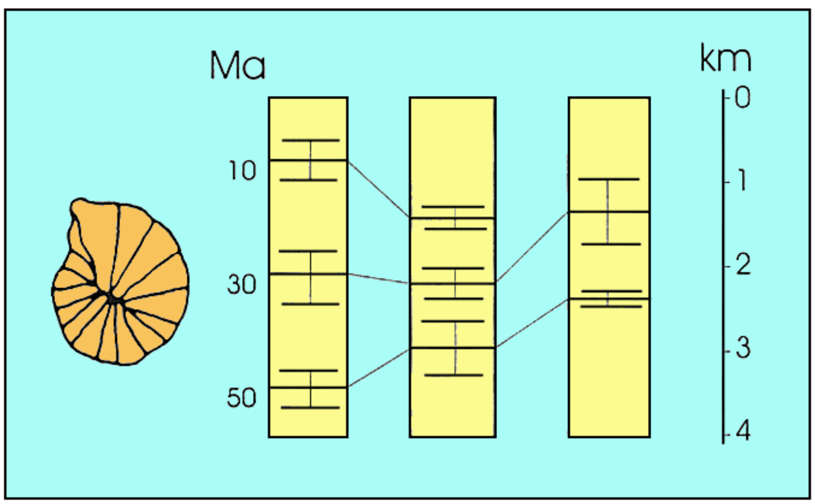
RASC and CASC

Tools for Biostratigraphic Zonation and Correlation

Version 18

User's Guide



New
Interactive colour graphics
for Windows ® 95, 98, 2000 & XP

RASC and CASC

Tools for Biostratigraphic Zonation and Correlation

Version 18 – User Guide

Version 18 prepared with the assistance of Quiming Cheng

User guide written by F.M. Gradstein; PDF version prepared by S. Filipescu.
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Table of Contents

(key chapters for use of the programs are printed bold)

User Information

RASC & CASC version 18 is bundled with programs MAKEDAT and COR in one executable module under MS- Windows and comes in two versions:

- A standard version on CD
- A demonstration version that may be down-loaded from website *http://www.q-strat.org*

The CD also contains subdirectories with:

- This technical manual
- Program MAKEDAT version 5.1a (1997) under DOS
- Datasets that serve as examples in this manual.

All programs perform on 80486 or 80586 (Pentium) personal computers with Windows ® 95, 98, 2000 or XP installed, using the 32 bit mode.

The following publication provides an up to date overview of the principle of RASC & CASC:

Agterberg, F.P. and Gradstein, F.M., 1999. The RASC method for Ranking and Scaling of Biostratigraphic Events. In: Proceedings Conference 75th Birthday C.W. Drooger, Utrecht, November 1997. Earth Science Review, vol 46, nos 1-4, p. 1 – 25.

Summary of the RASC and CASC Programs

RASC is an acronym for ranking and scaling of biostratigraphic events; CASC stands for correlation and standard error calculation, and COR for correspondence analysis; MAKEDAT imports and edits datasets.

The programs are designed to:

a. input/import and edit microfossil event data as input into RASC, using MAKEDAT
b. interactively calculate zonations with variance analysis and normality tests, using RASC
c. interactively calculate well to well correlations with error analysis, using CASC
d. analyse paleoecologic/geographic trends, using COR

Data sets may vary from 4 to 100 (or many more) wells or outcrop sections, depending on requirements.

The four programs operate as a single and integrated executable module under Windows ®. One windowing master menu controls all operations and results. Graphics results are displayed in colour, and may be edited with a built-in 2D chart control program; graphs can be colour printed and saved, many of them in JPEG format.

Alternatively, all results are also expressed in ASCII-type output files that may be browsed with the built-in DOS editor. These files may be formatted and printed with a word processor, using a non-proportional font like 'courier'.

Method and Programs
The four programs in the RASC& CASC module perform the following functions:

MAKEDAT

- stores the fossil event records of a great many taxa of different microfossil groups in wells (< 500)
- creates and orders a taxon dictionary, with synonyms for each taxon
- re-orders well sites in the master file
- creates subsets of the master data file that exclude specific well sites or specific taxa
- reformats (subset) data files for input in quantitative stratigraphy programs RASC, CASC and COR

RASC - ranking and scaling method for probabilistic zonations

- census information of input and run data
- biostratigraphic zonations with 95% confidence limits
- graphic correlation of well and zonation with uncertainty estimates
- normality testing of wells sites with 95% confidence limits
- event variance analysis to test difference between observed and stratigraphically expected position
- + frequency distribution
- error bar on observed event positions
- stratigraphic range of events

CASC - correlation and standard error calculation of RASC zonations

- most likely position of events in wells
- flattening on specific horizons in correlation panel

COR - correspondence type analysis of paleoecologic-geographic trends in RASC zonations.

Data input and throughput

Users invariably spend much more time with data files than with the actual operation of the programs or analysis of its results. A summary of data input and throughput between programs is as follows:

Program MAKEDAT under DOS is a stand-alone program. It operates with key-board commands explained in its help menu and in its manual, and allows to input biostratigraphic event data from scratch in projects (= *.mak files). It can import RASC run format data files for modifications It exports data in RASC format or report-type text format. .

Program MAKEDAT under Windows, bundled with RASC & CASC version 18 in one execution module, allows to input biostratigraphic event data from scratch or import data files from MAKEDAT under DOS or from IPS (Interactive Paleontology System). It stores data in MDB (Microsoft DataBase) binary format. Such data sets can than be modified and send to the RASC & CASC programs. The RASC input data files generated from these two MAKEDAT versions are identical in format and files convention.

RASC either reads in the data files from MAKEDAT under Windows, or data files generated with
MAKEDAT under DOS.

After operation of RASC the user may either run CASC or COR; both programs directly read-in files generated by RASC under Windows.

Software Installation and Files Overview

RASC & CASC version 18 under Windows is provided on CD. The version 18 of the programs integrates MAKEDAT, RASC, CASC, and COR in one interactive module, and displays both colour graphics results and ASCII-type results.

In order to install the Windows application, proceed as follows:

1. Place the CD in your CD-ROM drive. The installation program will start automatically. If not, select and execute file SETUP.

2. At the welcoming screen, click the 'install windows/graphics version' button, and follow instructions on the screen to complete the installation. The required password is written inside the CD jacket.

3. A button *RASCW* is created on your main windows screen; click this button to start execution of the programs.

4. The program is compiled under English Regional (Display) Settings. Users that experience problems with graphics results, or inadvertent termination of the program, should consult the Regional (Display) Settings under Control Panel of the main windows program, to see if this setting needs to be changed temporarily.

The total program takes about 3MB of space on a hard disk, while the file sizes of output results depend on the size of the data set, and on run parameters selected. On average, the output does not exceed 1 MB.

Also on the program CD are subdirectories with:

- Manual in PDF format for RASC & CASC version 18
- MAKEDAT version 5.1a (1997) under DOS with datasets and manual in PDF format
- Datasets, including RASC parameter files used as examples in this manual
- Abstract on Quantitative Stratigraphy in PDF format.

These files can be utilized directly from the CD or copied for use to directories on the personal computer.

What is New in Version 18 of RASC & CASC

The following new features have been implemented in version 18 of RASC & CASC:

- Under File menu the Project Space can be set, which allows a set of data files to be read in from a subdirectory and its output to be generated in that same subdirectory. This means that run and output files can be kept together in separate subdirectories.
- For noisy stratigraphic data error messages are generated in a Warnings file.
- The dictionary of event names now shows in how many wells an event occurs.
- Unique Events can be selected with a special function in the Parameter File Menu
- Event names and sample depths in the RASC & CASC scattergrams are shown in a special printable text box
- All well names are shown in the selection box for all scattergrams
- Seven new tables are shown under a button called 'TABLES', including:
    1. Summary table of run census data
    2. Error messages table
    3. Well name + well number table with vital statistics for each well
    4. (# of samples, # of events; # of and which unique events)
    5. Event occurrence table
    6. Stepmodel penalty points tables
    7. Normality test tables
    8. Events involved in more than 5 cycles, + their actual number of cycles
- Improved graphics design for the event-depth scattergrams in RASC & CASC
- All graphs and tables have print buttons
- Most graphs under GRAPHS button can now be saved directly in JPEG format

Demonstration files

For trial execution and results browsing of RASC & CASC the program is installed with a biostratigraphic dataset. This dataset, named *27CEN* contains the foraminifer and dinoflagellate events analysed and used by Gradstein & Bäckström (1996) to create a multifossil exploration zonation for deep marine Cenozoic strata in the North Sea and offshore.

A summary of the properties of dataset *27CEN* and its RASC results is shown below, and available in *Summary File* under Tables in the main program menu:

SUMMARY OF DATA PROPERTIES AND RASC18 RESULTS:

```
NUMBER OF NAMES (TAXA) IN THE DICTIONARY            471
NUMBER OF WELLS                                      27
NUMBER OF DICTIONARY TAXA IN THE WELLS              305
NUMBER OF EVENT RECORDS IN THE WELLS               1579
NUMBER OF CYCLES PRIOR TO RANKING                    86
NUMBER OF EVENTS IN THE OPTIMUM SEQUENCE             98
NUMBER OF EVENTS IN OPTIMUM SEQUENCE WITH SD < ave SD 63
NUMBER OF EVENTS IN THE FINAL SCALED OPTIMUM
   SEQUENCE (INCLUDING UNIQUE EVENTS SHOWN WITH **)  117
NUMBER OF STEPMODEL EVENTS WITH MORE THAN
   SIX PENALTY POINTS AFTER SCALING                  73
NUMBER OF NORMALITY TEST EVENTS SHOWN WITH * OR **    85
NUMBER OF AAAA EVENTS IN SCALING SCATTERGRAMS         51
```

This manual displays results generated with datasets *14CEN* and *CRETIA* that can be found in subdirectory Datasets on the program CD. Copy these datasets to the hard disk of the personal computer in subdirectories 14CEN and CRETIA under the RASCW directory. These datasets are smaller in size than *27CEN* bundled with the RASC program on CD, and their output is thus easier to display in this manual.

The *14CEN* dataset contains 1051 event occurrences of 294 microfossil taxa in 14 wells, offshore Norway, and is a subset of the *27CEN* dataset.

The *CRETIA* dataset contains 378 event occurrences of 135 Mesozoic microfossils and magnetochrons in 13 Atlantic and Indian Ocean sites of the Deep Sea Drillig Project (DSDP) and Ocean Drilling Project (ODP). The *CRETIA* data, and its zonation is described in detail by Gradstein et al. (1992).

After you have copied these datasets *14CEN* or *CRETIA* from the CD to their own subdirectories under the RASCW directory on your hard disk, select one of these datasets with the command *Set Project Space* under *File* button on the main menu and browse and/or execute it with the programs.

Introduction

RASC & CASC are computer programs originally developed in 1981/1985 by Frits Agterberg and Felix Gradstein, and associates, for probabilistic zonation and correlation, and standard error calculation, using fossil events. RASC stands for RAnking and SCaling, CASC for Correlation And Standard error Calculation. Fossil events commonly used for RASC & CASC are first and last occurrences of taxa in wells or outcrop sections, and also first common and last common occurrences of these taxa. The RASC & CASC method of biostratigraphy provides many functions and results not available in qualitative biostratigraphic analysis, as outlined in this manual, and in the literature cited. Literature on the method is extensive, and new program users are urged to familiarize themselves with aspects of theory and applications, prior to delving into this version of RASC & CASC. Chapter 3 summarizes history of the method and programs, and provides references for more detailed study of theory and applications.

An important aspect of RASC & CASC is the acquisition and organisation of suitable data sets. Invariably, much more time is spend on collection, organisation and testing of data than actual operation of programs, particularly with datasets of many (e.g. 25 or more) wells. The creation of the fossil event data set, its management and its formatting into RASC input files can be done with program MAKEDAT under DOS (version 5.1a). MAKEDAT creates files that are read directly by RASC under windows. Alternatively MAKEDAT output files can be read-in by a simple version of MAKEDAT that is bundled with RASC under windows With this simpler MAKEDAT minor data editing is done, and subsets of the data are created for various RASC runs. Since a majority of applications with the RASC & CASC method focus on frontier zonations in exploration geology, with its large, and often noisy datasets, use of MAKEDAT, or another multiwell event data manager is recommended for successful application of quantitative stratigraphy.

Starting with Version 17 of RASC & CASC, Correspondence Analysis, named program COR, is directly built-in as part of the main windows menu. Correspondence analysis determines clustering of fossil events within RASC zones according to well location. The Optimum Sequence obtained by ranking and scaling is based on the assumption that all events can be projected onto a single scale directed according to the arrow of time. This projection is carried out irrespective of the (paleo)geographic locations of the wells.

By means of variance analysis that is part of RASC, it is possible to study the validity of this assumption; e.g., events can be checked for the presence or absence of diachronism after ordering the wells according to their geographic position (latitude). There are other methods by which geographic location of the wells can be considered including Correspondence Analysis, which is discussed in Chapter 6, and in Bonham-Carter et al. (1987), and Agterberg & Gradstein (1999).

Together with their manuals the program MAKEDAT under DOS and the programs RASC, CASC and COR under windows (Figure 1) provide professional and academic biostratigraphers with rapid and versatile tools to input, organise, explore and interpret biostratigraphic data for zonation and geological correlation, with estimates of uncertainty.

MAKEDAT (under DOS or Windows) microfossil data input and data organiser	→	**RASC, CASC, COR** quantitative zonation and correlation, normality testing of wells, variance analysis of events, and geographic trends

Figure 1: Multiwell microfossil data input and data organisation is accomplished with program MAKEDAT. This program pre-processes data, and provides input files for the quantitative stratigraphy programs RASC, CASC and COR.

Chapter 1

Brief history of the RASC & CASC method

‘ *It is well-known that the method practised by astronomers to diminish the errors arising from the imperfections of instruments and of the organs of sense by taking the mean of several observations has not been so generally received, but that some persons of note have publicly maintained that one single observation, taken with due care, was as much to be relied on, as the mean of a great number’*. T. Simpson, 1755. Philos. Trans. R. Soc. London, vol. 46, p. 82.

The original RASC (Ranking and Scaling) computer program in FORTRAN for ranking and scaling of biostratigraphic events was developed by us between 1978 and 1985. The advent of mathematical - statistical theory suitable to biostratigraphy, and advances in computer programming led us to develop and apply ranking and scaling, as inspired in part by a pioneering publication entitled ‘Probabilistic Stratigraphy’ (Hay, 1972). The result was the modified Hay method, first outlined and applied in 1982. Chapter 10.4 on p. 404 - 407 in Agterberg (1990) documents in some detail the technical development of RASC & CASC from 1978 to 1989, and the interested user is referred to that text.

The principal ideas that are incorporated in the RASC and also the CASC programs originated during 1978, as part of research programs undertaken by F. Agterberg and F. Gradstein at the Geological Survey of Canada in Ottawa, Ontario and Dartmouth, Nova Scotia. The research greatly assisted in understanding the complex fossil event correlation patterns with benthic foraminifera and dinoflagelates in the thick Cenozoic mudstone sequences, along the western passive margin of the Labrador Sea. Initially, ranking, scaling and simplified normality testing were designed and tested, later followed by scattergrams and an early version of event variance analysis (the latter with M. D’Iorio). At the same time A. Jackson created the DENO program to display dendrograms of the scaled optimum sequences and optimum sequences in RASC on a CALCOMP plotter. As a second project during that time, semi-automated correlation of the RASC results was added (with the help of J. Oliver). The correlation project produced Fortran program CASC, initially called Correlation And SCaling in Time, rather than the current Correlation And Standard-error Calculation.

By 1985, personal computer hardware and Fortran software had advanced to the stage that RASC could be compiled and executed to perform on IBM PC’s. In cooperation with S.N. Lew, M. Heller and D. Gillis a personal computer version of RASC was developed, that became RASC 12, published as Geological Survey of Canada Open Files 1179 and 1203.

CASC with its cumbersome Tectronix graphics was not converted to operate on the micro computer.
On modern personal computers, the RASC & CASC programs take little time to execute. As an illustration of advances in performance and efficiency of desk-top computers and operating systems we recall testing in 1984 a slightly modified main frame (FORTRAN 77) version of RASC on an original 8 bit IBM-XT with a hard disk of 64 nanno seconds access time (and 10 megabyte storage). We were just about to give up, after 55 minutes of waiting on RASC to 'crunch' micropaleontology data in 21 Canadian offshore wells, when results appeared. These answers turned out to be virtually identical to those on a 64 bit CDC mainframe computer that routinely operated our program, inclusive of FORTRAN 4 compilation, in just under one minute. The answers confirmed that numerical precision routines operated close to satisfaction. At present, we routinely execute RASC on larger well files in less than 30 seconds, using an aging 486DX desktop computer, and an 11 nanno seconds access hard disk. On fast Pentium PC's the program executes in under 1 second.

Development of the present version of RASC & CASC was commenced in 1994. The updates became versions 15 (1996) and 16 (1999) of the programs, which are command driven under DOS version 6.2, or DOS under Windows. The program versions in between 12 and 15 were used for testing, teaching and personal use. The RASC versions 15 and 16 are more robust to diminished frequencies of co-occurring fossils in the same wells, which yields better defined scaling of optimum sequence events. Printing the results was greatly simplified through output redirection and files organisation. Other improvements were:

a) Insertion of Unique Events in both the Optimum and Scaled Optimum Sequences,
b) Curve fitting in the scattergrams with a measure of Event Deviation from the Line of Correlation,
c) Event Variance Analysis,
d) Rank Correlation of Wells, and
e) Better display of principal results.

In addition, partly due to improvements in curve fitting techniques, program CASC version 2 was added as a batch-run module to the new RASC version 16 program.

In late 1997, in cooperation with Quiming Cheng of York University, Ontario, Canada, a start was made on a version of RASC ands CASC under Windows 95 and NT, using Visual Basic programming tools. Now RASC, CASC, MAKEDAT and COR are seemlessly assembled in one menu that is completely windows driven and buttons operated, and has both colour graphics output and conventional ASCII-type output. This is the present version 18 of RASC & CASC, that has virtual no limitations in data dimension.

Although significant improvements and updates have been made to the programs, the basic stratigraphic philosophy underlying its development and use remain valid, and as we expect will be so in years to come.

The rapid growth of information in the applied and academic geological sciences steadily increases need for numerical models to organise and explain specific geologic problems.

