INTRODUCTION

FOREWORD

In ranking foraminifera according to taxonomic insight, biostratigraphic significance and paleobathymetrical utility, agglutinated foraminifera commonly are placed behind calcareous foraminifera. Why is this? One reason certainly is that agglutinated taxa are difficult to study, and are not considered as beautiful as calcareous ones. It is, as if the fairy tale is re-enacted on the two daughters of the emperor, the first one beautiful and courted by all the princes, the second one ugly and avoided by all. But when the second princess's hidden and enduring beauty is finally discovered, it is hard to stay away...

Such an event occurred over a century ago, when the founder of petroleum micropaleontology, Joseph Grzybowski from the Jagellonian University in Cracow, began to 'court' agglutinated foraminifera. Grzybowski put their utility in biostratigraphy and paleobathymetry in practice, and it was 50 years later at the same university that my friend Stanislaw Geroch followed in Grzybowski's big footsteps. Stan pioneered modern biostratigraphy of the Cretaceous - Paleogene of the Polish Carpathians, and as few demonstrated the scientific and esthetic beauty of these 'bugs', that predominate in flysch deposits.

The co-authors of the present, authoritative Atlas, an absolute first of its kind, both are again pioneers: FMG initiated the International Workshops on Agglutinated Foraminifera (1980-) and made an early start with the present global Atlas during his career with the Geological Survey of Canada. MAK was a Geroch student at the Jagellonian University, and became more and more involved with the Atlas project while still a Ph.D. student at Woods Hole and during his postdoctoral fellowship at Dalhousie University, Canada.

This Atlas, in my opinion, represents the best hommage to the at present flourishing studies of agglutinated foraminifera, by gathering in a single book, truly impressive practical knowledge, synthesized from over 20 years of microscope study and literature sleuthing. There is no doubt in my mind that this pioneering and remarkable synthesis will be rewarded by the appreciation of the younger generation of micropaleontologists. At the same time this effort needs to continue up and down the stratigraphic column, such that we will have an enduring insight in the evolutionary beauty and utility of this previously enigmatic group of microfossils which are so abundant in many deep marine basins around the globe.

Professor Theodor Neagu,
Member of the Romanian Academy,
Bucharest

Back on top | Preface | Acknowledgements | Introduction

PREFACE

This book is intended to serve as a handbook for micropalaeontologists working with agglutinated benthic foraminifera found in deep marine strata of Paleogene age around the world. Our approach t o this study has been to select Deep Water Agglutinated Foraminiferal (DWAF) species that are either used in Paleogene stratigraphy, or comprise an important component of Paleogene benthic assemblages in siliciclastic sediments. The overwhelming majority of species included in the atlas are cosmopolitan, and those few that are endemic are of regional stratigraphic significance. Since a number of the taxa are stratigraphically long ranging (mainly single-chambered forms), while others appeared either in Late Cretaceous time or extend into the Neogene, the atlas in fact covers more than just the Paleogene. We have aimed at a practical approach for the atlas, with taxa grouped in natural taxonomic units. There is concise text for each of the 130 taxa that represent the majority of species to be expected in Paleogene deep marine sediments. For each of these valid species we provide type illustrations, and one or more plates with SEM and optical photographs and/or camera lucida drawings, with characteristic views of the tests in samples from several different sedimentary basins. We offer this guide to our colleagues as a pathway through the 'jungle' of intercontinental taxonomic, stratigraphic and palaeoecologic literature. Over the last two decades we have endeavoured to stabilise the classical eastern European taxonomy through translation of major studies, re-study of type collections, re-discovery of 'lost' type localities, and completion of incomplete historical taxonomic procedures. Virtually all published uppermost Cretaceous through Paleogene DWAF taxa from the European and American continents have been 'under the knife' in our laboratories. Our direct involvement in exploration micropalaeontology of many petroleum basins where DWAF are important has been of considerable assistance to this project. We only decided that we had stumbled upon some unknown new species after many years of comparative study and consultations with colleagues well acquainted with local stratigraphy and micropalaeontology.

This *Atlas of Paleogene Cosmopolitan Deep Water Agglutinated Foraminifera* begins with an Introduction outlining the history of investigation and lists the important collections. The second chapter introduces the main biofacies and addresses topics on palaeoecology and its spinoff, palaeobathymetry - fields that are in demand for geoscience and petroleum modelling studies of deep marine basins. Chapter three summarises the biostratigraphical record of DWAF in offshore eastern Canada, the North Sea, offshore mid-Norway, Norwegian-Greenland Sea, Barents Sea, Beaufort Sea, Carpathian flysch basins, southern European Tethyan basins, West Africa, and Trinidad/Venezuela. Each main area of investigation has a stratigraphic range chart for key taxa. The following section constitutes the main part of this atlas: Systematic Taxonomy. The taxonomic chapter is followed by the master reference listing and the species index.

This publication aims at stabilising the systematics and enhancing the economic applicability of DWAF. The study had its early roots as far back as the early 1970's. At that time, W.A. Berggren (WAB), while preparing to go to sea on Leg 12 of the Deep Sea Drilling Project, was studying agglutinated assemblages in North Sea wells, and one of us (FMG) was trying to make sense out of Cenozoic agglutinated assemblages, offshore eastern Canada. It became apparent that similar assemblages are found in these two continental margin basins, and these display general similarity t o the flysch-type faunas of the mobile tectonic belts of the Carpathian Mountains. These facts became the basis for the long-term investigation on the agglutinated benthic foraminifera, which was an outgrowth of a larger project devoted to the study of Cenozoic Deep Water Benthic Foraminifera. At its acme, this program enjoyed the support of 14 major oil companies, including ARCO, BP, Chevron, Elf-Aquitaine, Exxon, Gulf, Mobil, Marathon, Phillips, Shell (Houston), Shell International (The Hague), Statoil, Texaco, and Unocal. During the last phase of the work on this Atlas, Saga Petroleum in Norway provided vital financial assistance.

We view this study as only a first step towards a more comprehensive documentation of the global DWAF faunas through geological time. These faunas

started to flourish in deep marine basins as early as Middle Jurassic, with major phases of evolutionary expansion in the Aptian-Turonian, Campanian, Paleocene, Early Eocene, and Early Miocene; the fauna is also an important constituent of bottom dwelling foraminiferal assemblages along modern continental margins. It is our wish that this atlas may be of help with the task of a more thorough and comprehensive evaluation of the taxonomy, stratigraphy and palaeoecology of this remarkably diversified and cosmopolitan group of benthic organisms that serve well in geological investigations.

M.A.Kaminski and F.M.Gradstein

Back on top | Foreword | Acknowledgements | Introduction

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Over the years, many people have assisted with the taxonomic and biostratigraphic work connected with "the Atlas Project". We especially wish to thank our collaborators who have all donated samples, illustrations, and their valuable time. Bill Berggren and Garry Jones both deserve special thanks for their encouragement and support at the crucial initial stage of the project, when the concept of a companion volume to the Van Morkhoven et al. (1986) atlas was formulated. One of the first tasks involved the revision and lectotypification of the Grzybowski Collection, and this would not have been possible without the enthusiastic assistance and advice of Stan Geroch. Specimens from the CHALLENGER Collection were re-studied and photographed with the kind assistance of John Whittaker, whose infectious enthusiasm for the project is very much appreciated. Frank Thomas and David McNeil provided valuable help with the microfossil collections housed at the Canadian Geological Survey, and contributed photos. Martin Buzas allowed access to the Cushman Collection in Washington, D.C.; Svetlana Yakovleva enabled access to the microfossil collections at VNIGRI in St. Petersburg; Humberto Carvajal-Chitty provided access to the P.J. Bermúdez Collection at INTEVEP in Caracas and contributed photos; Miroslav Bubík was instrumental in finding relevant material in the Hanzlíková collection at the Czech Geological Survey; and Fred Rögl provided drawings and photos from the Reuss and Hantken collections at the Natural History Museum in Vienna.

Although the idea of putting together this "agglutinated atlas" may be 20 years old, it would not have been possible to produce such a compilation back in 1984, as we knew so little about the taxonomy and distribution of even the cosmopolitan species. To partially address this problem it was necessary to collect new material from key areas. Our long-term collaborator Wolfgang Kuhnt deserves special thanks in this regard by providing material and valuable data from Morocco, Spain, Italy, and the Atlantic DSDP/ODP sites. Jenö Nagy contributed original data from the Barents Sea wells, Sven Backstrom helped with the compilation of biostratigraphic data from offshore Norway, Bob Liska donated samples from Trinidad; and P. Ramesh contributed information on the occurrences of the Atlas taxa in offshore eastern India; and Rodolfo Coccioni & Simone Galeotti provided help in the field on numerous occasions in Italy. Miroslav Bubík and Emil Platon provided with images of some of the *Recurvoides* species. We also grateful to Theodor Neagu for his encouragement and for allowing access to his collections in Bucharest.

