ROCKS AND FOSSILS
Editor: J. A. G. Thomas

1 *Snowdonia* M. F. Howells, B. E. Leveridge and A. J. Reedman

2 *The Weald* Wes Gibbons

About the author
Wes Gibbons completed this book whilst a member of staff in the Department of Geology, Portsmouth Polytechnic: he is now with the Department of Geology, University College, Cardiff. He has lived in the Weald for several years and has also had field experience as a research geologist in the Channel Islands and North Wales. He has also written *The rocks of Sark – a geological field guide to the island*, published by Manche Technical Services (Jersey).

Every effort has been made to ensure that the information presented in this book is accurate and up to date. However, readers are invited to draw our attention to any inaccuracies, particularly in the information concerning access to land covered in the excursions, by writing to the author, c/o George Allen & Unwin, PO Box 18, Park Lane, Hemel Hempstead, Herts HP2 4TE.

The Weald

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Return to The Weald

It is around 40 years since I wrote my guide to the geology of the Weald. Now, incarcerated at home in Barcelona as a result of the 2020 SARS-CoV-2 pandemic, I have finally got around to placing the book online. Well, better late than never then. The rocks are still there, and their interpretation has not changed fundamentally, so the book should still I hope be of some use to those who wish to introduce themselves to the basics of Weald geology. There have of course been many publications on this subject since 1980. Those freely available on the web include:

1. Jonathan Radley 2004. Demystifying the Wealden of the Weald (Lower Cretaceous, south-east England). OUGS Journal. https://ougs.org/files/ouc/archive/journal/OUGSJ_25_(1)_screen_res.pdf
2. Peter Hopson, 2005. A stratigraphical framework for the Upper Cretaceous Chalk of England and Scotland, with statements on the Chalk of Northern Ireland and the UK Offshore Sector. British Geological Survey Research Report. http://nora.nerc.ac.uk/id/eprint/3230/1/RR05001.pdf
3. Jonathan Ridley and Percival Allen 2012. The non-marine Lower Cretaceous Wealden strata of southern England. Proceedings of the Geologist's Association. https://reader.elsevier.com/reader/sd/pii/S0016787812000028?token=1AD419198D6DF703075D5D4EB5DC11F129AAC8FDD120DB75D45A67077A86BC2234C65C4448C4E479F4C2887D1AEC61A6
4. Matt Friedman, Hermione T. Beckett, Roger A. Close and Zerina Johanson 2015. The English Chalk and London Clay: two remarkable British bony fish Lagerstätten. Geological Society, London, Special Publications. https://sp.lyellcollection.org/content/430/1/165
5. Oladapo Odunayo Akinlotan 2015. Recent thesis on Wealden strata available online: https://www.researchgate.net/publication/316274822_The_Sedimentology_of_the_Ashdown_Formation_and_Wadhurst_Clay_Formation_southeast_England
6. Sanjeev Gupta et al. 2017. Two-stage opening of the Dover Strait and the origin of island Britain. Nature. https://www.nature.com/articles/ncomms15101
7. Christopher Pullan and Malcolm Butler 2018. Paleozoic gas potential in the Weald Basin of southern England. Geological Society, London, Special Publications . https://sp.lyellcollection.org/content/471/1/333

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I owe to my father an early geographic knowledge of the Wealden area. Sometime around 1960 he bought a piece of woodland south of our house in London in a remote part of the Weald called Greenwood, just northeast of Punnett's Town in East Sussex. The dream was to get away from the city at weekends, piling the family into a Ford Prefect (registration TPE142, if I remember correctly) and camping overnight. He (and my elder siblings) partly cleared the land and planted Christmas trees sure to earn a pretty sum in the future. As for me, too young for responsibility, I roamed the woodlands freely with my dog Midge, getting to know the area intimately. I have a clear early memory of geological exposures in the hidden deep valley banks of the nearby River Dudwell, rocks that I would later learn are Late Jurassic sediments belonging to the Purbeck Formation. Sadly the dream died young with my father, stricken with cancer at 51 years old and never to see his Christmas trees grow to maturity. Fifteen years later I wrote The Weald as a distraction from studying for my PhD thesis, and now looking back I guess the book was at least in part a direct legacy of those early years in Greenwood.

Several years ago Teresa and I twice walked across the area, stopping overnight in pubs and B&Bs. The first of these trips took a route crossing the central Weald directly south to finish at Eastbourne, whereas the second time we headed east from Gatwick airport to the coast at Rye. We were lucky with the weather, and both walks were rewarding experiences. The High Weald especially is a beautiful, secretive part of the world, once you get off the main roads and away from the towns. So near to London and the busy south coast, and yet so far, by-passed by the masses. And long may it remain so.

Wes Gibbons April 2020

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First published in Unwin Paperbacks 1981

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UNWIN® PAPERBACKS
40 Museum Street, London WC1A 1LU

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British Library Cataloguing in Publication Data

Gibbons, Wes
The Weald. – (Rocks and fossils).
1. Geology – England – Weald
I. Title II. Series
554.22'5 QE262.W4 80-41578

ISBN 0-04-554004-7

Set in 9 on 11 point Times by Typesetters (Birmingham) Ltd.,
and printed in Great Britain
by Hazell Watson & Viney Ltd, Aylesbury, Bucks.

Invited foreword

Over the past few years there has been increasing public interest in the geological sciences. This derives from an increased awareness of their twofold role: first, they sketch out the history of our planet, and secondly they help to provide the mineral resources on which modern society depends. Although this spread in interest is to be welcomed, it can lead to certain undesirable consequences as more and more visitors come to examine a finite number of instructive rock exposures.

The author and publishers of this book are fully aware of the need to make the best possible use of the outcrops it describes and have accordingly consulted with the Nature Conservancy Council, the official body responsible for conservation in Britain. All their efforts however will be nullified if today's readers choose to ignore their responsibility to students of the future.

It must be emphasised that the vast majority of geological outcrops are in private hands and that access to them is through the goodwill of the owners and occupiers. If lost, this goodwill will be difficult, if not impossible, to regain – it can take only one careless act to cause offence. Further, many geological localities can lose their interest through the cumulative effects caused by the unnecessary use of hammers. To observe and record, collecting any necessary specimens only from fallen rock, will in general give a better understanding of geology than will a physical assault on selected portions of the rock face. The indiscriminate use of hammers is thus as profitless as it is damaging.

The author and publishers of this guide have done their best to ensure the maximum benefit from your visit to the Weald; it remains for you to ensure that the same benefit remains available to your successors.

DR G. P. BLACK
Nature Conservancy Council

Preface

The Weald is that part of South-East England bounded by the North and South Downs and includes within it parts of Kent, Surrey, Sussex and Hampshire. The area is an excellent place to study geology, as it encompasses a wide variety of fossiliferous sedimentary rock formations, each of which has imprinted its own scenic hallmark upon the landscape. Furthermore, the formations have proved particularly important to man, from the sixteenth century iron industry to the brick-making, gypsum-mining and sand-quarrying of the present day.

This book has been written as an introduction to the study of the field geology of the Weald. The first four chapters provide a descriptive background, dealing with the oldest exposed rocks first and progressing through 135 million years of Earth history to the present day. Particular emphasis is given to the close relationship of geology to Wealden scenery. Geology is first and foremost a field subject; and as fieldwork provides the most pleasant way to learn about rocks, a series of descriptive field excursions is included, which allows readers to examine the rocks for themselves. These excursions are all located in scenically attractive areas easily accessible from London, and they should prove of value not only to private individuals but also to teachers of geology when planning fieldwork. A balance has been sought between those who know nothing of geology and those who are familiar with the subject. A glossary of geological terms for the non-geologist is given at the back of the book, and the style has been kept simple throughout. These terms are printed in bold type in the text. If a word appears unfamiliar and is not included in the glossary, the reader should refer to the index, which will indicate where the word is described more fully in the text.

WES GIBBONS
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1 The Central Weald

Purbeck Beds

The Purbeck Beds of the Weald appear at the surface in the remote country around Brightling (Fig. 3). The beds are the oldest **rocks** exposed in the Weald and usually occur at the base of the steep-sided valleys that dissect the sandy hills of the High Weald (Excursion 8). The rocks are mostly soft dark **shales** within which lie thin beds of hard pale **limestones** and yellow–brown **sandstones**. The stratigraphic column (Fig. 3c) indicates the sequence of **beds**. At the base of the **formation** a number of valuable **gypsum** seams lie within the shales. These are overlain by more shales, which are capped by a series of thin limestones known as the Blues Limestones – a name given by the eighteenth-century miners who worked the stone. Above the Blues are more shales, interbedded with thin **cross-bedded** sandstones and a few limestones, some of which contain **fossil** oyster shells. Similar beds packed full of oysters are found at the same level in the Purbeck Beds of Dorset, where they are called the 'Cinder Beds'. This horizon is important, because it is usually where the boundary line between the Jurassic and Cretaceous is drawn. About 30 m above these Sussex equivalents of the Cinder Beds lies a second group of thin limestones, called the Greys Limestones by the old miners. These distinctive thin limestone beds are usually crowded with fossil **bivalve** shells and are very different in character from the less fossiliferous, bluish, more crystalline Blues Limestones. The Purbeck Beds are about 130 m thick, although the lowest 20 m may only be examined in the gypsum mines.

