1

Past, present and future foraminiferal research

This chapter deals with past, present and future foraminiferal research.

1.1 Past research (retrospective)

Although they are classed as microfossils, at least certain Foraminifera, the so-called larger benthic Foraminifera, or LBFs, are large enough to be visible to the naked eye. The group has therefore been known to Humankind since early antiquity. The first written reference to Foraminifera is by Strabo, who wrote, of his observations of what we now know to be the LBF *Nummulites gizehensis*: 'There are heaps of stone chips lying in front of the pyramids and among them are found chips that are like lentils both in form and size . . . They say that what was left of the food of the workmen has petrified and this is not improbable'.

There may be said to have been two, partially overlapping, phases of past research on the Foraminifera, namely, the descriptive and the interpretive. The emphasis shifted between the two phases, from pure to applied research.

The descriptive phase began with the first formal descriptions of species of Foraminifera dating back to the late eighteenth to nineteenth centuries. Those undertaken by the so-called 'Continental School', personified by the great French naturalist Alcide Dessalines d'Orbigny, embodied a narrower, or 'splitting', species concept than would be widely accepted today, albeit possibly a more accurate one (le Calvez, in Hedley & Adams, 1974); while those undertaken by the 'English School', personified by Henry Bowman Brady, embodied a wider, or 'lumping' concept (Jones, 1990, 1994; Jones, in Lightman, 2004; Jones, in Matthew, 2004; Jones, 2007; Jones, in Bowden *et al.*, in press; see also Box 1 below).

The earliest classification schemes were undertaken by the likes of d'Orbigny and Brady in the nineteenth century, and by the American Joseph Augustine Cushman in the early twentieth (for a fuller review, see Cifelli & Richardson, 1990; see also Section 3.3.2). More modern, later twentieth-century schemes

Box 1

Henry Bowman Brady (1835–91): The Man, the Scientist, and the Legacy

Brady the Man

Henry Bowman Brady was born in 1835 in Gateshead in the north-east of England, the son of Henry Senior and Hannah, *nee* Bowman (Adams, in Hedley & Adams, 1978; Jones, 1990, 1994; Jones, in Lightman, 2004; Jones, in Matthew, 2004; Jones, 2007; Jones, in Bowden *et al*., in press). His older brother was George Stewardson Brady, a noted ostracodologist. His younger brother Thomas's descendants survive to this day. (Thomas's great-granddaughter Pippa Senior recently worked as a Press Officer for the Royal Society.)

Brady received his education at two Quaker schools, Ackworth and Tulketh Hall, leaving in 1850 to serve as an apprentice to a chemist in Leeds. After going on to study pharmacy in Newcastle, he began a pharmaceutical career also in Newcastle, in 1855, and prospered from the start, eventually diversifying into the sale of scientific instruments, and thereby establishing contacts with a number of natural scientists. While still pursuing his career, Brady became an enthusiastic member of the Tyneside Naturalists' Field Club, and of the Northumberland, Durham and Newcastle-upon-Tyne Natural History Society, and wrote his first papers on the Foraminifera in the Transactions of the aforementioned societies, and in the Reports of the British Association for the Advancement of Science, in the 1860s. He was sufficiently successful in his career as to be able to retire, and to devote the remainder of his life to the full-time study of the Foraminifera, in 1876.

Brady died in early 1891 in Bournemouth in the south of England, where he had gone to attempt to recuperate from an illness contracted on his travels to the Upper Nile late the previous year. His obituary read 'Science has lost a steady and fruitful worker, and many men of science have lost a friend . . . whose place . . . no-one else can fill. His wide knowledge of many branches of scientific enquiry . . . made the hours spent with him always profitable; his sympathy with art and literature, and that special knowledge of men and things that belong only to the travelled man made him welcome also where science was unknown; while the brave patience with which he bore . . . enfeebled health . . . and a sense of humour which, when needed, led him to desert his usual staid demeanour for the merriment of the moment, endeared him to all his friends.'

