

## Applications of Palaeontology

### Techniques and Case Studies

Palaeontology, the scientific study of fossils, has developed from a descriptive science to an analytical science used to interpret relationships between Earth and life history. This book provides a comprehensive and thematic treatment of applied palaeontology, covering the use of fossils in the ordering of rocks in time and in space, in biostratigraphy, palaeobiology and sequence stratigraphy.

In this new book, Robert Wynn Jones presents a practical workflow for applied palaeontology, including sample acquisition, preparation and analysis, and interpretation and integration. He then presents numerous case studies that demonstrate the applicability and value of the subject to areas such as petroleum, mineral and coal exploration and exploitation, engineering geology and environmental science. Specialist applications outside the geosciences (including archaeology, forensic science, medical palynology, entomopalynology and melissopalynology) are also addressed.

Abundantly illustrated and referenced, *Applications of Palaeontology* provides a user-friendly reference for academic researchers and professionals across a range of disciplines and industry settings.



The author, struggling somewhat to come to terms with the equestrian demands of fieldwork in the Zagros mountains of Iran, April 2002. Photo courtesy of the author.

ROBERT WYNN JONES gained his B.Sc. in geological sciences at the University of Birmingham in 1979 and his Ph.D. at the University College of Wales, Aberystwyth, in 1982. Since then, he has worked as a micropalaeontologist and biostratigrapher in the petroleum industry, and has been a Principal Consultant Biostratigrapher at BG Group since 2009. His industrial work

involves analysis of micropalaeontological samples; interpretation of micro- and macropalaeontological data; and integration of palaeontological interpretations into geological models for petroleum exploration and reservoir exploitation. He has worked on petroliferous sedimentary basins from all around the world, and on rocks and fossils from wide ranges of ages and facies. Outside work, Dr Jones also maintains an active interest in academic

research, especially in the study of foraminiferal taxonomy, palaeobiology, biostratigraphy and historical micropalaeontology. He has over 100 scientific publications to his name, including six books. He is a Scientific Associate in the Department of Palaeontology at the Natural History Museum in London.

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Robert Wynn Jones

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*Dedicated to the memory of my late colleague and friend, Garry D. Jones, a great exponent and proponent of applied palaeontology.*

## Contents

<i>Preface</i>	page ix	4 Sequence stratigraphy	200
<i>Acknowledgements</i>	xiii	4.1 Definitions	200
1 Work-flows in applied palaeontology	1	4.2 General and clastic sequence stratigraphy	201
1.1 Project specification and management	1	4.3 Carbonate sequence stratigraphy	201
1.2 Sample acquisition	1	4.4 Mixed sequence stratigraphy	205
1.3 Sample processing	6	4.5 Seismic facies analysis	205
1.4 Sample analysis	7	4.6 Integration of palaeontological data	205
1.5 Analytical data acquisition	7	4.7 Chronostratigraphic diagrams	212
2 Biostratigraphy and allied disciplines, and stratigraphic time-scales	8	5 Petroleum geology	213
2.1 Summary of biostratigraphic significance and usefulness of principal fossil groups	8	5.1 Petroleum source-rocks and systems, reservoir-rocks, and cap-rocks and traps	213
2.2 Biostratigraphy	59	5.2 Applications and case studies in petroleum exploration	224
2.3 Proterozoic	62	5.3 Applications and case studies in reservoir exploitation	278
2.4 Palaeozoic	62	5.4 Applications and case studies in well-site operations	289
2.5 Mesozoic	62	5.5 Unconventional petroleum geology	294
2.6 Cenozoic	62	6 Mineral exploration and exploitation	295
2.7 Biostratigraphic technologies	62	6.1 Application and case study in mineral exploration	295
2.8 Allied disciplines	66	6.2 Applications and case studies in mineral exploitation	295
2.9 Stratigraphic time-scales	68	7 Coal geology and mining	299
3 Palaeobiology	90	7.1 Introduction to coal geology and mining	299
3.1 Summary of palaeobiological significance and usefulness of principal fossil groups	90	7.2 Applications and case studies in coal geology and mining	300
3.2 Palaeobiological, palaeoecological or palaeoenvironmental interpretation	122	8 Engineering geology	308
3.3 Palaeobathymetry	126	8.1 Applications and case studies in site investigation	308
3.4 Palaeobiogeography	143	8.2 Applications and case studies in seismic hazard assessment	311
3.5 Palaeoclimatology	150		
3.6 Palaeo-oceanography	153		
3.7 Quantitative and other techniques in palaeobiology	153		
3.8 Key biological events in Earth history	155		