Fossils are commonly preserved within the Purbeck sequence, particularly in the limestones, some of which are composed almost entirely of bivalve, **gastropod** and tiny **ostracod** shells (Fig. 4). Blackened plant fragments are common in the sandstones, fish remains have been found throughout the formation, and bones of the dinosaur *Iguanodon* have been discovered in the gypsum beds. The abundance of aquatic fossils indicates that the Purbeck sediments were mostly deposited under water. The fossils also show that the salinity of the water was variable, as some beds contain species that lived only in freshwater conditions (e.g. *Viviparus*), whereas others contain species that preferred slightly salty ('brackish') water (e.g. *Neomiodon*). The Cinder Beds oysters (e.g. *Liostrea*) indicate near marine conditions. Detailed study of the abundant ostracods (Anderson & Bazley 1971) has revealed alternations of species up through the succession of sediments. Thirty-nine of these alternations ('faunicycles') have been recognised, each seeming to reflect variations between more freshwater and more brackish conditions. A corresponding cyclic variation in average

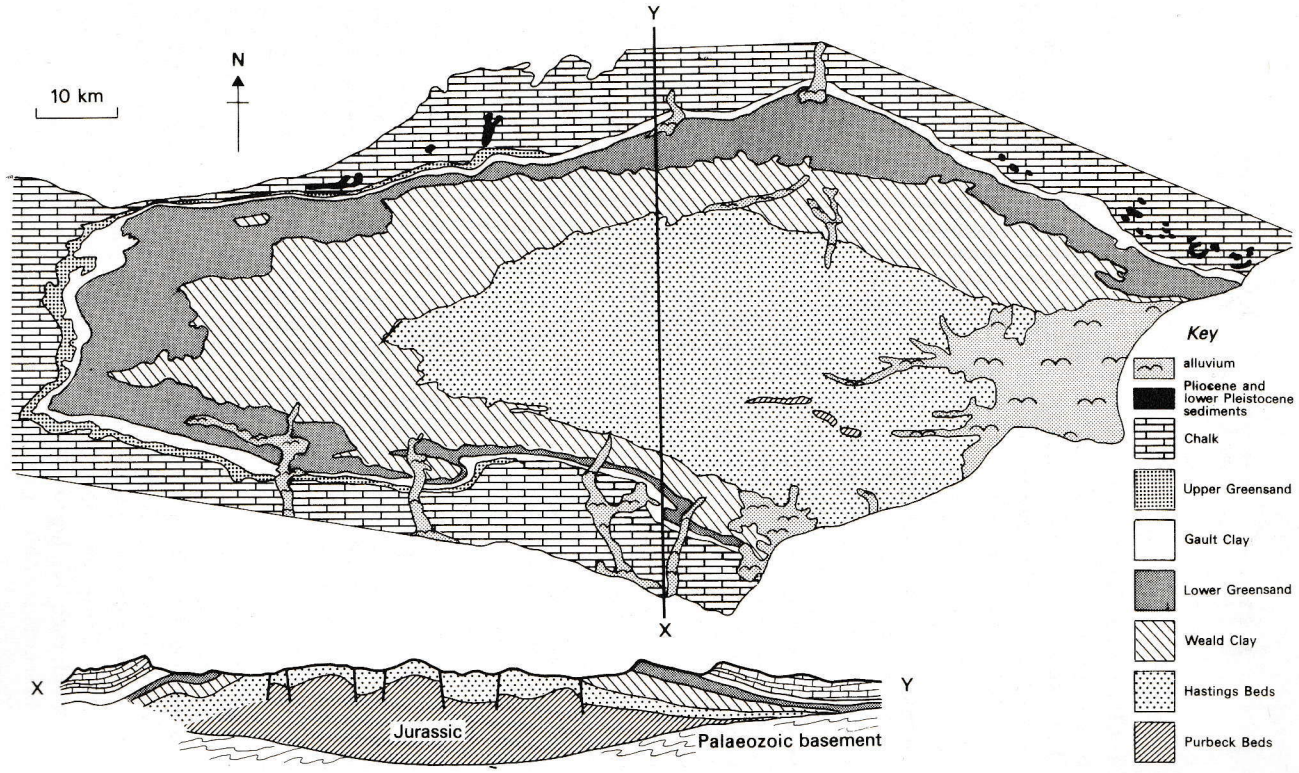


Figure 1 Geological sketch map and cross-section of the Weald.

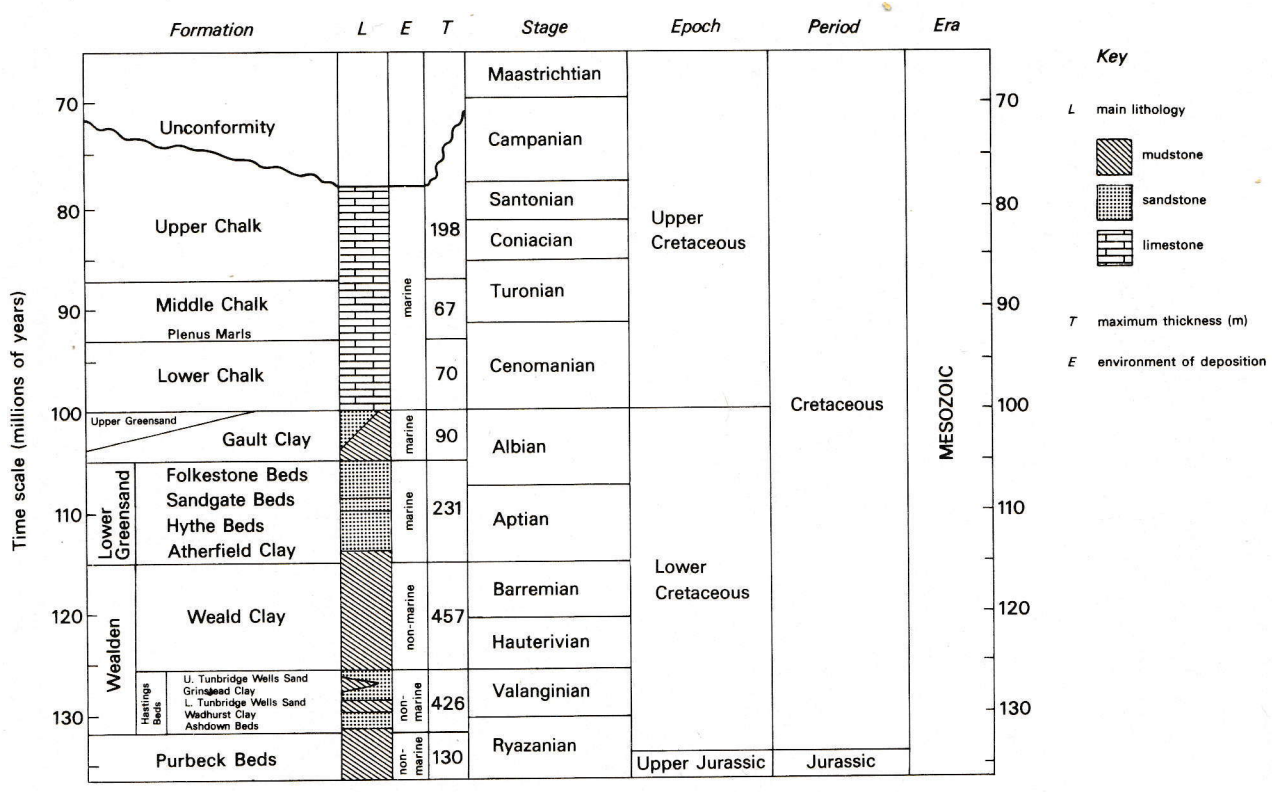


Figure 2 Stratigraphic table for the Mesozoic rocks exposed in the Weald.

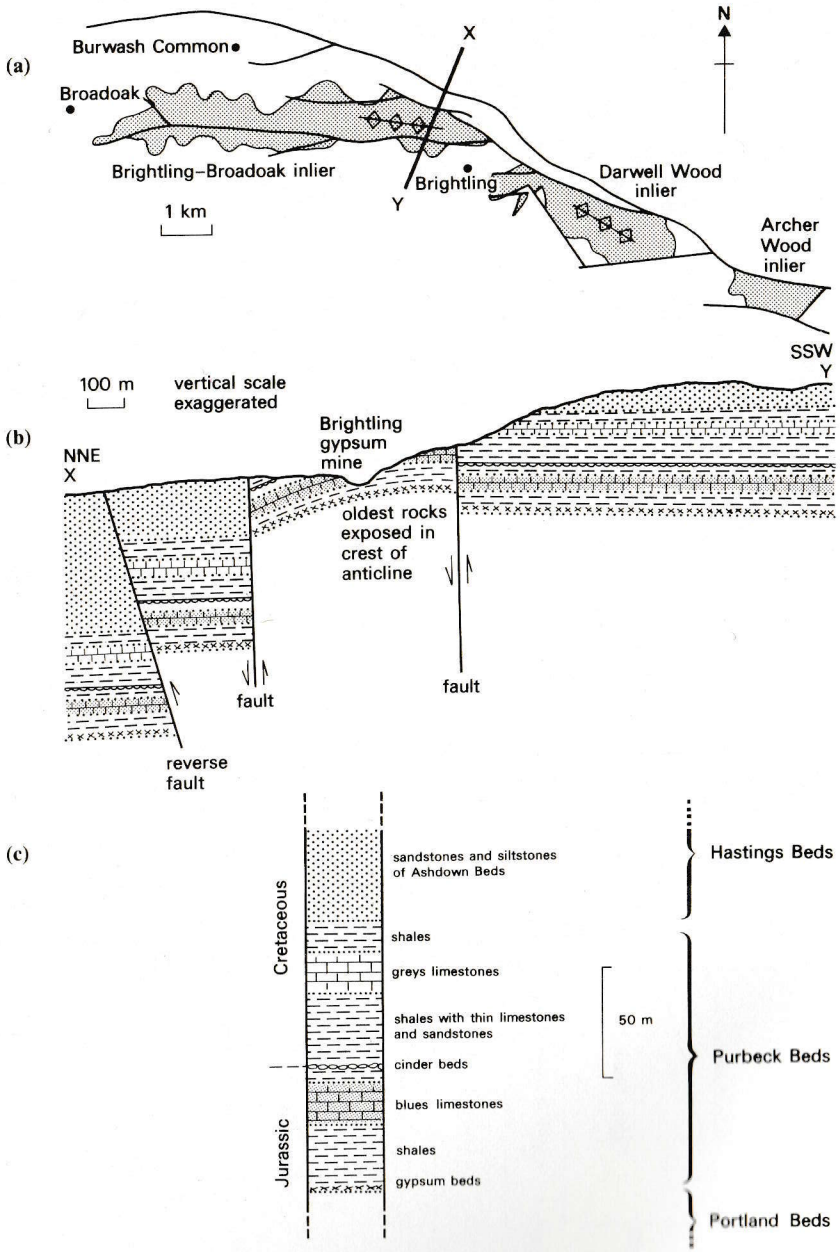


Figure 3 The Purbeck Beds in the Weald. (a) Outcrop map. (b) Geological cross-section (note faulting and folding). (c) Stratigraphic column.