Brady the Scientist

Brady ultimately produced over 30 important publications on the Foraminifera, ranging in age from Silurian to Recent, including some co-authored with other leading contemporary 'English school' foraminiferologists. Unfortunately, he died without achieving his final ambition – alluded to in a letter – on monographing the British Recent Foraminifera.

Box 1 (cont.)

In recognition of his services to foraminiferology, Brady was elected Fellow of the Geological Society in 1864, Fellow of the Royal Society in 1874, Corresponding Member of the Imperial Geological Museum of Vienna, and Honorary Member of the Royal Bohemian Museum, Prague, and was awarded an Honorary Doctorate from the University of Aberdeen, and a gold medal inscribed 'Insignia of the Royal and Imperial Austro-Hungarian Empire for Art and Science' from Emperor Franz Joseph I.

Report on the Foraminifera dredged by HMS Challenger . . .
The pinnacle of Brady's achievements as a foraminiferologist was undoubtedly the publication of the *Report on the Foraminifera dredged by H.M.S.* Challenger . . . , generally referred to simply as *The* Challenger *Report*, published, after six years work, in 1884, and which remains an indispensable reference even to this day (Jones, 1990, 1994; Henderson & Jones, 2006).

The Challenger *Report* describes, figures and includes distribution data on 915 species (15% of the total number of extant species), belonging to 368 genera (44% of the total number of extant genera), including the type-species of 284 (34%). It contains 814 pages of text, written in a delightfully discursive style, and 116 magnificent colour plates produced, under Brady's supervision, by A. T. Hollick (a deaf and dumb artist and lithographer, of whom it was said that 'these terrible disadvantages have been overcome by natural genius'). The quality of the plates was not matched until the advent of digital image capture technology in the 1990s, and has arguably never been bettered. It is perhaps Brady's most enduring legacy.

Brady's Legacy

The Literal Legacy
Brady left us a literal legacy of a library of books and miscellaneous papers relating to the Protozoa, which he bequeathed to the Royal Society in his will, together with a sum of money for the maintenance and augmentation of the same. The papers include three bound foolscap volumes of distribution data on *Challenger* Foraminifera, some of it not in the *The* Challenger *Report*. They include also letters to Brady from fellow natural scientists G. S. Brady, Carter, Guppy, Halkyard, Hantken, Howchin, Jukes-Browne, Millett, Murray, Robertson, Schwager and Sherborn. Incidentally, the letter from Jukes-Browne to Brady, written in 1889, enquires as to whether he had been able to interpret the palaeobathymetry of samples sent to him from the Oceanic Deposits of Barbados; and is accompanied by a scribbled note evidently written by Brady in preparation for his formal response, and referring to palaeobathymetries of '500 to 1000 fathoms' (see below).

Most of the *Challenger* Foraminifera are housed in the Heron-Allen Library in the Natural History Museum in London, including all of those figured by Brady in *The* Challenger *Report* (Adams, 1960; Adams *et al.*, 1980; Jones, in Lightman, 2004;

Continued

Box 1 (cont.)

Jones, in Matthew, 2004). The *Challenger* collection is the most important, most cited and most consulted collection of Foraminifera in the Natural History Museum.

There is also some ‘Bradyana’ in the Local Studies Department in the Central Library in Newcastle, including photographs of the Brady family and friends, Brady’s fellow foraminiferologists W. B. Carpenter, T. R. Jones, W. K. Parker, C. G. Ehrenberg, F. Karrer and A. E. Reuss, and other contemporary figures such as one might expect to have been admired by someone with Quaker sensibilities, such as the carer and social reformer Florence Nightingale and the abolitionist Abraham Lincoln (but also, bizarrely, one of ‘Crockett the Lion Tamer’, pictured in what one can only describe as a leopard-skin leotard).

Interestingly, there are two letters from Brady to Charles Darwin in the Darwin Archive in Cambridge, regarding observations on rattle-snake behaviour in relation to evolutionary theory, one dated 18 October, 1871 and the other 22 October, 1871. The tone of the latter indicates that Darwin may have written back to Brady regarding the former, although even if this were indeed the case, the whereabouts of Darwin’s letter is not known.