In the production stage of the project, Sorin Filipescu provided valuable help by performing digital magic with the SEM images and rangecharts, providing help in the field, and advice on the occurrences of the atlas taxa in Romania. We also appreciate the advice of John Van Couvering, and the practical assistance of Krzysztof Bąk. We thank the Grzybowski Foundation and Micropaleontology Press for permission to reprint some of the photos. Fred Rögl, Miroslaw Bubík, Theodor Neagu, and Krzysztof Bąk read a complete draft of the taxonomic chapters, and provided helpful suggestions and corrections. We appreciate the comments and suggestions of all the participants of the International Workshops on Agglutinated Foraminifera who have contributed to the project in any way. Finally, we are both grateful to our families, who have contributed assistance in kind by putting up with us on various informal occasions, and affording us the time to carry out this project (mostly in our "spare" time).

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Back on top | Foreword | Preface | Introduction

INTRODUCTION

Deep-Water Agglutinated Foraminifera (DWAF) are among the most common benthic organisms recovered from sediments deposited beneath the lysocline. Their ubiquitous occurrence in noncalcareous sediments as well as their commonly well-delimited biostratigraphical succession makes them extremely valuable microfossils for both biostratigraphical and palaeoenvironmental studies. The DWAF are routinely used for biostratigraphical purposes in such areas as the Circum-Atlantic petroleum basins (Gradstein & Berggren, 1981), the Arctic and Boreal Seas (Verdenius & Van Hinte, 1983, Schröder-

Adams & McNeil, 1994), in the Alpine-Carpathian flysch (Geroch, 1959, 1960; Geroch & Nowak, 1984) and at abyssal Deep-Sea Drilling Sites throughout the world ocean (Kaminski et al., 1989; Kuhnt et al., 1998). In these depositional settings where calcareous fossils are poorly preserved or lacking, often the DWAF can form diverse, well-preserved assemblages that represent an important tool for biostratigraphical work.

Historically, the DWAF were among the most understudied of the various groups of foraminifera. Variations in agglutination of the test from site to site within one species, collapse of the test wall during diagenesis, differences in silicification of tests as a function of burial depth, and difficulty in determining the early 'whorls' in many serial taxa, makes understanding their taxonomy a daunting task for the micropalaeontologist used to working with calcareous foraminifera. Until comparatively recently, the taxonomic and biostratigraphic framework for the Paleogene DWAF was based entirely upon isolated studies carried out largely in the Alpine-Carpathian belt, the Caucasus, and in Trinidad (Table 1). The lack of continuous stratigraphic successions in these tectonically active belts and paucity of index fossils for correlation to the standard chronostratigraphy was another major obstacle for the study of DWAF. Additionally, before the fall of the "iron curtain" many of the original type localities in eastern and central Europe could only be accessed with great difficulty, which virtually precluded serious study of the group.

With the advent of offshore drilling in the North Atlantic petroleum basins, and the first Deep Sea Drilling Program (DSDP) cruises, the situation changed dramatically. Now continuous stratigraphic successions became available for sampling and were studied for DWAF. The first DSDP cruises in the North Atlantic in the late 1960s (Legs 11 and 12) proved the existence of agglutinated foraminiferal assemblages that bear striking resemblance to the classic Carpathian faunas described by Grzybowski at the end of the 19th century (Berggren, 1972). When rich assemblages of DWAF were recovered from the first commercial wells drilled in the North Sea and Labrador Margin, the need to restudy the classic agglutinated foraminiferal faunas became readily apparent. The initial attempts to understand the Paleogene assemblages in the North Atlantic basins were frustrated by the near lack of taxonomic literature published in the English language.

A direct result of this renewed interest in agglutinated foraminifera, a new series of workshops was initiated by one of us (FMG) and W.A. Berggren to promote further study of this group of organisms and refine their usefullness for applied studies. "The First International Workshop on Arenaceous Foraminifera" (IWAF) was held in Amsterdam in September, 1981, and attracted over 60 participants. This meeting, together with the first landmark paper on the biostratigraphy and palaeoecology of the DWAF (Gradstein & Berggren, 1981) can be viewed as the catalyst that initiated the modern phase of studies on agglutinated foraminifera. In the 20 years that followed, over 130 research papers dealing primarily with the agglutinated foraminifera have now been published in the IWAF proceedings alone.

This volume is a direct outcome of the renewed interest in DWAF in basins worldwide. The original aim of this study was to produce a companion volume to "Cosmopolitan Cenozoic Deep-Water Benthic Foraminifera" published by Van Morkhoven et al., in 1986. That volume was compiled by members of the "Deep-Water Benthic Foraminifera Project" initiated by W.A. Berggren and Frank Van Morkhoven at the Woods Hole Oceanographic Institution, and colleagues at other marine laboratories in the US and Canada. Within the framework of this project, members of that working group undertook systematic studies of the agglutinated faunas from the Labrador Sea (Miller et al., 1982; Kaminski et al., 1989), Trinidad (Kaminski & Geroch, 1986; Kaminski et al., 1988), the North Sea and Labrador Margin (Gradstein et al., 1988, 1992, 1994), the Norwegian-Greenland Sea (Kaminski et al., 1990; Kaminski & Austin, 1999), and the Beaufort Sea (Schröder-Adams & McNeil, 1994a,b) and studies of the modern DWAF faunas (Schöder, 1986, 1988; Schöder-Adams, 1990; Kaminski et al., 1988). At an early stage in that project, we realised the urgent need to restudy the faunas from the Carpathians and finally produce an annotated translation of the classic monographs of Grzybowski (Kaminski et al., 1993). This work was expanded to include a restudy of the Grzybowski Collection and the type localities in Poland (Kaminski & Geroch, 1993, Ślączka, 1993). Additional localities in the North Atlantic and Western Tethys were studied in collaboration with Wolfgang Kuhnt (Kuhnt & Kaminski, 1989, 1990, 1996, 1997; Kuhnt & Collins, 1996; Kuhnt et al., 1996, 1998; Kaminski et al., 1996, 1999); and the Paleogene assemblages of the Western Barent Sea were studied in collaboration with Jenõ Nagy (Nagy et al., 1997; 2000; 2004). Our main goal is to provide a stable taxonomic framework for the study of Cenozoic DWAF and to summarise their known stratigraphical and geographical distribution.

HIistory of investigations

As in any scientific endeavour, the study of Deep-water Agglutinated Foraminifera has undergone an "early discovery" phase, and a "development and refinement" stage, before entering the current "application" phase. In the case of the DWAF, contingency (people being at the right place at the right time) played an extraordinary role in the course of investigations which have largely been motivated by the search for petroleum and in later years by the Deep Sea Drilling Project and Ocean Drilling Program.

Modern benthic foraminifera from deep-sea soundings or dredgings have been studied since the middle of the 19th century. Early contributions by Jones & Parker (1860) and Henry Bowman Brady (1879, 1884) form the main basis for all subsequent work on modern and fossil deep-sea foraminifera.

The study of fossil deep-water agglutinated foraminifera originates in Austria in the latter half of the 19th century. Felix Karrer (1866) made the first tentative attempt at identifying species recovered from flysch sediments that outcrop in a suburb of Vienna. In Moravia, Anton Rzehak (1887, 1895) had realised that the Carpathian faunas were yet undescribed, and produced a list of new species names. However, it was the search for petroleum in the far reaches of the Austro-Hungarian Empire that inspired the first systematic studies of agglutinated foraminifera from the Carpathian oil fields (Table 1).

Table 1. *"Classic" systematic studies of Upper Cretaceous - Paleocene DWAF*

Author	Region	Comments
Karrer, 1866	Vienna woods	First report of Late Cretaceous agglutinates in the Alpine flysch
Rzehak, 1887	Moravian Carpathians	Published a list of new taxa (all nomen nudum) later validated by Grzybowski (1898)
Rzehak, 1895	Ibid	First report of Rzehakina in the flysch
Grzybowski, 1896	Wadowice, Poland	New taxa from the Upper Cretaceous & Paleocene of the Subsilesian Unit, Polish Carpathians
Grzybowski, 1898	Krosno, Poland	New taxa from the Paleocene-Eocene, Silesian Unit, Carpathians
Grzybowski, 1901	Gorlice, Poland	New taxa from the Paleocene-Eocene, Silesian and Magura Units, Carpathians
Friedberg, 1901	Debica, Poland	New taxa from the Upper Cretaceous, Skole Unit, Carpathians
Schubert, 1902	Lake Garda, Italy	New taxa from the Oligocene of the southern Alps.
Liebus & Schubert, 1902	Pieniny Klippen Belt, Slovakia	First descriptions of foraminifera from the Upper Cretaceous "Puchov Marls".

