Tim Daley

A Play for Oil

The Stories Behind the Discovery and Development of Oil and Gas

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ISBN 978-3-319-67984-6 ISBN 978-3-319-67985-3 (eBook)
https://doi.org/10.1007/978-3-319-67985-3

Library of Congress Control Number: 2017953941

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Introduction

It is the bargain that we make with modern civilisation: that one has to work. In the developed world where mankind is spared a subsistence existence, people have specialised in providing a service for the common need. My specialism is in geology, further narrowed into the field of geophysics and seismic interpretation with the objective of the exploration and production of hydrocarbons. My expertise would not keep me alive if stranded on a desert island, but industrialised society has developed a thirst for oil and gas to provide fuel, energy and a whole plethora of commodities.

I am very grateful that fulfilling my side of the bargain has been so interesting, always a challenge and, at times, unpredictable. After my interest in geology was stirred at school, I ignored gentle coercion to follow a more conventional path towards engineering or a 'proper' science like physics. Instead, I was lured by the earth sciences and, even more alluringly, by the prospects of field trips that a geology degree offered. I knew nothing of the employment potential that a knowledge of rocks and geological processes could offer.

Fast-forward to today and having spent more than thirty years in the oil business, this book is an attempt to relate some of my experiences of the industry from the perspective of the geologist. It is our challenge to describe the rock layers far below ground and unravel those features relevant to the exploration for and production of hydrocarbons. As with all specialisms, it has its own technical language, in my case the twin dialects of the geology and the oil patch. So while my prose seeks to share some stories, I have mingled them with my explanations of the geology of oil and how our quest is achieved while adding commentary on the global resources and how my own career has unfolded. I aim to appeal to the interested layman and to stir the curiosity of my colleagues within the industry, while students of science may even be stimulated to take on this career, which for me has proved to be so rewarding.

* * *

The experiences are all mine and I am responsible for how the events are recalled from my own account. Generally, these pages do not constantly cite references, but some websites and important sources are either indicated within the text or referenced at the chapter end. I have added a glossary of some geology and oil business terms, and these words are highlighted in bold at their first appearance.

I have made use of public access sites to provide facts and figures relating to global and country hydrocarbon resources, most notably the Energy Information Administration (EIA). The EIA is an independent USA energy research entity whose output is readily available and constantly quoted across the media and literature. Also the United States Geological Survey (USGS) are another source of resource estimates and analysis and home of their splendid earthquake catalogue, while the UK Oil and Gas Authority (OGA) provided supporting data for the United Kingdom and offshore waters. Photographs and figures are by my own hand unless otherwise indicated.

* * *

I would like to thank Steve Cannon for his encouragement on reading an early draft and to my editor at Springer, Alexis Vizcaino, who enthusiastically supported my project from the very beginning and has guided this book to a better place. Of course, the stories are nothing without the people and teams and I dedicate this volume to all the people I have worked with over the years, as my career passed through their regions of expertise during my ‘rocky’ course towards the next undefined assignment.

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Rocks Work

Last summer, when we inaugurated a new garden shed, sorting through the clutter revealed my basket of rocks. I'm sure many of my more dedicated geology minded colleagues have more extensive and better preserved collections than mine, but when my wife Caroline suggests they should go in a box in the garage or up in the loft, I become quite protective. This is the rock equivalent of a drawer of loose photographs which, as you pick through them, cast a nostalgic view back across time. This jumble of rocks and fossils are fragments of my history.

In pride of place is a creamy coloured curvaceous dome, dotted with pentagonal symmetry, whose shape is somewhat reminiscent of a jelly fish frozen in stone. This is 'Clive, The Clypeaster', a type of sea urchin from the comparatively recent Miocene times, and a prized find during my student field mapping in Spain. Behind it is a rust coloured sandstone containing a distinct tracing of a worm burrow, its digging into a delta of Pakistan some sixty million years ago now captured in rock. There is a short cylinder of grey sand with shelly layers, a piece of **core** drilled from a thousand metres or more below a desert and found unlabelled in an office cupboard in Tunis. I can see fossil **trilobites** bought for a few Dirhams in Morocco, superficially like larger versions of the woodlice that scattered when disturbed by my probing. There are pieces of petrified wood, a lump of densely pitted coral from a beach in Florida, **gypsum** petals of desert rose, a folded example of glistening **schist** and various scallop like shells imprinted in stone. I look among some flakes of shale for the delicate fret-saw traces of **graptolites** I collected in southern Scotland, but the passage of time and movements have reduced these

T. Daley, *A Play for Oil*, https://doi.org/10.1007/978-3-319-67985-3_1

traces to dust. Perhaps the piece representing the earliest part of my history is a robust half coil of a shell, a Gryphea or devils toenail, found when I was a school boy in a ploughed field of south Notts in the English Midlands.