The Philosophical Legacy

Brady may also be said to have left us a philosophical legacy, in the form of a way of looking at Foraminifera or, better, a way of seeing them rather than simply looking at them; and of interpreting them rather than simply analysing them. His publications, in particular the *Monograph on Carboniferous and Permian Foraminifera* ... (Brady, 1876) and *The* Challenger *Report* (Brady, 1884), may certainly be said to have set modern standards of accuracy of observation; and also of presentation of data. Brady’s data continue to have important applications both in biostratigraphy and in biology and palaeobiology. Importantly, he himself was apparently the first to apply – his own – bathymetric data in absolute palaeobathymetric interpretation, using uniformitarian principles, and in this respect was decades ahead of his time (see below).

Taxonomy. *The* Challenger *Report* (Brady, 1884) was conceived in the pervasive intellectual atmosphere of the ‘English school’ of the latter part of the nineteenth century, such that its taxonomy requires revision to enable it to be used in the type of synoptic and interpretive work being undertaken today (Jones, 1994). Brady’s comment on p. vi, that ‘the progress of knowledge will eventually break down all sharp demarcations and substitute series for divisions’, indicates that his species concept, which is considerably broader than that acceptable today, was influenced by Thomas Henry Huxley (‘Darwin’s bulldog’). His decision on p. 55 to base his ‘primary division’ of the Foraminifera on the perforation rather than structural composition of the wall indicates that his suprageneric classification scheme, which would otherwise be widely acceptable today, was influenced by Carpenter.

Box 1 (cont.)

Biostratigraphy. The *Monograph on Carboniferous and Permian Foraminifera* . . . (Brady, 1876) set new standards of documentation of collecting localities and incorporation of stratigraphic control. An indication of the consequent lasting value of this work is that it was reprinted as recently as 1970.

Biology and palaeobiology: biogeography and palaeobiogeography. *The* Challenger *Report* (Brady, 1884) documents the distributions of Foraminifera dredged during the voyage of the *Challenger* (1872–1876), and also those dredged on the North Atlantic voyages of the *Lightning* (1868), *Porcupine* (1869) and *Knight Errant* (1879), and the Arctic voyages of the Austro-Hungarian and British North Polar Expeditions (1872–1874 and 1875–1876, respectively). The contained data enable the recognition of five foraminiferal biogeographic provinces in the North Atlantic and Arctic, namely: the Arctic; Subarctic; northern Cool-Temperate; southern Cool-Temperate; and Warm-Temperate provinces (Jones, 2006; Jones & Whittaker, in Whittaker & Hart, 2010). The modern foraminiferal biogeographic data derived from *The* Challenger *Report* has been used as a proxy for interpreting palaeobiogeography, for example in the Pleistocene–Holocene of the British Isles (Jones, 2006; Jones & Whittaker, in Whittaker & Hart, 2010; see also Section 13.2.1).

Bathymetry and Palaeobathymetry. The contained data in *The* Challenger *Report* (Brady, 1884) also enables the recognition of seven foraminiferal bathymetric zones, namely: the inner, middle and outer shelf; the upper, middle and lower slope; and the abyssal plain, bathymetric zones. The modern foraminiferal bathymetric data derived from *The* Challenger *Report* has been used as a proxy for interpreting palaeobathymetry, for example in the Palaeogene of the North Sea (Charnock & Jones, in Hemleben *et al*., 1990; Jones, 1996; Jones, in Jones & Simmons, 1999; Jones, 2006; see also Sections 9.3.3 and 9.5.4). It has also been used as a proxy for interpreting the palaeobathymetric evolution or uplift history of Barbados (Jones, 2009).

As noted above, Brady himself was apparently the first to apply bathymetric data in absolute palaeobathymetric interpretation.