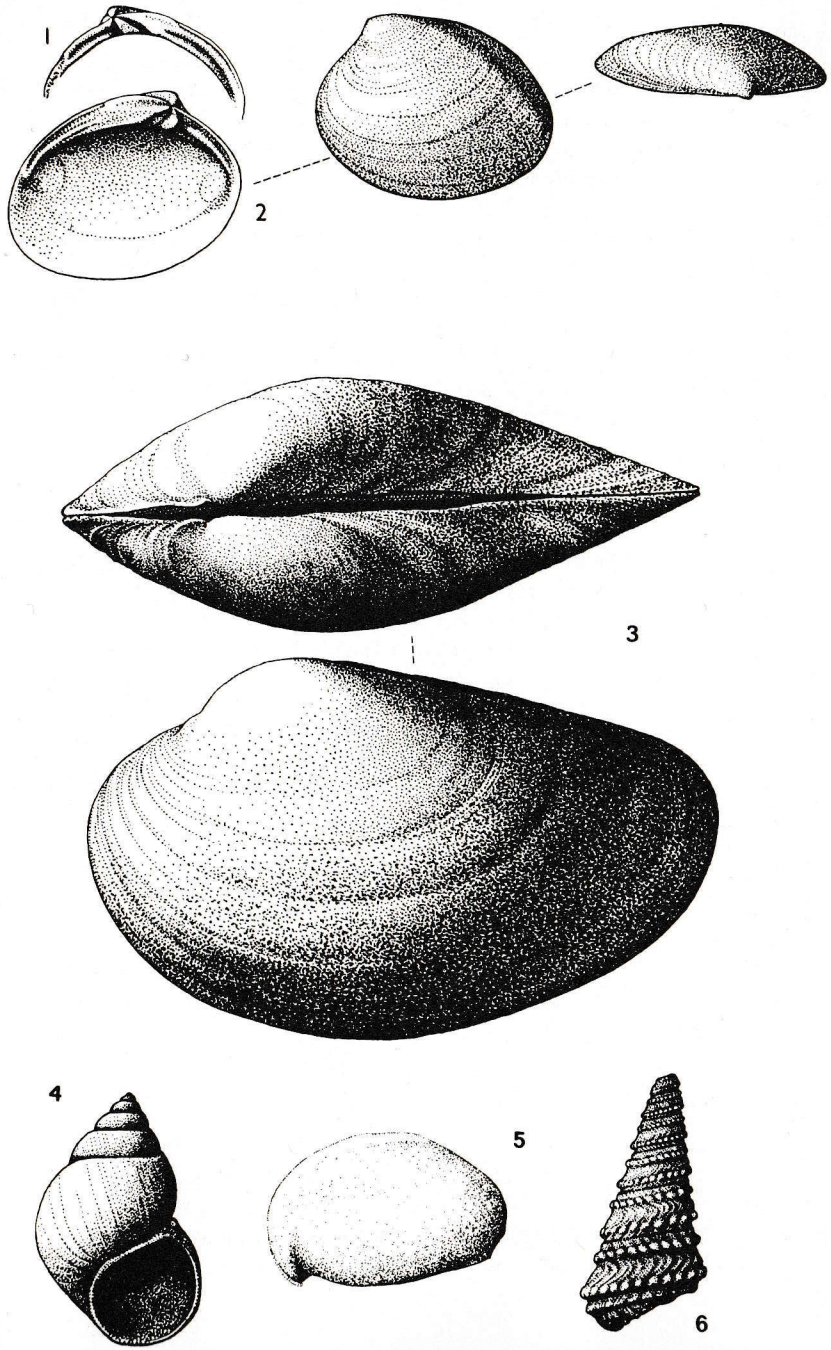
rainfall seems a likely explanation for this variation in salinity level. A sequence of many years of low rainfall would reduce the supply of fresh water to the area, which would become progressively more saline until the trend was reversed by a succession of wetter years.

The Purbeck rocks lie within the exposed core of the **Wealden Anticline** (Fig. 1), and the beds are usually horizontal or very gently dipping. Gentle anticlinal folds occur, but the most important structural feature of the **outcrops** is that they are cut, and often bounded by, many **faults**, which run WNW–ESE across the area parallel to the main anticlinal **fold axis** (Fig. 3). The Purbeck shales exposed in the valley bottoms are often strongly contorted by a phenomenon known as 'valley bulging': the soft rocks have been squeezed out into the valley side by the weight of what is commonly more than 100 m of overlying rock. The process may be likened to placing a pile of bricks on a slab of butter (Fig. 14).

Man's uses of the Purbeck Beds in the Weald have been far greater than the small area of outcrop may at first suggest. The rocks provide one of the very few sources of limestone in the central Weald, and during the eighteenth and early nineteenth centuries they were extensively excavated by stone-miners. The limestones were the chief source of agricultural lime for many kilometres around and were also used as building stone. Of greater importance to modern society was the discovery in 1873 of extensive gypsum deposits lying just below ground level in the area. This has led to the development of a thriving twentieth-century mining and processing industry based on the Purbeck gypsum – the only commercially exploited gypsum deposits of Jurassic age in the United Kingdom. The gypsum occurs as four main seams, which vary from 2 to 4 m in thickness, although only the top and bottom seams are worked. There are two mines, one near Mountfield (720194) and one near Brightling (677217), which together were producing 24% of the total UK gypsum output in 1976–7. The raw gypsum is carried from the mine by aerial ropeway (Fig. 5) to a processing plant in Robertsbridge, where it is mostly used either in the production of plaster and plasterboard or else in the manufacture of Portland Cement. Because of planning conditions, the absence of waste and the clean nature of the mineral, the gypsum industry makes very little impression upon the surrounding landscape.

Hastings Beds and Weald Clay

Lying above the Purbeck Beds are the Hastings Beds and Weald Clay, known together as the 'Wealden', the tongue-shaped outcrop of which stretches from Haslemere to Hastings. The older Hastings Beds occur within the centre of this area and are surrounded by a wide outer horseshoe of overlying Weald Clay (Fig. 1). The Hastings Beds have been divided into



five formations, each as deposited consisting dominantly of either sand or mud. The deposition of the muddy Purbeck Beds was followed by the sandy Ashdown Beds, which were succeeded in turn by the Wadhurst Clay, the Lower Tunbridge Wells Sand, the Grinstead Clay and the Upper Tunbridge Wells Sand. These alternating sandstones and shales were finally overlain by a great thickness of shales with some sandstone and shelly limestone beds, which together constitute the Weald Clay.

The Wealden sandstones are typically fine-grained buff-coloured rocks, which contain few well-preserved fossils but are often rich in blackened plant fragments. The beds are commonly cross-bedded and ripple marked, and the presence of such features as sun cracks and dinosaur footprints indicates original deposition of these rocks in very shallow water. The clay formations are similar to the Purbeck Beds, consisting of dark shales with a few **siltstones**, sandstones and thin shelly limestones containing bivalves (e.g. *Neomiodon*) or the gastropod *Viviparus*. Soil beds with plant roots still in place have occasionally been found; but in contrast to the sandstones, plant remains are generally less common than a well-preserved fauna of bivalves, gastropods and ostracod shells. The clays also locally contain bands and nodules of rusty-weathering ironstone, which provided most of the source ore for the old Wealden iron industry.

The difference in **lithology** between the dominantly shaly Weald Clay and the sandier Hastings Beds is reflected in the way the rocks have deformed during the formation of the Wealden Anticline. The Hastings Beds are crossed by many steeply dipping faults similar to those bounding the Purbeck Beds (Figs. 3 and 25), whereas few faults or folds affect the Weald Clay. It seems that, while the harder Hastings Beds were breaking up beneath them, the soft Weald Clay simply draped itself over the rocks below as slip along the **bedding planes** muffled the effect of faulting.

The scenery associated with the two main rock **groups** is markedly different. The sandy High Weald on the resistant Hastings Beds often assumes a hilly, wooded, attractively intimate character, with fine views over deep winding valleys dissecting a high sandy plateau (Excursion 11). Actual **exposures** of the formations are rare except in the outcrop of some of the more massive sandstone members, such as the Ardingly Sandstone, which occurs at the top of the Lower Tunbridge Wells Sand and has been

Figure 4 Fossils from the Purbeck and Wealden of the Weald.
1,2 *Neomiodon medius* × 2 (brackish to near-marine bivalve from the Weald Clay).
3 *Unio valdenis* × ½ (freshwater bivalve from the Wealden).
4 *Viviparus sussexensis* × 1 (freshwater gastropod from the Wealden).
5 *Cypridea tumescens* × 25 (freshwater ostracod from the Purbeck).
6 *Paraglauconia strombiformis* × 1 (freshwater gastropod from the Purbeck and Wealden).

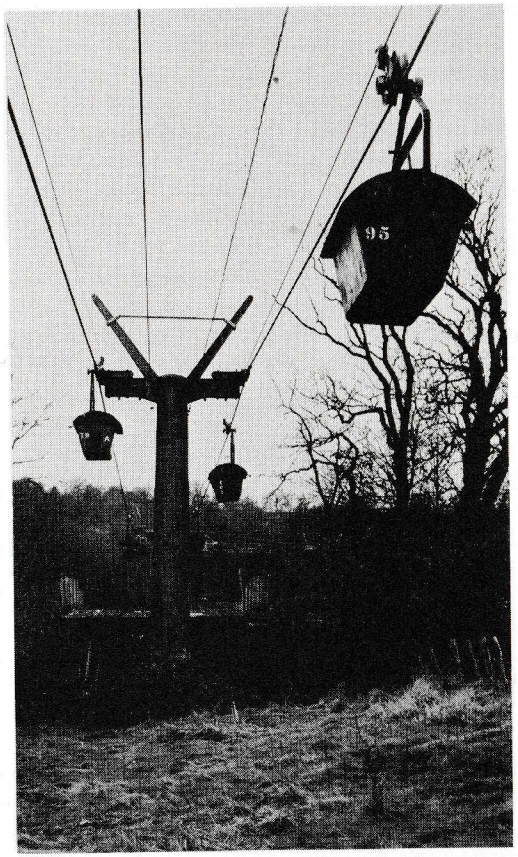


Figure 5 Aerial ropeway carrying raw gypsum from the Mountfield gypsum mines to the processing plant at Robertsbridge (Excursion 8).

naturally laid bare in many places to form the well-known 'rocks' of the High Weald (Fig. 9, Excursions 2 and 11). By contrast, the outcrop of the Weald Clay forms a wide 'clay vale' crossed by low rolling undulations where thin beds of harder sandstone or limestone come to the surface to form subdued scarps.

As elsewhere in the Weald the geology not only controls the scenery but also is the most important influence upon agriculture, as the underlying rocks affect the nature of the soil, the natural drainage and the contour of the ground. The badly draining impermeable nature of the Weald Clay has long been a tribulation to those who farm the land above it. Cobbett

claimed that 'the bottomless clay would only grow three things well, oak trees, wheat and grass'. About a quarter of the area is still coppiced oak and ash woodland, and most of the remaining land is pasture, although, where the sandstone and limestone beds occur, the soils locally become light enough to encourage arable cultivation. There are also abrupt changes into far richer soils wherever river alluvium has locally been deposited on the clay: for example, between Tonbridge and Yalding (650470) the Medway has covered the clay with a fertile spread of loam and gravel upon which hops and fruit have long been grown. Perhaps surprisingly, many of the soils above the sandier Hastings Beds are also poorly drained and covered only by woodland and pasture. This is mainly due to the very fine-grained nature of most of the sands and the common occurrence of silt and clay beds. A notable exception to this is provided by the high heathland of Ashdown Forest, where the Ashdown Beds are covered by leached sandy infertile soils (Excursion 11).