Noth, 1912	Barwinek, Poland	New taxa from the Eocene, Magura Unit, Carpathians
Dylążanka, 1923	Gorlice, Poland	New taxa from the Upper Cretaceous of the Silesian Unit of the Carpathians
White, 1928	Tampico, Mexico	Described new Paleocene taxa from Mexico
Berry, 1928	Paleocene, Peru	First descriptions of new DWAF from the Lobitos shales of northwestern Peru.
Cushman & Jarvis, 1928, 1932	Lizard Springs Fm., Trinidad	First reports of Paleocene DWAF from the Caribbean region, with new species.
MacFadyen, 1933	Burdwood Bank	First report of Paleogene DWAF from submarine dredgings in the South Atlantic
Glaessner, 1937	Caucasus, USSR	First report of Paleogene DWAF from flysch units in the Caucasus, with descriptions of new species
Finlay, 1939, 1940	New Zealand	First reports of Paleogene bathyal benthics from New Zealand, with descriptions of new DWAF
Staeche & Hiltermann, 1940	NW Germany	First reports of Paleogene bathyal benthics from exploration wells in NW Germany
Cushman & Siegfus, 1939, 1942	Kreyenhagen Shale, California	First report of Eocene DWAF in California
Cushman & Renz, 1946	Lizard Springs Fm., Trinidad	Revision of earlier work and description of new taxa from the Paleocene of Trinidad
Cushman, 1947	Santa Anita Group, Venezuela	Report of a "Lizard Springs fauna" in the Paleocene Vidońo Fm. of Venezuela
Vasíček, 1947	Moravia	New taxa from the Eocene of the Moravian Carpathians
Cushman & Renz, 1948	Navet Fm. Trinidad	Extension of the previous work into the Eocene, with description of new taxa
Pokorný, 1949	Moravia	Revision of Rzehak's fauna from the Moravian Carpathians
Mjatliuk, 1950	Ukrainian Carpathians	First report of DWAF from the Ukrainian sector of the Carpathians
Subbotina, 1950	Caucasus, USSR	Revision of Paleogene DWAF from flysch units in the Caucasus with additional new species
Noth, 1951	Austrian Alps	Described foraminifera from the Cretaceous of the Flysch Zone and Helvetikum of the Austrian Alps, with new species.
Israelsky, 1951	Lodo Fm, California	Bathyal benthic foraminifera from the Eocene of California, with description of new taxa.
Todd & Knicker, 1952	Agua Fresca Shale	First report of DWAF from southernmost Chile, with description of new taxa
Hanzlíková, 1953	Zukov Borehole, Moravia	Descriptions of Paleogene DWAF from the Carpathians in Czechoslovakia
Emiliani, 1954	Apennines, Italy	First report of Paleogene bathyal benthic foraminifera from Italy, with description of new taxa
Maslakova, 1955	Ukrainian Carpathians	Revision of Paleogene DWAF from flysch units in the Ukraine, with new taxa
Homola & Hanzlíková, 1955	Moravia	Descriptions of Paleogene DWAF from the Carpathians in Czechoslovakia

In 1895, Henryk Walter, a Petroleum Geologist who was working at the time in the oil fields of the Krosno district, visited the Geology Department of the Jagiellonian University and approached Prof. Władisław Szajnocha with a proposal. The oil-bearing strata of the fields near Krosno contained no visible fossils, and there was a need to attempt to correlate them by other means. Prof. Szajnocha assigned a Ph.D. student by the name of Józef Grzybowski the task of examining samples from the oil fields with the purpose of studying the microfauna. Grzybowski had earlier published a paper on the "Microfauna of the Carpathian Sandstone" (Grzybowski, 1894) and was at the time working on the microfauna from the red clays of Wadowice for his Ph.D. project (Grzybowski, 1896). Alongside his thesis work, he then began a series of studies that culminated in the publication of two monographs of Paleogene DWAF from the Krosno and Gorlice districts, respectively (Grzybowski, 1898a, 1901) as well as a stratigraphical study in which he used foraminiferal assemblages to correlate subsurface strata in the Potok oil field (Grzybowski, 1898b).

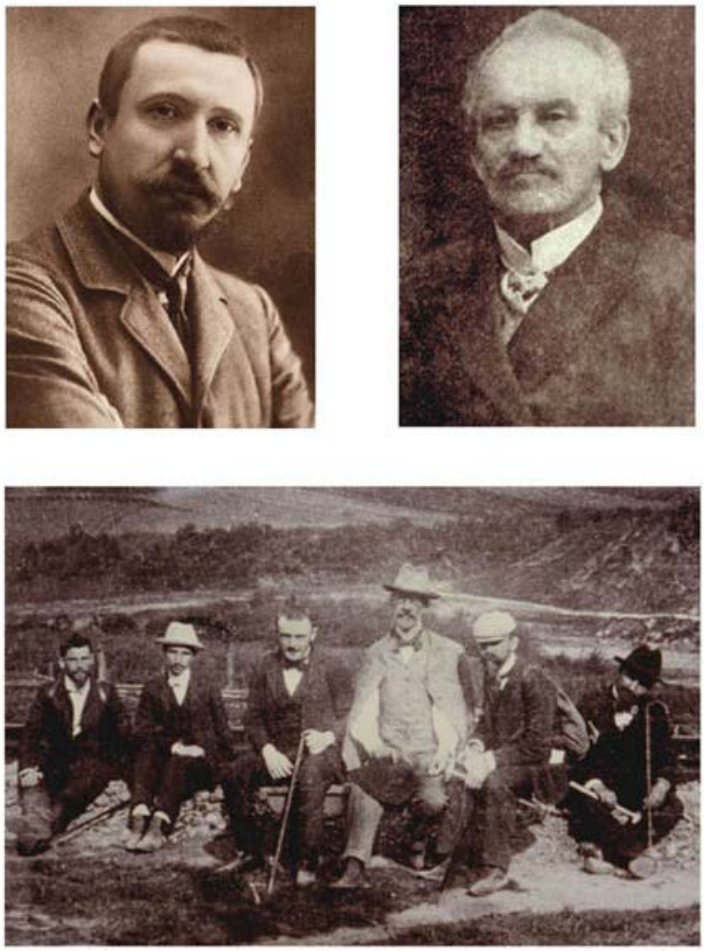


Figure 1. *Top Left: Józef Grzybowski, portrait at the Jagiellonian University; Top Right: Henryk Walter. Bottom. Prof. Władisław Szajnocha during a field excursion in 1900. Grzybowski is seated on the far right.*

In addition to being the first to use DWAF for applied research, Grzybowski correctly interpreted the environmental significance of these fossils in the Carpathian flysch deposits. Grzybowski was in possession of H.B. Brady's monograph of foraminifera from the HMS Challenger reports, and had realised that in the Carpathian flysch he was dealing with a cosmopolitan deep-sea fauna. After he had completed his study of the foraminifera from the Krosno area in late 1898, Grzybowski applied for a research grant to the "Academy of Knowledge in Kraków". In his grant proposal, which is still held on record in the archives of the Polish Academy of Sciences in Kraków, Grzybowski wrote that he needed 1000 marks to travel to England for a year to study the Brady Collection. En route to London, Grzybowski wanted to stop at the University in Munich to view the Egger Collection. Because of budgetary constraints and the fact that the proposal of Prof. Estreicher (who compiled the first Encyclopedia in the Polish Language) was ranked higher, Grzybowski was awarded only half of the requested amount. This enabled him to spend six months in Munich where he collaborated with Carl Zittel and A. Rothpleth, and produced a monograph on Tertiary molluscs from Peru. The question will always remain "What if Grzybowski had been awarded the full amount of his travel grant?" Upon his return to Kraków, Grzybowski took up an unpaid position teaching Palaeontology at the Jagiellonian University, supporting himself by consulting for the petroleum industry. In 1912, he founded the first Petroleum Research Institute in the town of Boryslaw (now in the Ukraine) and was its first director.

Meanwhile at the Geological Survey in Vienna, Grzybowski's colleague Richard Schubert made use of Grzybowski's taxonomical monographs and produced papers on the Oligocene foraminifera from the Lake Garda region (Schubert, 1902) and from the Pieniny Klippen Belt (Liebus & Schubert, 1902) in which new species of DWAF were described; and Rudolf Noth (1912), then a student of Victor Uhlig at the University of Vienna, described new species of Eocene DWAF from the red shales of the Magura flysch collected near his home town of Barwinek, south of Dukla. After the First World War, Grzybowski returned to the field of Micropalaeontology, this time as a full-time Professor of Palaeontology at the Jagiellonian University, and upon his death in 1922 was working on a monograph of Miocene miliolids from the Carpathian foredeep. In 1923, Grzybowski's Ph.D. student Maria Dylążanka published a paper describing the Upper Cretaceous DWAF from the Gorlice region.

The study of fossil Deep-Water Agglutinated Foraminifera was taken up by Joseph A. Cushman in the late 1920's. Earlier in his career, Cushman had investigated the modern deep-sea faunas from the North Pacific and North Atlantic collected during the ALBATROSS expeditions, and was in an excellent position to undertake serious studies of the Paleogene DWAF. In collaboration with P.W. Jarvis (who sent Cushman sample material from the oil fields of Trinidad), Cushman produced a series of papers on the fauna from the Lizard Springs Trinidad (Cushman & Jarvis, 1928, 1932). Although Cushman was undoubtedly aware of the work of Grzybowski in the Carpathian oilfields, there is no evidence that Cushman was able to use Grzybowski's taxonomy to any great extent (Grzybowski published the bulk of his papers in Polish, with German abstracts). As a result, a number of the new species described by Cushman & co-workers from Trinidad were synonymous with those described earlier by Grzybowski. In the 1940's the taxonomy of Paleogene deep-water foraminifera from Trinidad and Venezuela was later revised and expanded in collaboration with H.H. Renz (Cushman & Renz, 1946, 1947a,b, 1948). Other important works in this period include the studies of White (1928a,b; 1929) from the Paleocene of Mexico; Berry (1928) from the Mel Paso Shale of Peru; MacFadyen (1933) from the Burdwood Bank in the Falklands, and studies of the California deep-water clastic sediments by Cushman & Campbell (1934) and by Cushman & Siegfus (1939, 1942). In New Zealand, Finlay (1939, 1940) undertook a survey of index species of foraminifera which included several new species of DWAF, including the well-known species Conotrochammina whangaia.