A paper he wrote on the so-called soapstone of Fiji (Brady, 1888) includes a palaeobathymetric interpretation, as follows: ‘The depth at which the deposit may originally have taken place can . . . be determined approximately. Comparing the list of species with similar lists compiled from material collected on the *Challenger* Expedition at various Pacific stations within the tropics, it is found to include several forms not recorded from depths of less than 129 fathoms, and certain others of which the minimum depth is about 150 fathoms; besides a few . . . which are best known from much deeper water. . . . [J]udging from its general facies, the Rhizopod-fauna is one that I should expect to find in a deposit forming at from 150 to 200 fathoms (more rather than less) in the neighbourhood of any of the volcanic islands of the Pacific.’

Continued

Box 1 (cont.)

A later paper on the geology of Barbados (Jukes-Browne & Harrison, 1892) includes a 'Report by the [then] late H. B. Brady', which in turn also includes a palaeobathymetric interpretation, as follows: 'I have made a preliminary examination, in respect of the Foraminifera they contain, of most of the samples you sent me. The results, though far from complete, possess considerable interest, and as I am unable at present [presumably, at this time, through ill health] to continue the investigation I send them to you as they stand. . . . The aspect of the rhizopod fauna . . . is not inconsistent with the idea of a sea-bottom of considerable depth, perhaps from 500 to 1000 fathoms.'

include those of Haynes, Saidova, Loeblich & Tappan, Lee and Mikhalevich (again, see Cifelli & Richardson, 1990; see also Section 3.3.2).

The interpretive phase began with the first use of Foraminifera in biostratigraphy, by the Pole, Josef Grzybowski, in the oilfield area of the Polish Carpathians, in the late nineteenth century (Charnock & Jones, in Hemleben *et al*., 1990; Kaminski *et al*., 1993). It continued with further applications in the petroleum industry, in areas as diverse as California, the US Gulf Coast, Iran, Nigeria, Papua New Guinea and Sarawak, in the early twentieth century. Applications in academia began with the establishment of regional larger benthic and, importantly, global planktic foraminiferal biostratigraphic zonation schemes in the late twentieth century (Bolli *et al*., 1985); accompanied by improvements in the understanding of foraminiferal ecology, oceanography, palaeoecology, palaeoceanography and palaeoclimatology, and of biogeochemical proxies (Scott & Medioli, 1980; Vincent *et al*., 1981; Lutze & Coulbourn, 1984; Corliss, 1985; Delaney & Boyle, 1987; Gooday & Lambshead, 1989; Mix, in Berger *et al*., 1989; Herguera & Berger, 1991; Kaiho, 1994; Jorissen, in Sen Gupta, 1999; Pearson & Palmer, 2000). Significant advances on all fronts accompanied the 'big science' initiatives of the time, including the Deep-Sea Drilling Project or DSDP and succeeding Ocean Drilling Program or ODP, and CLIMAP (CLIMAP Project Members, 1981; Imbrie *et al*., in Berger *et al*., 1984; Shackleton *et al*., 1990).

1.2 Present research (perspective)

Probably the most important advances in foraminiferology in recent years have been in the fields of molecular biology (Gregory *et al*., 2006; Murray, 2006; see also Section 3.3.2). Advances have also been made in the fields of imaging technology (Briguglio & Hohenegger, 2010; Mucadam, 2010; Speijer *et al*., 2010b; Szinger *et al*., 2010; Gorog *et al*., 2012); and of automated species identification (see, for example, Shan Yu *et al*., 1996; Ranaweera *et al*., 2009a; b; see also Section 2.3). Innovative uses have been made of Foraminifera in the fields of mineral and engineering geology (Hart *et al*., in Jenkins, 1993; see also, respectively, Chapters 10 and 11); environmental science (Martin, 2000; see also Chapter 12); and archaeology (Whittaker, in Whittaker *et al*., 2003; Jones & Whittaker, in Whittaker & Hart, 2010; see also Chapter 13). And if only for its massive economic impact, or what I once referred to as 'bang for your bug', then surely well-site operations in petroleum geology, and especially 'biosteering' must merit at least a mention (Jones *et al*., 1999; Jones *et al*., in Koutsoukos, 2005).