The most important present economic use of the Wealden is brick-making, and there are a number of working quarries in the various clay formations (mostly Weald Clay). Some of the Wealden sandstones have been much used as sources of building stone; Bateman's House (Fig. 6, Excursion 8) provides a good example of the use of Ashdown Sandstone. Although there is little active quarrying today, Philpots quarry (Excursion 11) still works the massive Ardingly Sandstone. Shelly limestone from the Weald Clay has been extensively used for ornamental pieces, such as baptismal fonts (e.g. Lurgashall, 273938), and as building stone for churches (e.g. Tenterden, 884334) and various houses (Excursion 1). This rock, packed full of *Viviparus* shells, has been given various titles (e.g. 'Sussex marble') but was simply called 'winkle stone' by the less grandiose. Finally, the more permeable sand formations, usually the Ashdown Beds, are sometimes drilled for water supply, although these rocks are only minor **aquifers** compared with the Chalk and Lower Greensand.

The Wealden iron industry

Iron has been worked on a small scale in the Weald probably since Neolithic times, but it was not until the sixteenth century that an important iron industry developed. The chief source of iron was the lower beds of the Wadhurst Clay, although smaller amounts were locally obtained from other formations, such as the Weald Clay and Purbeck Beds. The ore was dug from bell-shaped pits a few metres in diameter, which widened downwards to a depth of some 6 m. A wide variety of items was made in the Weald, including tools, firebacks, grave slabs and the railings around St Paul's Cathedral, although by far the most important product was military equipment. The first casting of iron cannon took place in Buxted (500234)

Figure 6 Bateman's House, the home of Rudyard Kipling, built from local Ashdown sandstone (Excursion 8).

in 1543 and set the scene for a virtual monopoly in gun-casting enjoyed by the Weald for the next two centuries. Such a trade was inevitably subject to fluctuations, reaching a peak when the country was at war, but in 1709 it received a mortal blow when Darby discovered how to substitute pit coal for the costly charcoal in blast furnaces. The Wealden ironmasters were unable to compete with the low price of both foreign iron imported into London (their chief market) and iron produced with the aid of coal elsewhere in Britain, and by the early nineteenth century the industry was dead:

> So ended, after some 300 years of life, one of the most important industries of these islands. In its prime it had employed a notable proportion of the inhabitants, and was not only a means of prosperity to the countryside but a source of strength to the nation.
>
> Little, save some of the ponds, remains to be seen today; many a once busy site is hardly to be distinguished in the dense tangle of brushwood and bracken that has overgrown it. The buildings have gone, almost every stick and stone has been utilised elsewhere. The great bays are crowned with noble trees of many years growth and the once threatened woods have come into their own once more. (Straker 1931)

The Purbeck–Wealden landscape

The deposition of the Purbeck and Wealden sediments took place over about 22 million years, during which time the dominant lithology, either

sand or mud, accumulated in a low-lying region bounded by higher ground to the north and west. The fossils indicate that, whereas most of the sands were deposited in fresh water, the muds formed in conditions of variable salinities from freshwater to brackish. The environment in which these beds were deposited was for long believed to be deltaic, with sandy deltas building out from the north over 'pro-delta' muddy waters and swamps to the south. The constant alternation of sand and mud found throughout the Wealden succession was explained essentially in terms of the gradual growth and consequent decay of these deltas. More recent work, however, has led Allen (1975) to reject his earlier deltaic model in favour of one that envisages the sediments being deposited by rivers on a wide low-lying floodplain. The 'deltaic' sands now become sands deposited by fast-flowing **braided rivers**, and the 'pro-delta' muds accumulated instead beneath sluggish muddy waters and swamps in shifting mazes of mudbanks and innumerable pools of variable salinity. A picture of the Purbeck–Wealden environment may be drawn as follows.

For much of the Jurassic a wide sea had covered southern England from Devon to the Weald, and a thick sequence of mostly marine sediments had been deposited. Towards the end of this period, however, the sea gradually retreated southwards to leave a coastal plain of swamps, alluvial flats and lagoons. Palaeomagnetic studies indicate that the new landscape lay in tropical latitudes of about 30°N. The area was initially subjected to phases of inhospitably arid conditions under which the gypsum beds were formed, after which more fresh water became available and muddy sediments were deposited in a warm, wet and possibly monsoonal climate. The landscape had become transformed into a wide flat muddy floodplain bordering a sea to the south, with sediment being supplied mostly by sluggish rivers draining higher ground to the north. Occasional flooding brought small quantities of sandy sediments down to the area from the northern uplands. Salinities varied from freshwater in rivers to brackish in pools and lagoons, the salty nature of which was probably a result of low rainfall, high evaporation and, perhaps, periodic incursions by the sea. Such an influx of sea water may have been responsible for the environment in which the Cinder Beds oysters lived. The fauna clearly reflected the varying salinity, with shelly animals such as *Viviparus, Unio* and cypridean ostracods thriving in the freshwater lakes and channels, and *Neomiodon* and non-cypridean ostracods preferring more saline lagoonal conditions. Thin limestone formed wherever these calcareous organisms accumulated in clear mud-free waters.

A dramatic change in **sedimentation** occurred at the end of the Purbeck. The supply of fresh water greatly increased, and rapidly flowing **braided rivers** poured vast quantities of sand over the previously muddy plain. Such a transformation of the landscape is thought to be due to sudden uplift of

the northern source area by faulting. The gradient of the rivers increased correspondingly, and they became capable of carrying sand down on to the Wealden plain. Between individual (monsoonal?) floods fast-growing herbaceous horsetails often successfully colonised the sands and silts, forming a vegetation cover luxuriant enough to support large herbivorous dinosaurs, such as *Iguanodon*. The dominance of the dinosaurs during the Cretaceous would undoubtedly have provided the most impressive aspect of any Wealden landscape.

The deposition of the sandy Ashdown Beds was brought to a close by a period of weathering and erosion. The coarse sand supplies failed, possibly as a result of faulted subsidence of the 'London' uplands, and erosive winnowing left a thin pebble bed lying on top of the sands over much of the Weald. This bed, called the Top Ashdown Pebble Bed, was overlain by the shales of the Wadhurst Clay, which began the 'coarsening-upward' cycle anew (Fig. 7). The landscape reverted to a mudplain with occasional localised deposition of shelly limestones and sandstones as described for the Purbeck Beds. Localised concentrations of iron ore were formed by **diagenetic** redistribution of ferruginous material brought down to the Weald by the muddy rivers. Ideal conditions for iron enrichment of muddy sediments involve a hot humid climate, low-lying ground, intense chemical weathering and slow rates of sedimentation. Eventually, renewed uplift of the London source area rejuvenated the rivers and poured coarser sediments into the area to form the Lower Tunbridge Wells Sand (Figs 8 and 9), which is also capped by a top pebble bed (Excursion 11). Another cycle of this nature is recorded by the Grinstead Clay and overlying Upper Tunbridge Wells Sand. The environment in which the sandy Wealden formations were formed has been compared to the present-day braided floodplains of the Brahmaputra River in northern India.

Upon the Upper Tunbridge Wells Sand lies a great thickness of Weald

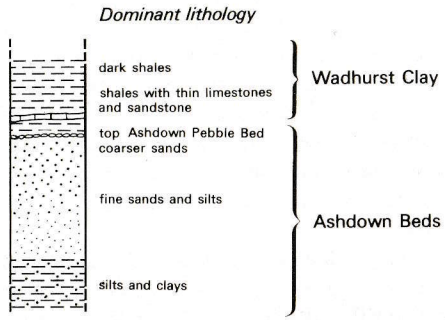


Figure 7 The Ashdown–Wadhurst megacycle.

Clay, which records a reversion to dominantly muddy swamp conditions for about 10 million years, longer than ever before (Fig. 2). Shelly 'Sussex Marble' limestones composed of the freshwater gastropod *Viviparus* or the

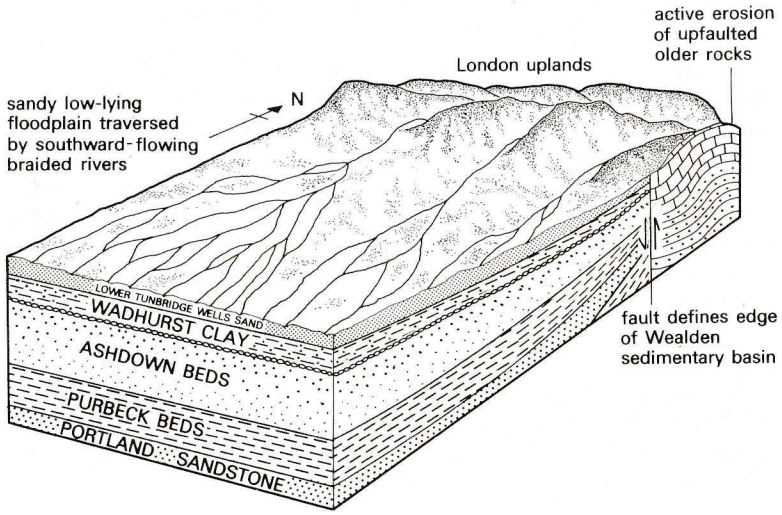


Figure 8 Diagrammatic reconstruction of Wealden geography during the deposition of the Lower Tunbridge Wells Sand (based on Allen 1975).

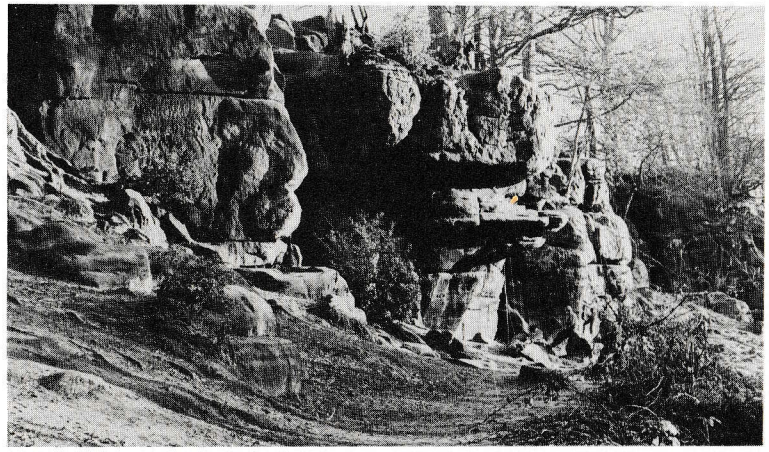


Figure 9 Lower Tunbridge Wells Sand forming Harrison's Rocks, near Groombridge (532356).

near marine–brackish bivalve *Filosina* were laid down where these organisms flourished briefly in clear waters of widely differing salinities. Thin sands (e.g. 'Horsham Stone') were again occasionally poured by rivers into the Wealden plain, but most of these appear to have come from a source upland area to the west. The old London uplands had probably subsided into low-lying ground.