## viii Contents

<b>9</b> Environmental science	312	<b>10</b> Other applications and case studies	316
<b>9.1</b> Applications and case studies in environmental impact assessment	312	<b>10.1</b> Applications and case studies in archaeology	316
<b>9.2</b> Applications and case studies in environmental monitoring	312	<b>10.2</b> Applications and case studies in forensic science	340
<b>9.3</b> Applications and case studies in bioremediation	314	<b>10.3</b> Miscellaneous other applications	341
<b>9.4</b> Applications and case studies in anthropogenically mediated global change	315	<i>References</i>	342
		<i>Index</i>	392

## Preface

Humankind has always been fascinated by fossils, by their beauty and their mystery, their charm and their strangeness, their mute testimony to lives and worlds lost unimaginably long ago. In prehistoric times, our forebears not only collected fossils, but evidently treated them as valued artefacts, as evidenced, for example, by the discovery of an ammonite at an Upper Palaeolithic burial site in Aveline's Hole in Burrington in the West Country in Britain, and numerous different types of fossil at Cro Magnon sites in the Vezere valley in the Perigord region of France, truly the birthplace of European civilisation (many of which are now displayed in the magnificent 'Museum of Prehistory' in Les Eyzies). The habit persisted both in so-called primitive and so-called advanced societies through historical times.

Palaeontology, that is, the scientific study of fossils, may be said to have originated at least as long ago as the sixteenth century, and, obviously, continues to be practised in the present day. The earliest written observations on fossils were made by the German Bauer, or Agricola, in his book '*De natura fossilium*', and the earliest illustrations by the Swiss Gesner in his book '*De rerum fossilium lapidum et gemmarum*', both of which date from the sixteenth century. The usage by these and other early observers of the term 'fossil', from the Latin *fodere*, meaning 'to dig', pertained to literally anything dug up from the ground or mined, including what we would now classify as minerals, crystals and gemstones. The earliest interpretations as to the nature of what we would now accept as fossils were made by the Danish anatomist Stensen, or Steno, working in the Medici court in Florence, in his publications dating from the latter part of the seventeenth century. Steno applied Descartes' 'method of doubt' and his own deductive logic to demonstrate that the so-called *glossopetrae* or 'tongue stones' much valued in medieval Europe for their supposed medicinal properties were in fact not the tongues of snakes turned to stone by St Paul, as was the

superstition, but the fossilised equivalents of the sharks' teeth he was familiar with from his dissection work. Elsewhere in his writings, Steno established three important principles of stratigraphy, namely the 'principle of superposition', the 'principle of original horizontality' and the 'principle of lateral continuity', such that he is regarded by many as the true founder of that science. Incidentally, in later life, he renounced science for religion, and was recently made a saint by John Paul II.

There may be said to have been three, partially overlapping, areas or phases of subsequent palaeontological study: the descriptive; the synoptic; and the interpretive. The emphasis through the three phases has shifted from the documentation of fossils to their application in establishing the ordering of containing rocks in time and in space; from pure to applied. The pure descriptive phase began with the first descriptions of fossil species conforming to modern standards, made following the introduction of the binomial system for the naming of species by Linne, or Linnaeus, in the late eighteenth century. The synoptic phase has continued into the twenty-first century, with the establishment of higher-level taxonomic classification systems based on morphology and phylogeny, made following the publication of '*On the Origin of Species . . .*' by Darwin in the late nineteenth century, and the advances in cladistics and molecular biology in the twentieth. The applied interpretive phase, ultimately resulting in the development of, and advances in, the applied sub-disciplines of biostratigraphy and palaeobiology, began with the establishment of the 'Law of Superposition' and the 'Law of Strata identified by organised Fossils' by the Briton William ('Strata') Smith in the late eighteenth and early nineteenth centuries; and by the publication also by Smith of the first geological map, of Great Britain, 'the map that changed the world'. The first application of biostratigraphy in the petroleum industry was by the Pole Josef



Grzybowski in the late nineteenth and early twentieth centuries. At a time when (micro)palaeontology was essentially in a stage of synthesis, it was he who first used the discipline in an analytical fashion to solve geological problems encountered in the oil-fields of the eastern Carpathians, those around the village of Potok being the oldest still in production anywhere in the world. His contribution to biostratigraphy and also to palaeobiology has long been recognised and justly acclaimed in his own country, but is sadly seldom acknowledged in the west. In the future, applied palaeontology will continue to play a vital role in exploiting the world's discovered petroleum and other mineral resources, and in exploring for undiscovered reserves. In view of the growing concern about the environment, applications in environmental science, and outwith the exploitative industries, are also likely to come to the fore.

Unlike its immediate predecessor (Jones, 2006), this book deals essentially only with applied palaeontology, and contains many more case studies of applications. It will be of value to professionals in industry and elsewhere; including not only applied palaeontologists, palaeobiologists and biostratigraphers, but also petroleum, minerals, mining and engineering geologists, and environmental scientists, and, to a lesser extent, archaeologists, forensic scientists and others.