It may be illustrative to reach back in history, and recall what we wrote in 1982 (Gradstein and Agterberg, 1982, p. 122): in ‘Models of Cenozoic Foraminiferal Stratigraphy - Norwthwestern Atlantic Margin’, under the chapter “ Why Should Probabilistic Biostratigraphy be Applied?”:

> …........“In summary, the data base shows the following properties, ranked according to their importance towards stratigraphic resolution:
> Samples are predominantly cuttings, which forces use of the highest part of stratigraphic ranges or of the highest occurrences (tops, exits), and restricts the number of stratigraphically useful taxa.
> There is limited application of standard planktonic zonations, due to the mid-to high-latitude setting of the study area and the presence of locally-unfavourable facies.
>
> 1.There are minor and major inconsistencies in relative extinction levels of benthonic taxa.
> 2.Many of the samples are small which limits the detection of species represented by few specimens; this contributes to factor (3) and to erratic, incoherent geographic distribution pattern of some taxa.
> 3.There is geographic and stratigraphic provincialism in the benthonic record from the Labrador to Scotian Shelves which makes details in a general zonation difficult.
>
> Despite the limiting factors, it is possible to erect a zonation based on a partial data base which uses few taxa. Increase of the Cenozoic data base through incorporation of more wells clarified the broader correlation pattern, and increased the number of chronostratigraphic calibration points based on planktonic foraminifera occurrences. It also increased noise in the stratigraphic signal (factors 3 and 4) due to more stratigraphic inconsistencies and geographic incoherence of exits. In an attempt to optimize stratigraphic resolution based on all observations that could be employed for a zonation, the ‘optimum’ biostratigraphy methods of this study were developed.”.........…

Since 1982, application of RASC has been to a wide variety of microfossils, including dinoflagellate cysts, pollen/spores, radiolarians, benthic and planktonic foraminifers and also physical log markers, inserted in zonations. A majority of applications is with well data sets from industry and from scientific ocean drilling.

Applications of RASC in industry generally are not made public. Over the last 10 years RASC amongst others was used in research or operational centres of BP (UK), Shell (Canada and Norway), Marathon (USA), Unocal (USA), Petrobras (Brasil), Norsk Hydro (Norway), Saga

(Norway), Instituto Colombiano del Petroleo (Columbia), ARCO, USA, and the National Oil and Gas Commission (India). Data sets cover the stratigraphic distribution of a wide variety of fossil groups in frontier basins from Thailand, Yemen, Columbia, Gulf Coast, Alaska, North Sea and Norwegian Sea.
One of the more original and well documented studies, also involving quantitative correlation with STRATCOR, is that by R. Woollam, U.K. on Upper Jurassic biostratigraphy of the Troll Field, northern North Sea, executed for Shell. Also noteworthy are the detailed studies by Wang and Zhou (1998) on Neogene Stratigraphy of the South China Sea (Wang and Zhou, 1998), and by Cooper et al. (1999) on the deterministic and probabilistic biostratigraphy of the Taranaki Basin, New Zealand, using both the CONOP9 and RASC programs.

Below we summarize more comprehensive studies, dealing with theory and applications:

Ranking – Theory	**Ranking and Scaling (RASC) – Theory**	**Quantitative Correlation (CASC) – Theory**
Hay, 1972	Agterberg & Nel, 1982a,b	Gradstein et al., 1985
Hay & Southam, 1978	Gradstein, 1984	Agterberg, 1990
Harper, 1981	Gradstein et al., 1985	Agterberg et al., 1999.
Agterberg, 1984	D'Iorio & Agterberg, 1989	Cooper et al., 1999
Brower & Burrough, 1982	Agterberg, 1990	
	D'Iorio, 1990	
	van Buggenum, 1991	
	Gradstein & Agterberg, 1998	
	Agterberg & Gradstein, 1999	

RASC/CASC - Applications	**Computer Programs**
Gradstein & Agterberg, 1982	RASC12 – Heller et al., 1985
Doeven et al., 1982	RASC12 – Agterberg et al., 1985
D'Iorio, 1986	CASC – Agterberg et al., 1985
Williamson, 1987	RASC & CASC 18 – This Release
Gradstein et al., 1994, 1996, 1999	
Whang & Zhou, 1998	
Cooper et al., 1999.	

For a detailed and up to date introduction to the RASC & CASC method the reader is referrred to Agterberg and Gradstein (1999).

Chapter 2

Why Use Probabilistic Biostratigraphy ?

Traditionally,biostratigraphy has been the domain of experts that subjectively judge the fossil record for stratigraphic interpretation, taking into account both presence and absence of fossils. Gaps in the record and outliers are noted from regional experience. Records are discarded or given extra weight, depending on the perception of ‘good and bad’ fossils. As will be re-iterated in Chapter 3, biostratigraphers may give almost as much weight to the absence as to the presence of a particular set of fossils, when interpretating the record. In contrast, quantitative stratigraphy only relies on the observed fossil record from (preferably) many overlapping stratigraphic sections. Without such overlap, no optimum sequence can be constructed. Weights may be assigned to the record to enhance zonation, but its effect is limited. Also, no weight can be assigned to missing data, unless a regional knowledge data base would be consulted by the method.

In the previous chapter, the case was outlined that the nature of the fossil record sampled may favour application of probabilistic stratigraphy. Many industrial and also academic data bases may benefit from this approach. That there are intrinsic benefits also, independent of a particular set of data, is shown below:

1. Standardisation in the fossil record and stratigraphic methods gives access to all data and results.

2. Data sets and results are easy to communicate and rapidly updated with new information.

3. Integration of all fossil and also physical (e.g. isotope, well-log) events in one stratigraphic solution, increases resolution and practical use.

4. Methods and results (zonation + correlation) are more objective than hand-made solutions.

5. Analysis of uncertainty in the event record and in the quantitative zonation greatly improves insight in true stratigraphic resolution and reliability of event correlation.

6. Interpolation of most likely (including missing) event positions in sections increases detail in correlations between sections.

7. Unlike subjective stratigraphy, the quantitative methods generally provide more than one possible solution, depending on run conditions, that provide biostratigraphy with multiple working hypothesis.

8. Quantitative stratigraphy methods can handle large and complex data sets, and calculate stratigraphic solutions fast and easy .

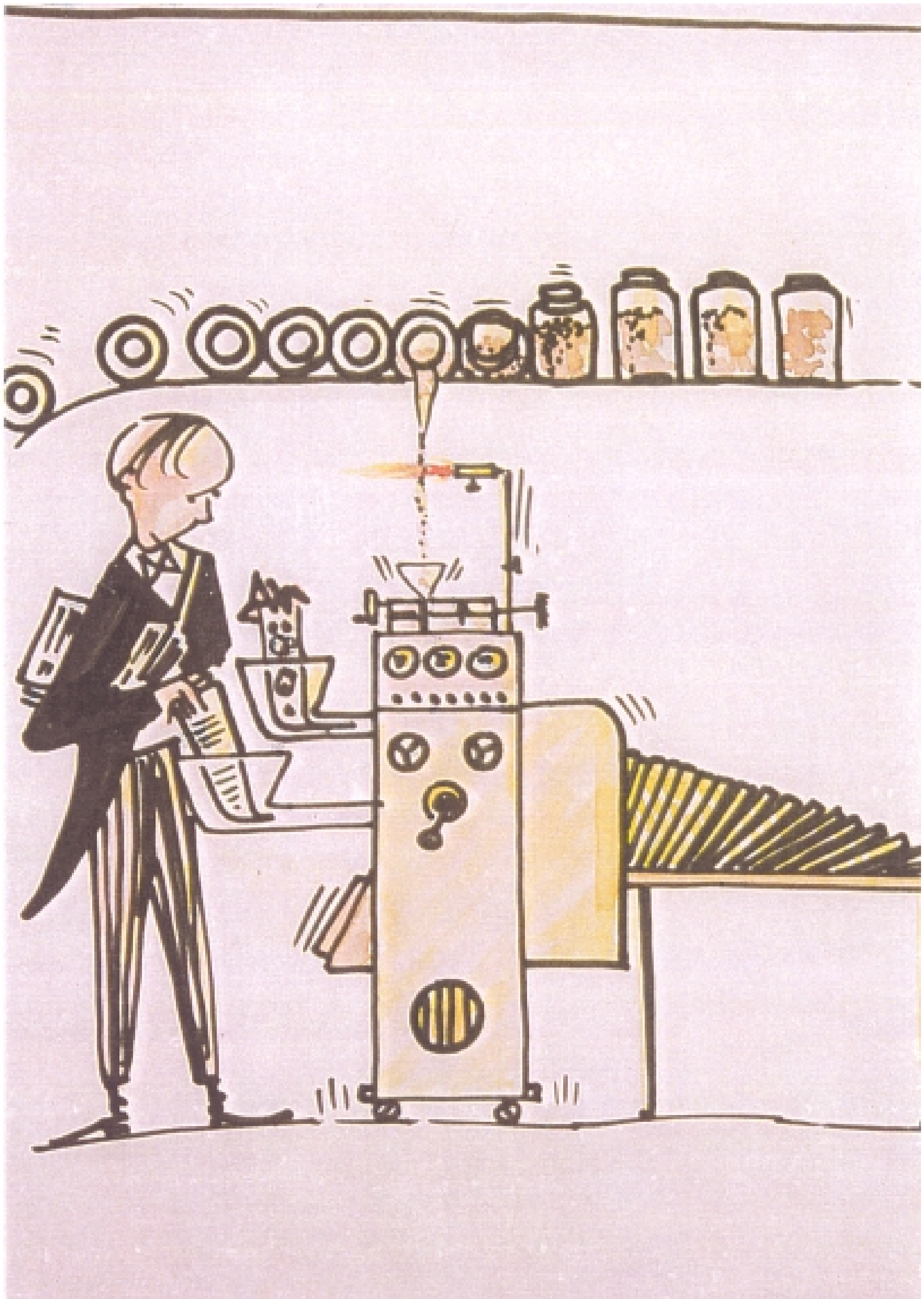


Figure 2: Artistic vision by J. van der Linden, Utrecht (1972) of one of the authors (FMG) working in the micropaleontology laboratory. He is seen ‘feeding’ processed microfossil residues into a ‘quantitative stratigraphy’ black box, thus directly yielding his Ph.D thesis..

That is not to say that there are no limitations to quantitative biostratigraphy, e.g. :

a. The fossil record cannot be modelled a-priori for spatial and temporal distributions.

b. It is difficult to directly weigh records (observations) in terms of stratigraphic quality

c. It is generally time consuming to organise (well) data for quantitative stratigraphic treatment

Items a and b may be addressed *a posteriori* as follows. Insight in distributions of the fossil record and its variance, after operation of the programs, may be used to insert specific weights to records, re-arrange data spatially, and delete records that objectively fall in the outlier (noise) category. After that, the user may execute a more final data run. A simplified flow chart of such a run procedure, using MAKEDAT, RASC & CASC to generate biostratigraphic zonations and geological correlations with uncertainty limits, is outlined in Figure 3.

Organisation of well data for quantitative treatment may be greatly simplified and enhanced through use of a suitable data organiser and processor, like program MAKEDAT under DOS and under Windows. Spread sheet programss like EXCEL, LOTUS, and many others, also can be adapted to perform this task.

With experience in application of quantitative biostratigraphy methods, the benefits of the quantitative approach will outweigh limitations to a great extent, and enhance the quality of digital data sets and applied biostratigraphy.

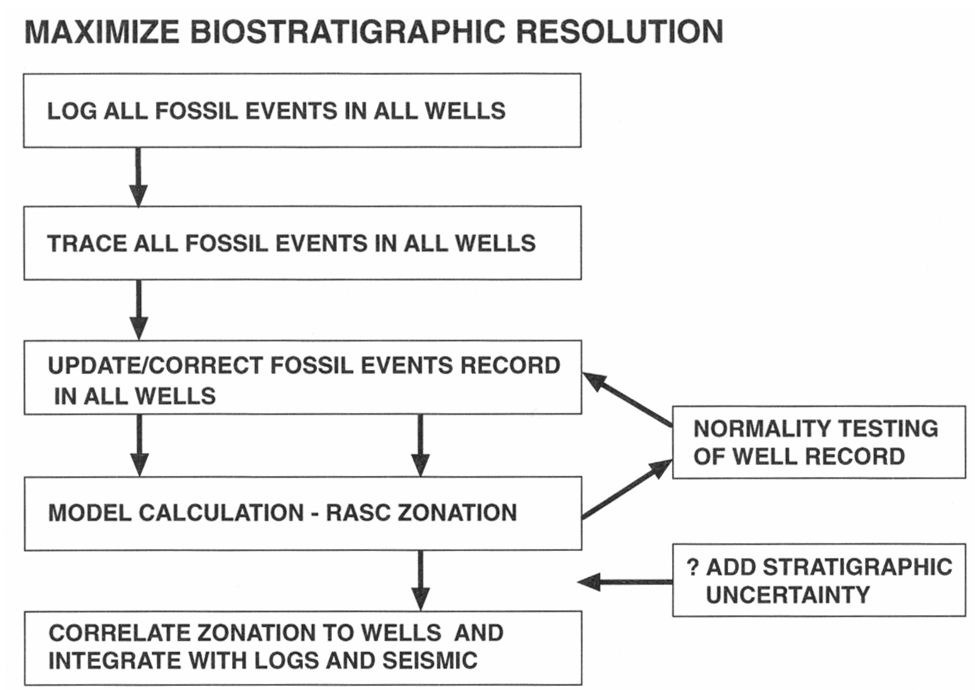


Figure 3. Flow chart of steps in logging, tracing and updating the fossil record, prior to and during zonation, followed by correlation and assignment of stratigraphic uncertainty.

Chapter 3

Properties of Fossil Event Data

The ranking and scaling method operates on fossil events that occur in a reasonable number of wells or outcrop sections. A paleontological event is the presence of a taxon in its time context, derived from its position in a rock sequence. For stratigraphic purposes we apply certain events only, such as the first occurrence (appearance in time or entry), the last occurrence (disappearance from the geologic record or exit). The stratigraphic range is the interval in relative time between an entry and an exit. The paleontologic events are the result of the continuing evolutionary trends of Life on Earth. They differ from physical events in that they are unique, non-recurrent, and that their order is irreversible. Deviations from the ‘axiom’ of irreversibility are rare, and never more than one ‘species unit’ along the trend of single evolutionary lineages (Drooger et al., 1979). Often, first and last occurrences of fossil taxa are relatively poorly recognizable events, based on a scattered well record with few specimens. Particularly with difficult to find and rare first and last occurrences of taxa, it is useful to define a first common occurrence (FCO), and last common occurrence (LCO). Alternatively, first or last consistent occurrence events may be defined, where an observed first or last occurrence is called consistent when the endpoint is part of a continuous stratigraphic range (record).

The population of all observed FCO’s or LCO’s in a group of wells maybe a representative sample of the local stratigraphic range of a fossil. It remains to be determined if the local range matches the total stratigraphic range.

The shortest spacing in relative time between successive fossil events is called resolution. The greater the probability that such events follow each other in time, the greater the likelihood that correlation of the event record models isochrons. Most industrial data sets make use of both LO and LCO events. In an attempt to increase resolution in stratigraphy, particularly when many sidewall cores are available, efforts may be made to recognize up to five events along the stratigraphic range of a fossil taxon (fig. 4) , including last stratigraphic occurrence ('top' or LO event), last common or consistent occurrence (LCO event), last abundant occurrence (LAO event), first common or consistent occurrence (FCO event) and first occurrence (FO event). Unfortunately, the practise of event splitting may not yield the desired increase in biostratigraphic resolution sought after, for reason of poor event traceability.

Event traceability is illustrated in figure 5, where for several industrial and academic data sets cumulative event distribution is plotted against number of wells. All curves are more or less asymptotic, showing an inverse relation between event distribution and the number of wells. None of the events occur in all wells; clearly, far fewer events have a record in 5 or 6 wells than in 1 or 2 wells. Hence, the cumulative frequency of the event record drops quite dramatically with a small increase in number of wells.

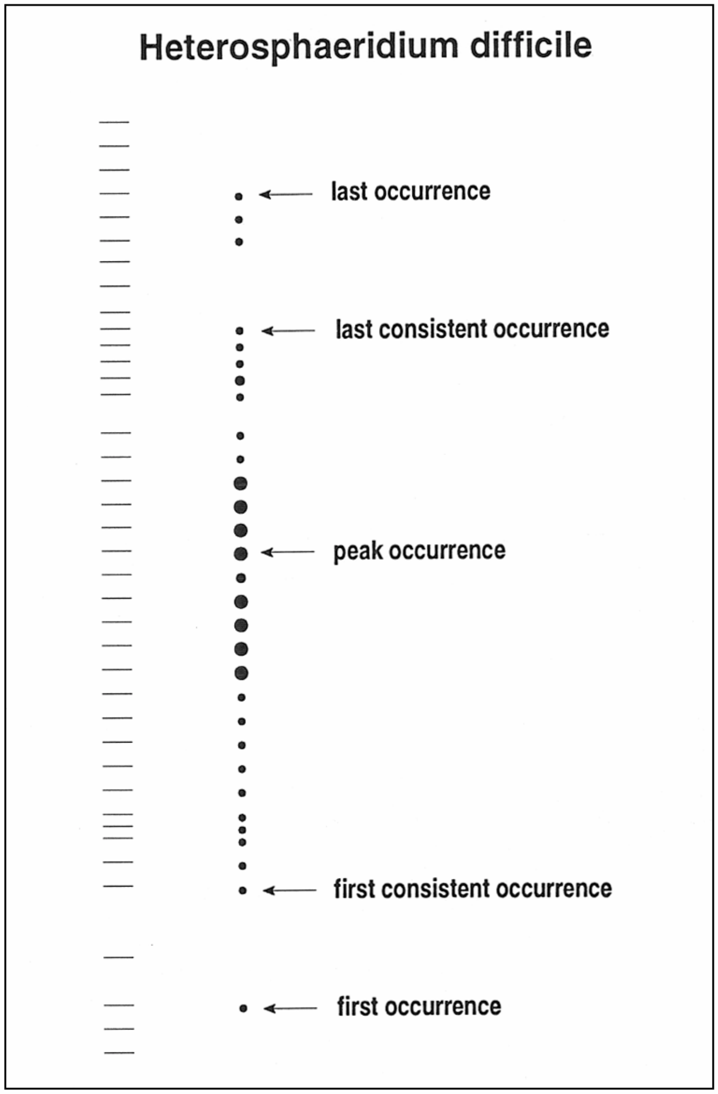


Figure 4. In order to increase biostratigraphic resolution, attempts are made to recognize up to 5 correlative events along the stratigraphic range of a taxon, as shown here for the (theoretical) total range of *Heterosphaeridium difficile*. Unfortunately, such events often have limited geographic traceability. The vertical scale shows sampling levels in relative time.

Data sets with above average traceability of events are those where one or more dedicated observers have spent above average time examining the well record, verifying taxonomic consistency between wells, and searching for 'missing' data. In general, routine examination of wells by consultants for drilling completion reports yields only a fraction of taxa and events that may be detected with a slightly more dedicated study.

The presence of 118 Upper Cretaceous nannofossil events in 10 wells, offshore Eastern Canada, yields 865 records, (Doeven et al., 1982). There are more events in more wells than for the other data sets (fig. 5). The reasons are a greater fossil abundance in a chalky facies, detailed side wall core sampling and relatively uniform geographic distribution of these calcareous planktonics.