Rocks work. Even from these disparate samples I can imagine something of the history of the distant past but only because I associate them in time and space with other rocks. When described and associated with environment and structure, rocks record the sequence of events and even though there are gaps in the playback of the time line, there is much we can infer of the history of the planet. This story starts as I learn the building blocks of this interpretation, in my case adopting the language of geology to a career spent in the quest to satisfy the demand of humankind for **hydrocarbons**. But equally geoscience provides the context for many global issues; the geography for all the countries, the distribution of resources, climate change and the many natural hazards of our dynamic Earth. Rocks work for all of us, the geological interpretation essential to locate what humankind needs and offering predictions of adverse phenomena.

An assortment of rocks, along with the attention grabbing cinematography of dinosaurs and volcanoes, are probably as far most kids get with their interest in geology. For me, this was always a part of my interest in natural history, which was nurtured as I foraged in the local library for science and nature books. Furthermore, my school was rather unusual in offering Geology as an option alongside the more usually studied arts and sciences. Our teacher, Mr. Trevorrow, would sometimes exchange a morning in the classroom by taking us off to view the thin gypsum bands lining the red cliffs by the River Trent, or to visit a church atop a limestone **inlier** near Ashby de la Zouch. His trips included a miner's cage plunging us deep into a coal mine below Nottingham, where a constant warm, dusty breeze blew through the tunnels along which trains ran, transporting men or hoppers of coal. On another day, a Land Rover drove us beneath the rich farmland near school into a gypsum **drift mine**, where an alabaster wall was being methodically blasted into a series of passages and pillars to extract this raw product of plaster.

A prerequisite for a geologist is not to be perturbed by the great passages of time available in the history of our planet and to be able to imagine a succession of ancient geographical landforms, one after the other. The building blocks are rocks and at the elementary level, rocks definitively have a name and a family. **Sedimentary** rocks were deposited at the surface and become sandstones, shales and limestones; **igneous** rocks solidified from molten rocks, either like granites underground or at the surface, such as basalt lava flows; **metamorphic** rocks have been changed by pressure and temperatures deep in the earth to make finely layered slates or crystalline banded schists. The Earth sciences continued to hold my attention, especially when compared to the other pure sciences and the increasingly abstract journey that is advanced mathematics. The collection of colourful minerals and curious fossils added to the distinction, further differentiated by the field trip acting as laboratory.

* * *

However, there was an intriguing development between the earlier taught syllabus and the later one. The first basic level course explained mountain building by **geosyncline theory**, a somewhat mysterious process whereby long linear belts of **continental crust** first subsided and accumulated a thick pile of sediments that were subsequently deformed and elevated into mountain chains. However, the later advanced level syllabus taught the introductory concepts of **plate tectonics**, in which slabs of **ocean crust** are created at and spread apart from sub-oceanic ridges while continental plates sail across the globe to collide with other plates to form the mountain chains. Even while I reasoned at the time that this new theory had not been developed between 1977 and 1978, it alerted me that geology was a dynamic science with new observations and interpretations being developed at a rapid pace.

I now wanted to study geology at university. Having determined that Oxford had the course content with the most geology, I was honoured to be selected by them to spend my student days among the dreaming spires and in the laboratories of the Geology Department by the Pitt Rivers museum. It became rapidly apparent that degree level geology vastly expanded the scope of learning, it drawing from strands from all the sciences plus physical geography and also the art of depicting maps and sketches. But above all, to cover anything like the breadth of all of geology requires a familiarity with rocks, be they sedimentary, igneous or metamorphic, together with fossils and minerals, **folds** and **faults** and the whole lot bound together by time and place.

And the details count in the work flow of science; observation, identification, interpretation. Sandstones can be coarse, fine or silty, shaley or pebbly, texturally or mineralogically mixed or uniform, well graded or not, all with implications for the provenance and processes of their deposition in ancient rivers or along former coastlines. Granites are a defined end member along a gradational family of igneous rocks leading to diorite on the compositional path to gabbro, each related to a different tectonic setting. Each fossil group were housed in dozens of wooden draws containing hundreds of examples of shelled, segmented or skeletal remains, bearing witness to their preserved forensic record of age and environment. Volcanic eruption theories were being rewritten as we studied, blasted by the observations and consequences of the cataclysmic explosion in 1980 of Mount St Helens in Washington State, North America. The point is that, while the details are beyond the scope of this text, there is a great breadth of knowledge that contributes to the final conclusions.