The second phase of research on agglutinated foraminifera began after the Second World War, when the focus for research shifted mainly to the national Geological Surveys and their equivalents. A number of separate "schools" emerged, again largely in support of the continued search for hydrocarbons. Unfortunately, the dark realities of the Cold War prevented much interaction between the different schools, and the taxonomy that developed during this period reflects this. In the Soviet Union, Nina Subbotina and co-workers at VNIGRI undertook studies of flysch-type faunas in the Caucasus and in the Ukrainian part of the Carpathians (Subbotina, 1950; Maslakova, 1955; Mjatliuk, 1939, 1950, 1966, 1970) and the Soviet Far East (Voloshinova & Budasheva, 1966). Among the most prolific micropalaeontologists at VNIGRI was Elena Mjatliuk, who produced monographs of the foraminifera from the Carpathian and Peri-Caspian oil fields, and described many new taxa of agglutinated foraminifera. Elsewhere in the Soviet Union, Paleocene agglutinated faunas were studied by O.S. Vialov (1967) in the Ukrainian Carpathians, by M. Serova (1969, 1987) in the Soviet Far East, and their epicontinental equivalents in Siberia were first studied by Vera Podobina (1966). Suleymanov (1960, 1963) undertook taxonomic studies of DWAF in Uzbekistan.

In Czechoslovakia, research on the Carpathian Paleogene faunas was taken up by Miroslav Vasíček (1947) and later in a series of papers published by Eva Hanzlíková and co-workers (1953-1983) and Ondrej Samuel (1977) at the Geological Survey of the Czechoslovak Republic, and by Vladimir Pokorný (1949-1960) at the Charles University in Prague (see Table 1). In Poland, research on the Carpathian DWAF assemblages was carried forward by the "Grzybowski School", first by Franciszek Bieda (a former student of Grzybowski), and later by Stanisław Geroch and students at the Jagiellonian University in Kraków. Additional systematic studies were carried but by Henryk Jurkiewicz at the Polish State Petroleum Company, by J. Morgiel, J. Liszkowa, B. Olszewska, and co-workers at the Geological Survey, and by A. Jednorowska at the Academy of Sciences in Kraków. By the early 1980's a biostratigraphical zonation of the Carpathian flysch deposits had been achieved which paved the way for wider stratigraphical applications of DWAF. Studies of (mostly Cretaceous) deep-water assemblages in the Southern Carpathians and Transylvania were carried out both at the Romanian Geological Survey and at the University of Bucharest by Theodor Neagu (1962, 1990) and J. Săndulescu (1973). At the Austrian Geological Survey, Rudolf Noth (1951, 1952) studied the foraminifera from the Alpine flysch, and Walter Grün and co-workers (1964, 1969) undertook systematic studies of the fauna of the Vienna Flysch. In Germany, research on agglutinated foraminifera was carried out by Heinrich Hiltermann and co-workers at the Geological Survey in Hannover. Staesche & Hiltermann (1940) were the first to document the predominantly agglutinated assemblages in the upper Paleocene and lower Eocene of northwestern Germany and produce a zonal scheme. In Bavaria, the group of Herbert Hagn in Munich studied the alpine flysch deposits. Among these, the monograph of Axel von Hillebrandt (1962) and the Ph.D. thesis of Uwe Pflaumann (1964) stand out as important taxonomic contributions. In Italy, the investigations of E. Montanaro-Gallitelli in the 1940s and early 1950s, and C. Emiliani (1954) as well as the later the work of J.-P. Beckmann (1982) drew attention to the presence of DWAF assemblages in the northern Apennines and southern Alps.

Figure 2.*Important early contributors to the study of agglutinated foraminifera. Top left: August Emmanuel Reuss, Top Centre: Felix Karrer, Top Right: Richard Schubert, Middle Left: T. Rupert Jones, Middle: Henry Bowman Brady, Middle right: Rudolf Noth, Bottom Left: Nina Nikolevna Subbotina; Bottom Centre: Elena Vasilevna Mjatliuk, Bottom Right: Joseph A. Cushman with Alfred Loeblich Jr. and Helen Tappan.*

Far fewer studies of the Paleogene DWAF were carried out in the Pacific Rim. In Japan, the work of Takayanagi (1960) documented the occurrence of assemblages containing agglutinated foraminifera in the Upper Cretaceous of Hokkaido, and described new species. The work in Hokkaido has been

continued by Kunio Kaiho (Kaiho, 1984a,b; 1992; Kaiho et al. 1993). In New Zealand, research on the Upper Cretaceous and Paleogene DWAF was carried out by N. de B. Hornibrook and co-workers (Scott, 1961; Webb, 1972, 1975). A concise summary of the taxonomy and palaeoecology of cosmopolitan DWAF in Hamurian Â– Porangan (Maastrichtian Â– Lutetian) siliciclastic basins in New Zealand can be found in the excellent "Manual of New Zealand Permian to Pleistocene Foraminiferal Biostratigraphy" (Hornibrook et al., 1989). Most recently, Milner (1997) studied the Paleocene DWAF from Papua New Guinea.

In the Americas, Israelsky (1951) and Mallory (1959) documented the benthic foraminifera from the Lodo and Kreyenhagen Formations of California; Pedro Bermúdez and co-workers in Caracas studied the Eocene of Caribbean localities, and J.-P. Beckmann (1960) made an early contribution to the study of the Cretaceous/Paleogene boundary in Trinidad. The paper of Todd & Kniker (1951) stands out as the only study of agglutinated assemblages from the Andes in southernmost South America. Trujillo (1960), and Sliter (1968) studied the Upper Cretaceous benthic foraminifera from southern California and Baja California.

At the close of this second period of discovery and development, the palaeoenvironmental significance of DWAF assemblages began to be emphasised. At Shell Oil in the Netherlands, J. Brouwer became involved with the study of Upper Cretaceous and Paleogene deep-water agglutinated assemblages from the Alps and Italy. In a classic paper published in 1965, Brouwer termed these assemblages "Rhabdammina" faunas and compared them with modern deep sea faunas of Saidova (1961). He concluded that "an abyssal environment of deposition must be considered as the most probable one for those deposits bearing fossil 'Rhabdammina' faunas." In Poland, M. Książkiewicz (1975) favoured an upper to middle bathyal interpretation for these "Rhabdammina" faunas in the Carpathian flysch, whereas Hesse & Butt (1976) noted the occurrence of assemblages in the eastern Alps beneath the CCD. In another classic paper published in 1976 that summarised the occurrence of agglutinated foraminiferal assemblages in northwest Europe, Thierry L. Moorkens at Deutsche Texaco concluded that "potential source rocks are often characterised by the occurrence of 'agglutinated-foraminifera-facies', as agglutinated foraminifera prefer a reducing environment which is also favourable for the preservation of organic matter".

Original taxonomical investigations in this period peaked in the mid 1960's, but important synthesis papers were published in the early 1980's, largely in response to the momentum created by the First International Workshop on Agglutinated Foraminifera (IWAF), (e.g., Morgiel & Olszewska, 1981; Hanzlíková, 1983; Verdenius & Van Hinte, 1983; Geroch & Nowak, 1984; Olszewska, 1984).

At the time that these initial studies on Cretaceous and Paleogene DWAF from the Western Tethyan and North Atlantic realms came to fruition, important taxonomic and stratigraphic studies were underway in the U.K., focussing on the British sector of the North Sea (King, 1983, 1989; Charnock & Jones, 1990; Gillmore, 1991). The study by King introduced a letter-zonation that carved a path through the Cretaceous deep water fauna of the Central and Viking Grabens, later expanded by Gradstein et al., (1999) with focus on offshore mid Norway. Alongside this work, original taxonomic contributions by F.T. Banner and students on the canaliculate wall structure of some Cretaceous genera opened up new insight into the evolutionary development of calcareous-cemented forms (Banner & Pereira, 1981; Desai & Banner, 1987).