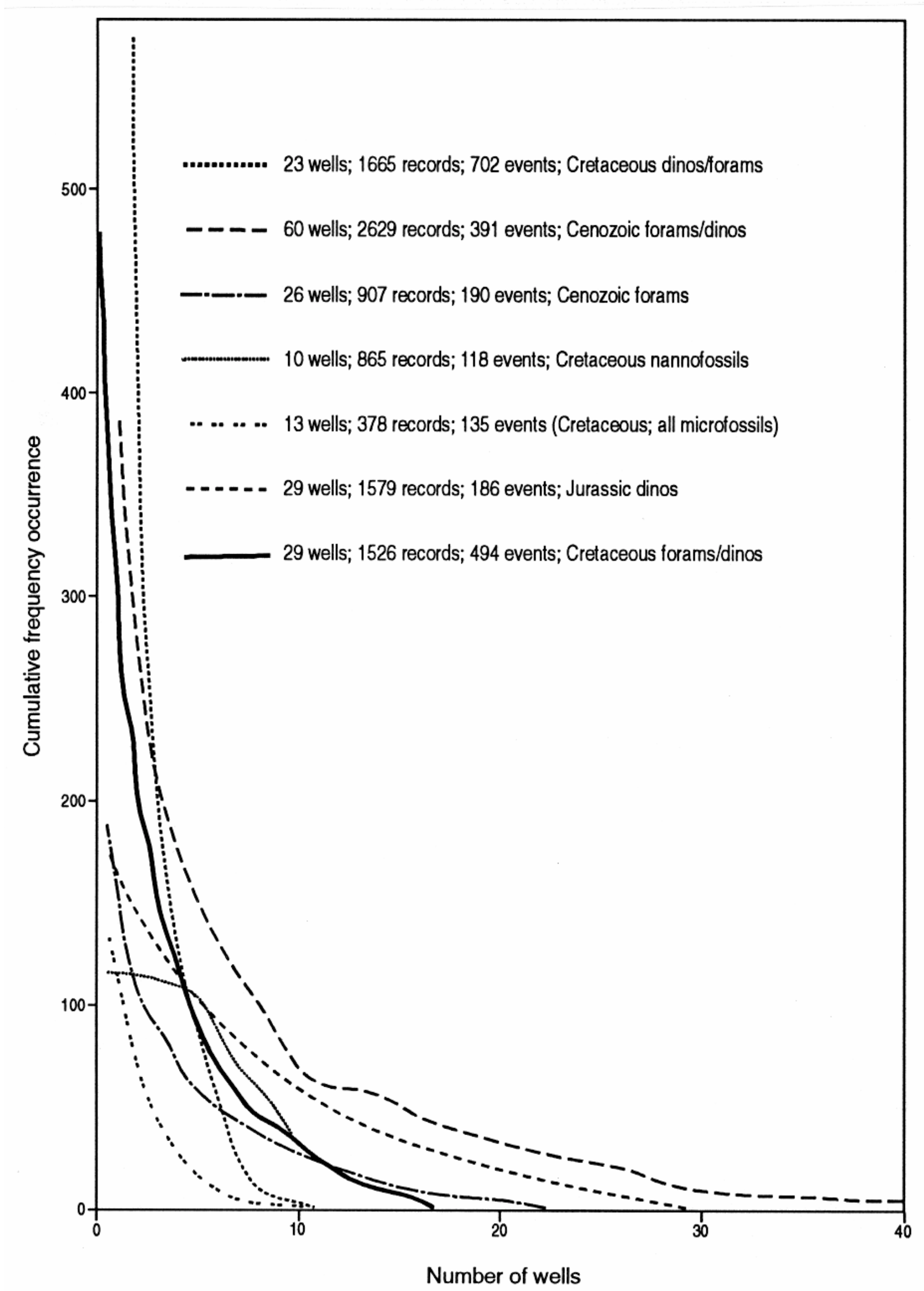


Figure 5. Cumulative frequency of microfossil event occurrences versus number of wells for several subsurface data sets in the North Sea, offshore Canada, and Atlantic and Indian Oceans (simplified after Gradstein & Agterberg, 1999).

There are other reasons than lack of detail from analysis why event traceability is relatively low, e.g. lateral variations in sedimentation rate change the diversity and relative abundance of taxa in coeval samples between wells, particularly if samples are relatively small. It is difficult to understand why fossil events might be locally missing. Since chances of detection depend on many factors, stratigraphical, mechanical, and statistical in nature, increasing sampling and studying more than one microfossil group in detail is more beneficial than bio-event splitting within one taxon.

General factors affecting event detection are shown in figure 6; not observing fossil events may not mean that they are absent. Even in the absence of coarser (sand- size) fractions, variable sedimentation rates, biodegradation of organic matter, pyritisation, and diaenetic dissolution of carbonate severly decrease the chance of event detection. Detailed analysis of large and closely spaced samples, with equal weight to different groups of microfossils, decreases bias in the fossil record.

In the case of geological factors it will not be possible, prior to exhaustive sampling and analysis to evaluate the effects of errors that help to calculate the chance that a species at a locality was detected.

Before further addressing the RASC input data, a word of caution on absences of fossil events in sediments. As mentioned earlier, biostratigraphy relies almost as much on the absence as on the presence of certain markers, although the former may not be mentioned. This remark is particularly tailored to microfossils that generally are widespread and relatively abundant, and harbour many stratigraphically useful events. Only if non-existence of events is recognized in many, well-sampled sections, may absences be construed as affirmative for stratigraphic interpretations. If only small samples are available over long stratigraphic intervals, the chance to find long-ranging taxa considerably exceeds the chance to find short-ranging forms, unless the latter are abundant. In actual practise, so-called index fossils have a short stratigraphic range, and generally are less common, hence easily escape detection, hence the reason why their absence should be used with caution.

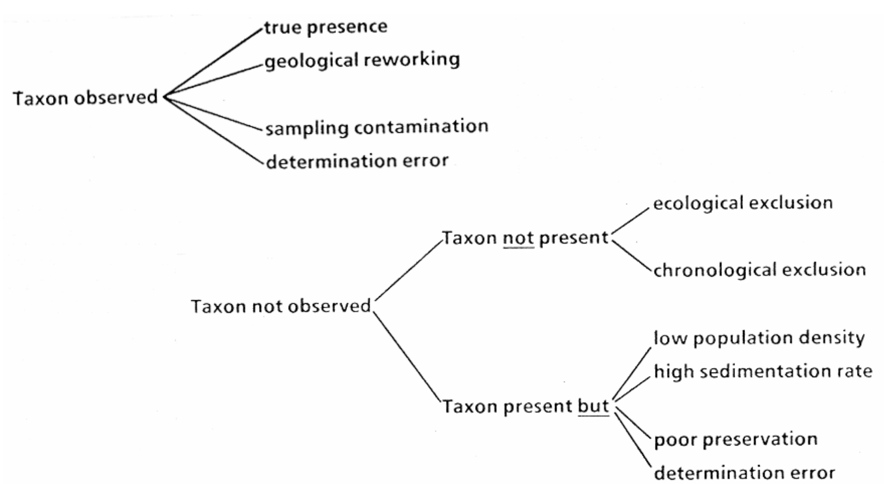


Figure 6. Reasons why taxa might, or might not be observed, leading to incomplete sampling.

Chapter 4

RASC and CASC Data Input Files

This chapter explains the files format of RASC&CASC input datasets, that can be accomplished with wordprocessors, spreadsheet programs, or MAKEDAT and RASC.

Technically, the files on which RASC operates are four:

1 - The parameter file that sets the thresholds under which RASC operates, named *.*inp*
2 - The file that lists for each well the sequence of fossil events, named *.*dat*
3 - The file that lists for each well the depth of each sample in feet or meters, named *.*dep*
4 - The file that lists the names of all fossils, named *.*dic*

For example, the 14CEN dataset is contained in four files:

14CEN.INP - Parameter file with run instruction for RASC (CASC and COR operate without *.inp file);
14CEN.DAT - Data file that lists for each well the sequence of fossil events;
14CEN.DEP - Data file that lists for each well the depth of each sample in feet or meters;
14CEN.DIC - Data file that lists the names of all fossils.

The three digit DOS endings of the four files are by convention only; the asterisk * stands for a name of maximally 7 characters, selected by the user. Note that programs CASC and COR depend on RASC output, and may be executed after RASC is executed first. Program CASC requires data files 2, 3 and 4, and no parameter file. Program COR requires two files to operate the program and a data file (*.dat). Instructions on operation of RASC & CASC are in Chapter 5, and for COR in Chapter 6.

4.1. Parameter file (*.inp)

An *.*inp* file can be created using a text editor that saves in ASCII and fixed file fortran (I4) formats; the same may be accomplished semi-automatically with *Revise Parameter File* under the *RASC* button in the main menu.

Seven parameters for running RASC occur on the first line (record #1) of the *.*inp* file. These are, respectively:

1. total number of wells, e.g. 14
2. minimum number of wells in which an event must occur (e.g. 6) = first threshold value in ranking and scaling
3. three indicators for unique events/marker horizons (1 or 0), scaling run (1 or 0) and CASC run (1 or 0) - 1 means unique events, and 0 means no unique events, etc.

4. minimum number of wells in which a pair of events should occur (e.g. 3) = second threshold value; used for scaling only; this second threshold is a smaller value that the first threshold.
5. indicator if sample depth values are in feet (= 0) or in meters (= 1)

Lines (records) #2 and #3 of the **.inp* file contain unique events and marker horizons, respectively. These numbers require fixed (I4) format. For example, if 6 and 58 are the first two unique events to be listed, record # 2 of the file starts with three blanks, then 6, followed by two blanks, then 58, etc. The maximum number of unique events is 20; there also can be 20 marker horizons.

The parameter run file for the metric data set 14cen, called *14cen.inp* looks as follows:

```
14 6 1 1 1 3 1
    6  58 348 368 413
```

No marker horizons were selected, hence line (record) #3 is left blank.

4.2. Event dictionary (*.dic)

For this input file the user creates a listing of taxa (or physical stratigraphic events), one per line. Names will be used exactly as assigned in the dictionary. Author names to taxa can be assigned if desired. The order of the entries in the dictionary automatically corresponds to their unique dictionary number, with the top entry assigned number 1 by the program. The maximum number of entries allowed in the dictionary is unlimited, but the three digit input format for the event-sequences input file (*.dat) at present restricts the number of taxa to less than 999. The word LAST or last must occur on the bottom line of the file, but is not listed in output.

A sample dictionary for 20 events looks as follows:

```
Neogloboquadrina pachyderma
Globorotalia inflata
Tiliaepollenites sp.
Neogloboquadrina acostaensis
Log marker no. 4
Globigerina praebulloides
Deflandrea phosphoritica
Asterigerina gurichi
Flood of diatoms
Globoconusa daubjergensis
Gyroidina girardana
Coscinodiscus spp.
Sigmoilopsis schlumbergeri
Turrilina alsatica
Coarse agglutinated foram spp.
Uvigerina ex.gr. miozea-nuttali
Spirosigmoilinella compressa
Areoligera semicirculata
seismic horizon no. 3
Ammosphaeroidina pseudopaucilocul ata
LAST
```

During execution, RASC automatically creates an alphabetical dictionary, and prints both the numeric and alphabetical dictionaries in the output (in file **b.out*).

4.3. Event-sequence file (*.dat)

The user must creates an "events in all wells" file in ASCII format. In exploration biostratigraphy listing of the last and/or first occurrences of taxa will start at the top, instead of the base of each well. There is no limit to the number of events per well. Each well sequence starts with a title of less than 40 characters, followed by lines with coded events, using the unique dictionary number for each event, in 20I4 fortran format. This means each event occupies 4 spaces, with 20 events per line; coeval events are connected by a hyphen; each well sequence ends with -999. On the last line of the file must be the word Last or last.

A sample event-sequences file looks as follows (note that the numbers used in this example do not correspond to taxa in the above dictionary, but normally must do so):

```
well 1
  38 -87-103  15 102 -10  69   9 111   8  50  60 112  18 -53  13 115  11  17  62
  85  61  68  82  43 -34  99 -72  98 -21  40  20  81  49  27 -95 -96 107  39  59
 106  80  79  44  37  29  45 -55  66-110-109  58  70 114-121  71 -33 -92  78  77
 -28 -31 -93-116 -30-999
well 2
  38  87-102  15  86  83 100  -7 -89 -50-104  -8-111 -56  63 -91  17  73 -43 -60
  62  82  35  20  95  40 -34  99  59  94  96  49  81-114  27  41  -3  65 -25 -26
-107  47  14 -39  67  80  79  44 -37  29 109  78-999
well 3
  38 -87 -32-103  15  -1  -3  86   4-102 101  35  42  89 -52  -8 111 -10  18  83
  17  56  61 -16 -73 -43  82 127 -96-113  95 -97  49  98  34  20 -74  81  99-107
 -27  23 -25  40  22 106  14  39  80  79  66  37  59 109  24  29  46 -31 -28-105
  30  93 -12-999
LAST
```

4.4. Event-depth file (*.dep)

Each event, or groups of coeval events in the event-sequence file has a corresponding depth in the event-depth file, **.dep*. The maximum number of depths per well in RASC is 150. The format of the **.dep* file
can be two: A non-decimal one, with depths like 40 or 4000 (ft or m), or a decimal one, for depths with decimal numbers like 40.50m or 4000.76 m.

4.4.1. Non-decimal depth file

Following the well title line, which must be identical to that for the corresponding well title in the event-sequence file, the second line has the rotary table height above sealevel preceded by f or m (capitals allowed) to indicate feet or meters units for all depths in the well. After the rotary table height follows the local water depth. The next lines contain the successive event depths in FORTRAN format 13F6.1. This means each depth can be a 5 digit number followed by a period; there are 13 depths per line. Each well in the event - depth file must have the same number of lines, which means that 00000.0 values or blanks are added as needed. The last line of the file must contain the word LAST or last.

A sample event-depth file that matches the sample event-sequence file shown previously, is listed below:

```
well 1
f030.001330.0
01330.01390.01500.01776.01780.01786.01840.01870.01900.02230.02260.02530.02550.
02680.02710.02770.02800.03040.03070.03159.03580.03880.04210.04280.04380.04429.
04510.04810.04840.05309.05310.05470.05531.05850.05910.05940.05970.06060.06120.
06150.06310.06343.06505.06591.06665.00000.00000.00000.00000.00000.00000.00000.
well 2
m010.000200.0
00850.00870.00890.00900.00907.00920.01000.01040.01080.01260.01275.01330.01450.
01460.01490.01500.01510.01570.01600.01690.01805.01875.01885.01895.01905.01935.
01945.01950.01993.02005.02015.02055.02320.00000.00000.00000.00000.00000.00000.
00000.00000.00000.00000.00000.00000.00000.00000.00000.00000.00000.00000.00000.
well 3
f035.000880.0
01250.02090.02110.02320.02385.02410.02700.02950.02980.03400.03704.04000.04090.
04580.05025.05100.05200.05250.05643.05665.05671.06923.07060.07069.07103.07296.
07354.07375.07402.07411.07572.07694.07903.07940.07958.08460.08480.08623.08924.
08990.09025.00000.00000.00000.00000.00000.00000.00000.00000.00000.00000.00000.
LAST
```

4.4.2. Decimal depth file

The decimal depth file, that is automatically generated by MAKEDAT when well sections have decimal sample depths, like 3975.50 m, looks as follows:

```
DECIMAL DEPTH FILE
Well A,
M045.001203.0
AUTHOR none
1841.00,1863.00,1878.00,1884.50,1904.00,1923.00,1938.00,1982.00,2027.00
2044.00,2046.00,2074.00,2102.00,2110.00,2128.00,2155.00,2162.00,2245.00
2281.00,2306.60,2313.90,2318.00,2335.00,2440.00,2463.50,2500.00,2502.00
2515.20,2525.45,2545.00,2575.00,2620.00,2650.00,2675.00,2685.70,2710.00
2725.00,2815.00,2830.00,3004.00,3094.00

Well B
M023.000524.0
AUTHOR none
2605.00,2710.00,2750.00,2875.00,2925.00,3145.00,3200.00,3268.50,3322.00
3695.00,3710.00,3735.00,3999.00,4050.00,4101.00,4134.00,4221.00,4441.00
```

```
Well C
M024.000110.0
AUTHOR none
2514.00,2535.00,2631.00,2691.00,2709.00,2751.00,2931.00,2937.00,2949.00
2955.00,2982.70,3075.00,3079.00,3093.00,3125.00,3149.00,3155.00,3172.00
3616.00,3642.00,3671.00,3679.00,3689.00,3731.00,3754.00,3782.50
LAST
```

It should be noted that MAKEDAT allows relative abundances of taxon events to be entered, but the present version 18 of RASC does not take into account relative abundance of events. We have experimented with a version of Ranking using not only event records, but also relative abundance (number of specimens) of a record in a sample. Optimum sequences with or without relative frequencies do not appear to differ much, reason why this option at present is not part of RASC. The use of events noted as ‘species name’ LCO and ‘species name’ FCO in the dictionary and data sets is an effective way to utilize relative abundance data in stratigraphy.

Chapter 5

Operation of MAKEDAT, RASC & CASC

This chapter outlines the menus and files of the programs MAKEDAT, RASC & CASC.

Program RASC calculates most likely biostratigraphic zonations, both ordinal and scaled. For all events variance analysis is executed, displayed with the ordinal zonation (optimum sequence) and for each event separate. In addition, it tests each well site for stratigraphic normality and generates census-type bookkeeping information of the well dataset.

Program CASC calculates the most likely correlation of the (Scaled) Optimum Sequence events. For all wells it calculates the most likely depths and its minimum and maximum values at the 95% confidence level for all optimum sequence events. It also calculates the 95% confidence interval of the depths at which events in all wells are observed. Results may be used for contouring event - age isochrons at a given confidence level. The technique is an extension of so-called “graphic correlation”.

After opening the program module, the main menu on the first screen display shows:

File Makedat Rasc Casc Cor Output Files Graphs Tables Windows Dictionary Help

The menus under these buttons and its meanings are:

File:

Set Project Space - selects and execute dataset in a subdirectory on the hard disk under RASCW
New Data Base - starts small dataset from scratch
Open Data base - opens *.mdb (Microsoft Database) files
Import
Makedat Files (DOS) - looks for a *.lst and *.dic file from Makedat under DOS
IPS Files - imports IPS data file
Exit - exits program

Makedat

Dictionary - opens an empty menu for input, or displays an imported dictionary for edit
Wells - opens an empty menu for input, or displays imported well data for edit
Rasc Input - selects wells and/or deselect events for a run file

RASC

Enter Parameter, Data and Output Files - selects run and output files (semi-automatic)
Revise Parameter File - modifies run parameter file, incl. unique events (hold CTRL key to select bunch of unique events from special dictionary) save modified parameter file

Apply - executes program
Cancel - cancels menu

CASC
RASC Data File - selects RASC data file (semi-automatic)
Output File - selects RASC output file (semi-automatic)
Apply - executes program
Cancel - cancels menu

COR
Parameter File - selects parameter file (semi-automatic)
Rasc Data File - selects data file (semi-automatic)
Rasc Output File - selects data file (semi-automatic)
Output File - names results file
Revise Parameter File - revises parameter file
Apply - executes program
Cancel - cancels menu

Output Files - opens DOS menu to read and print all ASCII output of the programs (see Chapter 9)

Graphs
Rasc - principal results of the program in numerous colour graphs that can be further edited and saved, including:
Cumulative Frequency of fossil event occurrence
Ranked Optimum Sequence of fossil events = ordinal zonation
Scaled Optimum Sequence of fossil events = scaled zonation
Scattergram_Ranking, that shows graphic correlation of all wells with ranked optimum sequence
Scattergram_Scaling that shows graphic correlation of all wells with scaled optimum sequence
Variance Analysis_Ranking that shows standard deviation of events per well and its normality, using the optimum sequence of events as standard
Variance Analysis_Scaling that shows standard deviation of events per well and its normality, using the scaled optimum sequence of events
Event Ranges_Ranking that shows estimates of the probable minimum, - maximum, and average event position, relative to the ranked optimum sequence
Event Ranges_Scaling that shows estimates of the probable minimum, - maximum, and average event position, relative to the scaled optimum sequence
Casc - principal results of the program with numerous colour graphs that can be further edited and saved, including:
Scattergram_Ranking that shows graphic correlation of well sequence and ranked optimum sequence, with scale in depth units (feet or meters)
Scattergram_Scaling that shows graphic correlation of well sequence and scaled optimum sequence, with scale in depth units (feet or meters)
Correlation_Ranking that opens a detailed menu for event correlation in wells using the optimum sequence

Correlation_Scaling that opens a detailed menu for event correlation in wells using the scaled optimum sequence

Tables - principal results of the RASC program in printable table format, including:
Summary Table of data properties and run results of RASC
Warnings with information on noisy data results
Well Names with information on its data used
Occurrence Table showing (scaled) optimum sequence events versus wells
Penalty Points displays the results of the scores in the Stepmodel
Normality Test displays the normality test reults for each well.
Cyclicity shows how many event cycle (rings) occurred and in how many cycles those events participated.