For millions of years during early Cretaceous times rivers had poured their debris into a wide, gradually subsiding lowland area. The enormous thickness of sediment that accumulated in the floodplain shows both large and small-scale rhythmic fluctuation in the amount of sand or mud deposited. These rhythms were induced by climatic variation and perhaps by fault movements affecting the sediment source areas, which produced, on a large scale, three 'megacycles' (Fig. 7). These megacycles, used as a basis for the classification of the Hastings Beds into a group of sand and clay formations, were followed by the deposition of the thick Weald Clay. The latter formation differs from the older Cretaceous sediments beneath in having a more western provenance for most of its fluvial sandstones. Also, towards the top of the Weald Clay the fossil assemblages often suggest increasing salinity and herald the beginnings of a trend back towards a marine environment after more than 20 million years of fluvial rule.

2 The Greensands and Gault

The Greensand and Gault formations lie above the Weald Clay, and their outcrop forms a distinctive arc from Folkestone to Farnham, around to Petersfield and back to Eastbourne. This pattern clearly reflects the large scale geometry of the Wealden Anticline, the beds lying above and dipping away from the older rocks exposed in the fold core (Fig. 1). Exposures inland are usually restricted to sandpits, roadbanks and stream beds, although there are good coastal sections at Folkestone (Excursion 1) and Eastbourne (Excursion 7).

'It is traditional for those who write about the Lower Greensand to repeat the gibe that the formation is seldom green and frequently not sand' (Casey 1961). This peculiar accident of geological nomenclature originates from work in the early nineteenth century, when Smith and Webster described the **glauconite**-bearing 'Greensands' found above the Gault Clay. However, it was not generally appreciated that glauconitic sandy beds also existed *below* the Gault, and for a time the term 'Greensand' became the source of much confusion, as it was applied by geologists to the sandstones both above and below the Gault. When the error was realised, the name had become firmly established within the geological literature of the time, and so a compromise of 'Lower Greensand' (below the Gault) and 'Upper Greensand' (above the Gault) was reached in 1825.

The Lower Greensand is subdivided into four formations: the Atherfield Clay, Hythe Beds, Sandgate Beds and Folkestone Beds. Although variable in thickness and lithology, each formation is distinct from the others and can be traced all along the outcrop (Fig. 10). The lowest and therefore oldest formation of the Lower Greensand, the Atherfield Clay, lies upon the Weald Clay. Unlike the latter, however, the Atherfield Clay contains a rich collection of *marine* fossils, in contrast to the brackish and freshwater types preserved in the Weald Clay (Fig. 11). Towards the top the Atherfield Clay becomes more sandy and grades up into the Hythe Beds. Although the latter formation in the western Weald is composed mostly of soft sandstone with hard **chert** bands, in the east it contains beds of limestone and is known by the old quarryman's name of 'rag and hassock'. The hard sandy limestones are known as 'ragstone' and alternate with soft sands called 'hassock' (Excursion 2).

The lithologies found within the Sandgate Beds are also distinctively different in the east and west. In Kent the formation consists mostly of dark silts, whereas in Surrey and western Sussex the beds include various

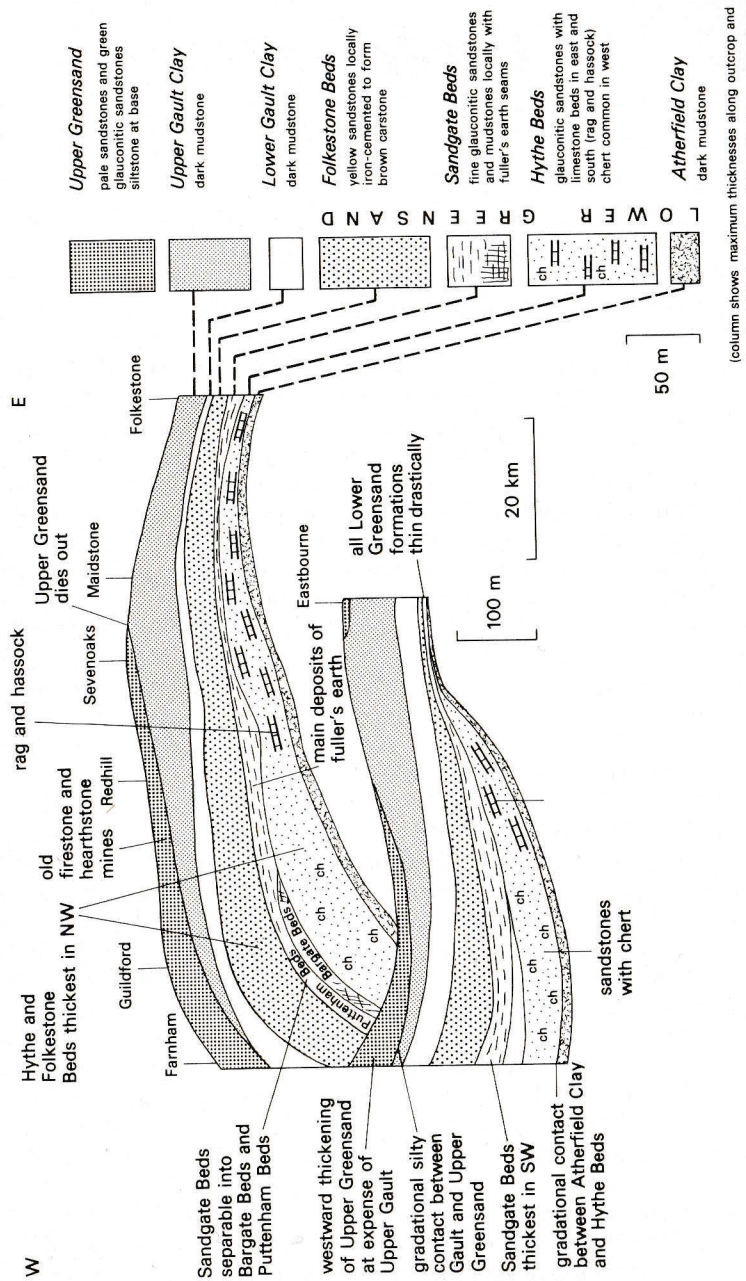


Figure 10 Variations in the Lower and Upper Greensands and Gault across the Weald.

sandstones and limestones and contain economically important seams of **fuller's earth**. West of Dorking it is possible to subdivide the Sandgate Beds into a lower **member** containing hard calcareous sandstone (Bargate Beds) and an upper member of softer iron-stained sands and silts (Puttenham Beds). The highest formation in the Lower Greensand, the Folkestone Beds, has a very similar lithology in most places across the Weald (Figs 12 and 13). it forms a thick series of often loosely cemented cross-bedded sandstones, usually stained yellow–brown by oxidised iron and containing thin beds of small pebbles and, more rarely, clay. In the west hard brown iron-rich sandstones, known as 'carstone', are common.

The Gault is a stiff dark fossiliferous blue–grey clay, divided simply into the Lower Gault and Upper Gault. The former can be traced as a clay formation right around the Weald, but the Upper Gault thins westwards and becomes replaced by the Upper Greensand (Fig. 10), which consists mostly of white or green sandstones. Many of these sandstones weather to distinctive pale-coloured rocks known as 'malmstone', varieties of which were once mined extensively in the Redhill area.

Scenery and soils

The most characteristic feature of Lower Greensand scenery is the high escarpment that bounds the central flat lands of the Weald Clay. This line of hills can be followed through Kent, Surrey and down into southwestern Sussex, its most striking development being in the Hindhead area and around Leith Hill, which, at 294 m OD, is the highest point in the Weald. The highest hills are invariably those capped by beds of rock particularly resistant to erosion; hard chert bands in the Hythe Beds protect the summits of such hills as Ide Hill (486518) and Leith Hill (139432), and brown masses of ironstone in the Folkestone Beds protect the top of St Martha's Hill (Excursion 4) and the conical hills of the Devil's Jumps (Excursion 5). The escarpment is less obvious in eastern Kent, where it has been extensively eroded. In the southern Weald the sandy formations thin out drastically, and the escarpment is lost altogether between Lewes and Eastbourne.

A spring line commonly emerges at the base of the escarpment, where rain water percolating down through the sandy formations is obstructed by the impermeable Atherfield Clay. The erosive effects of this 'spring sapping' have produced some spectacular scenic features, such as the Devil's Punch Bowl (Excursion 5). In this case a northward-flowing stream has eroded a valley deep into the Hythe Beds, eventually reaching the impermeable Atherfield Clay in Highcomb Bottom. Springs around the valley head seep from the sand/clay junction, and the undermined valley sides have become widened and steepened by erosion of the sands to form

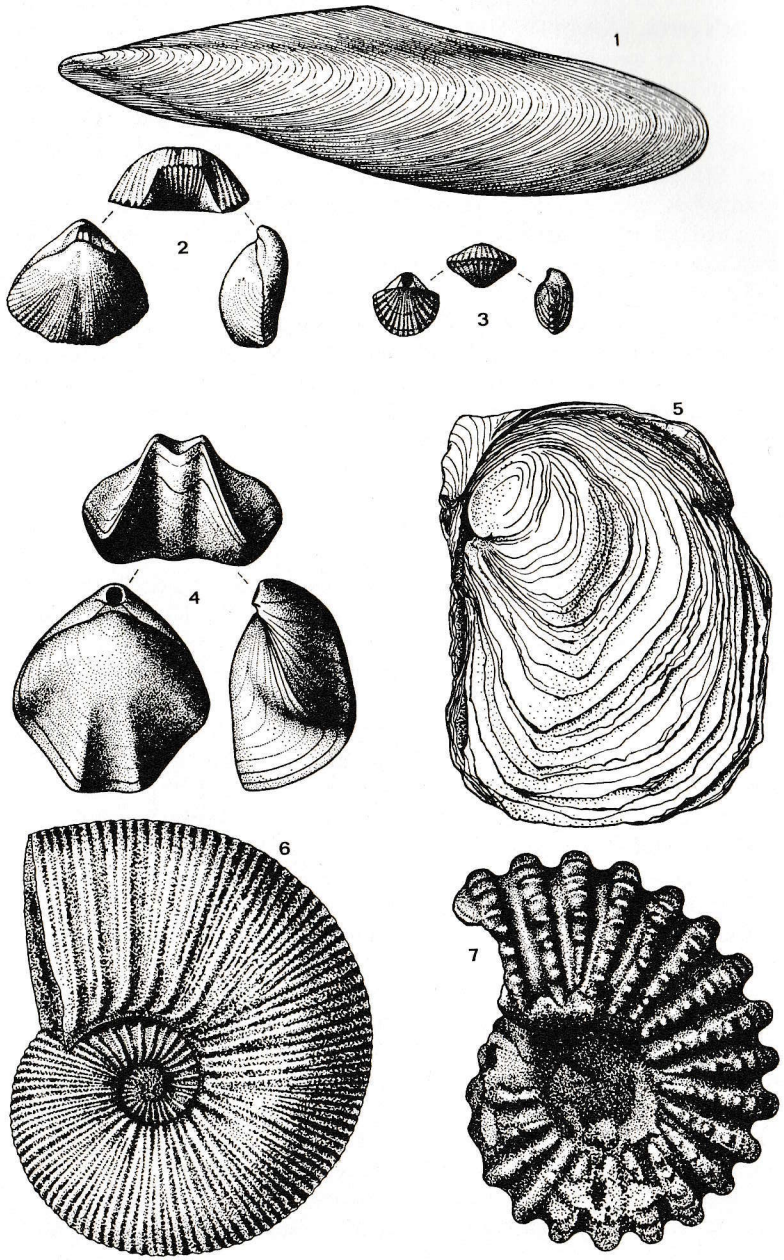


Figure 12 Contact between the Folkestone Beds and overlying Gault Clay at Squerryes pit, near Westerham (Excursion 2).

the wide Punch Bowl. Further north, the northward-dipping clay disappears below ground level, and the valley assumes a normal shape as the spring line is lost (Fig. 14).