Table 1 (continued). *Major studies devoted primarily or exclusively to Cretaceous to Paleogene DWAF.*

Author	Region	Comments
Geroch & Gradzinski, 1955	Subsilesian Unit	First biostratigraphical scheme of the Subsilesian Unit of the Polish Carpathians
Geroch, 1959, 1960	Silesian Unit	First biostratigraphical scheme of the Silesian Unit of the Polish Carpathians
Pokorný, 1960	Moravia	Biostratigraphy of the Magura and Zdanice units in Moravia.
Von Hillebrandt, 1962	Austrian Alps	Monograph of benthic foraminifera (including DWAF) from the Gossau Unit of the Alps in Austria
Pflaumann, 1964	Bavaria	Monograph of benthic foraminifera (including DWAF) from the Helvetica Unit of the Alps in Bavaria
Brouwer, 1964	Switzerland, Italy	First synthesis of "Rhabdammina faunas" paleobathymetry
Grün et al., 1964	Vienna Flysch	Taxonomy of DWAF, with stratigraphical occurrences
Huss, 1966	Subsilesian Unit	Compilation of DWAF in the Subsilesian Unit, with new species
Geroch et al., 1967	Polish Carpathians	Review of lithostratigraphy & foraminifera in Polish Carpathians
Jurkiewicz, 1960, 1967	Krosno District, Carpathians	Major taxonomical monograph & First calibration of DWAF ranges in various tectonic units to lithostratigraphy in the central Carpathians.
Jednorowska, 1968	Magura Unit	Taxonomy of Paleocene DWAF from the Magura Unit, with new species
Serova, 1966, 1969	Kamchatka	First reports of Paleogene DWAF from N. Pacific region, with new species
Grün, 1970	Vienna Flysch	Illustrated 27 species from the Maastrichtian Flysch
Neagu, 1970	Eastern Carpathians	Described Campanian-Maastrichtian DWAF, one new species
Mjatliuk, 1970	Ukrainian Carpathians	Major monograph of Paleocene species from the Carpathain flysch, with many new species.
Hanzlíková, 1972	Moravia	Upper Cretaceous species from the Carpathain flysch
Krasheninnikov, 1973, 1974	DSDP sites, Pacific	First report of Upper Cretaceous Abyssal faunas, with many new species.
Jednorowska, 1975	Magura Unit	Illustrated 40 species of DWAF from the Paleocene
Hiltermann, 1975	Carpathians	Discussed the stratigraphic significance of DWAF in the Carpathians
Hesse & Butt, 1975	Alps	Discussed importance of the CCD.
Webb, 1975	283, Tasman Sea	Established the cosmopolitan nature of Paleocene DWAF
Rögl, 1976	323, 325, Southern Ocean	Upper Creteous Â– Paleocene.
Moorkens, 1976	NW Europe	Review of factors controlling agglutinated assemblages in NW European basins. Relation to source rocks.

Săndulescu, 1976	Eastern Carpathians	Upper Cretaceous foraminifera from Romanian Carpathians
Krashenninikov & Pflaumann, 1977	367, 368, E. Atlantic	Upper Cretaceous of W. African DSDP sites.
Morgiel & Szymakowska, 1978	Skole Unit, Carpathians	Discussion of Paleogene biostratigraphy & acmes in the Skole Unit of the Polish Carpathians
Morgiel & Olszewska, 1981	Polish Carpathians	Cretaceous Â– Paleogene biostratigraphy of the Polish Carpathians
Liszka & Liszkowa, 1981	Silesian Unit	First revision of Grzybowski's collection from Wadowice
Butt, 1981	Bavarian Alps	Comprehensive review of DWAF in the Bavarian Alps
Beckmann, 1982	Italian Southern Alps	Illustrated Campanian-Paleocene DWAF from southern Alps.
Verdenius & Van Hinte, 1983	345, 346, 347, 348, 349, 350	First synthesis of Eocene-Miocene DWAF in the Norwegian Sea DSDP Sites. Classification of wall texture.
Hanzlíková, 1983	Moravia	DWAF calibrated to P-zones in the Moravian Carpathians
Geroch & Nowak, 1984	Polish Carpathians	Tithonian-Eocene. Proposed a formal zonation for the Carpathian Flysch applicable to Tethyan deep sea faunas.
Hemleben & Tröster, 1984	543, W. Atlantic	Santonian to Paleocene, western N. Atlantic
King, 1983	North Sea	First deterministic zonation of the North Sea, with ranges
King, 1989	North Sea	DWAF zonation of the North Sea, with alphanumeric zones
Charnock & Jones, 1990	North Sea	Taxonomy of North Sea DWAF
Beckmann, in: Bolli et al., 1994	Trinidad	Revision of the Albian to Eocene foraminifera and benthic foraminiferal biostratigraphy of Trinidad
Osterman & Spiegler, 1996	909, 913, Norwegian Sea	Eocene-Miocene DWAF of the Central Norwegian Sea

The "Deep-Water Agglutinated Foraminiferal Project"

The current phase of studies on DWAF began in the late 1970's, with the work largely carried out at oceanographic institutions in North America, and later in Europe and the Pacific rim. The inspiration for the current effort to study these faunas comes from two main sources: (1) the discovery of diverse abyssal assemblages in the early phase of Deep Sea Drilling, with the recovery of new Paleogene assemblages in the North Atlantic (Berggren, 1972; Van Hinte, 1976; Krashenninikov & Pflaumann, 1977) and in the Upper Cretaceous of the Indo-Pacific region (Krasheninnikov, 1973, 1974; Webb, 1975; Rögl, 1976), and (2) the search for Petroleum in the North Sea and continental shelves of northwestern North America (Gradstein & Berggren, 1981). Suddenly, there was a pressing need to restudy the classical Carpathian faunas and carry out new biostratigraphical studies in support of both scientific deep sea drilling and offshore petroleum exploration. This resulted in the inception of an informal working group inspired by the need to conduct taxonomical research which became known as the "Deep-Water Agglutinated Foraminiferal Project". Over 65 research papers have resulted from this project (Table 2).

Table 2. *Major studies devoted primarily or exclusively to the subject of Cretaceous to Paleogene DWAF since the initiation of the Deep-Water Agglutinated Foraminiferal Project.*

Author	Region	Comments
Gradstein & Berggren, 1981	North Sea & Labrador Sea	Synthesis of taxonomy & occurrence of the "Flysch-Type" agglutinated faunas & their paleoceanographic significance
Miller et al., 1982	112, Labrador Sea	Paleocene-Eocene of the Labrador Sea and Lab. Margin
Schröder, 1986	NW Atlantic	Taxonomy & bathymetric distribution of modern DWAF.
Kaminski, 1988	N. Atlantic	Synthesis of biostratigraphy & distribution of Cenozoic DWAF in the North Atlantic region.
Kaminski et al., 1988	Trinidad	Revision of Campanian-lower Eocene DWAF from Trinidad, with comparisons to the Carpathian faunas
Gradstein et al., 1988	North Sea	First quantitative zonation of the North Sea, with ranges
Gradstein & Kaminski, 1998	North Sea & Labrador Margin	New species of Paleocene DWAF from the North Sea and Labrador Margin
Kaminski et al., 1989	647, Labrador Sea	First continuous record of abyssal Eocene-Oligocene DWAF in North Atlantic, with 2 new species.
Kuhnt & Kaminski, 1989	W. Med.	Review of Upper Cretaceous to Paleocene DWAF faunas
Kuhnt et al., 1989	W. Med, N. Atl.	Upper Cretaceous Â– Paleocene biofacies.
Kuhnt & Kaminski, 1990	N. Atlantic DSDP	Upper Cret Â– Paleocene DWAF biogeography & taxonomy
Kaminski et al., 1990	643, Norwegian Sea	Eocene-Oligocene at ODP Site 643 in the Norwegian Sea
Kuhnt, 1990	Italy, Spain	First report of the Upper Cretaceous "Scaglia-type" fauna
Kaminski & Huang, 1991	767, Celebes Sea	First report of Eocene-Oligocene DWAF in the Celebes Sea
Kuhnt et al., 1992	Atlantic DSDP	Upper Cretaceous zonal scheme basedon DWAF
Kuhnt & Kaminski, 1993	Sopelana, Spain	Faunal change across the K/T boundary
Kaminski & Geroch, 1993	Carpathians	Revision of the Grzybowski Collection
Gradstein et al., 1994	North Sea, Labrador Margin	Revised quantitative zonation of the North Sea and Labrador Margins, calibrated to palynology
Schröder-Adams & McNeil,		First detailed taxonomy & biostratigraphy of DWAF in deep-water facies of the Beaufort-

1994a,b	Beaufort Sea	MacKenzie Basin.
Gradstein & Bäckström, 1996	Offshore mid-Norway	First quantitative zonation of exploration wells on the Norwegian margin using DWAF & palynology.
Bubík, 1995	Carpathians	Albian to Eocene taxonomy of the Carpathians in Moravia
Kaminski et al., 1996	Rif, Morocco	Paleogene DWAF from the Numidian Flysch
Kuhnt & Kaminski, 1996	Italy, Spain	Review of DWAF across the K/T boundary
Kuhnt & Collins, 1996	897, 899, 900, Eastern Atlantic	Paleogene DWAF of the Iberian Abyssal Plain
Kuhnt & Kaminski, 1997	Zumaya, Spain	Upper Cretaceous to Paleogene DWAF biostratigraphy
Gradstein & Kaminski, 1997	North Sea & offshore Norway	New species of Paleocene DWAF from the North Sea and offshore mid-Norway.
McNeil, 1997	Arctic	New species from the Upper Cretaceous & Paleogene
Evans & Kaminski, 1997	Arctic	First study of Neogene DWAF from the Central Arctic
Nagy et al., 1997	W. Barents Sea	First Paleocene Â– lower Eocene record from W. Barents Sea with calibration to dinoflagellate cyst & diatom stratigraphy.
Kuhnt et al.1988	959, E. Atlantic	Upper Cretaceous to Paleocene DWAF from Ivory Coast, with discussion faunal changes across the K/T boundary
Gradstein et al., 1999	Offshore Norway	First Cretaceous zonation using DWAF, offshore Norway.
Kaminski & Austin,1999	985, Norwegian Sea	Oligocene record from the Icelandic Plateau
Van den Akker et al., 2000	West of Shetlands	First published account of Upper Cretaceous to Paleocene DWAF
Nagy et al., 2000	W. Barents Sea, Spitsbergen	Discussion of Paleocene biofacies and palaeobathymetry.
Kuhnt et al., 2002	South China Sea	First documentation of Oligocene DWAF from ODP Site 1148
Bąk et al., 2004	Dukla Unit, Poland	Maastrichtian to EoceneDWAF and Paleoenvironments, Dukla Unit
Galeotti et al., 2004	Gubbio, Italy	Detailed record of DWAF across the Paleocene/Eocene boundary
Nagy et al., 2004	W. Barents Sea	First quantitative zonation of Paleocene-E. Eocene using RASC