* * *

Observation and description are the fundamentals for a geologist, the identification just a label. More important is the final integration of all the lines of enquiry to postulate an interpretation of events. The preserved burrow in the coarse sandstone in my basket of rocks tells a story of a rapidly deposited sand bar at the front of a delta. That in itself is only a single piece of the jig-saw in a snap shot of the wider environment at that time. A complete mapping and sampling of the region will describe where the river came from, where the sediments went to and perhaps how, when and why the **strata** came to lie where they are found today.

So it is not the mind numbing and infinite amount of data that intrigues, but how all the lines of evidence can be pulled together to make a story of the area, of the region, or of the Earth. At the time of my degree a new book, 'The Dynamic Stratigraphy of the British Isles' (Anderton et al. 1979), was newly published which attempted to synthesise the events effecting the UK through the ages, and for the first time introducing the plate tectonic context. This provided the drama of the country's geologic past, absent from previous texts, which by comparison were mere tabulations of piles of rock and their analyses, listed like an accountant's ledger.

Detailed descriptions of four hundred and fifty million year old Ordovician trilobites, perhaps tedious to some if considered in isolation, yielded different species in England to their Scottish equivalents. The exhaustive geochemical analyses of the Borrowdale volcanics from the Lake District suggests their provenance as an island arc above a plate destruction zone, perhaps as the Japanese islands are today. A pipeline dug across the Southern Uplands of Scotland uncovered the distinct and complex fold and fault structure style of an imbricate thrust zone, where a succession of rock slices overlap each other like a series of slipped roof tiles. Together, and related by time and space in the Dynamic Stratigraphy, they are combined and interpreted as the record of events associated with the closing of the former Atlantic Ocean, the join long since buried somewhere below the current England-Scotland border. It is curious to think that Scotland was formerly part of the North American continental mass, but was left behind when the current Atlantic Ocean opened. Not that one should attach any political significance to this, the former closing event some four hundred million years ago and the later opening some sixty million years before the present.

* * *

Having just introduced millions of years as units of time, which are casually bandied around by geologists like diary entries, I am reminded again that the immense passage of geologic time is one of those concepts we must accept. The Earth is 4.5 billion years old, most creatures with shells or skeletons have existed for 550 million years and our ancestors have only been recognisable as humans for a couple of million years. All of these times are long and none are imaginable. Whole crustal plates move across the globe and are bent, deformed, elevated and eroded but in time scales far beyond the perception provided by human life times. The Indian Plate separated from East Africa and surged towards the Himalayan collision with Asia at the geologically break neck speed of ten to twenty centimetres per year yet taking over a hundred millions years over it. By comparison, the opening of the Atlantic Ocean along the central ridge is increasing the separation of Europe and Africa from the Americas by a more sedate two to three centimetres per year.

The grand unifying theory for geology is plate tectonics. It governs the character of all the terrains on the surface of the Earth and the distribution of resources. At its simplest, it makes a distinction between thicker, lighter, older, granitic crust of the continents and thinner, denser, younger, basaltic crust of the oceans. The separation of two plates leads to new oceanic crust being formed along elongate submarine ridges as molten basalt lava wells up to fill the gap. Since the Earth is not expanding, oceanic crust is destroyed at **subduction zones** where it is forced below buoyant continental masses, these plate boundaries being characterised by long, Andean type mountain chains or Japan style island arcs, both studded with volcanos. If continent to continent collision occurs, an immense mountain building ensues as neither plate is consumed and the crust is much thickened compared to the norm, to which the enormity of the Himalayas testify. Currently there are several continental sized plates and numerous smaller ones and it is important when looking back in time to reconstruct the former configurations. For example, before the South Atlantic Ocean opened, the Brazilian bulge of South America neatly nestled into the Gulf Guinea of West Africa a hundred and fifty million years ago, forming part of a far larger continent.

The relevance of this is that the history of geological provinces (Plate 1.1) is closely related to their plate tectonic setting and from the oil geology