Windows - standard Windows function

Dictionary
Open a dictionary - browse taxonomic dictionary of event names

Help - opens this manual (function not operational in version 18 of the programs)

All colour graphic results for RASC & CASC under *Graphs* may be edited with the 2-D Graphics Chart Control editor. This program menu is activated when pressing the left mouse button while a graph is diaplayed on screen, and is explained in Chapter 7.

Prior to version 17 of RASC & CASC results were stored in ASCII format output files, numbered from *a.out through *j.out, where * is a user selected 7 digit alphanumeric code name. These files are printed in Chapter 9.

Starting with version 17 of the programs these ASCII files *.out through *j.out are found under Output Files in the main menu, including:

Bookkeeping:
Value of Input Parameters - **a.out*
Sequence of Wells - **a.out*

Tabulation of Event Record - **a.out*
a. Frequency of Event Occurrence - **a.out*
b. Cumulative Frequency of Event Occurrence - **a.out*
Summary of Data Properties of RASC15 Results - **a.out*
Dictionaries of Events - Numerical and Alphabetic Listings - **b.out*
Occurrence Table - **b.out, *g.out*

Ranking and Scaling (= probabilistic zonation), - *all results in file *a.out***:**
Optimum Sequence of Events
Optimum Sequence of Events with Unique (rare) Events inserted
Final Scaling of Optimum Sequence of Events
Final Scaling with Unique Events inserted.

Normality 'Testing' of Event Well Record:
Graphical Correlation of Well Sequence Record and Optimum Sequence, with estimation 'how far' events are off best fit line - **c.out, *e.out*
Step Model per Well, with Penalty Points for Out of Place Events - **b.out, *g.out*
Rank Correlation of Event Well Sequences with (Scaled) Optimum Sequence - *b*.out,*g.out*
Normality Test per Well, with Second Order Difference Statistics for all Events - *g*.out*
Comparison of Observed and Expected Second Order Difference Values - **g.out*

Variance Analysis *(results in files *d.out and *f.out)***:**
Standard Deviations of Events per Well
Event Variance Analysis (Difference in each Well between Observed and Stratigraphically Expected
Event Position + Frequency Distribution)
Summary of Event Variance Analysis Results
Estimation of Event Ranges (numerical and graphical representation of Probable Minimum -, Probable
Maximum - , and Average Observed Stratigraphic Event Position)

When CASC is executed following RASC, the ASCII format results are stored in *file *j.out*, where * is the master output file name selected by the user. Results with the CASC program may be browsed in text format under the buttons *Output Files* in the main menu, similar to results with RASC. The file that should be to opened with program Edit under *Output Files* is **j.out* (e.g. *14cenj.out*). A non-proportional font like Courier (8 points) provides satisfactory viewing and print results, when using word processors. An example of results on a well in *14cenj.out* is shown at the end of Chapter 9.

Chapter 6

Operation of COR

Program COR performs correspondence analysis to study clustering of fossil events within RASC zones according to well location, and operates on the RASC (scaled) optimum sequence.

Introduction

The optimum sequences obtained by ranking and scaling are based on the assumption that all events can be projected onto a single scale directed according to the arrow of time. This projection is carried out irrespective of the (paleo)geographic locations of the wells. By means of variance analysis it is possible to study the validity of this assumption; e.g., events can be checked for the presence or absence of diachronism after ordering the wells according to their geographic position (latitude). There are other methods by which diachronism of events can be considered, including correspondence analysis.

Bonham-Carter et al. (1987) proposed the use of correspondence analysis in a study dealing with Cenozoic Foraminifera from 36 offshore wells along the northwestern Atlantic Margin. The wells were ordered from north to south so that well numbers could be used for location (latitude). The other variable considered was presence (=1) or absence (=0) of the fossil events (last occurrences of taxa) in the wells.

Like Bonham-Carter et al., we have used the algorithm described by Hill (1979) for correspondence analysis by means of reciprocal averaging, because it can deal with large data sets. Bonham-Carter et al. pointed out that this technique produces results similar to those obtained by means of seriation (Burroughs and Brower, 1982). The first eigenvector resulting from correspondence analysis of presence-absence data from ordered sample locations tends to diagonalize the presences. Both the taxa and the wells receive scores according to which they are ordered along the axis of time as well as in the north-south direction. Bonham-Carter et al. concluded that useful results were obtained by restricting the analysis to taxa from specific RASC zones, rather then including all taxa. Severe distortions of stratigraphic order occurred when events from the entire Cenozoic were used simultaneously.

Within RASC zones (time-slices), it could be seen from the scores that the occurrence of some planktonic taxa was restricted to the southern part of the study area whereas some benthonic taxa occurred in the north only. We have included this method in the computer program COR with the following additional features.

For any slice from a (scaled) optimum sequence defined by the events at its top and bottom, correspondence analysis can be performed on events that occur in at least a minimum number of wells. If this threshold is set equal to 1, all events will be used. However, small-sample effects, like events occurring in a single well necessarily ending up on the diagonal, can be avoided by choosing a threshold greater than 1. COR also contains the optional method of simultaneously ordering the event according to their average values along the time axis as well as the north-south direction.

Finally, it can provide various types of constrained solutions. For example, events can be clustered along the diagonal while their order in time as given in the (scaled) optimum sequence is preserved.

Tables 4 and 5 show COR analysis results on 6 stratigraphically successive events in the scaled optimum sequence for the 14cen.* data file, using the RASC interval extending from event 236 (*G. ex.gr. prseascitula zealandica*) to 7 (*Areoligera semicirculata*). Table 4 shows the well scores, and Table 5 the event scores; north-south differentiation of taxa, if it exists at all, is not pronounced in the current data set. Negative results of this type favour validity of the RASC approach which performs best when all events are evenly distributed throughout the study region.

WELL	#	NAME	SCORE
1	9	BP (UK) 15/20-2	2.333
2	12	Amoco (N) 2/8-1	2.333
3	11	Shell (UK) 22/6-1	2.667
4	5	Esso (N) 16/1-1	3.000
5	10	Saga (N) 2/2-4	3.250
6	2	Statoil (N) 6407/4-1	3.500
7	14	Saga (N) 6406/2-1	4.000
8	4	Hydro (N) 34/8-1	4.000
9	13	Saga (N) 35/3-1	4.000
10	3	Elf Aquitaine (N) 6406/8-1	4.333
11	1	Saga (N) 6407/2-3	4.500
12	6	Saga (N) 34/4-5	4.500
13	7	Hydro (N) 6407/7-1	4.500

Table 4. Well scores of correspondence analysis output for interval zone (see Fig. 18) within scaled optimum sequence of 14cen.* data. There only is a weak ranking of wells from south to north.

INTERVAL ZONE OCCURRENCE TABLE

NUMBER		EVENT NAME	WELL NUMBER 9	12	11	5	10	2	14	4	13	3	1	6	7
16	236	G. ex.gr. praescitula zealandica	X	X	X	X	X	X	X						
17	17	Asterigerina gurichi	X	X	X	X	X			X	X				
18	3	Deflandrea phosphoritica						X		X	X	X	X	X	X
19	25	Coarse agglutinated spp.	X	X		X	X	X		X	X	X	X	X	X
20	24	Turrilina alsatica			X	X			X	X	X		X	X	X
21	7	Areoligera semicirculata					X	X	X	X	X	X	X	X	X

Table 5. Event scores of correspondence analysis output for interval zone (see Fig. 18) within scaled optimum sequence of 14cen.* data. There only is a weak suggestion of south to north gradient in the results.

Operation of COR

Program COR is executed after a RASC run, using either its ranked or scaled optimum sequence. Operation of the program is resides under the *COR* button in the main menu..

The menu *Enter Parameters and Data Files to Run Cor* operates on the RASC data file **.dat*, and the RASC output file **h.out*, and on the parameter file named **.par*. In the examples, the *14cen.** data are used. In addition, a COR output file name is required, here assigned for convenience the name *14cenk.out*. Results with the COR program may be browsed in DOS text (ASCII) format under the buttons *Output Files* in the main menu, similar to results with RASC & CASC discussed earlier. The DOS file can be opened with program Edit under *Output Files*. A non-proportional font like Courier (8 points) provides satisfactory viewing and printing results, when using word processors. An example of results on the optimum sequence with the 14cen data in *14cenk.out* is shown at the end of Chapter 9.

The program includes a parameter file named *cortemp.par*, which may be modified by the user using the submenu *Revision of Parameters to Run Cor*. In this menu the most important item is the window with event names under *Add Zone Limit.* This windows shows the RASC (scaled) optimum sequence of events, in which the user can select two events that bracket the zonal interval upon which COR will operate. The user also should tick off the boxes *Maintain Ranking Order* or *Maintain Well Order*, which either results in shuffling of the well scores, or of the events scores in the optimum sequence. The minimum number of wells in which each event should occur, also can be modified in this submenu. By default this number is the same as in the RASC run. All this done, the user in the window *New Name* either selects and saves the existing parameter file *cortemp.par*, or saves the parameter file under a new name.

Chapter 7

2-D Graphics Chart Control

This chapter introduces the graphics editor 2D Chart Control, which is functional when a graphic display under *Graphs* in the main menu is opened. This menu is called up by pressing the left mouse button. The menu allows to:

a. Scale the chart,
b. Move the chart,
c. Zoom an area of the chart
d. Edit the chart for font and colour
e. Edit the chart for titles and labels
f. Save the chart
g. Load the chart

To Scale the Chart: Press CTRL, and hold down both mouse buttons (or middle button on a 3-button mouse). Move the mouse down to increase chart size, or move the mouse up to decrease chart size.

Alternatively, click on ChartArea, followed by clicking Location. This produces the four dimension windows *Left*, *Top*, *Width* and *Height*. Setting *Left* at 20, *Top* at 55, *Width* at 610, and *Height* at 860 produces a full page sized display on a printer.

To Move the Chart: Press SHIFT, and hold down both mouse buttons (or middle button on a 3-button mouse). Move the mouse to change the position of the chart inside the ChartArea.

To Graphics Zoom an Area of the Chart: Press CTRL, and hold down the left mouse button. Drag the mouse to select zoom area and release mouse button.

To Edit the Chart for Font and Colour there are many options. The user might start with the possibilities under the buttons ChartArea + Interior, Axes + Font, ChartStyles, etc.

To Edit the Chart for Titles and Labels, there are equally many options, and the user might experiment with the options under the buttons ChartLabel + Interior, Title + Label, etc.

Default or modified displays may be saved using the Save button, and re-diplayed at later stage, using the Load button..Files have the default ending *.OC2.

There are many more functions in the chart control menu, and the user should try and experiment with the many options to create the display layout, font, size and colour of the graphs as desired.

Chapter 8

Display of Selected RASC & CASC Graphics

On the next few pages we illustrate several RASC & CASC colour graphs, details of which may be found in a recent study by Gradstein et al. (1999) on the Cretaceous petroleum stratigraphy, offshore Norway. Using the distribution of 1755 foraminiferal and dinoflagellate microfossil events in over 30 exploration wells, a RASC (Ranking and Scaling) probabilistic zonation served as a template to built a Cretaceous zonal model with 19 assemblage and interval zones, including over 100 events. Variance analysis ranked 72 events according to reliability in correlation. Three new index taxa include *Uvigerinammina una* and *Ammoanita globorotaliaeformis* (Albian), and *Fenestrella bellii* (Campanian). Widespread planktonic flood events occur in late Albian through early Cenomanian, early - mid Turonian, late Santonian - earliest Campanian and mid-Maastrichtian, the result of northwards shifts of warmer water masses, and disruptions in water stratification in the dysaerobic basins.

The five graphs that were selected for display in this manual have been edited with 2-D Graphics Control to add titles, zone names etc.; the only exception are the age and zone names in figure 8 which were drafted ‘by hand’, and pasted on the page. The 2-D Graphics Control editing commands were introduced in Chapter 7.

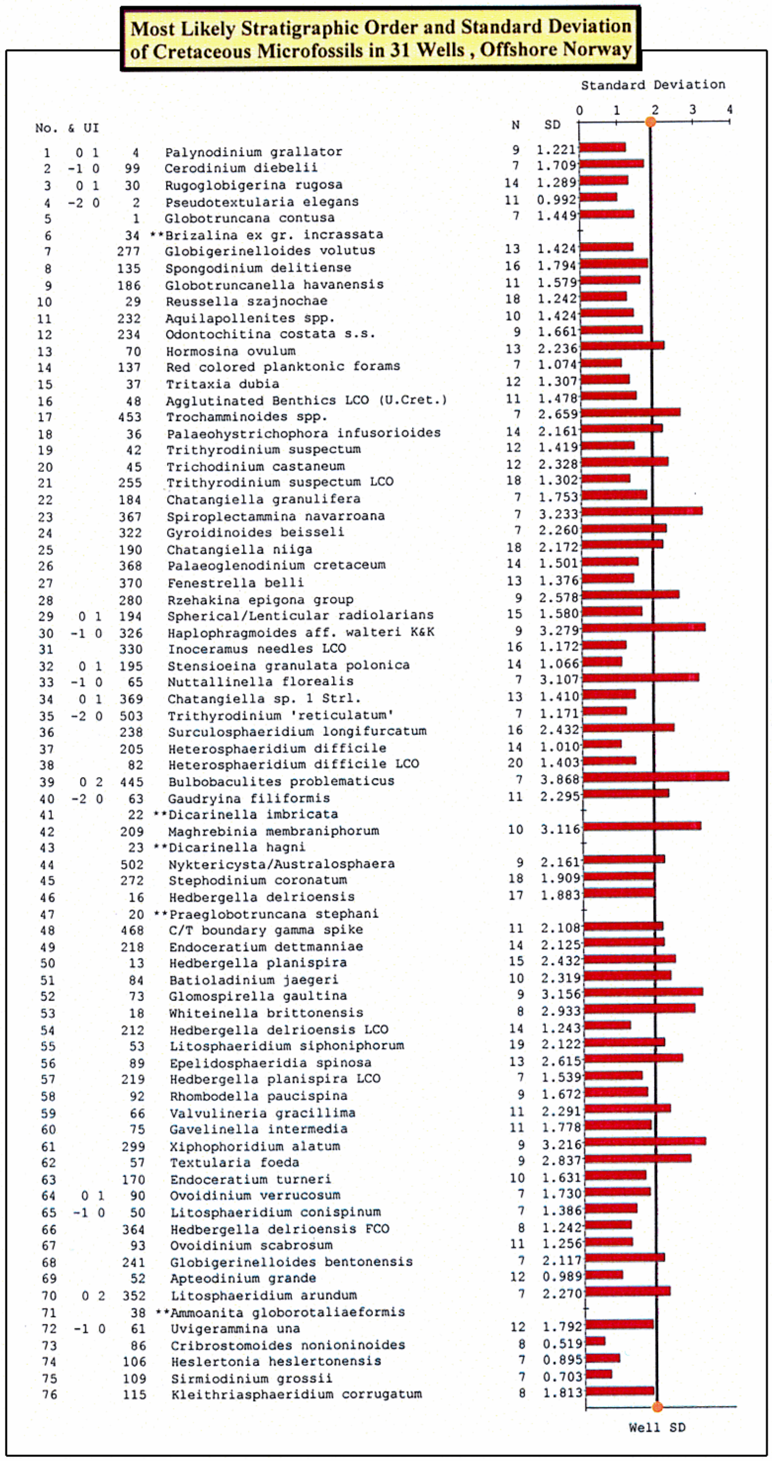


Figure 7. Event variance analysis in the RASC optimum sequence. To the left the optimum sequence of Cretaceous microfossil events in 31 wells, offshore mid-Norway, where each event occurs in at least 7 out of 31 wells. N is the number of wells sampled to calculate the s.d. per event (N equal or larger than 7), where s.d. is the standard deviation from the line of correlation in each well. The average standard deviation of 1.8903 is the sum of all s.d.'s, divided by the total number of events (72) in the optimum sequence. The asterisk behind events indicates an event with an s.d. that is smaller than the average s.d. From event s.d. theory it follows that events with a below average s.d. correlate the same stratigraphic level more faithfully from well to well than events with a higher s.d.

