waves are partially absorbed. This suggests that the material is partially molten (only a few %) and behaves plastically. This lower zone, known as the asthenosphere

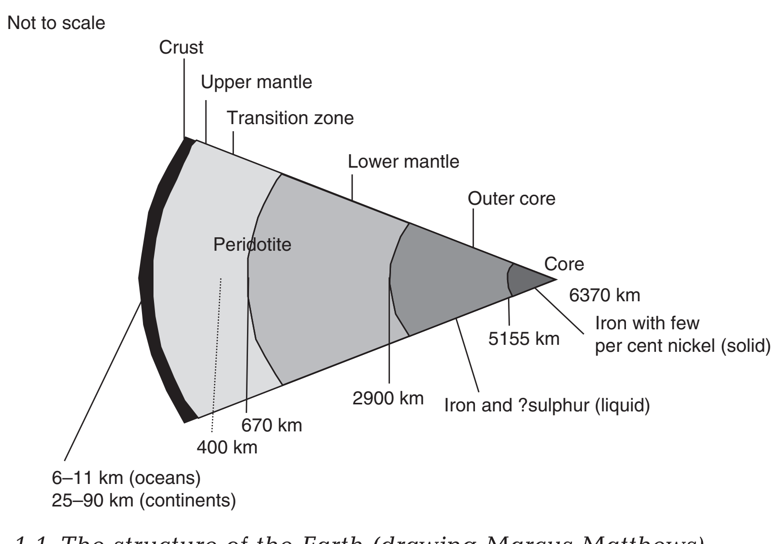


*Fig. 1.1 The structure of the Earth (drawing Marcus Matthews)*