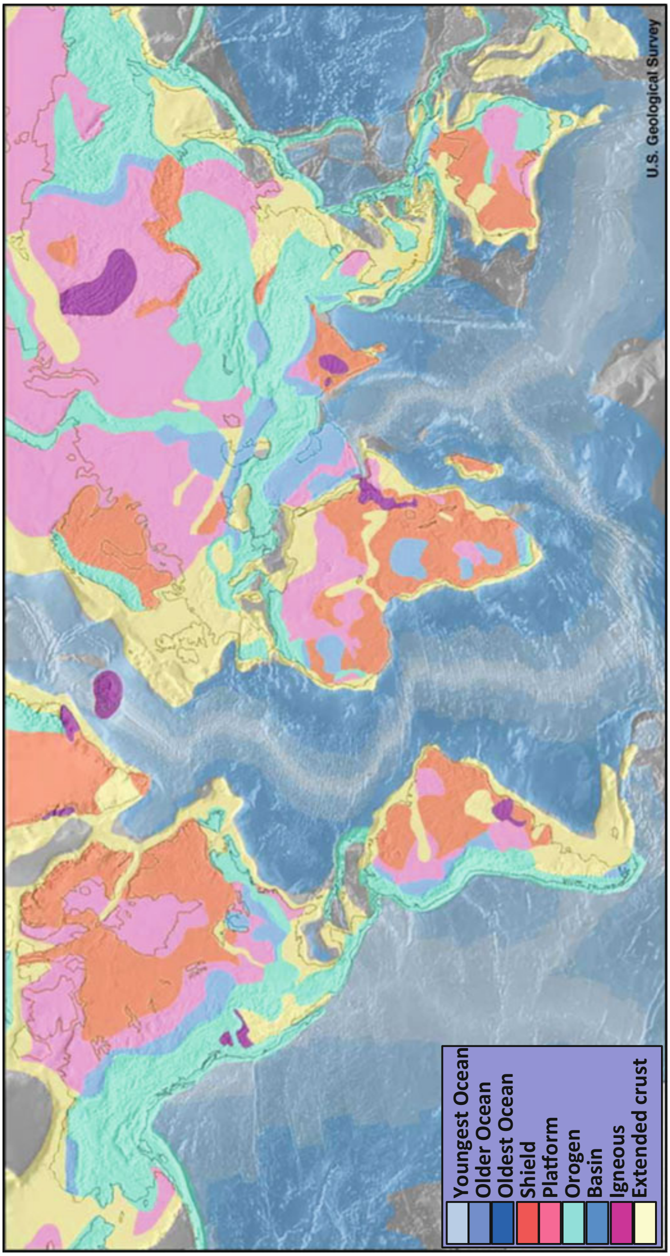

Plate 1.1 Geological provinces of the World from USGS (derived from Tectonic Map of the World by Exxon, 1985)

perspective, defines where significant thicknesses of sedimentary rocks will accumulate. In the core of the continental interiors are the shield regions, the ancient heart of the plate where little sediment cover lies above the crystalline igneous and metamorphic massifs. Other parts of the continents were denuded becoming low lying and the focus for deposits draining from adjacent highlands. Times of high sea level could flood across these platform regions which for the most part have a stable sedimentary history although locally subsidence is amplified into intra-continental **basins** where thicker piles of sediment accumulate. The margins of the continents are areas of thinned crust, a legacy of the original stretching and splitting, and these regions are often noted by thick sedimentary deposits associated with the **rifting** and subsequent sag. The last of the major tectonic provinces of the continental crust are **orogenic** belts, usually mountain chains along destructive or colliding plate margins. These regions have the most complex history, the original sedimentary basins now uplifted and concertinaed by the tectonic forces.

For the most part, the oceanic crust is beneath a deep column of sea water and distant from sediment input from the continents such that only a veneer of clay and ooze has settled from suspension. Although the map of Plate 1.1 does not depict the plate boundaries, their locations are quite implicit; from the youngest ages of crust at the **mid ocean ridges** at divergent margins and the broad orogenic swathes of the collision zones. The current plate motions are well documented, measured in centimetres per year and increasingly sophisticated plate reconstructions for the past ages are the subject of ongoing research and debate.

However, some geological events occur very rapidly. A volcanic eruption can create an island, or lay down several metres of lava in a matter of days. A major earthquake dislocates the earth's surface or sea bed along hundreds of kilometres within seconds. At a more mundane level, the coming in and out of the tides lays down sand bars each day, perhaps a metre thick. I've often thought that if a tide or a river can deposit a metre of sand in a day, and given the millions of years of time to play with, there should be millions of metres of sandstone rock. But we have to remember that most days the sand is deposited, the next day it is washed away. The sand bar that solidifies to rock is the one that was *preserved*, perhaps because the sea floor subsided and the sand avoided being recycled by wave erosion. So there is always this distinction between rapidly occurring events and the slower rate at which subsidence and tectonics occur, a combination of which will write the rock record of the past.

* * *

A fundamental concept used to help with the decoding of the evidence from the geological record is uniformitarianism, ‘the present is the key to the past’. That is to say the processes and consequences that we can see happening now have acted in the past. So if we can see the geometry and types of modern sand channels being deposited today in rivers, deltas or shallow seas, we can compare them with the rock record and reasonably assign their environment of deposition at that time. This concept is applied across many disciplines, from modern animals versus their fossil equivalents, to the phenomena observed today at constructive and destructive crustal plate margins and helps our interpretation of ancient terrains.