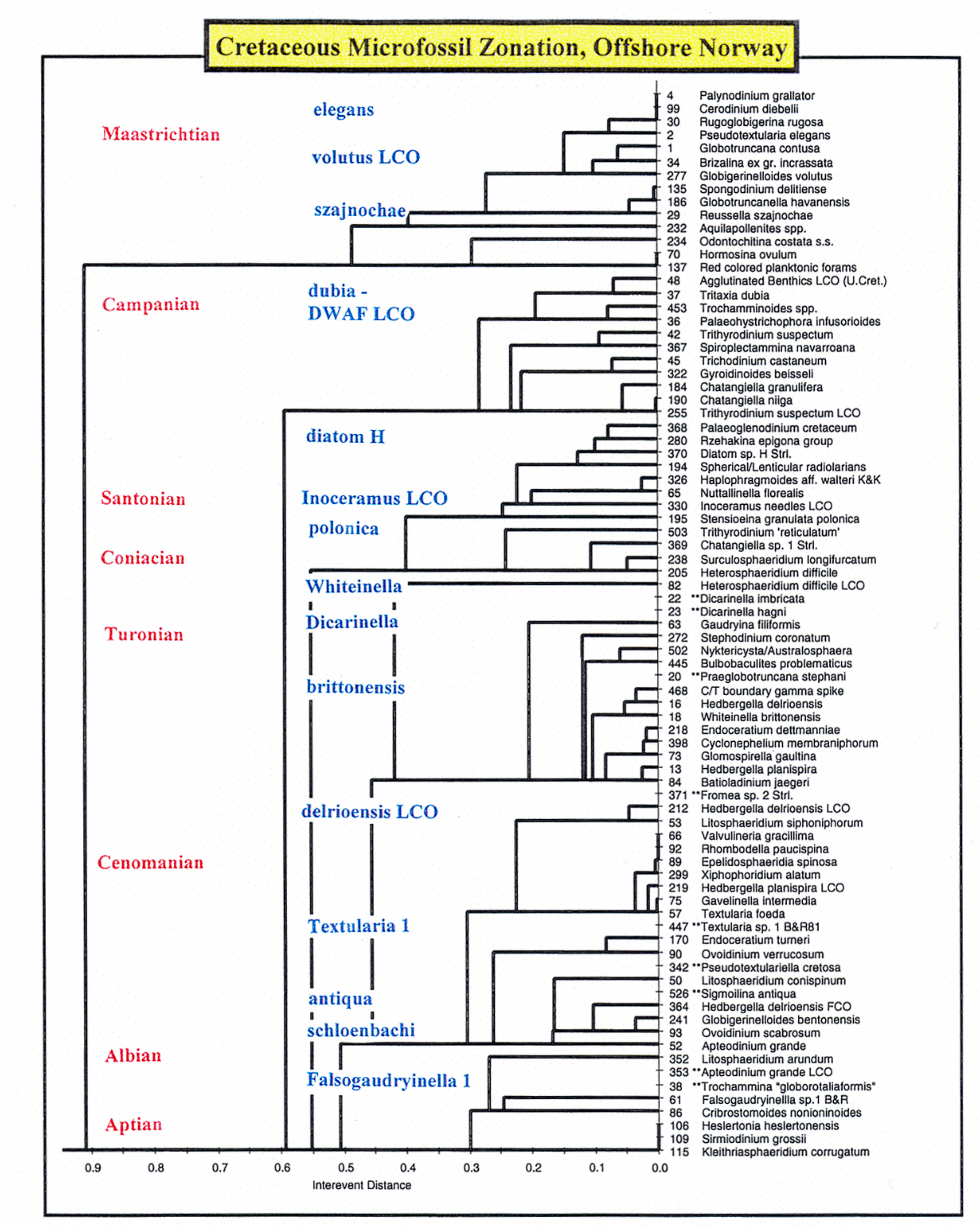


Figure 8. Cretaceous microfossil zonation, calculated with RASC and expressed in dendrogram format, based on 1746 occurrences of 92 events in 31 wells, offshore Norway. Each event shown occurs in at least 7 of 31 wells. The ‘arrow of time’ is upwards; the relative interevent distances are plotted on the scale to the left. Large breaks (at events 137, 255, 205, 84 and 52) indicate transitions between stratigraphically successive natural microfossil sequences, related to hiatussen and facies changes.

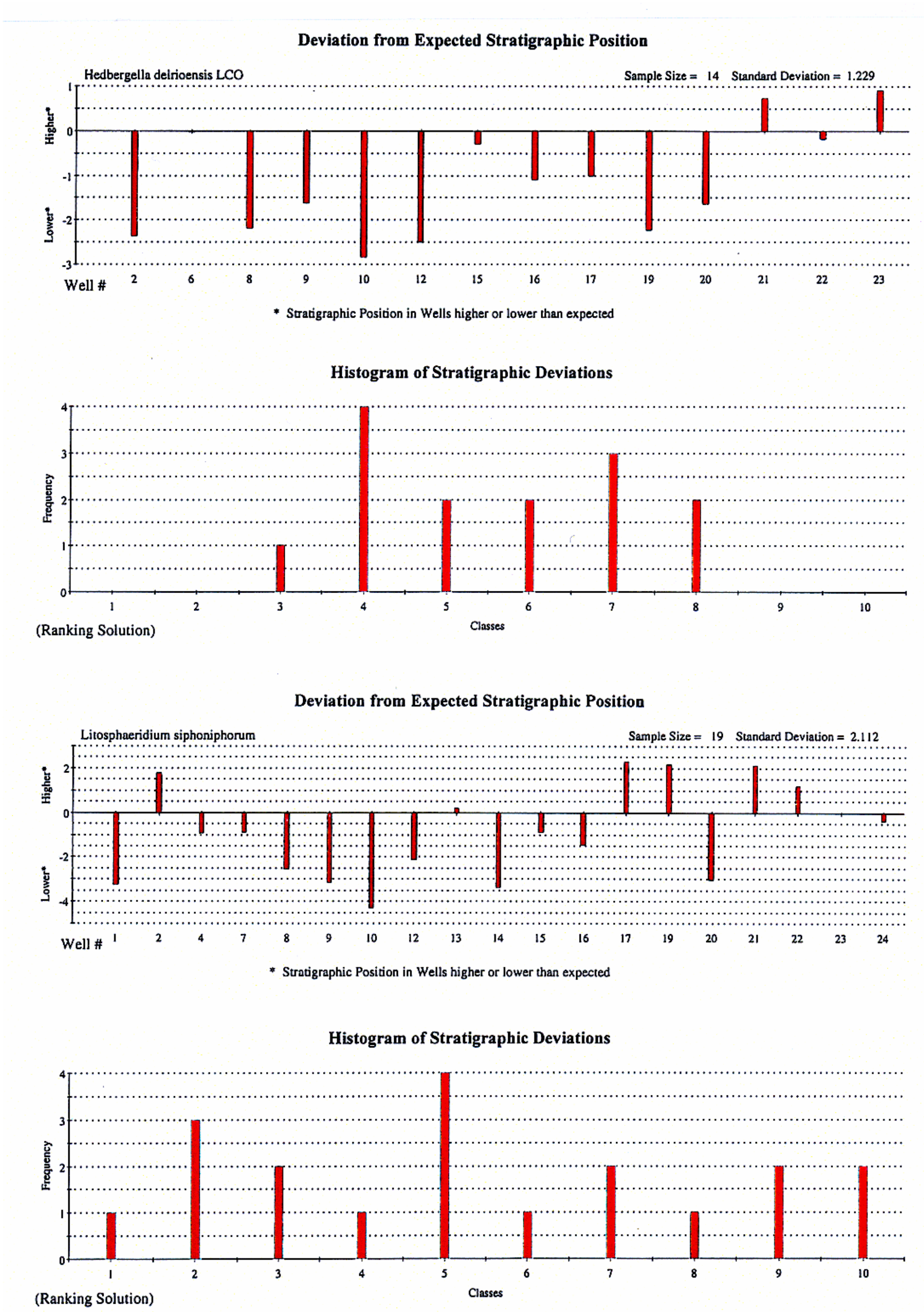
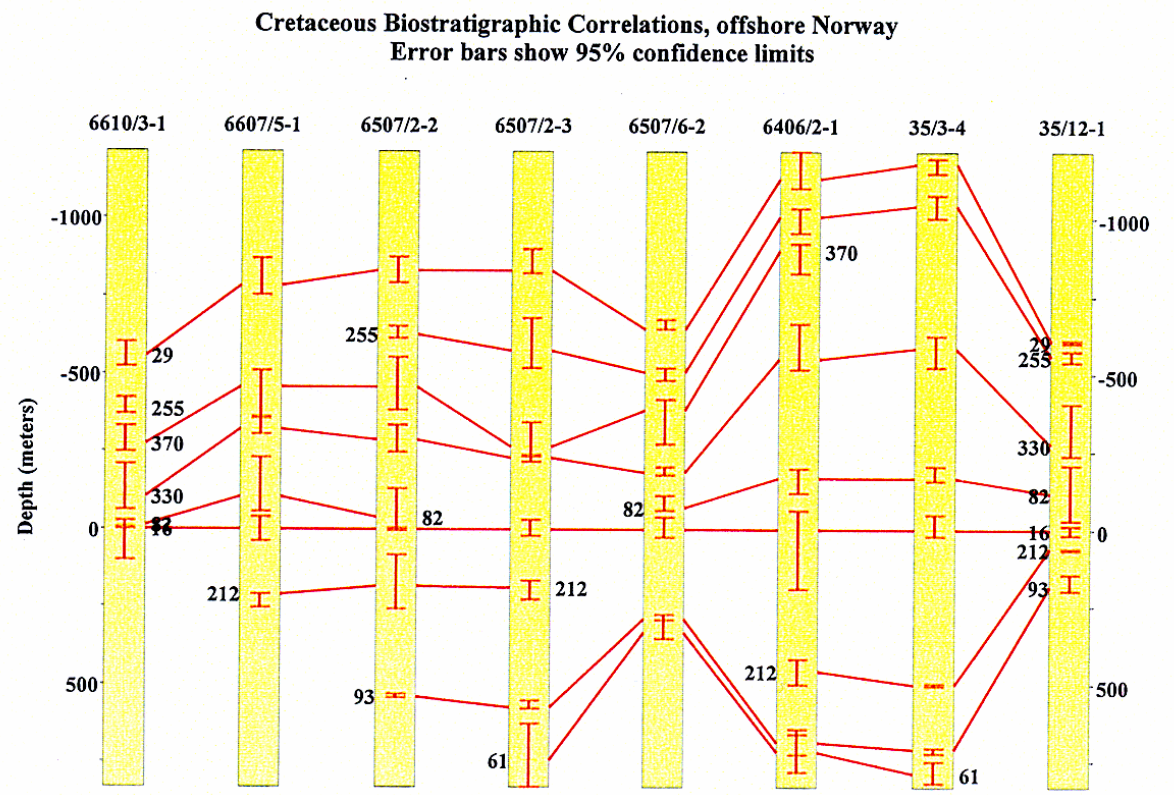


Figure 9. Variance analysis with RASC on two Cenomanian marker events, offshore Norway. *Hedbergella delrioensis* LCO (last common occurrence) has a low standard deviation, and a normal distribution of the stratigraphic deviations over 14 wells. The same is not true for *Lithosphaeridium siphoniphorum*, which is not a reliable regional stratigraphic marker.



Ranking - File: JJ	6610/3-1	6607/5-1	6507/2-2	6507/2-3	6507/6-2	6406/2-1	35/3-4
16 Hedbergella delrioensis	SD/Ave SD = .92						
Observed Depth	2815	3642	2848	2893	2807	4145	2665
Min Observed Depth	2471	3197	2651	2833	2570	3164	2463
Max Observed Depth	2730	3678	3004	3011	2830	4146	3158
Probable Depth	2526	3467	2830	2856	2721	3597	2675
Min Probable Depth	2525	3427	2825	2828	2682	3537	2627
Max Probable Depth	2626	3507	2833	2879	2748	3790	2700
212 Hedbergella delrioensis LCO	SD/Ave SD = .649						
Observed Depth				3178	2932		3199
Min Observed Depth				2912			2716
Max Observed Depth				3189			3217
Probable Depth		3678	3015	3045		4056	3179
Min Probable Depth		3678	2912	3023		4017	3172
Max Probable Depth		3719	3088	3082		4101	3183
93 Ovoidinium scabrosum	SD/Ave SD = .643						
Observed Depth			3355	3378	2962		3402
Min Observed Depth			3343	3335	2968		3381
Max Observed Depth			3366	3526	3069		3430
Probable Depth			3371	3431	3011	4287	3388
Min Probable Depth			3364	3409	2995	4243	3383
Max Probable Depth			3377	3438	3016	4324	3397

Figure 10. Most likely correlation, using CASC program on the event record in wells 35/12-1, 35/3-4, 6406/2-1, 6507/6-2, 6507/2-3, 6507/2-2, 6607/5-1, and 6610/3-1. Events used are *R.szajnochae* (29), *T.suspectum* LCO (255), *Fenestrella bellii* (370; previously named Diatom sp. H), *Inoceramus* LCO (330), *H.difficile* LCO (82), *H.delrioensis* (16), *H.delrioensis* LCO (212), *O.scabrosum* (93), and *Falsogaudryina una* (61; previous named *F.* sp. 1).

Chapter 9

Complete RASC, CASC and COR Results

Results files a - k:

There are nine RASC output files labelled **a.out* to **i.out*, a single CASC output file (**j.out*), and a single COR output file (**k.out*). All these files can be browsed under *Output Files* on the main menu, and printed on A-4 and A-3 format printers. A non-proportional font like Courier (8 points), wider page margins and 85% reduction of a page will provide satisfactory print results, when utilizing word processors.

*a.out - Ranking, scaling, (cumulative) event frequency, run parameters and run summary

General information on RASC with references is followed by explanations of the contents and formats of the **.inp, *.dat,* and **.dic* files. This file contains principal results of ranking and scaling.

The run parameters, sequence of wells, unique events (with their names and frequencies) and marker horizons are tabulated, followed by two tables with frequencies of event record occurrences. The first table shows in how many wells each event occurs; the second table gives cumulative number of events occurring in 1, 2, 3, 4, ... wells.

Principal ranking results begin with the optimum sequence of the events used (with uncertainty ranges and names). The procedure used is presorting followed by modified Hay method. The next table is for positioning unique events in this sequence. Ranking the events consists of ordering them in time without calculating variable intervals between successive events. For positioning unique events, a method similar to that used for scaling is applied by setting all interevent distances in the ranking solution equal to 1.0000. The unique events occupy intermediate positions between the successive, equally spaced, optimum sequence events, depending on the observed sequence(s) in the section(s) containing them. The final optimum sequence in principal ranking results shows all events (with names) after re-inserting the unique events.

Principal scaling results consist of two tables with distance estimates followed by the dendrogram of interevent distances. Unique events are re-inserted as shown in the last table and dendrogram. Column 1 in the first table shows rank after scaling. The order in the scaled optimum sequence is generally different from that in the optimum sequence obtained after ranking, which serves as the initial input for scaling.

Estimated interevent distances resulting from scaling can be negative. Events with negative values are re-ordered along the cumulative event distance scale. Ideally, all negative interevent distances disappear after several successive re-orderings. Then the two tables preceding the first dendrogram provide the same set of positive interevent distances. However, final re-ordering does not necessarily provide a solution without negative interevent distances in the first table.

Other useful statistics tabulated include sample size (= number of separate estimates of an interevent distance before averaging), weight (replaces number of separate estimates after weighting them according to numbers of pairs of events on which they are based), and standard deviation (S.D.). Interevent distances for very small samples are replaced by zeros. Interevent distances involving unique events are not plotted as lines in the final dendrogram but shown in parentheses only.

Summary statistics concerning the entire RASC run are given at the end of the *a.out file.

*b.out - alphabetic and numeric taxon dictionaries, occurrence table, step model

This file contains numerical and alphabetical listings of all fossil events, followed by supplementary ranking results. When the modified Hay method of ranking is applied, inconsistencies involving three or more fossil events (cycles) have to be identified. Individual cycles are listed in the order in which they were encountered in the stratigraphically downward direction. The effects of cycles are eliminated by temporarily ignoring the superpositional frequencies of one of the pairs of events involved. Such frequencies are re-introduced later, before scaling.

The occurrence table in the *b.out file shows in which wells the optimum sequence events occur. The stepmodel (next table) provides a way to check whether or not the position of an event in a well corresponds to its position in the optimum sequence, representing its average relative position in all wells. An event in a well receives a penalty point when it is out of order with respect to (above or below) another event, or half a point (0.5) when it is observed to be coeval with another event. For example, a taxon that has been subjected to significant reworking in one well would receive relatively high penalty score for that well. Adding the penalty scores of all events in the same well provides a sum statistic that, after standardization, becomes Kendall's rank order correlation coefficient. This is a measure of how precisely the observed order of events in a well compares with the optimum sequence which is an average order based on all wells.

*c.out - scattergrams of wells versus ranked optimum sequence; with event deviations

Scattergrams are given for all wells with the optimum sequence going downward in the vertical direction, and the observed order in the well plotted to the right. Events from the same sample, which are observed to be coeval, are plotted with the same horizontal distance. Usually, the number of observed events in a well is less than the number of events in the optimum sequence.

The points plotted in a scattergram tend to fall within a zone that dips to the right, in the stratigraphically downward direction for both axes. The angle of dip of this zone is not necessarily constant but may increase or decrease. A quadratic curve can be fitted according to a statistical model assuming that the observed events in a well deviate from a line of correlation associated with the optimum sequence. In general, each well has its own line of correlation. Deviations from it in the scattergram are measured in the horizontal direction. The standard deviation of these distances provides a measure of how precisely the observed order of events in a well compares with the optimum sequence. A relatively small standard deviation for a well goes together with a rank correlation coefficient close to one. Points that are less than one standard deviation away from the line of correlation are shown as 'oo' in the scattergram; those that are between one and two standard deviations away are shown as 'xx'; and those that are more than two standard deviation away as AAAA. On average, two thirds of the points are within one standard deviation. Only 5% deviate more than two standard deviation. Thus the points plotted as

AAAA may be anomalous. Usually an event plotting as AAAA in a well also has relatively high penalty score in the stepmodel.

*d.out - variance analysis using ranked optimum sequence

This file provides analysis of variance results based on ranking. The first set of tables show numerical output corresponding to the scattergrams of the *c.out file. This information can be used as input for a spreadsheet with good graphic capabilities (e.g., EXCEL) to provide better plots of observed data for wells shown together with the lines of correlation.

Deviations from the lines of correlation can be collected for each event separately. Three different types of graphical tabulation are given for each event:

Firstly, the deviations are plotted against the sequence of wells. If the sequence of wells follows a meaningful paleogeographic order, this type of plot may be helpful to ascertain diachronous behaviour of an event. In many cases, however, the deviations for an event are approximately random.

Secondly, basic statistics are given for the deviations for each event. These are the mean value which should be close to zero, standard deviation and skewness. A histogram of the deviations is also shown. A small standard deviation goes together with a narrow histogram. Events of this type have the property that they are close to the line of correlation for each well in which they occur. They may be good markers. On the other hand, events with relatively large standard deviations are relatively poor markers. This category includes events that are anomalous (AAAA in the scattergrams) in one or more wells. Often sample size is too small to provide a statistically satisfactory estimate of the skewness.

Thirdly, the deviations for the same event are projected along the optimum sequence axis. This is useful for comparing patterns of deviations for different events with one another, and also provides information required as input for CASC.

The information in the preceding tabulations for successive events is summarized in the tables at the end. It is useful to compare the standard deviations of the events with one another, and with the overall average standard deviation. For example, when the observed positions in the wells of events with small standard deviations are connected by lines for stratigraphic correlation, these lines may provide a consistent pattern without cross-overs.

The final table and chart show the average position of each event in the optimum sequence in comparison with its positions in the two wells where it reaches its stratigraphically highest and lowest position, respectively. These event ranges are measured along the optimum sequence which remains a relative time axis. If both the first occurrence in time (FAD) and the last occurrence (LAD) of a taxon are included in the optimum sequence, the interval extending from the stratigraphically lowest position of its FAD to the highest position of its FAD provides a "conservative" estimate of its range along the relative time scale used.

*e.out - scattergrams of wells versus scaled optimum sequence; with event deviations

Scattergrams after scaling. See *c.out for explanation.

*f.out - variance analysis using scaled optimum sequence

Analysis of variance of deviations after scaling. See *d.out for explanation.

*g.out - Normality test results and interim scaling tables

Remaining scaling results including normality testing. Table of distance calcultions are dendrogram are those obtained at the beginning of the scaling analysis, immediately after using the optimum sequence resulting from ranking as input (cf. explanations in *a.out). The occurrence table and step model results are similar to those discussed for ranking in the explanations of *b.out.

The normality test consists of comparing the observed position of an event with those of its two neighbours in the same well. From the frequency distribution of the second-order differences of all events in all wells, 95% and 99% confidence limits are computed. These are helpful to see whether or not an event occurs in its stratigraphically "normal" position in a well. Anomalous events which are stratigraphically too high may indicate reworking. The final table tests the normal Gaussian distribution model for all second-order differences. If the first or last class contain significantly more than 10% of the values, this may indicate a relatively large number of anomalous events. Pearson's chi-squared test is used to test for overall normality.