The soils that overlie the Lower Greensand are extremely variable in quality across the Weald. In general, the soils tend to be richer in the east than in the west, and so the scenery changes from cultivated land in Kent towards a dominance of sandy heathland in western Surrey and eastern Hampshire. The rag and hassock Hythe Beds in the east are usually covered by deep fertile permeable soils extensively used to produce high yields of arable and, in places, fruit crops. Although there are small areas of infertile heathland in Kent, such as Hothfield Common (970458), the widest tracts of poor soils are found above the Hythe and Folkestone Beds west of Dorking. These beautiful woodlands and heathlands, such as Hindhead Common (Excursion 5), are the 'rascally heaths' of Cobbett and owe their

Figure 11 Fossils from the Lower Greensand.
1 *Gervillella sublanceolata* × 0·43 (bivalve).
2 *Sulcirhynchia hythensis* × 1 (rhynchonellid brachiopod).
3 *Gemmarcula aurea* × 1 (brachiopod).
4 *Sellithyris sella* × 0·75 (terebratulid brachiopod).
5 *Exogyra latissima* × 0·45 ('oyster' bivalve).
6 *Parahoplites nutfieldiensis* × 0·3 (ammonite).
7 *Douvilleiceras mamillatum* × 0·88 (ammonite).

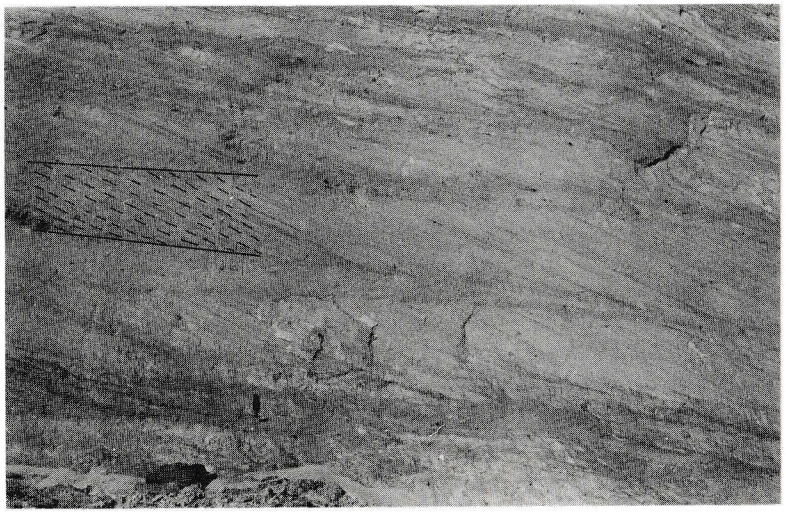


Figure 13 Cross-bedding in the Folkestone Beds, Chantry Lane quarry, Storrington (Excursion 6). Bedding planes indicated by solid lines; cross beds indicated by dashed lines.

character to the acid sandy soils, which drain rapidly and so do not readily conserve moisture for plant growth.

The Gault occupies a narrow flat belt of cultivated country of lower elevation than the adjacent Greensands. The heavy wet soils are similar to those found above the Wealden clays, except that the former show more of a tendency to shrink and crack in summer – a process that aids draining and makes the ground easier to cultivate. Also, beneath the Chalk Downs in the east and the Upper Greensand escarpment in the west, the clay is often enriched by landslip material from the slopes above. The hummocky ground produced by landslipping is a feature common at the base of escarpments in the Weald (Excursion 5).

The Upper Greensand is too thin in its northeastern area of outcrop to make any appreciable effect upon the scenery. Westwards from Godstone, however, it can be traced along the face of the North Downs as a low but distinct terrace. The escarpment is best developed around Selborne in the extreme west, where the formation is thickest. The soils derived from the malmstone around Selborne are renowned for high fertility and have long been used for growing hops and fruit. Gilbert White, in his *Natural history of Selborne*, has commented on the variety of soils encountered when crossing the **strike** eastwards from the Upper to the Lower Greensand in Woolmer Forest (Excursion 5):

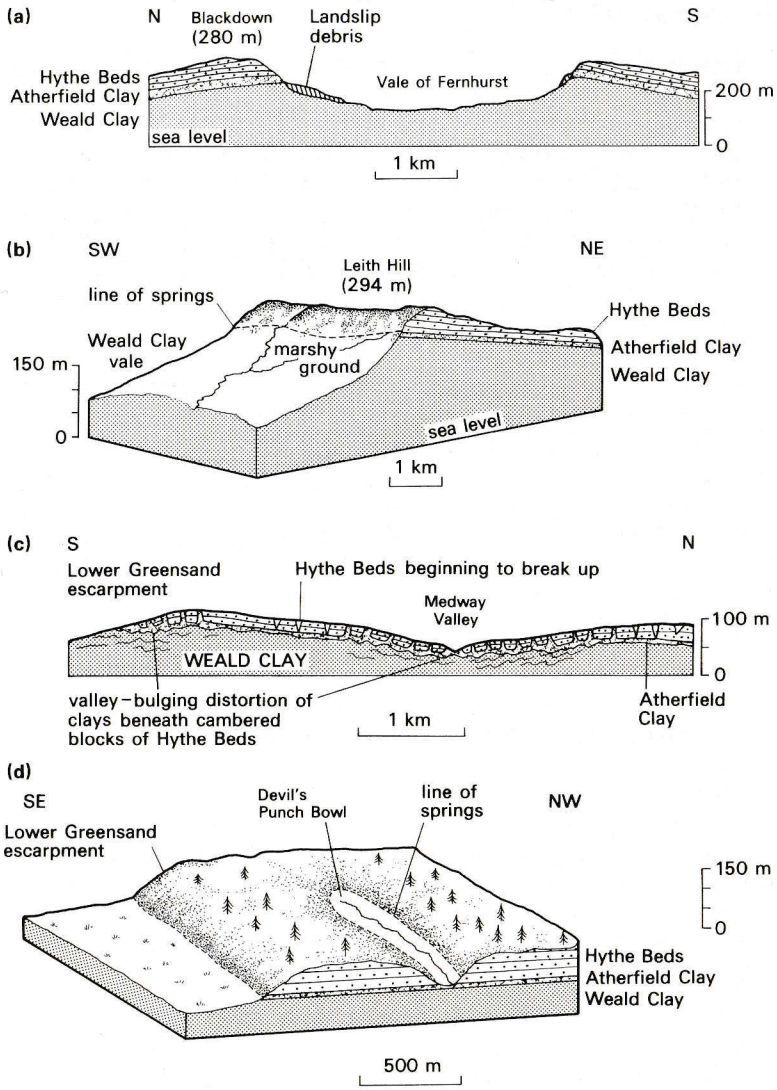


Figure 14 Scenic features associated with the Lower Greensand escarpment.
(a) Section through the Vale of Fernhurst (915270). Erosion of the Lower Greensand from the anticlinal fold core has produced a clay vale between the two Hythe Beds escarpments ('inverted' relief). Note the landslip debris below the escarpments (Excursion 5).
(b) Hythe Beds escarpment at Leith Hill (page 21).
(c) Cambering in the Hythe Beds west of Maidstone (page 24, after Worssam 1965). Arrows indicate the direction of movement of cambered blocks.
(d) The Devil's Punch Bowl, near Hindhead (Excursion 5).

As the parish still inclines down towards Woolmer Forest, at the junction of the clays and sands, the soil becomes a wet sandy loam, remarkable for timber but infamous for roads (GAULT). The oaks of Temple and Blackmore stand high in the estimation of purveyors, and have furnished much naval timber: while the trees on the freestone (UPPER GREENSAND) grow large, but are what workmen call shakey, and so brittle as often to fall to pieces when sawing. Beyond the sandy loam the soil becomes an hungry, lean sand (FOLKESTONE BEDS) till it mingle with the forest; and will produce little without the assistance of lime and turnips.

In some places the Lower Greensand has been strongly affected by **cambering**, particularly on valley sides in the Maidstone area, where the Hythe Beds have broken up into enormous blocks separated by large fissures filled with soft loose sediments. The blocks are tilted at various angles towards the centre of the valley and in places have descended the valley sides by as much as 30 m. The clays beneath are commonly distorted by valley bulging (Fig. 14). Although there is still uncertainty regarding the exact origin of cambered structures, it is generally agreed that they developed during the recent ice age, when the Weald area experienced an intensely cold climate with repeated surface freezing and thawing. During periods when the top of the permafrost was thawing, the melting of ground ice may have produced water saturation in the clays on the valley floor, which then become unable to support the weight above.

Many inland exposures in the Weald occur in the banks of sunken lanes, which are picturesque reminders of how man may act as an agent of erosion. The constant passage of people with their animals and wheeled transport prevented the stabilising growth of plants and broke up the soft road surface, so allowing rapid erosion by rain water. The process now is mostly a thing of the past, as the lane surfaces have been protected by tarmac. Gilbert White has described the sunken lanes cutting through the Upper Greensand escarpment near Selborne (Excursion 5):

> These roads, running through the malm lands, are by the traffic of ages and the fretting of water, worn down through the first stratum of our freestone, and partly through the second, so that they look more like watercourses than roads, and are bedded with naked rag for furlongs together. In places they are reduced sixteen or eighteen feet beneath the level of the fields.

In describing the effects of a violent storm that occurred in June 1794, White has noted: 'The hollow lane towards Alton was so torn and disordered as not to be passable till mended, rocks being removed that weighed two-hundred weight' (Fig. 15).