There are caveats to the universal application of uniformitarianism, such as the gradual versus instantaneous processes dilemma introduced above and whether we can observe today examples of all the events that may have occurred in the past. There are no living dinosaurs, we cannot see granite bodies cooling from magma at ten or more kilometres depth and our human experiences are but a scratch on the surface of time. We know there were periods when the sea level was much higher or lower, than today, or controversially, when climates were hotter or colder. There were times when the continental plates were clumped together into ‘supercontinents’ which we have to speculate imparted important climate control, disrupting oceanic currents and yet facilitating wide dispersal of land fauna. There are discrete occasions when coral reefs or their predecessors were ubiquitous and yet the record is dominated by times when such framework building organisms were absent.

How does a geologist attempt make sense of all the strands of evidence that contribute to the whole? To the mantra of ‘observation, description and interpretation’ we can add depiction. The fundamental data record for a geologist is a map. Hikers are familiar with contoured topography maps, annotated with roads, paths, buildings, water courses and environmental symbols. A surface geological map attempts to depict the distribution of the different rocks across a region, which is easier to establish where they crop out, such as a granite tor, a limestone pavement or sandstone escarpment, but more problematic where the land is covered by soil, forests, lakes or towns. The acceptance that isolated or fragmented exposures of rocks at surface could be correlated and mapped was not recognised until the nineteenth century and William Smith, the renowned surveyor and canal builder of Britain, is widely credited with realising this. While working across the length and breadth of the country, he saw similar rocks, with similar fossils occurring across England and documented a predictably changing succession of fauna across the strata. His landmark maps, compiled into, ‘A Delineation of the Strata of England and

Wales', are beautiful works of art and fundamentally similar to the current British Geological Survey versions after almost 200 years more study.[1]

There are some key principles guiding geological mapping, common sense to geologists but perhaps not instinctive to a wider audience. The Law of Superposition is a fancy way of saying that the oldest rocks are at the bottom and that younger rocks must have been formed above. As sediments are initially laid down horizontally, or perhaps on a gentle slope, even if they are later tilted and folded, the older at the base leading in a continuous sequence to younger at the top is valid. As well as providing a vertical template of a rock sequence that can be compared from place to place, a relative age dating is implicit.

An extension of this rule is Walther's Law which states that lateral changes in environment during deposition will be reflected in the vertical rock record. So imagine a river entering a delta today; the river load settles, forming a sand bar and finer mud is carried further offshore. As the sand bar continues to build out into the sea, it will cover the previous mud deposits and if the sequence is preserved into the rock record, sandstone will appear above mudstone (Fig. 1.1). Rocks associated with specific environments are called **facies**, and the argument of the rule is that, without time breaks, facies that are adjacent at a particular time will form a contiguous vertical section of rock strata. We will see later how the lateral and vertical association of facies has been developed further by the oil industry when correlating data collected in boreholes and by seismic lines.

An important caution in the use of the principle of superposition and Walther's law is the **unconformity**, describing the situation when rocks are deposited on a previously uplifted, possibly tilted or folded sequence. When such a break in deposition sequence is identified, the rock successions above and below the unconformity need to be considered separately. However, these basic principles provide a relative dating framework of observed rock strata, and apart from the time gap across an unconformity, allow a geologist to propose the geologic history of this region.

* * *

Surface geology mapping is a rite of passage for students of geology and an individual mapping survey is an important part of the final degree result, usually undertaken during the second summer. It is a challenge of planning,

[1] Website strata-smith.com contains a digital compilation of these works and comparisons to modern maps.