1.3 Future research (prospective)

I personally would like to see more of the same, please, in petroleum geology, especially as regards reservoir exploitation; in mineral and engineering geology and in archaeology; and, especially, in environmental science (at least this last is well underway in preparation for the implementation of the European Water Framework Directive or ENFD in 2015 and European Marine Strategy Framework Directive or EMSFD in 2020 (see, for example, Barras *et al*., 2010; Jorissen, 2010; Schonfeld *et al*., 2012)). And maybe some strategic research into how to explore for and exploit the world's remaining, in many cases stratigraphically rather than structurally trapped, petroleum reserves most efficiently and, at the same time, with the least environmental impact.

2

Research methods

This chapter deals with research methods. It contains sections on work-flow; on sample acquisition and processing; on analytical data acquisition; on interpretation; and on integration. The section on sample acquisition and processing includes separate sub-sections on sample acquisition and on sample processing.

2.1 Work-flow

A generic work-flow for applied (micro)palaeontology is shown in Fig. 2.1. It will be seen that the key constituent elements are sample acquisition and processing (also analysis), analytical data acquisition, interpretation and integration. Each of these is discussed in turn below.

2.2 Sample acquisition and processing

2.2.1 Sample acquisition

Field acquisition of samples of live Foraminifera

The acquisition of samples of live Foraminifera, for laboratory culture and/or analysis, including sea-bed samples for benthics and sea-surface samples for planktics, is discussed by, among others, Murray (1973), Haynes (1981), Green (2001), Schonfeld (2012) and Schonfeld *et al*. (2012) (see also the Scientific Committee on Oceanic Research (SCOR) website). The best sea-bed samples for benthics are those acquired through the use of multiple or box corers, which preserve the sediment–water interface.

Field acquisition of samples of fossil Foraminifera

The field acquisition of samples of fossil Foraminifera for laboratory analysis is discussed by Green (2001), Jones (2006) and Jones (2011a) (see also Coe, 2010).