*h.out - plot file of ranked and scaled optimum sequences

This file contains selected optimum sequence and dendrogram results which can be used as input for plotting programs.

*i.out - CASC input file, generated by RASC

RASC output required as input for the CASC program for correlation and standard error calculation.

*j.out - CASC results; correlation and standard error of (scaled) Optimum Sequence events

Output from CASC program for correlation and standard error calculation. This file is produced automatically from input consisting of *i.out, *.dat and *.dep. Results based on ranking are followed by similar results based on scaling. The first three columns show the probable position of an optimum sequence event in meters along the depth scale of a well and its 95% confidence interval extending from minimum to maximum depth in the stratigraphically downward direction. Events with estimated maximum or minimum depth exceeding 200m are not listed. The last three columns show observed position with its 95% confidence interval. Not all optimum sequence events occur in each well. In general, the 95% confidence interval for the observed position of an event is wider than that for its probable location.

Examples of RASC & CASC results:

Below are printed selected results from operation of RASC & CASC on data file 14cen.* with (mostly) LCO and LO event data from 282 Cenozoic microfossils in 14 wells, northern North Sea and offshore Norway, producing 983 records. The data file is part of the 27 well file in (Gradstein & Bäckström, 1996).

The wells are:

1 Saga (N) 6407/2-3
2 Statoil (N) 6407/4-1
3 Elf Aquitaine (N) 6406/8-1
4 Hydro (N) 34/8-1
5 Esso (N) 16/1-1
6 Saga (N) 34/4-5
7 Hydro (N) 6407/7-1
8 6407/7A-1
9 BP (UK) 15/20-2
10 Saga (N) 2/2-4
11 Shell (UK) 22/6-1
12 Amoco (N) 2/8-1
13 Saga (N) 35/3-1
14 Saga (N) 6406/2-1

The final RASC & CASC results selected are from a run with thresholds 6/3, which means that all events must occur in at least 6 of 14 wells, and each pair of event in the (scaled) optimum sequence in a minimum of 3 wells. The following taxa were deleted from the data, prior to the final run: All *Karreriella,* all *Cystammina, R.jarvisi, C.cancellata, all Cenosphaera, and C.pachyderma.* The reason is an erratic stratigraphic record in the wells selected, as concluded from interim RASC results (not shown).

The events of five taxa occured in fewer than 6 wells, but were deemed stratigraphically important. These events were introduced as Unique Events (line 3 of the input parameter file), and printed in the (Scaled) Optimum Sequence with an *.

DICTIONARY OF EVENTS (in file *b.out)
(only 18 out of 524 taxa printed below)

```
         NUMERICAL LISTING                    ALPHABETIC LISTING

     1  Neogloboquadrina pachyderma        25  "Turborotalia" aff. ampliapertura
     2  Globigerina apertura               90  Acarinina densa
     3  Deflandrea phosphoritica          357  Acarinina ex. gr. spinulosa
     4  Globorotalia inflata               37  Acarinina pentacamerata
     5  Globorotalia crassaformis         160  Acarinina pseudotopilensis
     6  Neogloboquadrina acostaensis       52  Acarinina soldadoensis
     7  Areoligera semicirculata          439  Acarinina sp
     8  Orbulina universa                  96  Acarinina wilcoxensis
     9  Fursenkoina gracilis              434  Accarinina praeangulata
    10  Uvigerina canariensis             436  Achilleodinium biformoides
    11  R. actinocoronata FO              391  Achomosphaera andalousiense
    12  Areosphaeridium diktyoplokus      244  Achomosphaera andalousiensis LCO
    13  Heteraulacacysta porosa           289  Adercotryma agterbergi
    14  Eatonicysta ursulae LCO            70  Alabamina scitula
    15  Globigerina praebulloides         423  Alabamina tangentialis
    16  Ceratobulimina contraria           39  Alabamina wilcoxensis
    17  Asterigerina gurichi              114  Alisocysta margarita
    18  Spiroplectammina carinata          30  Alisocysta margarita LCO
```

SEQUENCE OF WELLS (in file *a.out)

```
  1   Saga (N) 6407/2-3
  2   Statoil (N) 6407/4-1
  3   Elf Aquitaine (N) 6406/8-1
  4   Hydro (N) 34/8-1
  5   Esso (N) 16/1-1
  6   Saga (N) 34/4-5
  7   Hydro (N) 6407/7-1
  8   6407/7A-1
  9   BP (UK) 15/20-2
 10   Saga (N) 2/2-4
 11   Shell (UK) 22/6-1
 12   Amoco (N) 2/8-1
 13   Saga (N) 35/3-1
 14   Saga 6406/2-1
```

UNIQUE EVENTS (in file *a.out)

NUMBER	FREQUENCY	NAME
6	4	Neogloboquadrina acostaensis
58	1	Neogloboquadrina atlantica (dextral)
348	2	Sphaeroidinella disjuncta
368	5	Chiropteridium mespilanum
413	3	Silicious biofacies

TABULATION OF EVENT RECORD OCCURRENCES (in file *a.out)

NUMBER OF WELLS	1	2	3	4	5	6	7	8	9	10	11	12	13	14
CUMULATIVE NUMBER	282	195	146	106	73	55	42	32	24	14	12	2	0	0

SUMMARY OF DATA PROPERTIES AND RASC15 RESULTS (in file *a.out)

NUMBER OF NAMES (TAXA) IN THE DICTIONARY	524
NUMBER OF WELLS	14
NUMBER OF DICTIONARY TAXA IN THE WELLS	282
NUMBER OF EVENT RECORDS IN THE WELLS	983
NUMBER OF CYCLES PRIOR TO RANKING	7
NUMBER OF EVENTS IN THE OPTIMUM SEQUENCE	55
NUMBER OF EVENTS IN THE FINAL SCALED OPTIMUM SEQUENCE (INCLUDING UNIQUE EVENTS SHOWN WITH **)	60
NUMBER OF STEPMODEL EVENTS WITH MORE THAN 6 PENALTY POINTS AFTER SCALING	4
NUMBER OF NORMALITY TEST EVENTS SHOWN WITH * OR **	25
NUMBER OF AAAA EVENTS IN SCALING SCATTERGRAMS	15

FINAL OPTIMUM SEQUENCE WITH UNIQUE EVENTS (in file *a.out)

RANK	FOSSIL #	FOSSIL NAME
1	77	Elphidium spp.
2	228	Cassidulina teretis
3	1	Neogloboquadrina pachyderma
4	31	Cibicidoides scaldisensis
5	316	Trifarina fluens
6	171	Buccella frigida
7	270	Cibicidoides grossa
8	4	Globorotalia inflata
9	23	Sigmoilopsis schlumbergeri
10	269	Neogloboquadrina atlantica
11	91	Diatoms/radiolarians LCO
12	58	**Neogloboquadrina atlantica (dextral)
13	6	**Neogloboquadrina acostaensis
14	15	Globigerina praebulloides
15	363	Hystrichosphaeropsis obscura
16	362	Cannosphaeropsis utinensis
17	219	Martinotiella cylindrica
18	236	G. ex.gr. praescitula zealandica
19	348	**Sphaeroidinella disjuncta
20	413	**Silicious biofacies
21	17	Asterigerina gurichi
22	24	Turrilina alsatica
23	368	**Chiropteridium mespilanum
24	3	Deflandrea phosphoritica
25	7	Areoligera semicirculata
26	41	Wetzelliella symmetrica
27	25	Coarse agglutinated spp.
28	97	Cyclammina placenta
29	182	Spirosigmoilinella compressa
30	289	Adercotryma agterbergi
31	198	Glomospirella biedae
32	324	Aschemonella grandis
33	261	Haplophragmoides walteri
34	321	Dorothia seigliei
35	29	Reticulophragmium amplectens
36	32	Ammosphaeroidina pseudopauciloculata
37	12	Areosphaeridium diktyoplokus
38	229	Recurvoides ex.gr. walteri
39	263	Ammomarginulina aubertae
40	72	Rottnestia borussica
41	68	Spiroplectammina spectabilis LO
42	92	Diphyes ficusoides
43	260	Haplophragmoides kirki
44	175	Reticulophragmium intermedia
45	99	Eatonicysta ursulae
46	54	Spiroplectammina navarroana
47	279	Recurvoidella lamella
48	50	Subbotina patagonica
49	108	Deflandrea oebisfeldensis
50	22	Coscinodiscus spp.
51	28	Apectodinium augustum
52	105	Rzehakina minima
53	76	Reticulophragmium paupera
54	283	Reticulophragmium garcilassoi
55	57	Spiroplectammina spectabilis LCO
56	114	Alisocysta margarita
57	310	Saccammina placenta
58	129	Trochammina ruthven murrayi
59	134	Hormosina excelsa
60	118	Palaeoperidinium pyrophorum

** INDICATES A UNIQUE (RARE) EVENT

Numerical and Graphical Output of Scaling
(in file *a.out)

DISTANCE ANALYSIS WITH WEIGHTED DIFFERENCES

RANK	FOSSIL PAIRS	FOSSIL DISTANCE	CUMULATIVE DISTANCE	SUM DIFF Z VALUES	SAMPLE SIZE	WGT	S.D.
1	77-228	0.0236	0.0236	0.3447	9	14.6	0.1119
2	228- 31	0.2456	0.2692	3.4926	9	14.2	0.1325
3	31- 1	0.0759	0.3451	1.0971	8	14.5	0.1194
4	1-171	0.6087	0.9538	8.4805	8	13.9	0.1348
5	171-316	0.0575	1.0113	0.6671	8	11.6	0.1890
6	316-270	0.0332	1.0445	0.4516	8	13.6	0.2045
7	270- 4	0.7041	1.7486	8.4113	8	11.9	0.0892
8	4- 23	0.1045	1.8531	1.3928	8	13.3	0.1579
9	23-269	0.6264	2.4796	9.5659	11	15.3	0.1276
10	269-363	1.0519	3.5315	8.0963	6	7.7	0.2817
11	363- 91	0.0332	3.5647	0.3653	11	11.0	0.1668
12	91-219	0.2025	3.7671	2.5789	12	12.7	0.1732
13	219- 15	0.0346	3.8018	0.5530	12	16.0	0.1911
14	15-362	0.2107	4.0124	2.4766	10	11.8	0.2018
15	362-236	0.3033	4.3158	2.7853	9	9.2	0.2284
16	236- 17	0.2480	4.5637	2.5015	7	10.1	0.1092
17	17- 3	0.2972	4.8609	2.0499	6	6.9	0.2891
18	3- 25	0.4932	5.3540	7.2043	15	14.6	0.1711
19	25- 24	0.0162	5.3702	0.3534	21	21.9	0.1683
20	24- 7	0.0146	5.3848	0.3034	16	20.9	0.1323
21	7- 97	0.0478	5.4326	1.4802	24	31.0	0.1335
22	97- 41	0.0634	5.4959	1.8433	24	29.1	0.1033
23	41-182	0.2303	5.7262	4.3487	11	18.9	0.2027
24	182-324	0.3743	6.1005	6.4705	14	17.3	0.1309
25	324-289	0.0266	6.1271	0.4447	14	16.7	0.1463
26	289-198	0.1390	6.2661	2.7441	15	19.7	0.1038
27	198-261	0.3401	6.6062	9.6949	22	28.5	0.1035
28	261-321	0.0691	6.6753	2.4484	23	35.5	0.0761
29	321- 12	0.1303	6.8056	3.2533	19	25.0	0.1495
30	12- 29	0.0601	6.8657	1.3043	16	21.7	0.1026
31	29- 32	0.0156	6.8813	0.3790	18	24.4	0.1253
32	32-229	0.1043	6.9856	1.8962	18	18.2	0.0950
33	229- 72	0.2217	7.2072	3.5751	18	16.1	0.1445
34	72- 68	0.3334	7.5406	6.6569	20	20.0	0.0973
35	68-263	0.0872	7.6278	2.1481	16	24.6	0.1574
36	263- 92	0.0144	7.6422	0.2849	16	19.7	0.1578
37	92-260	0.2355	7.8778	5.0205	15	21.3	0.1333
38	260-175	0.3692	8.2470	6.9868	14	18.9	0.1315
39	175- 99	0.1351	8.3821	1.5170	7	11.2	0.1213
40	99-279	0.1601	8.5422	2.2191	8	13.9	0.2447
41	279- 54	0.0585	8.6007	1.1137	14	19.0	0.1228
42	54- 50	0.4076	9.0084	8.6868	14	21.3	0.1589
43	50-108	0.5013	9.5096	5.6166	10	11.2	0.1782
44	108- 22	0.5804	10.0901	3.3712	4	5.8	0.2844
45	22- 28	0.4804	10.5704	3.3332	8	6.9	0.1522
46	28- 76	0.8335	11.4040	11.9915	12	14.4	0.1030
47	76-105	0.0971	11.5010	1.1384	12	11.7	0.0718
48	105-283	0.0626	11.5636	0.6334	12	10.1	0.0906
49	283- 57	0.1278	11.6914	1.7033	12	13.3	0.1234
50	57-114	0.0989	11.7903	1.2408	8	12.5	0.1354
51	114-310	0.1074	11.8977	1.1714	8	10.9	0.1277
52	310-129	0.3620	12.2597	4.2148	8	11.6	0.0738
53	129-134	0.1168	12.3765	1.0448	6	8.9	0.1296
54	134-118	0.5221	12.8985	3.6575	6	7.0	0.0928

EVENTS ARE SORTED ON THE BASIS OF CUMULATIVE DISTANCE
TO OBTAIN ONLY POSITIVE INTEREVENT DISTANCES

NOTE: IN ORDER TO RECALCULATE STANDARD DEVIATIONS AFTER SORTING,
DISTANCE VALUES MUST BE RECALCULATED

NEW SEQUENCE	DISTANCE FROM 1ST POSITION	FOSSIL PAIRS	INTER EVENT DISTANCE
77	0.0000	77-228	0.0236
228	0.0236	228- 31	0.2456
31	0.2692	31- 1	0.0759
1	0.3451	1-171	0.6087
171	0.9538	171-316	0.0575
316	1.0113	316-270	0.0332
270	1.0445	270- 4	0.7041
4	1.7486	4- 23	0.1045
23	1.8531	23-269	0.6264
269	2.4796	269-363	1.0519
363	3.5315	363- 91	0.0332
91	3.5647	91-219	0.2025
219	3.7671	219- 15	0.0346
15	3.8018	15-362	0.2107
362	4.0124	362-236	0.3033
236	4.3158	236- 17	0.2480
17	4.5637	17- 3	0.2972
3	4.8609	3- 25	0.4932
25	5.3540	25- 24	0.0162
24	5.3702	24- 7	0.0146
7	5.3848	7- 97	0.0478
97	5.4326	97- 41	0.0634
41	5.4959	41-182	0.2303
182	5.7262	182-324	0.3743
324	6.1005	324-289	0.0266
289	6.1271	289-198	0.1390
198	6.2661	198-261	0.3401
261	6.6062	261-321	0.0691
321	6.6753	321- 12	0.1303
12	6.8056	12- 29	0.0601
29	6.8657	29- 32	0.0156
32	6.8813	32-229	0.1043
229	6.9856	229- 72	0.2217
72	7.2072	72- 68	0.3334
68	7.5406	68-263	0.0872
263	7.6278	263- 92	0.0144
92	7.6422	92-260	0.2355
260	7.8778	260-175	0.3692
175	8.2470	175- 99	0.1351
99	8.3821	99-279	0.1601
279	8.5422	279- 54	0.0585
54	8.6007	54- 50	0.4076
50	9.0084	50-108	0.5013
108	9.5096	108- 22	0.5804
22	10.0901	22- 28	0.4804
28	10.5704	28- 76	0.8335
76	11.4040	76-105	0.0971
105	11.5010	105-283	0.0626
283	11.5636	283- 57	0.1278
57	11.6914	57-114	0.0989
114	11.7903	114-310	0.1074
310	11.8977	310-129	0.3620
129	12.2597	129-134	0.1168
134	12.3765	134-118	0.5221
118	12.8985		

DENDROGRAM OF WEIGHTED INTEREVENT DISTANCES
(in file *a.out)

SCATTERGRAM of WELL (x-axis) versus OPTIMUM SEQUENCE (y-axis)
[in files *c.out (ranking) and *e.out (scaling)]

FOSSIL NAME	NUMBER
Elphidium spp.	77
Cassidulina teretis	-228
Neogloboquadrina pachyderma	-1
Cibicidoides scaldisensis	-31
Trifarina fluens	316
Sigmoilopsis schlumbergeri	23
Cibicidoides grossa	-270
Buccella frigida	171
Globorotalia inflata	4
Neogloboquadrina atlantica	269
Globigerina praebulloides	15
Cannosphaeropsis utinensis	362
Cyclammina placenta	97
Diatoms/radiolarians LCO	91
Hystrichosphaeropsis obscura	363
Turrilina alsatica	24
Areoligera semicirculata	7
Deflandrea phosphoritica	3
Coarse agglutinated spp.	25
Areosphaeridium diktyoplokus	12
Haplophragmoides walteri	261
Rottnestia borussica	-72
Glomospirella biedae	-198
Recurvoides ex.gr. walteri	229
Diphyes ficusoides	92
Reticulophragmium amplectens	29
Eatonicysta ursulae	99
Spiroplectammina navarroana	54
Subbotina patagonica	-50
Haplophragmoides kirki	-260
Apectodinium augustum	28
Deflandrea oebisfeldensis	-108
Trochammina ruthven murrayi	129
Spiroplectammina spectabilis LCO	57
Hormosina excelsa	-134
Reticulophragmium paupera	76
Palaeoperidinium pyrophorum	118

OCCURRENCE TABLE
[in files *b.out (ranking) and *g.out (scaling)]