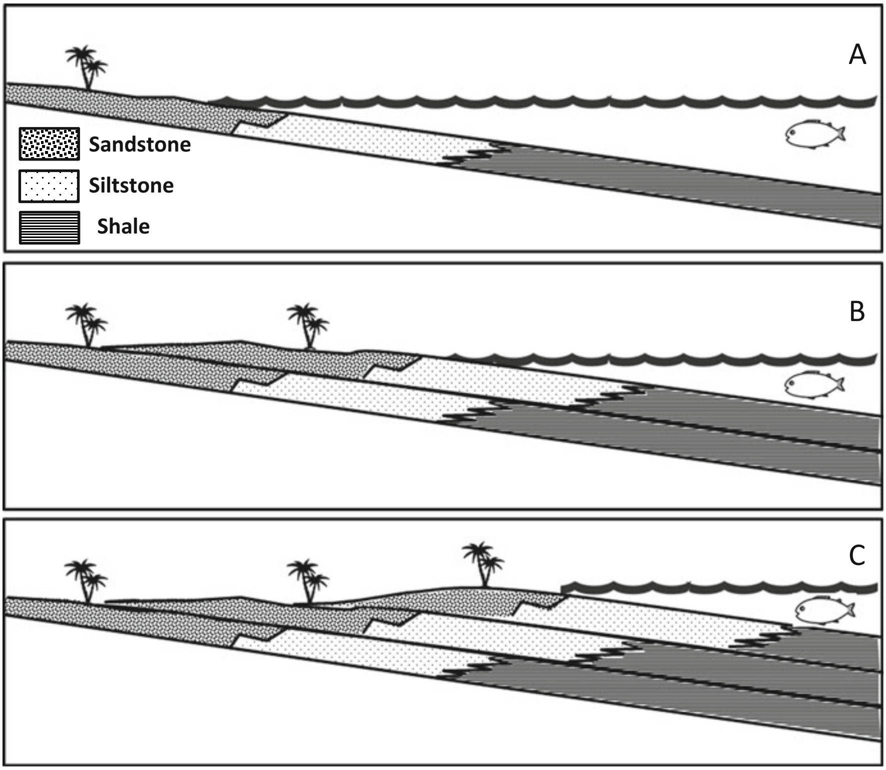

Fig. 1.1 Facies succession: According to Walther's Law, from time '**a**' to '**c**', sand from river builds out into sea to cover the previously time equivalent silts and shales resulting in a continuous vertical section, youngest at the top (Each sequence nominally 10–50 m thick, cross section span of several kilometres)

organising, data collection and compilation, while at the same time testing resolve, patience, stamina and interest. As a doctor's stethoscope defines their profession, so the compass clinometer for field measurements is the symbol of the geologist.

I missed the first year field trip during the Easter break, when the class was exposed to the rudiments of field mapping. However, a small grant was offered to three of us to undertake a mapping project during our first summer and I was happy to have the chance to catch up on this essential skill, especially as an area in northern Spain familiar to our tutor was proposed. So after a couple of months of summer jobs, Jon, Paul and I assembled in the south coast port of Plymouth with all our kit attached precariously to bicycles and we set about town for fish and chips and beers. As we were catching an early morning ferry to Santander, accommodation was considered an unnecessary expense and after our evening victuals we set up to spend the night at a shelter on the promenade of the Plymouth Hoe.

However, Paul realised he was missing his straw hat and he set off at a trot with Jon to retrace steps, leaving me to mind the bikes and bags. They returned half an hour later with both the hat and an accompanying police officer. Alas, after having reunited the said apparel with Pauls head and while they were returning to our humble abode, they had been apprehended on suspicion of burglary. It seems that a café on the sea front had reported a break in and shortly after, a description of two men in the area; one in a striped tee shirt and other wearing a cowboy hat. This was manifestly them. They persuaded the officer to come and see that they were bedding down for the night nearby and unlikely therefore to have attempted a robbery just a stone's throw away. I think the police were convinced of this case, but it seemed a complaint had been filed, a process started and hence there was a requirement to attend the 'station'. A Black Maria duly arrived and Paul and Jon, plus bikes and gear, were loaded in the back, but there was no room for me. The van set off, me in absurd pursuit by bicycle, trying to keep the van in sight as it weaved through the back streets. There followed much waiting around at the station, an interview of sorts and then release, but no lift back to the Hoe.

After the excitement of the night before, the rhythmic beat of the engine, a warm sun and a bottle of cheap red wine soon saw us snoozing on the deck as the ferry headed south across the Bay of Biscay. Spain in 1980, although its *costas* were already a familiar holiday destination, was on an unsteady path to being an established democracy, post General Franco's death in 1975. Various fascist groups, plus the Basque centric ETA, were committing occasional acts of terrorism and indeed, there was an attempted coup the following year. However, we were looking forward to some weeks in the sun and maybe some rocks thrown in too.

On arrival at the Santander streets near the docks we were met by a hooting chaos of fuming cars, trucks and buses, their exhaust mingling with occasional wafts of distinctly drain like smells. The shabby, shop fronted avenues were deeply immersed between tenement blocks wreathed in telephone cables and adorned with advertisements. We managed to purchase train tickets for us and our bikes and lunched on the first of many '*tortilla Española*', thick potato filled omelettes. Our plans fell awry when we missed the train because we had failed to move forward our time one hour. (This was our first lesson on planning.) When we attempted to board the next train showing Aguilar de Campoo, there was no provision for bikes and there followed an incomprehensible discussion with the guard. Reluctantly, we had to surrender our bikes to his care, to be sent forward to an intermediate station, while we departed on the passenger train. Thus we found ourselves at siesta time in Reinosa, a rainy hill town with a deserted, shuttered high street, without bikes or water proofs. Surely it doesn't rain in Spain? (This was a second lesson in planning.)