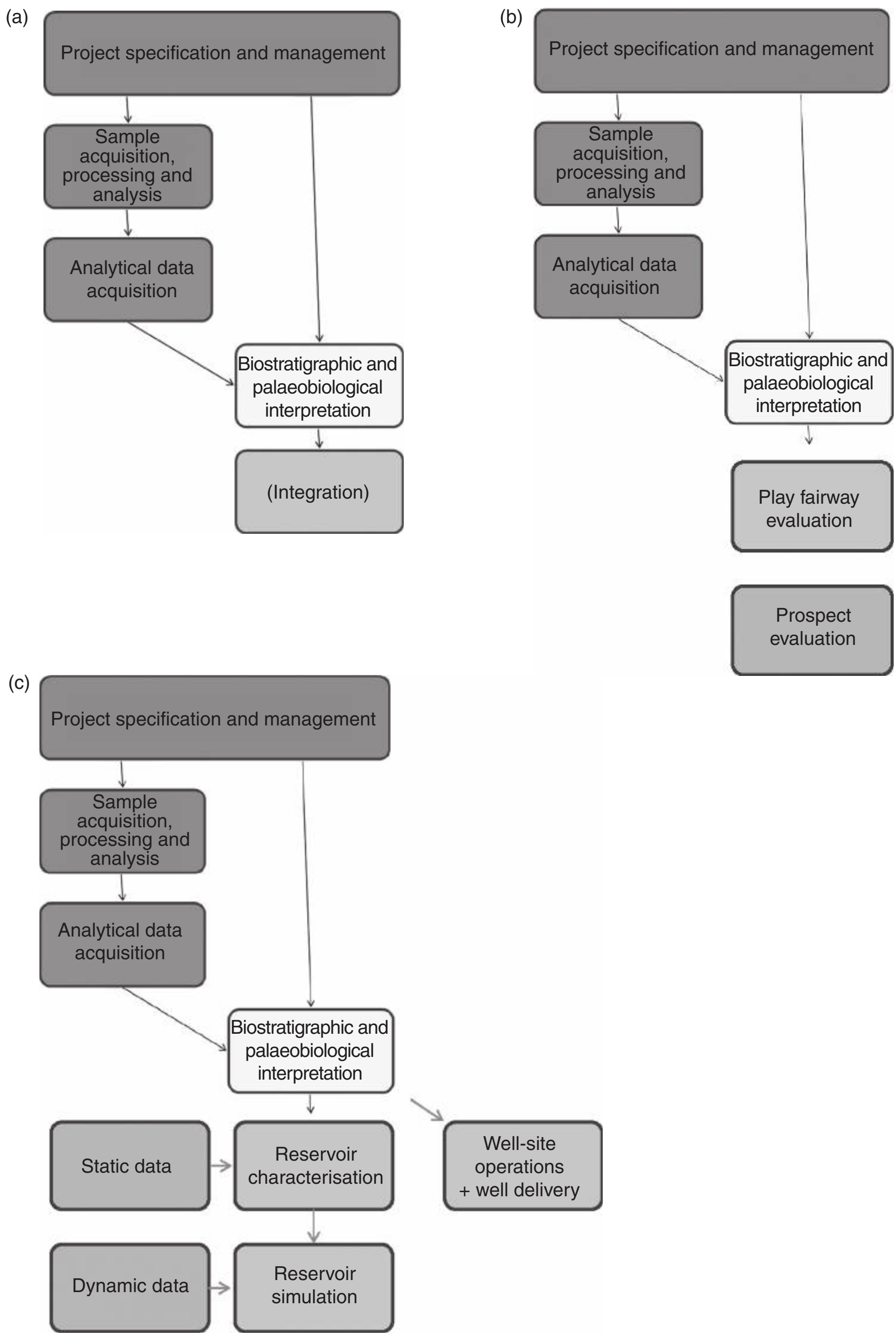

Fig. 2.1 **Work-flow for (applied) micropalaeontology**. (a) General; (b) petroleum exploration; (c) reservoir exploitation; from Jones (2011).

Sample acquisition is necessary for field mapping and laboratory research purposes, but it should still be undertaken responsibly and sustainably, so as to conserve or preserve a finite natural resource for future generations. Note in this context that sample acquisition is restricted in Sites of Special Scientific Interest, or SSSIs, in the United Kingdom, and indeed is restricted by nature conservation and by national monument protection legislation in 'geotopes' ('parts of the geosphere . . . clearly distinguishable from their surroundings in a geoscientific fashion') in Germany.

The overall objectives of the field-work should be considered when determining the sampling strategy. For example, if the objective is reconnaissance mapping, spot sampling might be all that is required, whereas if the objective is detailed logging, closer sampling will be required. As a general comment, the biostratigraphic or palaeoenvironmental resolution of the analytical results will depend as much on the sampling density as on the fossils themselves. Partly on account of this, and partly on account of the logistical effort and financial cost of mobilising field parties, it is always advisable to collect what might be thought of as too many rather than too few samples. However, any restrictions should be respected (see above).

Lithology Foraminifera are common in essentially all at least marginally marine mudstones, marls and limestones. Fresh rather than weathered samples should be acquired, through digging, augering or trenching, if necessary.

Size of sample A 'Standard British Handful' is generally sufficient to ensure recovery of Foraminifera. However, larger samples are required in areas characterised by high sediment accumulation rate, which trends to dilute the fossil content, such as parts of the Polish Carpathians.

Well-site acquisition of samples of fossil Foraminifera (in the petroleum industry)

The well-site acquisition of samples of fossil Foraminifera for laboratory analysis is discussed by Jones (2006) and Jones (2011a). The most useful are conventional- or side-wall- core samples, and the least useful are ditch cuttings (see also Section 9.1.2). This is because ditch-cuttings samples are prone to contamination not only from caved material, but also on occasion from the drilling mud.

As above, the overall objectives of the well-site work should be considered when determining the appropriate strategy, ideally well in advance. For example, if the objective is routine monitoring in the exploration phase, coarsely-spaced ditch-cuttings sampling might be all that is required, whereas if the objective is integrated reservoir characterisation in the exploitation phase, closely-spaced cuttings, or conventional- or side-wall- core sampling might be required. Also as above,