In 1975/76 one of us (FMG) began a study of the Maastrichtian to Paleogene flysch-type assemblages from exploration wells in the North Sea and Labrador Shelf acquired at the Bedford Institute of Oceanography in Canada and the Woods Hole Oceanographic Institution in the USA. We quote from the original publication of this research (Gradstein & Berggren, 1981):

"This study was initiated when we first noticed that:

1. Maastrichtian to Eocene mudstones of the Labrador Shelf and northeast Newfoundland Shelf contain often exclusively (silicified) agglutinated foraminiferal assemblages, whereas coeval ones to the south, approximately south of 48°N, on the Grand Banks and Scotian Shelf do not. The mudstone agglutinated foraminifera assemblage is rich in specimens and species with over sixty taxa recognized. In the south, in more carbonate-rich coeval sediments rich planktonic and calacerous benthic foraminiferal assemblages occur with agglutinated forms being much less common or even absent.
2. Foraminiferal assemblages from Upper Paleocene - Eocene shaly sediments in the central North Sea are very similar to the agglutinated one mentioned from Labrador and Newfoundland shelf wells. In the North Sea this agglutinated assemblage appears suddenly in the fine-grained terrigenous sediments overlying Maastrichtian-Danian chalk. Not only is this assemblage in part coeval in these regions on each side of the North Atlantic Ocean, but the overlying Neogene foraminiferal assemblages also resemble each other in that arenaceous and planktonic species are largely absent, and many similar calcareous taxa occur (e.g., of the genera Uvigerina, Asterigerina, Cibicidoides, Ceratobulimina, Pullenia, Melonis, Elphidium and Cassidulina).
3. The agglutinated assemblages of the Labrador and North Seas bear resemblance to the so-called Rhabdammina fauna which occurs in the pelitic interval of flysch-type sequences (e.g. Brouwer, 1965) in the alpine orogenic belts of the world. This type of assemblage has been interpreted as being indicative of (very) deep water, of lagoons or brackish realms, or has been essentially related to potential hydrocarbon source rock. No major category of foraminifera has seen such divergent (paleo) bathymetric and intriguingly complex (paleo) environmental interpretations as agglutinated dominant assemblages.

It is this wide divergence in paleoecologic interpretations coupled with the (partly) coeval occurrence of the agglutinated assemblages in basins on each side of the North Atlantic Ocean, which at that time underwent rapid differential subsidence that has led us to undertake the present research. The primary goal is thus to understand what governs the presence of this controversial microfauna in relation to the development of basins".

The authors concluded that depth alone is not considered a significant factor in their occurrence, but that at bathyal to abyssal depths a number of interrelated physico-chemical factors at or near the sediment-water interface account for the observed distribution pattern of these flysch-type assemblages. These factors include rapid deposition of fine grained, organic rich, carbonate poor terrigenous clastics, under somewhat restricted bottom water circulation in compartmented basins.

At the time that this first taxonomic and paleoecologic/stratigraphic synthesis of the DWAF from the North Atlantic Petroleum basins was prepared, Woods Hole Ph.D. student Ken Miller undertook a detailed study of the abyssal agglutinated assemblages recovered earlier by WAB from DSDP Site 112 in the Labrador Sea. These assemblages were compared to the assemblages from the sedimentary wedge of the Labrador margin in the collections of the Bedford Institute (Miller et al., 1982).

Meanwhile one of us (MAK) had decided to undertake a masters degree at the Jagiellonian University (UJ) after graduating from Rutgers University (having worked as a Laboratory Assistant for R.K. Olsson in 1979). Upon commencing studies at UJ, Stanislaw Geroch suggested a thesis project dealing with agglutinated foraminifera (as in his opinion no one in the United States was working on the subject at that time). In 1981, FMG and WAB came to visit Stan

Geroch for the first time to study the the classical DWAF collections, and enthusiastically made plans to bring MAK into the Deep-Water Benthic Foraminifera Project. Hence, upon completion of his M.Sc. thesis (on spiroplectamminids from the Carpathian flysch), MAK joined this project as a Ph.D. student at Woods Hole, and later as a post-doctoral fellow at Dalhousie University in Canada with FMG and colleagues to continue the work on agglutinated foraminifera. As a first step, a taxonomic study was conceived that involved the first direct transatlantic comparison of the DWAF assemblages from Trinidad with those from the classic localities in Poland (Kaminski & Geroch, 1986; Kaminski et al., 1988). This was made possible through the important donation by R. Liska to FMG of well samples from Trinidad to support the study. In the years that followed, this taxonomic database served as a platform for studying Paleocene faunas recovered during ODP Legs 104 and 105, when the JOIDES Resolution drilling vessel returned to drill the northern North Atlantic in 1985 (Kaminski et al., 1989a,b, 1990). Also within the framework of this project Claudia J. Schröder and Frank Thomas carried out studies of the taxonomy and bathymetrical distribution of modern DWAF from the western North Atlantic at Dalhousie University. Box core samples were studied from transects on the Nova Scotian margin and Nares Abyssal Plain to document faunal trends (Thomas, 1985; Schröder, 1986). These studies provide a reasonable modern analog to the Paleogene DWAF assemblages from the Atlantic. Meanwhile at Union Oil, Garry Jones (1988) studied faunal trends along a paleobathymetrical (seismic paleoslope) transect in the North Sea.

In 1987, Wolfgang Kuhnt completed his Ph.D. research at the University of Tübingen on the flysch sediments and their agglutinated assemblages from the Gibraltar Arch, and in 1988 joined the effort to produce a stable and workable taxonomy for Upper Cretaceous to Paleogene DWAF and document their occurrences in the western Tethys and North Atlantic. A series of papers in the 1990s reviewed the occurrences of agglutinated assemblages and their environmental significance (Kuhnt & Kaminski, 1989, 1990; Kuhnt et al., 1989, 1996; Kuhnt & Moullade, 1993; Kaminski & Kuhnt, 1995; Kaminski et al., 1999) and documented Upper Cretaceous to Paleocene assemblages from different deep-sea drilling sites and outcrop localities in the western Tethys (Kuhnt, 1990; Kuhnt & Kaminski, 1993, 1996, 1997; Kaminski et al., 1996; Kuhnt & Collins, 1996; Kuhnt et al., 1989, 1992, 1998). The stratigraphy and paleobathymetry of Paleogene agglutinated assemblages in the western Barents Sea was studied by Nagy et al., (1997, 2000), which represents the northernmost documented occurrence of DWAF.

Alongside this work, we began an effort to formalise and revise the classic collection of Józef Grzybowski, housed at the Geological Museum of the Jagiellonian University. In the course of our taxonomic revision of the Lizard Springs faunas published in 1988, we realised that the key to a stable taxonomy for Paleogene DWAF would be the lectotypification of the 60+ species described by Grzybowski (1898, 1901) in his classic papers. Part of this revision work (Grzybowski's fauna from Wadowice) had already been accomplished by Liszka & Liszkowa in 1981. Largely thanks to the efforts of Stanislaw Geroch, many of Grzybowski's plesiotypes were located in the collections and photographed, and in some cases neotypes were designated based on newly collected samples. This revision (Kaminski & Geroch, 1993) was accompanied by translations of Grzybowski's classic papers (Kaminski et al., 1993).

During the same period, C. Schröder-Adams and D.H. McNeil began their detailed inventory of DWAF from the Cenozoic sediments of the Beaufort Sea wells at the Geological Survey of Canada in Calgary. A provisional biostratigraphical framework had been published by McNeil (1989), and some species illustrated in Dixon et al., (1992). This new taxonomical work culminated in the publication of two articles by Schröder-Adams & McNeil (1994a,b), and a revised range chart of Cenozoic DWAF by McNeil (1996), followed by a richly illustrated taxonomic monograph with descriptions of 36 new species of aggutinated foraminifera (McNeil, 1997).