Remarkably, our bikes did arrive, and our next train took us onwards to Aguilar, arriving much later than we had intended. We made slow progress out of town as bits of luggage detached or scraped the wheels of our over loaded bikes, the main fixing agent to hand being string. Aguilar de Campoo smelled strongly of biscuits and this was confirmed by the siren and workers streaming out from a huge factory making the famous Spanish '*galletas*'. Advancing twilight arrested our journey at Salinas de Pisuerga, a more heartening Spanish village complete with tiled church that had a squat square tower and a multi-arched stone bridge over a clear running river. We pitched tents down near the Río Pisuerga and ate our supplies of bread, cheese and salami. The local boys came down to see what was happening and we shared duty free cigars and they provided our first taste of orange liqueur, Ponche Cabellero, swigging it from the distinctive silver bottle.

The next morning was sunny and clear, and we felt ourselves properly in Spain, looking out from dew covered tents at the tranquil valley flanked by low green hills and ripening wheat fields. It was a pleasant route along the valley, through the next village of Rueda and we were soon at the next small town of Cervera de Pisuerga. After a short, strong coffee to wash down more tortillas, we continued the final few kilometres via the hamlet of Ruesga, up past the dam to the *embalse* or reservoir, where we had been advised to set up our base. The reservoir, locally known by the synonym *el pantano*, was barely five hundred metres wide and narrowed to the northwest, was accessed by a gravel road following the southern margin. Two embayment's flanked a promontory jutting into the lake, around which a few family tents were scattered. Behind was a hill well-defined by a sloping ridge of yellow-brown limestone merging into dry scrub beneath it. We found a vacant grassy area sloping down to the water and this was our idyllic base camp for the next six weeks.

That day we made camp, swam in the lake and pottered round the *pantano*, making nodding acquaintance with the families around us. A perfect day ended with the first of many visits to the Restaurant El Refugio in Ruesga, where invariably we chose *tortilla Española* with sumptuous green salad, dipping the rough bread till it dripped with olive oil and washed down with local red wine freshened by adding a little *gaseosa*, a lemony soda. This was the life. Our planning and organisation, while not perfect, had delivered us to the starting post.

* * *

We spent the next few days exploring the geology around the Pisuerga valley, guided by the descriptions and figures from a text we had brought. We scaled the local mountains behind the camp and could confirm they were limestones (‘*Caliza de Montaña*’) and Carboniferous in age from the few small discs from **crinoid** stems they contained but we could glean little more from their unstructured character. Looking between a mountain pass, the hazy plain that is the *meseta* was visible stretching to the south of the Cantabrian mountain chain. On another day, we cycled to a now abandoned coal mine, but very different to the one I had descended into below Nottingham. Here the coal seams were preserved in small inliers among steep sided valleys where the strata dipped steeply. The buildings and winding mechanism were still present but we did not enter the shaft down which train tracks sloped at a frankly terrifying angle into the ground. Later, we found the coal measures exposed below the dam, where the shales and silts, contorted and shattered, were planed off and covered by almost flat lying Mesozoic, a span of tens of millions of years missing across this unconformity.

My mapping area was to study the younger rocks above the unconformity east of Cervera and south of the small villages of Vado, Ligüérzana and Quintanaluengos, all farming hamlets with a small church, some old stone buildings and a few modern concrete horrors. This was the agricultural country we saw that first morning cycling from Salinas; broad flat valleys with fields of wheat now being harvested and the cut sheaves were being taken to a huge threshing machine powered by a diesel generator. Among the open fields are low limestone hills where soils are thin and rock crops out and sheep and cows are set to graze. Every step taken across the dry grasses and spikey blue corn flowers sent up a spray of red, blue or green grasshoppers that melted into the background again on landing. Occasionally one would surprise a hoopoe from behind a bush, its looping flight a blur of black and white and pink and once, a volley of tiny quail burst in a feathery explosion from under my feet.

I set about logging the first geological section from the cliffs behind Vado, that is to say describing the rocks in vertical order starting at the bottom and drafting a stylised **lithology** into a scaled strip. At the base was the pebbly rock, conglomerate, which lay on top of tilted and deformed shales and silts (the older coaly series), a fine example of the unconformity. On scrambling up the section, that is, forward in time, the conglomerate changed to sheets of coarse sandstones that became more channelized up the slope, describing lens shapes, tens of metres wide, with interbedded shales and thin coals. The geological history could be read as; an ancient landscape was pushed up into mountains, shedding scree (the conglomerate) while they are eroded, the topography progressively levelled into a smooth plain across which river systems deposited sandstones.