The first part, comprising Chapters 1–4, deals with general applications of palaeontology in the interpretation of Earth and life history and environments.

Chapter 1 deals with *work-flows in applied palaeontology*, and includes sections on project specification and management; on sample acquisition, processing and analysis; and on analytical data acquisition.

Chapter 2 deals with *biostratigraphy and allied disciplines, and stratigraphic time-scales*, and includes sections on the biostratigraphic significance and usefulness of the principal fossil groups; on biostratigraphy; on Proterozoic, on Palaeozoic, on Mesozoic and on Cenozoic biostratigraphy; on biostratigraphic technologies; on allied disciplines; and on stratigraphic time-scales. The section on biostratigraphy includes sub-sections on biostratigraphic zonation or biozonation, and on correlation. The section on biostratigraphic technologies includes sub-sections on graphic correlation; on constrained

optimisation (CONOP); on ranking and scaling (RASC); and on cluster analysis. The section on allied disciplines includes sub-sections on chemostratigraphy; on cyclostratigraphy; on heavy minerals; on magnetostratigraphy; on radiometric dating; and on Quaternary dating methods. The section on stratigraphic time-scales includes a sub-section on global stratotype sections and points (GSSPs).

Chapter 3 deals with *palaeobiology*, and includes sections on the palaeobiological significance and usefulness of the principal fossil groups; on palaeobiological, palaeoecological or palaeoenvironmental interpretation; on palaeobathymetry; on palaeobiogeography; on palaeoclimatology; on palaeo-oceanography; on quantitative and other interpretive techniques in palaeobiology; and on key biological events in Earth history. The section on palaeobiological, palaeoecological or palaeoenvironmental interpretation includes sub-sections on palaeoenvironmental interpretation on the basis of analogy; and palaeoenvironmental interpretation on the basis of functional morphology. The section on palaeobathymetry includes sub-sections on non-marine environments; on marine environments; on marginal marine environments; on shallow marine environments; and on deep marine environments. The sub-section on marginal marine environments covers deltas; and, in some detail, the palaeontological characterisation of marginal marine, peri-reefal sub-environments. The sub-section on shallow marine environments covers reefs, and covers, in some detail, the palaeontological characterisation of peri-deltaic sub-environments. The sub-section on deep marine environments covers oxygen minimum zones, submarine fans, and deep marine hydrothermal vents, 'nekton falls' and 'cold (hydrocarbon) seeps'; and, in some detail, deep-water agglutinated foraminifera, the palaeontological characterisation of submarine fan sub-environments, and benthic foraminifera and ostracods associated with cold (hydrocarbon) seeps. The section on palaeobiogeography includes sub-sections on Palaeozoic, on Mesozoic and on Cenozoic palaeobiogeography. The section on palaeoclimatology includes sub-sections on Palaeozoic, on Mesozoic and on Cenozoic palaeoclimatology. The section on quantitative and other interpretive

techniques in palaeobiology includes sub-sections on palaeobathymetric interpretation techniques; palaeobiogeographic and palaeoclimatological interpretation techniques; cluster analysis and 'fuzzy C means' (FCM) cluster analysis; and 'fuzzy logic'. The section on key biological events in Earth history includes sub-sections on the Proterozoic, on the Palaeozoic, on the Mesozoic and on the Cenozoic. It also covers in detail foraminiferal diversity trends through time, new evidence for land mammal dispersal across the North Atlantic in the Early Eocene, and aspects of the palaeogeography and palaeoclimate of the Oligocene–Holocene of the Old World, and consequences for land mammal evolution and dispersal.

Chapter 4 deals with *sequence stratigraphy*, and includes sections on definitions; on general and clastic sequence stratigraphy; on carbonate sequence stratigraphy; on mixed sequence stratigraphy; on seismic facies analysis; on integration of palaeontological data; and on chronostratigraphic diagrams. It also covers, in some detail, palaeontological inputs into the characterisation of systems tracts.

The second part, comprising Chapters 5–10, deals with specific applications of palaeontology in industry and elsewhere, and with case studies of applications.