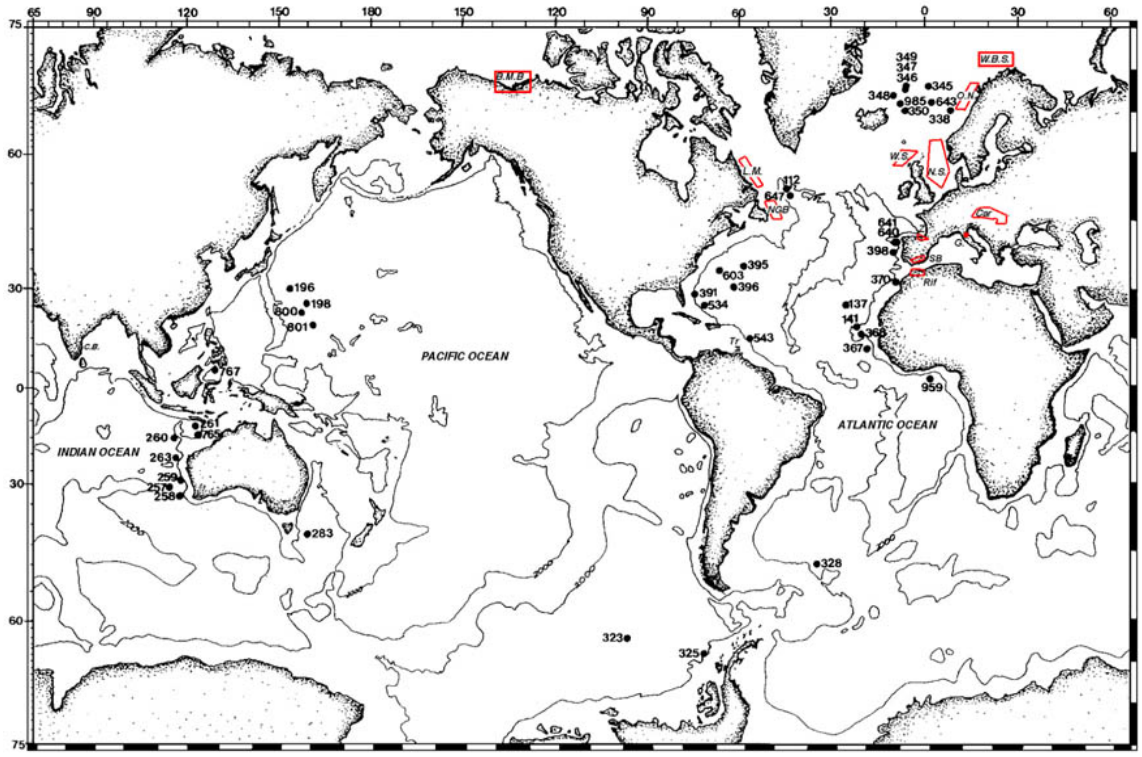


Figure 3. *Localities and offshore basins studied for Upper Cretaceous to Paleogene DWAF, with positions of additional DSDP/ODP sites mentioned in the text. BMB = Beaufort MacKenzie Basin, Car = Carpathians. C.B. = Cauvery Basin, offshore India, G. = Gubbio, Italy, L.M. = Labrador Margin, N.G.B. = Northern Grand Banks, N.S. = North Sea, O.N. = Offshore mid-Norway, S.B. = Sub-Betic Unit, Rif = Rif Mountains of Morocco, Tr = Trinidad, W.B.S. = Western Barents Sea, W.S. = West of Shetlands, Z = Zumaya, Spain.*

Material studied

While this Atlas is an attempt to compile information on the global distribution and stratigraphic ranges of Paleogene DWAF, our primary studies have been concentrated in the Atlantic Ocean and its continental margins, the Arctic Ocean, and Western Tethys (Table 2). Many of the species that were first

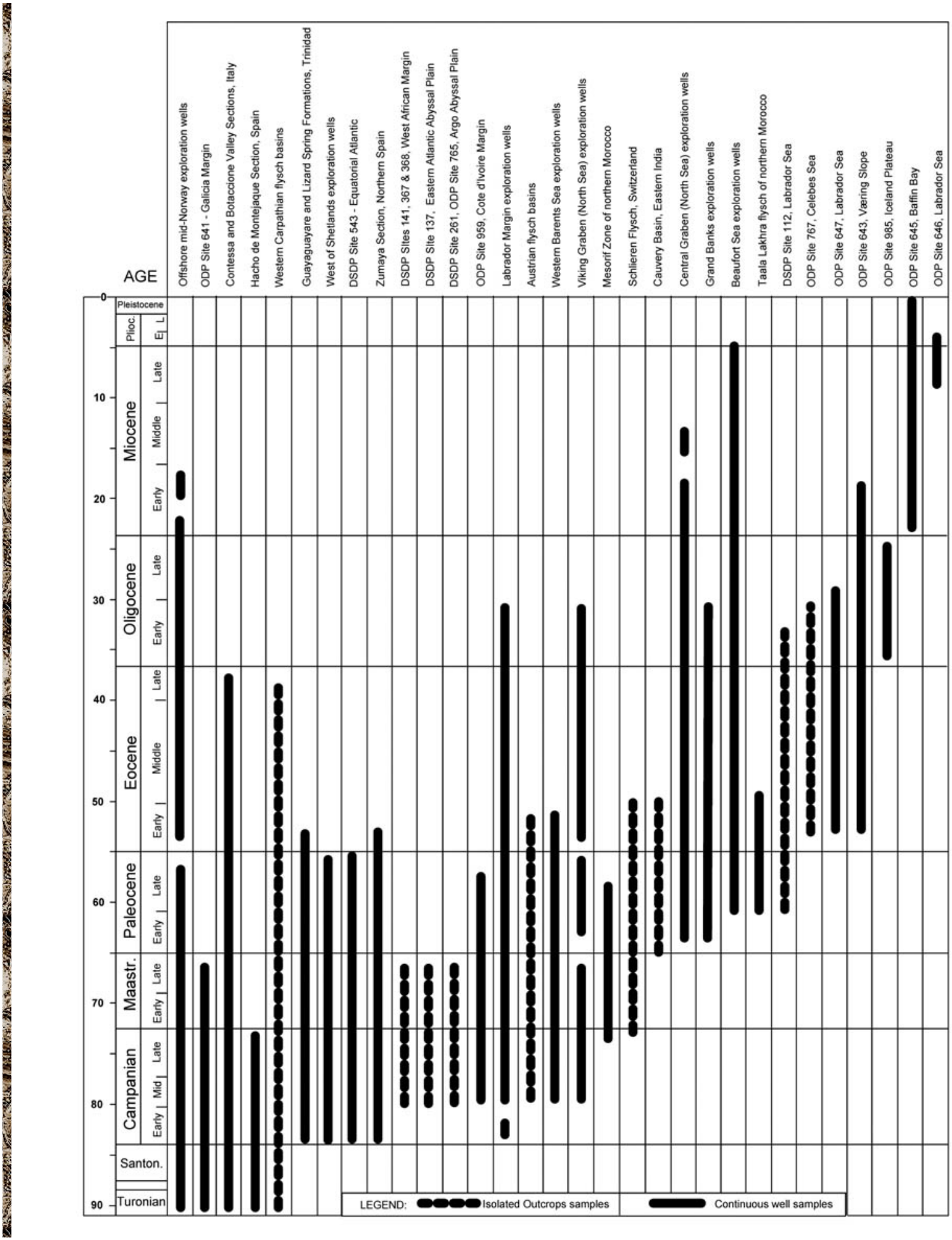
described from Atlantic and western Tethys are now known to be cosmopolitan, and we have made an attempt to compile their worldwide occurrences to the extent that they are known. Figure 3 presents a geographical overview of the known occurrences of Flysch-type and Abyssal agglutinated assemblages studied by us and/or reported in the literature.

a. Primary sample material

The sample material studied for this atlas consists of assemblages from several regions and sites distributed over the circum North and South Atlantic realms, the Arctic, Central and Western Europe, and North Africa (Figure 4). Stratigraphically more scattered samples were studied from the Austrian and Schlieren Flysch in the Alpine Belt, the western Carpathian Flysch, the Italian Apennines, outcrops in southern Trinidad, eastern Venezuela, the Moroccan Rif, the sub-Betic region of southern Spain, and some older DSDP holes that were not continuously cored. Stratigraphically more continuous and more densely spaced samples were at our disposal from numerous exploration wells in Trinidad, offshore Canada and Norway, the Central North Sea, the western Barents Sea, the Foula Basin west of the Shetland Islands, the Beaufort-MacKenzie Basin, and the offshore Cauvery Basin of southeastern India. The ODP material studied includes stratigraphically continuous intervals from Sites 643 and 985 (Norwegian Sea), Site 647 (Labrador Sea), Site 767 (Celebes Sea), Site 959 (Ivory Coast), and several sites on the Iberian Abyssal Plain. We additionally sampled stratigraphically continuous outcrop sections in Zumaya Spain, the Moroccan Rif near Tangiers, and the Paleogene of the Contessa section, near Gubbio. All the primary samples, including most of the plesiotypes photographed for this Atlas are currently housed in the microfossil collections at University College London and at the KLFR in Hendon, U.K. All primary types have been deposited in permanent microfossil collections at the Smithsonian and at the Natural History Museum (London).

For comparative purposes, we examined samples from sites in the Indo-Pacific region, DSDP Sites 260 and 261 on the Argo Abyssal Plain, and ODP Sites 196 and 198, in the western Pacific. These sites were mainly sampled for acquaintance with the unique Late Cretaceous abyssal "Krasheninnikov" fauna. No material was studied by us from the circum-Pacific rim, but Paleogene flysch-type faunas are known to occur in deep-water, carbonate-poor mudstones in New Guinea (Milner, 1997), Japan (Takayanagi, 1960), Kamchatka (Serova, 1969, 1987), New Zealand (Hornibrook et al., 1989), California (Sliter, 1968), and Chile (Todd & Knicker, 1952).