At the top of this slope was a remote cultivated bowl within an almost treeless plateau without settlements or roads, although a single rail track meandered its way across the ochre steppe, the occasional passing train barely exceeding walking place. I was much surprised to see in Europe a bullock hauled harvester, the steel edged wooden paddles cutting a laborious swathe through the wind rustled wheat. The back drop to this scene was framed by a long curtain of limestone cliffs marked with gullies of scrub and bushes. This widespread limestone at the top of my geological section indicates an inundation across the region by warm seas distant from rivers or deltas.

Over the following days, I hiked back and forth across my area, taking notes and annotating field maps with rock types and their dip directions. I described and measured other vertical sections and gradually a sense of the complete rock column emerged, Cretaceous in age. By projecting their dip angle, rock boundaries at the surface can be projected under soil covered parts and the map can be filled with bands of colour. Some of my vertical rocks sections were similar to earlier visited sites, but their dip projection did not suggest direct continuity with the other locality. Between, there was no **outcrop** and the cause of the misalignment was not immediately apparent. One convenient solution is to postulate a fault; a vertical displacement of the strata and since faults are often zones of weakness and prone to weathering, they are not always exposed.

Although I became familiar with the geography and rock types of my area, many of my suppositions about the rock facies and geological history seemed inconclusive after departure, leaving me somewhat wishful of missing details that should have been recorded. While using the law of superposition, placing the younger rocks at the top, to create a time sequence of strata was achieved, more astute observations were required to propose map wide correlations from which to interpret a more complete geological narrative.

I am now reminded of the passion and insight of our distinguished college tutor, Harold Reading, on the second year field trip to Pembroke in the west of Wales that we joined as soon as we'd returned from Spain. Our year group was assembled on a wet and windy rocky shore as Harold recounted the story of change from the arid dry lands of the Triassic rocks to the gradual encroachment, or transgression, of the sea marking the start of the Jurassic period. I can only paraphrase the description as we approached this boundary, but from my recollection let's go with, 'We observe thick oxidised red dunes of cross bedded sandstone and occasional leached bands of mud cracked soils indicating extreme aridity with not even a sniff of the sea!', where upon we were all drenched as one by the breaking of a large wave. There was ironic humour in this moment, but I saw also his instinct for conveying the story and the level of detail required to do so.

* * *

When the second student summer came round and with a year more classes completed, Jon, Paul and I were readied for another trip to Spain, this time down to the far southeast to tackle the mapping submission for our dissertation. Between ourselves and university staff, a sedimentary basin between Sorbas and Tabernas in Andalusia, north of the Sierra Alhamilla, was thought to be suitable for undergraduate mapping projects. We had access to a 1:50,000 geology map which appeared to show a suitable variation of rock types of Miocene sediments lying above metamorphic **basement**. This sheet was the only source of topographic contours available to us and we needed field maps at five times their scale. We achieved the enlargement by using a light table and tracing the contours by hand, using aerial photographs to add more detail.

This time, we were equipped with motorised transport, Jon now the overly proud owner of a VW Variant and this afforded us the luxury of a number of departure soirees in Birkenhead, Nottingham and Southend, and a day in Paris. It was when we reached the sun belt, driving south past the Auvergne mid-way down France, that the car began to play up. It being air cooled and the air getting hot seemed to conspire to cause a breakdown every day at four in the afternoon, which would take an hour or so to resolve. Another impediment to our southerly progress was caused by the Pyrenean Principality of Andorra, where its cheap booze could not be resisted, the evening culminating unwisely with vodka. Recuperative sleep was interrupted by the sultry heat rapidly rising in the tent the following morning and our urge to continue south was sluggish. Descending from the Pyrenees into Spain, the temperature continued to rise and the air blowing around inside the car was as if from an oven. Inevitably, the car broke down at four o-clock and in order for Jon to fuss around with the engine, inconveniently located in the back, we had to unload all our gear. Now well prepared for such stops, Paul and I set about brewing up some tea and together with a bag of the little cakes known as *Magdalena*s, moral was restored. When sufficiently fretted over, or simply cool enough, the car started and we drove late into the evening to camp just south of Barcelona. We were keen to test the waters of the Mediterranean, even though it was dark and adjacent to a flood lit oil terminal and it proved to be stony and littered with sea urchins. We had a nicer swim the following evening after the long drive that took us to Mazarrón, south of Alicante.