Chapter 5 deals with *petroleum geology*, and includes sections on petroleum source-rocks and systems, reservoir-rocks, and cap-rocks and traps; applications and case studies in petroleum exploration, in reservoir exploitation, and in well-site operations; and unconventional petroleum geology. It also covers, in some detail, palaeontology and health, safety and environmental issues in the petroleum industry. The section on petroleum source-rocks and systems, reservoir-rocks, and cap-rocks and traps covers, in some detail, palaeontological inputs into petroleum systems analysis, nummulite banks and reservoirs, rudist reefs and reservoirs, the palaeontological characterisation of cap-rocks, and stratigraphic and palaeobiological controls on source-, reservoir- and cap-rock distributions. The section on applications in petroleum exploration includes case studies on the Middle East; on the North Sea; on northern South America and the Caribbean; on the South Atlantic; and on the Indian subcontinent. The section on

applications in reservoir exploitation includes case studies on reservoir characterisation in shallow marine, peri-reefal carbonate reservoir (Al Huwaisah, Dhulaima, Lekhwair and Yibal fields in Oman, and Shaybah field in Saudi Arabia); in marginal to shallow marine, peri-deltaic clastic reservoirs (Gullfaks, Snorre and Statfjord fields in the Norwegian sector, and Ninian and Thistle fields in the UK sector, in the North Sea; and Pedernales field in Venezuela); and in a deep marine, submarine fan, clastic reservoir (Forties field, UK sector, North Sea). The section on applications in well-site operations includes case studies in 'biosteering' in a shallow marine carbonate reservoir (Sajaa field, United Arab Emirates); in a deep marine carbonate reservoir (Valhall field, Norwegian sector, North Sea); in a shallow marine clastic reservoir (Cusiana field, Colombia); and in a deep marine, submarine fan, clastic reservoir (Andrew field, UK sector, North Sea). The section on unconventional petroleum geology covers coal-bed methane (CBM) or coal-seam gas (CSG), shale gas, and gas or methane hydrate.

Chapter 6 deals with *mineral exploration and exploitation*, and includes sections on applications and case studies in mineral exploration and exploitation. The section on applications in mineral exploration includes a case study on La Troya mine, Spain. The section on applications in mineral exploitation includes case studies on Pitstone quarry, Hertfordshire, UK, and on East Grimstead quarry, Wiltshire, UK.

Chapter 7 deals with *coal geology and mining*, and includes sections on applications and case studies in coal geology and mining, in Great Britain, and in South Africa.

Chapter 8 deals with *engineering geology*, and includes sections on applications and case studies in site investigation, and in seismic hazard assessment. The section on applications in site investigation includes case studies on the Channel tunnel, UK; on the Thames barrier, UK; on 'Project Orwell', UK, and on site investigation in the petroleum industry, in Azerbaijan and Egypt. The section on applications in seismic hazard assessment includes case studies on the Strait of Juan de Fuca, Vancouver Island, Canada; on Iyo-nada Bay, Japan; on Hawke's Bay, New Zealand; on the Cabo de Gata lagoon, Almeria, Spain; on Lake Sapanca, Turkey; and on western Crete.

Chapter 9 deals with *environmental science*, and includes sections on applications and case studies in environmental impact assessment (EIA), in environmental monitoring, in bioremediation, and in anthropogenically mediated global change. The section on applications in EIA includes case studies on the North Slope of Alaska, and on Wytch Farm, Dorset, UK. The section on applications in environmental monitoring includes case studies on environmental monitoring of natural and anthropogenic effects on water quality, including domestic and industrial pollution, and environmental monitoring of coral reef vitality. The section on applications in bioremediation includes case studies on bioremediation of the *Exxon Valdez* oil spill, and bioremediation in the aftermath of Operation Desert Storm. The section on applications in anthropogenically mediated global change includes case studies on ocean acidification and carbon dioxide sequestration.

Chapter 10 deals with *other applications and case studies*, and includes sections on applications and case studies in archaeology, and in forensic science; and on miscellaneous other applications. The

section on applications in archaeology includes case studies on Westbury Cave, Somerset, UK (Early Palaeolithic); on Boxgrove, Sussex, UK (Early Palaeolithic); on Massawa, Eritrea (Middle Palaeolithic); on Goat's Hole, Paviland, Gower, UK (Middle Palaeolithic); on 'Doggerland', North Sea (Mesolithic); on Mount Sandel, Coleraine, Co. Derry, Northern Ireland (Mesolithic); on Fayum, Egypt ('Epipalaeolithic'–Neolithic); on Littleton, Co. Tipperary, Ireland (Neolithic to Medieval); on Skara Brae, Orkney, UK (Neolithic); on the Tyrolean Alps (Chalcolithic or Copper Age); and on the City of London (Medieval). It also covers, in some detail, the palaeoenvironmental interpretation of the Pleistocene–Holocene of the British Isles, using proxy Recent benthic foraminiferal distribution data. The section on applications in forensic science includes case studies on the use of calcareous nanofossils, of diatoms, of spores and pollen, and of insects, in forensic science. The section on miscellaneous other applications contains sub-sections on medical palynology; on entomopalynology; and on melissopalynology.

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