NAME	NUMBER	WELL NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Elphidium spp.	77		X	X	X	X	X	X	X	X	X	X	X		X
Cassidulina teretis	228	X	X	X	X	X	X		X	X	X	X	X	X	
Neogloboquadrina pachyderma	1	X	X	X	X	X	X	X	X		X	X	X	X	X
Cibicidoides scaldisensis	31	X	X	X	X	X	X		X		X			X	
Trifarina fluens	316	X	X	X	X	X	X	X	X		X	X	X		X
Buccella frigida	171	X	X		X	X	X		X		X			X	X
Cibicidoides grossa	270	X	X	X	X	X	X		X			X	X	X	
Globorotalia inflata	4	X	X	X	X	X	X	X	X						X
Sigmoilopsis schlumbergeri	23	X	X	X	X	X	X	X	X	X	X	X	X		X
Neogloboquadrina atlantica	269	X	X	X	X	X	X	X	X	X	X		X		X
Diatoms/radiolarians LCO	91	X	X	X		X	X				X	X		X	
Globigerina praebulloides	15	X	X	X	X	X	X			X	X	X	X		X
Hystrichosphaeropsis obscura	363		X	X			X				X			X	X
Cannosphaeropsis utinensis	362	X	X	X			X				X			X	X
Martinotiella cylindrica	219	X	X	X		X				X	X		X		X
G. ex.gr. praescitula zealandica	236		X			X				X	X	X	X		X
Asterigerina gurichi	17				X	X				X	X	X	X	X	
Turrilina alsatica	24	X			X	X	X	X				X		X	X
Deflandrea phosphoritica	3	X	X	X	X		X	X						X	
Areoligera semicirculata	7	X	X	X	X		X	X			X			X	X
Wetzelliella symmetrica	41	X	X	X	X	X		X			X				
Coarse agglutinated spp.	25	X	X	X	X	X	X	X		X	X		X	X	
Cyclammina placenta	97	X	X	X	X	X	X	X		X	X	X			
Spirosigmoilinella compressa	182	X	X	X	X	X				X	X	X	X		
Adercotryma agterbergi	289	X	X	X	X	X					X	X			X
Glomospirella biedae	198	X		X	X		X				X	X			
Aschemonella grandis	324	X	X	X				X			X	X			
Haplophragmoides walteri	261		X	X	X	X	X	X		X	X	X	X		X
Dorothia seigliei	321	X	X	X	X	X					X	X	X		X
Reticulophragmium amplectens	29	X	X	X	X	X	X	X		X	X		X		X
Ammosphaeroidina pseudopauciloculata	32	X	X	X	X			X		X	X	X			
Areosphaeridium diktyoplokus	12	X	X		X	X	X	X			X				X
Recurvoides ex.gr. walteri	229	X	X	X			X					X	X		
Ammomarginulina aubertae	263		X	X		X		X			X	X	X		
Rottnestia borussica	72	X	X		X		X	X			X				
Spiroplectammina spectabilis LO	68	X	X	X	X	X		X		X	X	X	X		X
Diphyes ficusoides	92	X	X	X	X		X	X							
Haplophragmoides kirki	260	X	X	X	X	X	X	X		X	X				
Reticulophragmium intermedia	175	X	X		X			X			X				X
Eatonicysta ursulae	99	X	X	X	X	X	X	X			X				X
Spiroplectammina navarroana	54	X	X	X	X	X	X	X		X	X	X	X		
Recurvoidella lamella	279	X	X		X	X		X		X	X				
Subbotina patagonica	50	X	X	X	X	X	X	X		X	X	X			X
Deflandrea oebisfeldensis	108	X	X	X	X	X	X	X						X	X
Coscinodiscus spp.	22	X	X	X	X	X				X		X		X	X
Apectodinium augustum	28	X	X	X	X	X	X	X	X	X	X	X		X	X
Rzehakina minima	105	X	X	X	X	X		X	X	X	X	X	X		
Reticulophragmium paupera	76	X	X	X	X	X	X	X		X	X	X	X	X	X
Reticulophragmium garcilassoi	283	X	X	X	X	X		X		X			X		X
Spiroplectammina spectabilis LCO	57	X	X	X	X	X	X	X		X	X	X		X	X
Alisocysta margarita	114	X		X	X	X		X		X			X	X	X
Saccammina placenta	310	X	X	X	X	X		X			X	X	X		X
Trochammina ruthven murrayi	129	X	X	X	X	X	X	X						X	
Hormosina excelsa	134	X	X	X	X	X	X	X	X	X	X	X		X	
Palaeoperidinium pyrophorum	118	X	X	X	X	X	X	X	X	X		X		X	

```
SEQUENCE OF WELLS:
   1   Saga (N) 6407/2-3
   2   Statoil (N) 6407/4-1
   3   Elf Aquitaine (N) 6406/8-1
   4   Hydro (N) 34/8-1
   5   Esso (N) 16/1-1
   6   Saga (N) 34/4-5


   7   Hydro (N) 6407/7-1
   8   6407/7A-1
   9   BP (UK) 15/20-2
  10   Saga (N) 2/2-4
  11   Shell (UK) 22/6-1
  12   Amoco (N) 2/8-1
  13   Saga (N) 35/3-1
  14   Saga (N) 6406/2-1
```

STEP MODEL
[in files *b.out (ranking) and *g.out (scaling)]

NORMALITY TEST RESULTS
(in file *g.out)

SECOND ORDER DIFFERENCE STATISTICS
N = 428 AVE = -.03021 SD = 1.27801 RATIO = 0.74 RHO = 0.377

EQUIVALENT NUMBER OF VALUES = 194
NOTE: PURPOSE OF SECOND ORDER DIFFERENCE STATISTICS IS TO FIT A GAUSSIAN FREQUENCY DISTRIBUTION CURVE TO THE CENTRAL PART OF THE HISTOGRAM OF ALL SECOND ORDER DIFFERENCES IN ALL WELLS. SUCCESSIVE VALUES ARE AUTOCORRELATED (RHO), IMPLYING THAT THE EQUIVALENT NUMBER OF VALUES IS LESS THAN THE ACTUAL NUMBER OF SECOND ORDER DIFFERENCES (N).

NORMALITY TEST Hydro (N) 34/8-1

		CUM. DIST.	2ND ORDER DIFF.	
Cibicidoides scaldisensis	31	0.2692		
Elphidium spp.	-77	0.0000	0.6143	
Neogloboquadrina pachyderma	-1	0.3451	-0.6666	
Cassidulina teretis	-228	0.0236	0.8690	
Buccella frigida	171	0.9538	-0.1355	
Globorotalia inflata	4	1.7486	-1.1162	
Cibicidoides grossa	-270	1.0445	1.1300	
Sigmoilopsis schlumbergeri	23	1.8531	-1.6505	
Trifarina fluens	316	1.0113	2.3101	
Neogloboquadrina atlantica	269	2.4796	0.6159	
Asterigerina gurichi	17	4.5637	-2.8461	*
Globigerina praebulloides	15	3.8018	1.8210	
Deflandrea phosphoritica	3	4.8609	-0.5498	
Turrilina alsatica	24	5.3702	-0.5255	
Coarse agglutinated spp.	25	5.3540	0.7710	
Spirosigmoilinella compressa	-182	5.7262	-0.6658	
Cyclammina placenta	-97	5.4326	1.5364	
Dorothia seigliei	-321	6.6753	-1.6945	
Haplophragmoides walteri	261	6.6062	-1.0412	
Wetzelliella symmetrica	41	5.4959	2.1242	
Adercotryma agterbergi	-289	6.1271	-1.7562	
Areoligera semicirculata	7	5.3848	2.2233	
Reticulophragmium amplectens	29	6.8657	-1.0827	
Ammosphaeroidina pseudopauciloculata	-32	6.8813	-0.4739	
Areosphaeridium diktyoplokus	12	6.8056	-0.4639	
Glomospirella biedae	198	6.2661	2.1512	
Haplophragmoides kirki	260	7.8778	-2.2822	
Rottnestia borussica	72	7.2072	1.1055	
Diphyes ficusoides	92	7.6422	0.4650	
Recurvoidella lamella	279	8.5422	-1.9016	
Spiroplectammina spectabilis LO	68	7.5406	1.8431	
Eatonicysta ursulae	99	8.3821	-0.9766	
Reticulophragmium intermedia	175	8.2470	0.8965	
Subbotina patagonica	50	9.0084	-0.2601	
Deflandrea oebisfeldensis	108	9.5096	0.0791	
Coscinodiscus spp.	22	10.0901	-0.1000	
Apectodinium augustum	28	10.5704	-2.4501	
Spiroplectammina navarroana	54	8.6007	5.3153	**
Reticulophragmium garcilassoi	-283	11.5636	-3.0255	*
Rzehakina minima	-105	11.5010	-0.4172	
Reticulophragmium paupera	76	11.4040	0.9735	
Saccammina placenta	-310	11.8977	-0.6011	
Alisocysta margarita	-114	11.7903	-0.3742	
Spiroplectammina spectabilis LCO	57	11.6914	0.7839	
Hormosina excelsa	134	12.3765	-0.8018	
Trochammina ruthven murrayi	129	12.2597	0.7556	
Palaeoperidinium pyrophorum	118	12.8985		

* -GREATER THAN 95% PROBABILITY THAT EVENT IS OUT OF POSITION
** -GREATER THAN 99% PROBABILITY THAT EVENT IS OUT OF POSITION

NORMALITY TEST Esso (N) 16/1-1

		CUM. DIST.	2ND ORDER DIFF.
Elphidium spp.	77	0.0000	
Cassidulina teretis	-228	0.0236	0.9973
Cibicidoides grossa	-270	1.0445	-0.7206
Sigmoilopsis schlumbergeri	23	1.8531	-1.8084
Neogloboquadrina pachyderma	-1	0.3451	2.9116 *
Globorotalia inflata	-4	1.7486	0.1067
Martinotiella cylindrica	219	3.7671	-3.3061 **
Neogloboquadrina atlantica	269	2.4796	2.3727
Diatoms/radiolarians LCO	91	3.5647	-0.3340
G. ex.gr. praescitula zealandica	236	4.3158	-0.7567
Globigerina praebulloides	-15	3.8018	0.7676
Asterigerina gurichi	17	4.5637	0.0284
Coarse agglutinated spp.	25	5.3540	-0.6484
Wetzelliella symmetrica	41	5.4959	-0.2676
Turrilina alsatica	24	5.3702	0.9900
Spirosigmoilinella compressa	-182	5.7262	-0.6496
Cyclammina placenta	-97	5.4326	1.0280
Dorothia seigliei	321	6.6753	-0.8034
Haplophragmoides walteri	-261	6.6062	-0.4101
Adercotryma agterbergi	-289	6.1271	1.7215
Haplophragmoides kirki	260	7.8778	-2.8228 *
Areosphaeridium diktyoplokus	12	6.8056	1.8943
Ammomarginulina aubertae	263	7.6278	-0.9094
Spiroplectammina spectabilis LO	68	7.5406	-0.5877
Reticulophragmium amplectens	29	6.8657	2.1912
Eatonicysta ursulae	99	8.3821	-1.3562
Recurvoidella lamella	279	8.5422	0.4067
Spiroplectammina navarroana	-54	8.6007	-0.1592
Subbotina patagonica	50	9.0084	0.0937
Deflandrea oebisfeldensis	108	9.5096	1.0679
Apectodinium augustum	-28	10.5704	-2.0495
Coscinodiscus spp.	22	10.0901	1.7943
Reticulophragmium paupera	76	11.4040	-1.1542
Reticulophragmium garcilassoi	283	11.5636	-0.0318
Spiroplectammina spectabilis LCO	57	11.6914	

* -GREATER THAN 95% PROBABILITY THAT EVENT IS OUT OF POSITION
** -GREATER THAN 99% PROBABILITY THAT EVENT IS OUT OF POSITION

NORMALITY TEST Saga (N) 34/4-5

		CUM. DIST.	2ND ORDER DIFF.	
Elphidium spp.	77	0.0000		
Cassidulina teretis	-228	0.0236	0.2979	
Neogloboquadrina pachyderma	-1	0.3451	-0.3974	
Cibicidoides scaldisensis	-31	0.2692	0.3219	
Trifarina fluens	316	1.0113	0.0997	
Sigmoilopsis schlumbergeri	23	1.8531	-1.1544	
Cibicidoides grossa	-270	1.0445	0.2219	
Buccella frigida	171	0.9538	0.8854	
Globorotalia inflata	4	1.7486	-0.0638	
Neogloboquadrina atlantica	269	2.4796	0.5912	
Globigerina praebulloides	15	3.8018	-1.1115	
Cannosphaeropsis utinensis	362	4.0124	1.2095	
Cyclammina placenta	97	5.4326	-3.2880	*
Diatoms/radiolarians LCO	91	3.5647	1.8347	
Hystrichosphaeropsis obscura	363	3.5315	1.8720	
Turrilina alsatica	24	5.3702	-1.8242	
Areoligera semicirculata	7	5.3848	-0.5384	
Deflandrea phosphoritica	3	4.8609	1.0170	
Coarse agglutinated spp.	25	5.3540	0.9584	
Areosphaeridium diktyoplokus	12	6.8056	-1.6510	
Haplophragmoides walteri	261	6.6062	1.2965	
Rottnestia borussica	-72	7.2072	-1.5422	
Glomospirella biedae	-198	6.2661	1.1645	
Recurvoides ex.gr. walteri	229	6.9856	-0.0628	
Diphyes ficusoides	92	7.6422	-1.4332	
Reticulophragmium amplectens	29	6.8657	2.2929	
Eatonicysta ursulae	99	8.3821	-1.2977	
Spiroplectammina navarroana	54	8.6007	0.6851	
Subbotina patagonica	-50	9.0084	-1.5382	
Haplophragmoides kirki	-260	7.8778	3.3272	**
Apectodinium augustum	28	10.5704	-3.2574	*
Deflandrea oebisfeldensis	-108	9.5096	3.3148	**
Trochammina ruthven murrayi	129	12.2597	-3.3183	**
Spiroplectammina spectabilis LCO	57	11.6914	1.7494	
Hormosina excelsa	-134	12.3765	-2.1537	
Reticulophragmium paupera	76	11.4040	2.4671	
Palaeoperidinium pyrophorum	118	12.8985		

* -GREATER THAN 95% PROBABILITY THAT EVENT IS OUT OF POSITION
** -GREATER THAN 99% PROBABILITY THAT EVENT IS OUT OF POSITION

Variance Analysis
(in files *d.out and *f.out)

EVENT NO.   50 Subbotina patagonica

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 WELL DEVIATION     STRAT. HIGHER/LOWER THAN EXPECTED

  1      0.580        I          I**        I
  2      1.327        I          I****      I
  3      1.915        I          I******    I
  4      2.506        I          I*******   I
  5      1.590        I          I*****     I
  6      0.861        I          I***       I
  7      0.404        I          I**        I
  9      1.280        I          I****      I
 10      3.818        I          I**********I
 11      2.236        I          I*******   I
 14      0.802        I          I***       I

 SAMPLE SIZE =   11         UNCORRECTED MEAN =     1.574
 ADJUSTED SD =   1.003      ADJUSTED SKEWNESS =    1.086


 HISTOGRAM AFTER CHANGING MEAN FROM  1.574 TO 0

 CLASS     LIMITS            FREQUENCY

   1  -9.99 TO -1.44        0  I          I
   2  -1.44 TO -1.08        1  I*         I
   3  -1.08 TO -0.72        2  I**        I
   4  -0.72 TO -0.36        1  I*         I
   5  -0.36 TO  0.00        2  I**        I
   6   0.00 TO  0.36        2  I**        I
   7   0.36 TO  0.72        1  I*         I
   8   0.72 TO  1.08        1  I*         I
   9   1.08 TO  1.44        0  I          I
  10   1.44 TO  9.99        1  I*         I


PROJECTION OF WELL DATA ONTO OPTIMUM SEQUENCE AXIS

 WELL DEVIATION LEVEL PROJECTION

  1     -0.995    23.    9.252
  2     -0.247    25.    9.522
  3      0.341    21.    9.817
  4      0.931    25.    9.833
  5      0.016    19.    9.646
  6     -0.714    22.    9.512
  7     -1.171    14.    9.167
  9     -0.295    14.    9.748
 10      2.243    30.   10.218
 11      0.662    23.   10.047
 14     -0.772    19.    9.381
```

Variance Analysis
(in files *d.out and *f.out)

EVENT NO. 28 Apectodinium augustum

```
WELL DEVIATION     STRAT. HIGHER/LOWER THAN EXPECTED

 1     -0.120        I         *I          I
 2      0.329        I          I*         I
 3      0.202        I          I*         I
 4      0.691        I          I**        I
 5     -1.391        I      ****I          I
 6     -0.696        I        **I          I
 7     -0.378        I        **I          I
10      0.869        I          I***       I
14      0.403        I          I**        I

SAMPLE SIZE =    9         UNCORRECTED MEAN =    -0.010
ADJUSTED SD =   0.718      ADJUSTED SKEWNESS =   -0.810
```

```
HISTOGRAM AFTER CHANGING MEAN FROM -0.010 TO 0

CLASS     LIMITS            FREQUENCY

   1  -9.99 TO -1.44        0  I          I
   2  -1.44 TO -1.08        1  I*         I
   3  -1.08 TO -0.72        0  I          I
   4  -0.72 TO -0.36        2  I**        I
   5  -0.36 TO  0.00        1  I*         I
   6   0.00 TO  0.36        2  I**        I
   7   0.36 TO  0.72        2  I**        I
   8   0.72 TO  1.08        1  I*         I
   9   1.08 TO  1.44        0  I          I
  10   1.44 TO  9.99        0  I          I
```

PROJECTION OF WELL DATA ONTO OPTIMUM SEQUENCE AXIS

WELL	DEVIATION	LEVEL	PROJECTION
1	-0.110	26.	10.519
2	0.339	28.	10.701
3	0.212	23.	10.655
4	0.701	28.	10.787
5	-1.380	20.	10.037
6	-0.686	23.	10.124
7	-0.368	17.	10.406
10	0.879	32.	10.840
14	0.413	22.	10.753

Variance Analysis
(in files *d.out and *f.out)

```
 EVENT NO.   76  Reticulophragmium paupera

 WELL DEVIATION     STRAT. HIGHER/LOWER THAN EXPECTED

  1     -1.073        I       ***I          I
  2     -0.763        I       ***I          I
  3     -0.800        I       ***I          I
  4      0.005        I          I*         I
  5     -1.631        I     *****I          I
  6      1.078        I          I****      I
  9     -1.027        I       ***I          I
 10     -0.838        I       ***I          I
 11      0.075        I          I*         I
 13      0.759        I          I***       I
 14     -0.445        I        **I          I

 SAMPLE SIZE =   11         UNCORRECTED MEAN =    -0.424
 ADJUSTED SD =   0.822      ADJUSTED SKEWNESS =    0.621


 HISTOGRAM AFTER CHANGING MEAN FROM -0.424 TO 0

 CLASS     LIMITS            FREQUENCY

   1  -9.99 TO -1.44        0  I          I
   2  -1.44 TO -1.08        1  I*         I
   3  -1.08 TO -0.72        0  I          I
   4  -0.72 TO -0.36        4  I****      I
   5  -0.36 TO  0.00        2  I**        I
   6   0.00 TO  0.36        0  I          I
   7   0.36 TO  0.72        2  I**        I
   8   0.72 TO  1.08        0  I          I
   9   1.08 TO  1.44        1  I*         I
  10   1.44 TO  9.99        1  I*         I


PROJECTION OF WELL DATA ONTO OPTIMUM SEQUENCE AXIS

 WELL DEVIATION LEVEL PROJECTION

  1     -0.650    27.   10.945
  2     -0.339    29.   11.099
  3     -0.376    24.   11.072
  4      0.429    30.   11.406
  5     -1.208    22.   10.800
  6      1.502    26.   12.198
  9     -0.603    16.   10.856
 10     -0.415    33.   11.147
 11      0.499    26.   11.439
 13      1.183    17.   12.206
 14     -0.021    23.   11.204
```

Variance Analysis
(in files *d.out and *f.out)

```
 EVENT NO.  118  Palaeoperidinium pyrophorum

 WELL DEVIATION     STRAT. HIGHER/LOWER THAN EXPECTED

  2     -2.440        I   *******I          I
  3     -2.426        I   *******I          I
  4     -1.016        I       ***I          I
  6      0.122        I          I*         I
  7     -0.201        I         *I          I
 13      0.373        I          I**        I