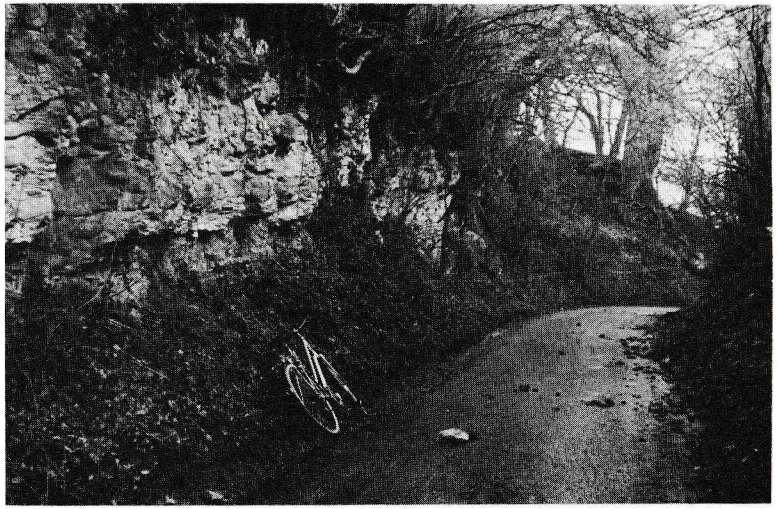


Figure 15 Sunken lane exposing the Upper Greensand (malmstone), near Selborne (Excursion 5).

Life in a lower Cretaceous sea

The Gault Clay is one of the most fossiliferous horizons in Britain. The fossils unearthed during any collecting session will invariably consist mostly of bivalves, cephalopods and gastropods, although a variety of other fossils, including fish teeth and bones, driftwood, crustaceans, corals, **echinoids** and **brachiopods**, also occurs. Commonest of the bivalves are species of *Inoceramus* and *Nucula* ('nut' shells), although scallops, oysters and various other forms may also be found. The gastropods include such genera as *Gyrodes* (an ancestor of today's winkle), *Buccinofusus* (an ancestor of the whelk) and *Anchura* with its peculiar fingerlike extensions of the aperture (Fig. 16). Both bivalves and gastropods once lived on the muddy floor of the Gault sea, and most are found at or near the spot where they died.

The most notable Gault fossil group, however, is the ammonites, which, like all **cephalopods**, were exclusively marine and adapted to free swimming. Although ammonites are extinct, present day representatives of the cephalopods include the octopus, squid and the pearly *Nautilus*. Because of their rapid evolution different ammonite species flourished at successive times during the deposition of the Gault, and identification of these has made possible the erection of a series of fossil 'zones' and 'subzones'. Each zone corresponds to a particular layer in the clay, which contains a characteristic ammonite species, as shown in Table 2.1 (page 26).

Table 2.1 Ammonite zones in the Gault Clay.

Formation	*Zone*	*Maximum thickness (at Folkestone) (m)*
Upper Gault	*Stoliczkaia dispar* (youngest)	14
	Mortoniceras inflatum	22
Lower Gault	*Euhoplites lautus*	3·5
	Euhoplites loricatus	5
	Hoplites dentatus (oldest)	2

The ammonite *Hoplites dentatus* is therefore the 'zone fossil' found in the lowest zone of the clay, and so on. Such were the complexities and rapidity of ammonite evolution that it has been possible to subdivide these five zones into no less than fifteen subzones, each based on its own distinctive ammonite fauna. Each zone represents a period of time when certain characteristic ammonite species swam in the lower Cretaceous seas, and despite the thinness of the sediment deposited in some zones one should perhaps always be reminded of the enormous amount of time involved; the five zones altogether represent a period of about 5 million years (Fig. 2).

Not all the Gault ammonites are coiled; some uncoiled varieties, such as *Hamites*, have unusually straight shells with U-shaped endings (Fig. 16). Probably the commonest fossil cephalopods in the Gault are not ammonities, however, but fragments of belemnite shells. The most resistant part of the animal was the 'guard', and the hard thin bullet-shaped remains of hollow guards belonging to the species *Neohibolites minimus* are everywhere in the clay.

The Lower Greensand generally does not yield the quantity of fossils so easily obtained from the Gault, mainly because calcareous shells have been dissolved (or leached) by water percolating through the sandy sediments. As exceptions to this general rule however, fossils are locally abundant in the rag and hassock Hythe Beds, the Bargate Beds and the fuller's earth areas of the Sandgate Beds. For many years the Lower Greensand was regarded as unrewarding to palaeontologists, and work concentrated on the more obviously fossiliferous horizons, such as the Gault. In 1961, however, a detailed study of Lower Greensand fossils was published by Casey, who found that: 'Not only in the ammonites, but in many other groups of Lower Greensand fossils, poverty turns to riches with patience.' Besides the bivalves, brachiopods, gastropods, corals, belemnites, nautiloids, echinoids, fish remains, dinosaur bones, various planktonic microfossils and drifted land-plant fragments recorded in the Greensand, it

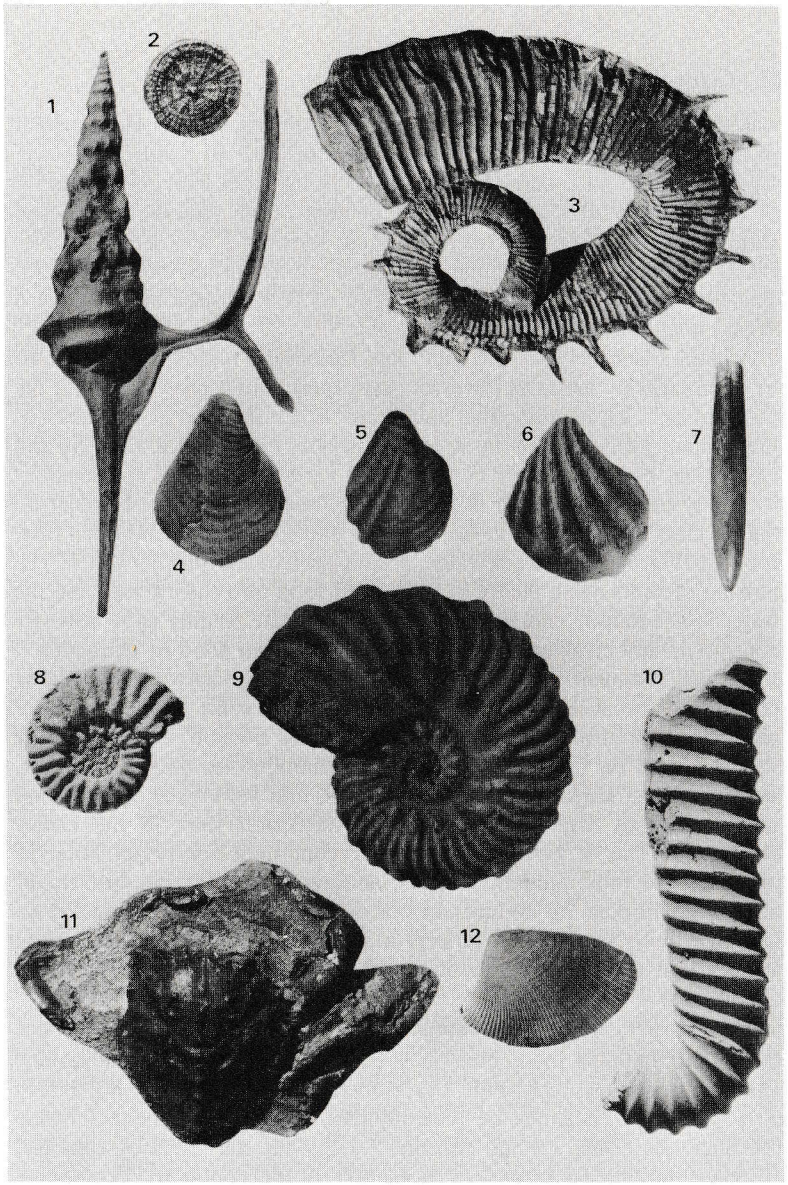


Figure 16 Fossils from the Gault Clay at Folkestone (Excursion 1). 1, Gastropod *Anchura carinata*; 2, 'button coral' *Discocyathus fittoni*; 3, uncoiled ammonite *Heteroclinus nodosus*; 4, bivalve *Inoceramus concentricus*; 5, bivalve *Inoceramus subsulcatus*; 6, bivalve *Inoceramus sulcatus*; 7, belemnite *Neohibolites minimus*; 8, ammonite *Hysteroceras orbignyi*; 9, ammonite *Euhoplites truncatus*; 10, uncoiled ammonite *Hamites gibbosus*; 11, crab *Notopocorystes stokesi*; 12, bivalve *Nucula pectinata*. All from the Lower Gault except 6 and 8, which were collected from the Upper Gault. Reproduced by permission of the Director, Institute of Geological Sciences; Crown Copyright reserved. Magnification × 6/7.

was the rapidly evolving ammonites that again proved the most useful palaeontological time-markers, and Casey was able to divide the Lower Greensand into nine ammonite zones and twenty-four subzones. Another of the results of this survey was the demonstration that the lithological formations of the Lower Greensand were sometimes not deposited over exactly the same period of time at different places throughout the Weald. The Atherfield Clay, for example, began to be deposited in the western Weald long before it did in eastern Kent.

A comparison between the Gault and Greensand fossils reveals both to be dominated by molluscs (bivalves, gastropods and cephalopods) but the Gault to be richer in ammonites and poorer in certain other groups, such as brachiopods, sponges and the large thick-shelled bivalves (e.g. *Exogyra* and *Gervillella*, Fig. 11). Many of the faunal variations can be explained by invoking the preferences of different organisms for different sediment on the sea floor. Organisms like brachiopods and sponges, which obtain their food by filtering it from sea water, usually prefer clear flowing water. The passing currents bring plenty of suspended food into their grasp, and the water is not muddy enough to block each delicate feeding apparatus. By contrast, many bivalves and gastropods obtain their food by extracting it from the sediment on the sea bed. These organisms prefer muddy conditions, because there is generally more organic matter in finer sediments; the currents are slack enough to allow organic particles to settle with the mud on the sea bed. The free-swimming ammonites, however, were not constrained by bottom conditions, and yet they show a greater abundance and diversity of species in the Gault than in the Lower Greensand. This is partly due to better conditions for preservation in the Gault, as most ammonite shells landing on a sandy sea bed would have been broken up by currents, those surviving being subjected to later leaching; but it also reflects a burst of worldwide evolutionary activity that took place in the ammonite group at the end of the lower Cretaceous.

Molluscan fossils again dominate the fauna preserved in the Upper Greensand, and of these bivalves are the most common. Ammonites, gastropods, sponges, echinoids, brachiopods, fish and marine reptiles have also been found, but they are generally rare. Much of the pale malmstone contains many tiny sponge 'spicules' – the skeletal parts of sponges. Another notable palaeontological feature is the common existence of animal burrows in the sediment (Excursion 7). Although the Upper Greensand of the western Weald was deposited at the same time as the Upper Gault of the eastern Weald, the fauna (and preservation) of each differs markedly, again reflecting contrasting conditions of sedimentation. Good exposures of the Upper Greensand are not common, and it is often difficult to obtain well-preserved fossils from this formation.