Altogether, the studied localities span the stratigraphic interval from the Upper Cretaceous through the Pliocene, with emphasis on the Paleogene. Ten of the studied DSDP and ODP sites are in the abyssal realm, including ODP Site 641, Galicia Margin, DSDP Site 543, Equatorial Atlantic, DSDP Site 137, Eastern Atlantic Abyssal Plain, DSDP Site 261, Argo Abyssal Plain, DSDP Site 112, Labrador Sea, ODP Site 767, Celebes Sea, ODP Site 647, Labrador Sea, ODP Site 643, Vøring Slope and ODP Site 985, Iceland Plateau. ODP Site 646 in the Labrador Sea is upper abyssal, above the CCD.


AGE
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Pleistocene
Plioc.
E
L
Miocene
Early
Middle
Late
Oligocene
Early
Late
Eocene
Early
Middle
Late
Paleocene
Early
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Maastr.
Early
Late
Campanian
Early
Mid
Late
Santon.
Turonian
Offshore mid-Norway exploration wells
ODP Site 641 - Galicia Margin
Contessa and Botaccione Valley Sections, Italy
Hacho de Montejaque Section, Spain
Western Carpathian flysch basins
Guayaguayare and Lizard Spring Formations, Trinidad
West of Shetlands exploration wells
DSDP Site 543 - Equatorial Atlantic
Zumaya Section, Northern Spain
DSDP Sites 141, 367 & 368, West African Margin
DSDP Site 137, Eastern Atlantic Abyssal Plain
DSDP Site 261, ODP Site 765, Argo Abyssal Plain
ODP Site 959, Cote d'Ivoire Margin
Labrador Margin exploration wells
Austrian flysch basins
Western Barents Sea exploration wells
Viking Graben (North Sea) exploration wells
Mesorif Zone of northern Morocco
Schlieren Flysch, Switzerland
Cauvery Basin, Eastern India
Central Graben (North Sea) exploration wells
Grand Banks exploration wells
Beaufort Sea exploration wells
Taala Lakhra flysch of northern Morocco
DSDP Site 112, Labrador Sea
ODP Site 767, Celebes Sea
ODP Site 647, Labrador Sea
ODP Site 643, Værring Slope
ODP Site 985, Iceland Plateau
ODP Site 645, Baffin Bay
ODP Site 646, Labrador Sea
LEGEND:
Isolated Outcrops samples
Continuous well samples

Figure 4. *Stratigraphical extent of outcrop sections, exploration wells, and DSDP/ODP sites studied for this Atlas. The massive bar indicates continuous or high resolution and high density sampling. Dashed bars means more scattered sampling. Upper Cretaceous stratigraphic sections also are shown.*

b. Museum collections

Another goal of this study was to examine the classic collections of agglutinated foraminifera with the aim of stabilising the taxonomy and recording any primary synonyms and/or geographical variants. Towards this goal, we have also examined microfossil collections housed in the following museums and institutions:

- The Natural History Museum (London). The micropalaeontological collections housed in the "Heron-Allen Library" are among the foremost in the world. Here the HMS CHALLENGER Collection (a.k.a the Brady Collection), and the DISCOVERY Collections (a.k.a. the Heron-Allen and Earland Collections) are the single most important resources for the study of agglutinated foraminifera. Also housed here are the collection of Jones & Parker containing the type specimens from the Mediterranean, and the BP (British Petroleum) collection of exploration wells from the North Sea and other localities worldwide. Holotypes and paratypes of species described by Gradstein and Kaminski and the new species described herein are also deposited here. Type specimens from the NHM were kindly photographed for this study by John Whittaker.
- The Geological Museum of the Jagiellonian University. The micropalaeontological collections in the Geological Museum (UJ) and the Grzybowski Foundation Library house the classical collections of Józef Grzybowski and his student Maria Dylążanka. Additionally, the type specimens and microfaunal collections of Stanisław Geroch are housed here. The Grzybowski Collection is the centrepiece of this study and is without doubt the most important collection for the study of Paleogene DWAF. Over 120 species were described by Grzybowski and Dylążanka, mostly from the western Carpathians in the area to the south and east of Kraków. Type specimens from the Grzybowski Collection were kindly photographed for this study by Stanisław Geroch, and additional topotype samples were collected from the type localites. Within the framework of this project, lectotypes and in some instances neotypes of the Paleogene species described by Grzybowski and Dylążanka were designated by Kaminski & Geroch (1993).
- The Department of Paleobiology, Smithsonian Institution. The "Cushman Collection" at the Smithsonian Institution houses three subcollections that are valuable for the study of DWAF. The "Albatross Collection" from the Atlantic and Pacific Oceans contains numerous new species of Recent deep water foraminifera. The "Trinidad Collection" of species from the Lizard Springs and Navet Formations studied by Cushman & Jarvis (1928; 1932) and by Cushman & Renz (1946, 1948) are an important resource for the study of the Paleocene Caribbean faunas. Additionally, Cushman's specimens from the Santa Anita and Vidoño Formations of Venezuela and the Navarro Formation of Mexico are housed here. Martin Buzas kindly provided access to the Smithsonian collections.
- The All-Soviet Geological Investigation Institute "VNIGRI". The "VNIGRI" collections in St. Petersburg, Russia house the collections of E.V. Mjatliuk from the Ukrainian Carpathians, N.N. Subbotina from the Caucasus, and Voloshinova from the Soviet Far East. These collections were examined during the course of this study, and selected specimens from the Mjatliuk Collection were photographed for this study. Svetlana Jakovleva kindly provided access to the VNIGRI Collections.
- The Natural History Museum, Vienna. The micropaleontological collections of the Geologische-Paläontologisches Abteilung, Naturhistorisches Museum Wien house some classical 19th century collections, including a collection of Badenian foraminifera collected by d'Orbigny from the Vienna Basin, the collections of Reuss (1844-45) from Bohemia, the Austrian-Hungarian North Pole Expedition (Brady, 1878, 1881) and paratypes of Hantken (1875) from the Oligocene of Hungary. Specimens from the collections of the NHM Wien were kindly photographed by Fred Rögl.
- The Czech Geological Survey, Brno Branch. The exploration wells from the Carpathians in Moravia studied by Vasíček and Hanzlíkova are housed here. Although the whereabouts of the M. Vasíček Collection are unknown, the numerous samples from the original wells are preserved in the collections. Additionally, the collections of M. Bubík including holotypes from the Carpathian flysch are housed here.
- The Pedro Bermúdez Micropaleontological Reference Center, Caracas Venezuela. This collection housed at INTEVEP in Los Teques on the outskirts of Caracas contains the collections of Pedro Bermúdez from Venezuela, Trinidad, the Dominican Republic, and Cuba. Additionally, slides of Recent deep sea assemblages from the South Atlantic are housed here. Specimens from the Bermúdez Collection were kindly photographed for the atlas by Humberto Carvajal-Chitty.
- Bedford Institute of Oceanography in Halifax-Dartmouth, Nova Scotia. The extensive collections of washed residues and picked slides from exploration wells, offshore Canada held here has been a major asset to our DWAF studies. The personal reference collection of FMG from this region was later greatly expanded with coeval North Sea and offshore Norway material, while working for Saga Petroleum, Oslo, Norway. At present that reference collection is with FMG at the Natural History Museum of the University of Oslo.
- The Institute of Sedimentary Geology, Geological Survey of Canada, Calgary. The extensive collection of well samples from the Beaufort-MacKenzie Basin, and the type collection of D.H. McNiel is housed here. This collection includes holotypes and paratypes of new species. New specimens from the Beaufort Sea were kindly provided for this study by Dave McNeil.
- Institut für Geowissenschaften, Christian-Albrechts Universität zu Kiel. The micropalaeontological collections at the University in Kiel house systematic collections assembled by G. Lutze and students, and contain rich collections of Recent deep-sea foraminifera from the Norwegian Sea, North Atlantic, and West Africa. Additionally, the collections of Wolfgang Kuhnt are housed here. These include assemblages from Spain, Morocco, West Africa, and from various ODP Sites from the Atlantic and South China Sea.
- The Bavarian State Museum, Munich. The collections of the University of Munich house the collections of H. Hagn, D. Herm, K. Weidich, and students from the Bavarian Alps. Although these collections mainly deal with Cretaceous foraminifera, some Paleogene slides are housed here.
- Institut for Geologi, Oslo University. The micropaleontological collections at Oslo University house the collections of Jenö Nagy and students. These include collections of Paleogene foraminifera from the exploration wells in the western Barents Sea and from outcrops in Spitsbergen.
- The Laboratory of Paleontology, University of Bucharest. The LP collections at the University of Bucharest include the extensive personal collections of Theodor Neagu. Although these deal mainly with Cretaceous foraminifera from the southern Carpathians and the Romanian Plain, some Paleogene forms are present, including the types of Aschemonella species described by Neagu (1964) from the Maastrichtian of the Romanian Carpathians. Access to these collections was kindly provided for this study by Theodor Neagu.

Back on top | Foreword | Preface | Acknowledgements