 SAMPLE SIZE =    6         UNCORRECTED MEAN =    -0.931
 ADJUSTED SD =   1.254      ADJUSTED SKEWNESS =   -0.456


 HISTOGRAM AFTER CHANGING MEAN FROM -0.931 TO 0

 CLASS     LIMITS            FREQUENCY

   1  -9.99 TO -1.44        2  I**        I
   2  -1.44 TO -1.08        0  I          I
   3  -1.08 TO -0.72        0  I          I
   4  -0.72 TO -0.36        0  I          I
   5  -0.36 TO  0.00        1  I*         I
   6   0.00 TO  0.36        0  I          I
   7   0.36 TO  0.72        0  I          I
   8   0.72 TO  1.08        2  I**        I
   9   1.08 TO  1.44        1  I*         I
  10   1.44 TO  9.99        0  I          I


PROJECTION OF WELL DATA ONTO OPTIMUM SEQUENCE AXIS

 WELL DEVIATION LEVEL PROJECTION

  2     -1.509    31.   11.902
  3     -1.494    26.   11.901
  4     -0.084    34.   12.602
  6      1.053    27.   13.000
  7      0.730    22.   12.791
 13      1.304    18.   13.325
```

SUMMARY OF EVENT VARIANCE ANALYSIS RESULTS
(in files *d.out and *f.out)

Optimum Sequence	N	MEAN	SD	SKEWNESS
Elphidium spp.	9	0.802	0.604	1.348
Cassidulina teretis	12	1.164	0.981	0.776
Cibicidoides scaldisensis	7	0.840	1.134	0.318
Neogloboquadrina pachyderma	10	0.949	1.093	-0.472
Buccella frigida	6	-0.148	1.336	0.656
Trifarina fluens	7	0.183	1.459	-0.674
Cibicidoides grossa	9	0.278	0.565	-0.186
Globorotalia inflata	8	-0.388	0.724	0.042
Sigmoilopsis schlumbergeri	12	-0.383	1.037	0.304
Neogloboquadrina atlantica	11	-0.468	0.598	-0.059
Hystrichosphaeropsis obscura	6	-0.959	1.539	-0.347
Diatoms/radiolarians LCO	8	-1.021	1.402	0.104
Martinotiella cylindrica	8	-1.078	1.383	0.327
Globigerina praebulloides	11	-1.044	1.536	-0.516
Cannosphaeropsis utinensis	7	-1.509	1.425	-0.733
G. ex.gr. praescitula zealandica	7	-1.182	0.579	-0.315
Asterigerina gurichi	7	-0.965	2.055	-0.656
Deflandrea phosphoritica	7	-0.473	1.250	-0.106
Coarse agglutinated spp.	11	-0.583	1.991	0.919
Turrilina alsatica	8	-0.516	1.841	-1.052
Areoligera semicirculata	9	-0.570	1.824	-0.749
Cyclammina placenta	10	-1.160	3.013	0.389
Wetzelliella symmetrica	7	-0.355	1.824	-1.643
Spirosigmoilinella compressa	9	-0.721	1.450	-0.550
Aschemonella grandis	6	-0.661	1.945	-0.412
Adercotryma agterbergi	8	-1.030	0.845	0.009
Glomospirella biedae	6	-0.969	2.355	-0.263
Haplophragmoides walteri	11	0.168	3.025	0.061
Dorothia seigliei	9	0.014	2.853	0.202
Areosphaeridium diktyoplokus	8	0.257	1.620	-1.142
Reticulophragmium amplectens	11	0.660	2.123	-0.159
Ammosphaeroidina pseudopauciloculata	8	0.400	1.377	-0.336
Recurvoides ex.gr. walteri	6	0.602	1.960	0.165
Rottnestia borussica	6	0.423	2.089	0.175
Spiroplectammina spectabilis LO	11	1.000	2.321	-0.525
Ammomarginulina aubertae	7	1.153	2.508	-1.497
Diphyes ficusoides	6	0.636	1.536	-0.248
Haplophragmoides kirki	9	0.782	2.236	0.480
Reticulophragmium intermedia	6	1.745	2.157	0.513
Eatonicysta ursulae	9	1.757	1.805	-0.352
Recurvoidella lamella	7	1.255	1.311	-0.097
Spiroplectammina navarroana	11	1.791	2.346	-1.481
Subbotina patagonica	11	1.574	1.003	-1.086
Deflandrea oebisfeldensis	9	0.894	1.067	1.022
Coscinodiscus spp.	9	0.424	0.615	1.255
Apectodinium augustum	9	-0.010	0.718	0.810
Reticulophragmium paupera	11	-0.424	0.822	-0.621
Rzehakina minima	6	-0.184	1.877	-2.262
Reticulophragmium garcilassoi	6	-0.406	1.368	-1.092
Spiroplectammina spectabilis LCO	11	-0.749	1.287	1.104
Alisocysta margarita	6	-0.487	0.812	-1.580
Saccammina placenta	8	-0.759	0.878	0.102
Trochammina ruthven murrayi	7	-0.679	0.814	0.641
Hormosina excelsa	6	-1.339	1.897	-0.520
Palaeoperidinium pyrophorum	6	-0.931	1.254	0.456

AVERAGE STANDARD DEVIATION FROM LINE OF CORRELATION = 1.7960

ESTIMATION OF EVENT RANGES
(in files *d.out and *f.out)

		OPTIMUM SEQUENCE	LOWEST	AVERAGE	HIGHEST
1	77	Elphidium spp.	1.016	0.000	-0.231
2	228	Cassidulina teretis	1.237	0.024	-0.356
3	31	Cibicidoides scaldisensis	1.244	0.269	-0.255
4	1	Neogloboquadrina pachyderma	1.648	0.345	0.246
5	171	Buccella frigida	1.458	0.954	0.072
6	316	Trifarina fluens	2.267	1.011	0.239
7	270	Cibicidoides grossa	1.556	1.045	0.686
8	4	Globorotalia inflata	2.010	1.749	1.147
9	23	Sigmoilopsis schlumbergeri	2.974	1.853	0.951
10	269	Neogloboquadrina atlantica	2.717	2.480	1.237
11	363	Hystrichosphaeropsis obscura	4.142	3.531	2.223
12	91	Diatoms/radiolarians LCO	3.851	3.565	2.427
13	219	Martinotiella cylindrica	4.068	3.767	1.967
14	15	Globigerina praebulloides	4.567	3.802	2.562
15	362	Cannosphaeropsis utinensis	4.571	4.012	2.755
16	236	G. ex.gr. praescitula zealandica	4.211	4.316	2.736
17	17	Asterigerina gurichi	6.646	4.564	3.054
18	3	Deflandrea phosphoritica	5.428	4.861	4.005
19	25	Coarse agglutinated spp.	7.472	5.354	3.489
20	24	Turrilina alsatica	6.791	5.370	4.335
21	7	Areoligera semicirculata	6.304	5.385	4.211
22	97	Cyclammina placenta	6.632	5.433	3.123
23	41	Wetzelliella symmetrica	6.643	5.496	4.652
24	182	Spirosigmoilinella compressa	6.486	5.726	4.457
25	324	Aschemonella grandis	7.257	6.100	4.920
26	289	Adercotryma agterbergi	6.215	6.127	5.092
27	198	Glomospirella biedae	7.100	6.266	4.920
28	261	Haplophragmoides walteri	8.580	6.606	4.920
29	321	Dorothia seigliei	8.548	6.675	4.821
30	12	Areosphaeridium diktyoplokus	7.976	6.806	6.301
31	29	Reticulophragmium amplectens	9.567	6.866	5.976
32	32	Ammosphaeroidina pseudopauciloculata	7.998	6.881	6.325
33	229	Recurvoides ex.gr. walteri	8.415	6.986	5.858
34	72	Rottnestia borussica	8.303	7.207	6.301
35	68	Spiroplectammina spectabilis LO	9.270	7.541	6.632
36	263	Ammomarginulina aubertae	9.980	7.628	7.232
37	92	Diphyes ficusoides	8.749	7.642	7.171
38	260	Haplophragmoides kirki	9.512	7.878	6.678
39	175	Reticulophragmium intermedia	9.588	8.247	7.668
40	99	Eatonicysta ursulae	9.913	8.382	8.029
41	279	Recurvoidella lamella	9.748	8.542	8.367
42	54	Spiroplectammina navarroana	11.098	8.601	7.986
43	50	Subbotina patagonica	10.218	9.008	9.167
44	108	Deflandrea oebisfeldensis	10.305	9.510	8.331
45	22	Coscinodiscus spp.	10.511	10.090	9.228
46	28	Apectodinium augustum	10.840	10.570	10.037
47	76	Reticulophragmium paupera	12.206	11.404	10.800
48	105	Rzehakina minima	13.337	11.501	10.856
49	283	Reticulophragmium garcilassoi	12.309	11.564	10.846
50	57	Spiroplectammina spectabilis LCO	12.272	11.691	10.168
51	114	Alisocysta margarita	12.233	11.790	11.157
52	310	Saccammina placenta	12.097	11.898	10.931
53	129	Trochammina ruthven murrayi	12.309	12.260	10.771
54	134	Hormosina excelsa	14.531	12.376	11.147
55	118	Palaeoperidinium pyrophorum	13.325	12.899	11.901

RANGE IS THE OBSERVED STRATIGRAPHIC SPREAD OF AN EVENT OVER ALL WELLS,
PROJECTED ALONG THE OPTIMUM SEQUENCE AXIS.

GRAPHICAL REPRESENTATION OF EVENT RANGES: M = RASC DISTANCE
(in files *d.out and *f.out)

```
         16.71          11.63           6.55           1.46          -3.62
           +              +              +              +              +
   1   77                                                ---M-
   2  228                                                ---M-
   3   31                                                ---M-
   4    1                                              ----M-
   5  171                                               --M--
   6  316                                             ---M---
   7  270                                               -M-
   8    4                                             -M--
   9   23                                           ---M---
  10  269                                           -M----
  11  363                                       --M----
  12   91                                        -M---
  13  219                                       -M------
  14   15                                      --M----
  15  362                                      -M----
  16  236                                       M----
  17   17                                ------M----
  18    3                                   --M---
  19   25                             -------M-----
  20   24                               ----M----
  21    7                                 --M----
  22   97                                ---M-------
  23   41                                ---M---
  24  182                                --M----
  25  324                              ---M----
  26  289                                 M---
  27  198                              ---M----
  28  261                          ------M-----
  29  321                          ------M-----
  30   12                            ---M--
  31   29                       --------M---
  32   32                            ---M--
  33  229                          -----M---
  34   72                           ---M---
  35   68                        -----M---
  36  263                      -------M-
  37   92                          ---M-
  38  260                       -----M----
  39  175                       ----M--
  40   99                      -----M-
  41  279                       ---M-
  42   54                   -------M--
  43   50                     ----M
  44  108                     --M----
  45   22                    --M--
  46   28                   -M--
  47   76               ---M-
  48  105            -----M--
  49  283               --M--
  50   57               --M----
  51  114               --M-
  52  310                M---
  53  129               M-----
  54  134        -------M---
  55  118            -M---
           +              +              +              +              +
         16.71          11.63           6.55           1.46          -3.62
```

95% confidence intervals for the observed events and for the estimated average locations of the optimum sequence events in well 22/6-1 (CASC result in file 14cenj.out)

Shell (UK) 22/6-1

		PROB DEPTH	MIN DEPTH	MAX DEPTH	OBS DEPTH	MIN OBS	MAX OBS
4	Globorotalia inflata	1014.	974.	1085.			
23	Sigmoilopsis schlumbergeri	1108.	996.	1217.	1109.	845.	1367.
269	Neogloboquadrina atlantica	1197.	1140.	1247.			
91	Diatoms/radiolarians LCO	1269.	1163.	1341.	1265.	990.	1399.
15	Globigerina praebulloides	1324.	1240.	1369.	1384.	985.	1405.
363	Hystrichosphaeropsis obscura	1360.	1292.	1382.			
362	Cannosphaeropsis utinensis	1376.	1353.	1388.			
219	Martinotiella cylindrica	1385.	1372.	1399.			
236	G. ex.gr. praescitula zealandica	1396.	1387.	1402.	1384.	1351.	1440.
17	Asterigerina gurichi	1403.	1389.	1417.	1356.	1234.	1521.
24	Turrilina alsatica	1407.	1395.	1473.	1801.	1187.	1712.
3	Deflandrea phosphoritica	1427.	1407.	1466.			
7	Areoligera semicirculata	1469.	1406.	1532.			
41	Wetzelliella symmetrica	1510.	1424.	1528.			
97	Cyclammina placenta	1530.	1467.	1675.	1402.	1321.	1861.
289	Adercotryma agterbergi	1559.	1522.	1654.	1532.	1528.	1801.
198	Glomospirella biedae	1666.	1525.	1801.	1503.	1400.	1883.
321	Dorothia seigliei	1801.	1662.	1849.	1859.	1409.	2053.
29	Reticulophragmium amplectens	1812.	1798.	1850.			
32	Ammosphaeroidina pseudopauciloculata	1830.	1804.	1855.	1759.	1580.	1918.
12	Areosphaeridium diktyoplokus	1848.	1818.	1860.			
229	Recurvoides ex.gr. walteri	1858.	1826.	1867.	1548.	1548.	2113.
263	Ammomarginulina aubertae	1860.	1828.	1927.	1937.	1533.	2254.
72	Rottnestia borussica	1864.	1859.	1916.			
68	Spiroplectammina spectabilis LO	1886.	1860.	1963.	2015.	1791.	2166.
92	Diphyes ficusoides	1921.	1874.	1967.			
260	Haplophragmoides kirki	1954.	1874.	2062.			
175	Reticulophragmium intermedia	1987.	1927.	2086.			
99	Eatonicysta ursulae	2035.	1965.	2120.			
54	Spiroplectammina navarroana	2093.	1971.	2126.	2124.	1848.	2325.
108	Deflandrea oebisfeldensis	2133.	2128.	2203.			
22	Coscinodiscus spp.	2182.	2132.	2250.	2263.	2123.	2318.
28	Apectodinium augustum	2248.	2183.	2293.			
105	Rzehakina minima	2294.	2127.	2325.			
76	Reticulophragmium paupera	2315.	2293.	2323.	2326.	2206.	2326.
283	Reticulophragmium garcilassoi	2323.	2284.	2326.			
57	Spiroplectammina spectabilis LCO	2325.	2311.	2327.	2328.	2178.	2329.
114	Alisocysta margarita	2326.	2323.	2328.			
310	Saccammina placenta	2327.	2325.	2329.	2320.	2317.	2328.
129	Trochammina ruthven murrayi	2328.	2326.	2329.			

Correspondence analysis (Program COR; see file 14cenk.out) on 6 successive events in the RASC optimum sequence using presences of events (not absences) and rank-constraint; wells are arranged approximately from south to north, showing that event distribution may have a weak geographic component.

RANK-CONSTRAINED SOLUTION: PRESENCES ONLY

WELL	#	NAME	SCORE
1	9	BP (UK) 15/20-2	2.333
2	12	Amoco (N) 2/8-1	2.333
3	11	Shell (UK) 22/6-1	2.667
4	5	Esso (N) 16/1-1	3.000
5	10	Saga (N) 2/2-4	3.250
6	2	Statoil (N) 6407/4-1	3.500
7	14	Saga (N) 6406/2-1	4.000
8	4	Hydro (N) 34/8-1	4.000
9	13	Saga (N) 35/3-1	4.000
10	3	Elf Aquitaine (N) 6406/8-1	4.333
11	1	Saga (N) 6407/2-3	4.500
12	6	Saga (N) 34/4-5	4.500
13	7	Hydro (N) 6407/7-1	4.500

INTERVAL ZONE OCCURRENCE TABLE

NUMBER		EVENT NAME	WELL NUMBER 9	12	11	5	10	2	14	4	13	3	1	6	7
16	236	G. ex.gr. praescitula zealandica	X	X	X	X	X	X	X						
17	17	Asterigerina gurichi	X	X	X	X	X			X	X				
18	3	Deflandrea phosphoritica						X		X	X	X	X	X	X
19	25	Coarse agglutinated spp.	X	X		X	X	X		X	X	X	X	X	X
20	24	Turrilina alsatica			X	X			X	X	X		X	X	X
21	7	Areoligera semicirculata					X	X	X	X	X	X	X	X	X

Acknowledgements

Since 1981, RASC has been presented at numerous international shortcourses and workshops. Application of RASC has been to a wide variety of microfossils, including dinoflagellate cysts, pollen/spores, radiolarians, diatoms, benthic and planktonic foraminifers and also physical log markers, inserted in zonations. A majority of applications is with well data sets from industry and from scientific ocean drilling. Published literature on and with the method is extensive.

Applications of RASC in industry generally are not made public. Over the last 15 years RASC amongst others was used in research or operational centres of BP (UK), British Gas (UK), Shell (Canada and Norway), Marathon (USA), Unocal (USA), Petrobras (Brasil), Norsk Hydro (Norway), Saga (Norway), Instituto Colombiano del Petroleo (Columbia), ARCO (USA), and the National Oil and Gas Commission (India). Data sets cover the stratigraphic distribution of a wide variety of fossil groups in frontier basins from Thailand, Yemen, Columbia, Gulf Coast, Alaska, Grand Banks, North Sea and Norwegian Sea.

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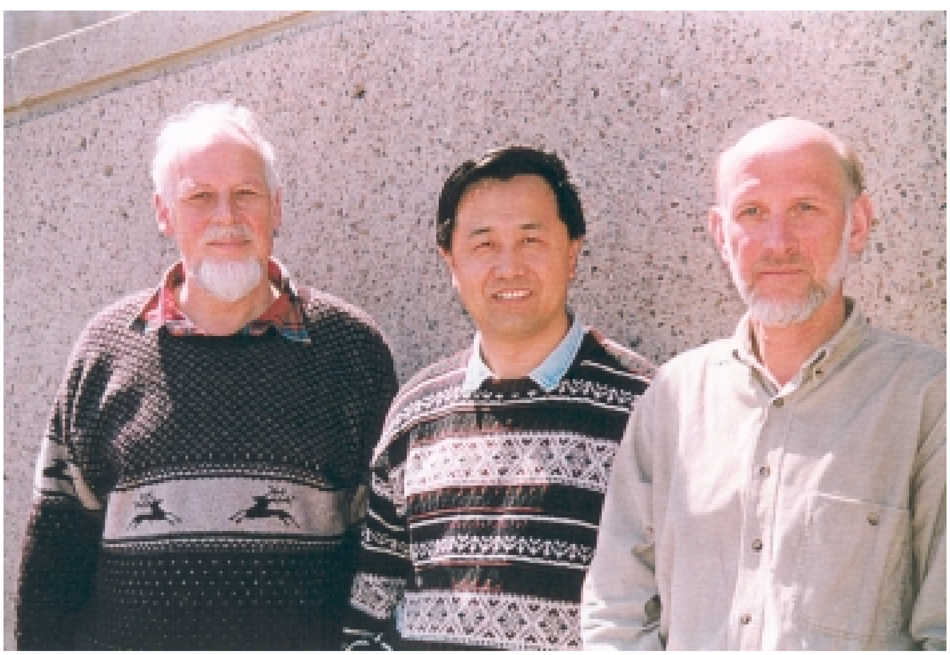

From left to right: Frits Agterberg, Quiming Cheng and Felix Gradstein.

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