Geological history of the Greensands and Gault

The essentially non-marine conditions of Wealden sedimentation were finally ended by the spread of the sea over what is now the Weald. This inundation took place quite rapidly in the west, but it was some time before marine conditions became established in eastern Kent. The underlying Weald Clay was slightly eroded by the encroaching seas, and the junction between this and the overlying Atherfield Clay is usually sharp. The dramatic effect of the marine transgression upon the animal and plant life is well recorded by the difference between the fossils in these two clay formations. After the quiet deposition of marine muds there was an influx of current-washed sandy sediment, which led to the formation of the Hythe Beds. The contact between the Atherfield Clay and the Hythe Beds is gradual, and the change was probably due to uplift (that may have been caused by faulting) of the landmass to the north, which was then able to supply more coarse sediment to the Weald. Following the formation of the Hythe Beds there was a period of tectonic disturbance during which areas were uplifted by gentle faulting and folding. This activity was particularly strong along the line of the Hog's Back, west of Guildford, north of which the Hythe Beds (and Jurassic rocks) were stripped off by erosion. 'Rolled fossils' from these beds were deposited at the base of the Sandgate Beds, which were formed at a time of renewed marine transgression (page 71).

Cross-bedding studies show cross-beds in the sandy sediments (Fig. 13) to dip consistently towards the southeast or SSE, indicating current transport of sediment from the northwest. The shoreline of the 'London landmass' was slowly pushed back northeastwards, until by Folkestone Beds times much of the London area may have been submerged to form a shoal. The Folkestone Beds record an environment of fairly shallow water crossed by strong currents from the northwest, which deposited vast quantities of cross-bedded sand. Towards the end of this period, however, less and less sand became available, particularly in the east, where non-deposition is recorded by the presence of **phosphatic nodules**. A widening and probably deepening Gault sea then became established, with quiet muddy bottom conditions prevailing. Rates of deposition were generally slow, and phosphatic nodules are found at a number of horizons. Many animal species preferring an actively current-swept sandy sea bed became replaced by those more at home in soft mud. During the deposition of the Upper Gault the sea grew to its widest since the Jurassic period and swamped most (or all?) of the London landmass. Although clays continued to form the dominant sediment in the east, Upper Greensand was deposited in the west.

The deposition of these sediments took place over a period of about 13 million years. Continental drift had moved Britain slowly northwards during the lower Cretaceous into subtropical latitudes around 35°N. Intense chemical weathering of the nearby land surfaces provided the large

quantities of silica needed for the production of the cherts in the Hythe, Bargate and Folkestone Beds. A great variety of dinosaurs still dominated the land fauna, but some species had become readapted for sea life as large marine reptiles. The sea teemed with invertebrate life, particularly with the rapidly evolving ammonities. In contrast to the steady rule of the dinosaurs, the plant kingdom was undergoing important changes, as flowering plants evolved and familiar deciduous trees, such as the poplar, oak and birch, replaced coniferous trees as the dominant land vegetation. Far away to the south and west the Atlantic Ocean was slowly widening by continental drift. Crustal plate movements were probably indirectly responsible for the ups and downs of lower Cretaceous sedimentation: the migration of the coastlines, sudden influxes of sandy sediment, non-deposition and erosion due to shallowing of the seas, and so on. Despite the occasional shallowing, however, the sea maintained and strengthened its hold over sedimentation in what is now South-East England throughout the late Lower Cretaceous and was to continue to do so for another 30 million years.

Greensands, Gault and man

The Greensands and Gault have, over the years, lent themselves to a wide variety of economic uses. The Lower Greensand provides important resources of ground water, fuller's earth, sand and roadstone. The Gault Clay is locally exploited for bricks (e.g. near Sevenoaks and Selborne,

Figure 17 Blocks of Upper Greensand surrounded by ornamental carstone chips in the wall of Plestor House, Selborne (Excursion 5).

Excursion 5), and is quarried in the Medway Valley and southern Sussex for use with chalk in cement manufacture. The Upper Greensand has no significant use today but has been extensively quarried for building stone (Fig. 17). Other former uses of these rocks include the collection of phosphatic nodules in the Gault and Upper Greensand for agricultural use and the burning of limestone from the Hythe Beds for lime.

The millions of litres of water used each day for industrial and domestic purposes in the Weald are obtained, with few exceptions, from underground sources. This vast store of ground water originates from, and is replenished by, rain water percolating into the rocks from the land surface. The Ashdown Beds, Hythe Beds, Folkestone Beds and Chalk are all important reservoirs of water **(aquifers)**, whereas the clay formations, such as the Gault, act as impermeable barriers to percolation **(aquicludes)**. The greensand aquifers owe their permeability to the interconnecting spaces between individual sand grains.

The Hythe and Folkestone Beds are the most extensively used aquifers in the Weald, although the loose fine-grained nature of these sediments usually necessitates the use in boreholes of sand screens or other devices that prevent sand from entering the supply. The Gault is an important aquiclude and forms a seal to the ground water in the Lower Greensand. The clay not only keeps the underlying water under pressure, thus making extraction easier, but also acts as a barrier to the infiltration of surface pollution. It also softens the water beneath (by base exchange), and as a result of these advantages many modern wells are sited on, and drilled through, the Gault (e.g. at Oakhanger, Excursion 5). Springs are commonly thrown out at the junction between the Gault and Upper Greensand (e.g. Silent Pool, Excursion 4), but these are rarely used as a source of public water supply.

Fuller's earth has been excavated from the Sandgate Beds in Surrey since at least Roman times, and this area is still the chief centre of UK production. The main fuller's earth beds extend for about 9 km east–west along the strike of the Sandgate Beds from Reigate to Godstone. They are best developed near Nutfield (294505), where they are worked by opencast quarrying, the worked-out ground being restored as the quarrying proceeds. The dark soapy yellow-weathering earths, formed mostly of the clay mineral montmorillonite, are probably the decomposition products of volcanic ash that once fell into the Wealden area during the eruption of some distant volcano. Although only small quantities of the earth are now used for cleaning, or 'fulling', woollen cloth, the clay has proved itself to be a remarkably versatile raw material for twentieth-century technology. The adsorptive clay is now mainly used in the refining of liquids, especially oils and syrups; other uses include water purification, pharmaceutical preparations (e.g. baby powder), chemical catalysts, carriers for

insecticides and herbicides, and pet litter. The addition of sodium carbonate converts the clay into thixotropic 'bentonite', used in oil drilling. A bentonitic clay suspension can be pumped down the drill hole while drilling is in progress. The suspension acts as a lubricant, helps to support and waterproof the sides of the well and carries the drill cuttings to the surface. When drilling stops, the clay suspension becomes a gel, which 'freezes' the drill cuttings being brought up and prevents them from settling back to the floor of the well.

'Kentish Rag' from the rag and hassock Hythe Beds, now a major source of roadstone and concrete aggregate, was for long an important building stone in South-East England. The stone was utilised in Roman and medieval times and widely used in the nineteenth century, particularly in and around London. Elsewhere in the Weald hard beds of sandstones and limestones occur locally in the Lower Greensand and, where worked, have been given titles such as 'Bargate Stone' and 'Folkestone Stone'. Over the outcrop of the ferruginous Folkestone Beds the hard brown veins and masses of carstone have been broken up for use as walling and paving and for other decorative purposes. Gilbert White (1789) has described the use of this unusual stone around Woolmer Forest:

> This is generally the colour of rusty iron . . . is very hard and heavy and of a firm compact texture, and composed of a small roundish crystalline grit, cemented together by a brown, terrene, ferruginous matter; will not cut without difficulty, nor easily fire with steel. Being often found in broad flat pieces it makes good pavement for paths about homes, never becoming slippery in frost or rain. In many parts of that waste [Woolmer Forest] it lies scattered on the surface of the ground; but it is dug on Weavers Down, a vast hill on the eastern edge of that forest, where the pits are shallow, and the stratum thin. This stone is imperishable.
>
> From a notion of rendering their work the more elegant, and giving it a finish, masons chip this stone into small fragments about the size of the head of a large nail; and then stick the pieces into the wet mortar along the joints of their freestone walls; this embellishment carries an odd appearance and has occasioned strangers to ask us pleasantly 'whether we fastened our walls together with tenpenny nails?' (Fig. 17, Excursion 5).

The Folkestone Beds provide the main source rock for building sand, and there are many extensive quarries across the outcrop, as in the Farnham area and between Redhill and Maidstone. The sand is used as general-purpose building sand and in the manufacture of concrete roofing tiles, paving stones, wall blocks, calcium silicate bricks and asphalt. The formation is also an important source of high-grade pure sand, known as

'silica sand', which is exploited in the Oxted and Borough Green areas. This sand is used mainly as foundry moulding sand and for glass-making, although there are a number of minor applications, such as in ceramics.

The Upper Greensand in the Redhill area provided the source rock for the development of a flourishing stone industry from the seventeenth to the nineteenth century, and the remains of twenty or thirty disused mines are known to exist along the foot of the North Downs from Dorking to Godstone. The rock extracted was a pale calcareous fine-grained sandstone known as 'firestone' and was obtained by excavating underground networks of passages into the escarpment face and down the gentle northward dip to the water table (Excursion 3). Although easy to work with, the stone was prone to weathering once out of the ground. In 1713 Christopher Wren, reporting on the stonework of Westminster Abbey, wrote:

> That which is most to be lamented, is the unhappy choice of the materials, the stone is decayed four inches deep, and falls off perpetually in great scales. I find, after the Conquest, all our artists were fetched from Normandy, they loved to work in their own Caen stone, which is more beautiful than durable. This was found expensive to bring hither, so they brought Rygate stone in Surrey, the nearest like their own, being a stone that would saw and work like wood but not durable, as is manifest; and they used this for the ashlar of the whole fabrick, which is now disfigured in the highest degree: this stone takes in water, which, being frozen, scales off, whereas good stone gathers a crust and defends itself, as many of our English free-stones do.

The development of the railways came as a severe blow to the Surrey firestone-miners, who suffered overwhelming competition from other quarrying areas (e.g. Bath) and from the rapidly expanding brick industry. By a strange quirk of fate, however, the decline in the mining industry's fortunes was reversed by the growth of a Victorian fashion for whitening doorsteps, hearths and stone floors. Besides the harder firestone beds the Upper Greensand of this area also contains layers of softer calcareous sandstone, which became known as 'hearthstone'; lumps of this, when wetted and rubbed on a stone floor, would leave a chalky white deposit. New mines were opened to cater for this trade, which continued into the present century, when the use of rough lumps of stone was superseded by sprinkler cartons of hearthstone powder sporting such trade names as 'Snow Drift Step Powder'. The trade passed its peak in the 1920s, following the introduction of quarry tiles and labour-saving devices into the home and the increasing difficulty and expense of obtaining domestic servants. A succession of mine closures followed, the last to survive being that at Colley Hill near Reigate, where underground operations finally ceased in 1961.