10. SYSTEM OF INTERACTIVE COMPUTER PROGRAMS FOR QUANTITATIVE STRATIGRAPHIC CORRELATION

Project 690038

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Abstract

A new system of interactive computer programs expands the use of the RASC (Ranking and Scaling) (bio)stratigraphy of exploratory wells or sections. The objective of this system is to achieve quantitative stratigraphic correlation and to aid in tracing the depositional history of sedimentary basins.

Introduction

During the past five years we have developed several statistical models for the ranking and scaling of biostratigraphic events. This work was largely performed under the auspices of Project 148 (Quantitative Stratigraphic Correlation Techniques) of the International Geological Correlation Project, which will be completed in 1983.

The resulting computer algorithms (1) rank fossil events in wells or outcrop sections to arrive at the average sequence in time, (2) scale the average sequence along a relative time scale, (3) test the stratigraphic-normality of the individual (well) sequences, and (4) allow participation of rare index fossil events or of a marker horizon occurrence in the scaled sequence. The program also prints the fossil name dictionary and a regional occurrence table of the events.

The new program has been used to erect the Cenozoic foraminiferal stratigraphy of the Canadian Atlantic Margin (Gradstein and Agterberg, 1982) and to establish a quantitative range chart for Cretaceous nannofossils in the same region (Doeven et al., 1982).

The algorithms for the RASC computer program for RAnking and SCaling were written in FORTRAN IV (Agterberg and Nel, 1982a, b). Recently, M. Heller Consultants, Halifax, N.S. have edited the RASC program for release on tape and has prepared a detailed Syllabus.

Early in 1982, a 3-year project was commenced with the objective to develop a new system of interactive computer programs. This project will attempt to achieve quantitative stratigraphic correlation of sections using the RASC biozonations and will also perform geohistory analysis in the sense of Van Hinte (1978; see also Gradstein and Srivastava, 1980).

The present contribution describes initial methodology and results. Assistance in programming by Jacqueline Oliver is gratefully acknowledged.

Spline-Fitting of RASC Results

Table 10.1 contains the "distances" from origin (at the top of the composite section) for highest occurrences (disappearance events) of microfossils as estimated using RASC in 18 wells on the Labrador Shelf and Grand Banks off Newfoundland. In this paper the standard of Table 10.1 will be applied to 5 wells on the Labrador Shelf only (Fig. 10.1). These relative distances between successive events in Table 10.1 were estimated from cross-over frequencies between the events. For example, if the difference between the successive events A and B is nearly zero, this probably means that the cross-over frequency is about 50 per cent.

Table 10.1

RASC distances estimated for highest occurrences of microfossils occurring in 18 wells, Labrador Shelf and northern Grand Banks

Fossil Name	Event Code	RASC Distance	Successive Difference	Cluster Code
Elphidium sp	77	0.0000	0.0000	1
Cassidulina teretis	228	0.0000	0.1795	1
Uvigerina canariensis	10	0.1759	0.1838	1
Coscinodiscus spl	65	0.3633	0.1215	1
Asterigerina gurichi	17	0.4848	0.5405	1
Ceratobulimina contraria	16	1.0253	0.0245	2
Coscinodiscus spp	22	1.0498	0.1788	2
Scaphopod spl	67	1.2286	0.3874	2
Spiroplectammina carinata	18	1.6160	0.0511	3
Epistomina elegans	71	1.6672	0.1592	3
Guttulina problema	21	1.8264	0.1382	3
Gyroidina girardana	20	1.9646	0.2301	3
Globigerina praebulloides	15	2.1946	0.1037	3
Uvigerina dumblei	26	2.2983	0.3424	3
Alabamina wolterstorffi	70	2.6407	0.1216	4
Turrilina alsatica	24	2.7623	0.2160	4
Coarse arenaceous spp	25	2.9783	0.1883	4
Eponides umbonatus	27	3.1666	0.2490	4
Globigerina venezuelana	81	3.4156	0.2569	4
Globigeriná linaperta	82	3.6725	0.0260	5
Pteropod spl	31	3.6985	0.0918	5
Turborotalia pomeroli	33	3.7903	0.0219	5
Nodosaria sp8	69	3.8122	0.3061	5
Cyclammina amplectens	29	4.1183	0.1289	5
Pseudohastigerina micra	85	4.2472	0.0289	5
Marginulina decorata	34	4.2761	0.0153	5
Bulimina alazanensis	40	4.2914	0.2141	5
Epistomina sp5	118	4.5050	0.1603	5
Plectofrondicularia spl	41	4.6659	0.2133	
Cibicidoides blanpiedi	30	4.8792	0.1418	6
Quadrimorphinella incauta	32	5.0209	0.0705	6
Cibicidoides alleni	42	5.0914	0.0517	6
Spiroplectammina dentata	35	5.1431	0.1303	6
Turrilina brevispira	86	5.2734	0.0625	6
Uvigerina batjesi	53	5.3359	0.0465	6
Osangularia expansa	49	5.3824	0.3780	6
Acarinina densa	90	5.7603	0.0247	6
Bulimina midwayensis	43	5.7850	0.0792	6
Pseudohastigerina wilcoxensis	36	5.8642	0.0899	6
Spiroplectammina spectabilis	57	5.9541	0.0047	6
Bulimina trigonalis	45	5.9587	0.3116	6
Acarinina aff. broedermanni	93	6.2703	0.0010	7
Megaspore spi	46	6.2714	0.0655	7
Textularia plummerae	54	6.3368	0.4009	7
Subbotina patagonica	50	6.7377	0.3058	7
Acarinina soldadoensis	52	7.0435	0.5844	7
Glomospiria corona	56	7.6279	0.4045	
Gavelinella beccariformis	55	8.0324	0.2045	8
Rzehakina epigona	59	8.2369		8

Successive difference represents difference between successive RASC distances.

Clusters codes 1-8 were defined as in Gradstein and Agterberg (1982, Fig. 10.9 based on 16 wells) with 1) Pliocene-Pleistocene; 2) Late Miocene; 3) Early-Middle Miocene; 4) Oligocene; 5) (Late) Middle-Late Eocene; 6) (Early). Middle Eocene; 7) Early Eocene; 8) Paleocene.

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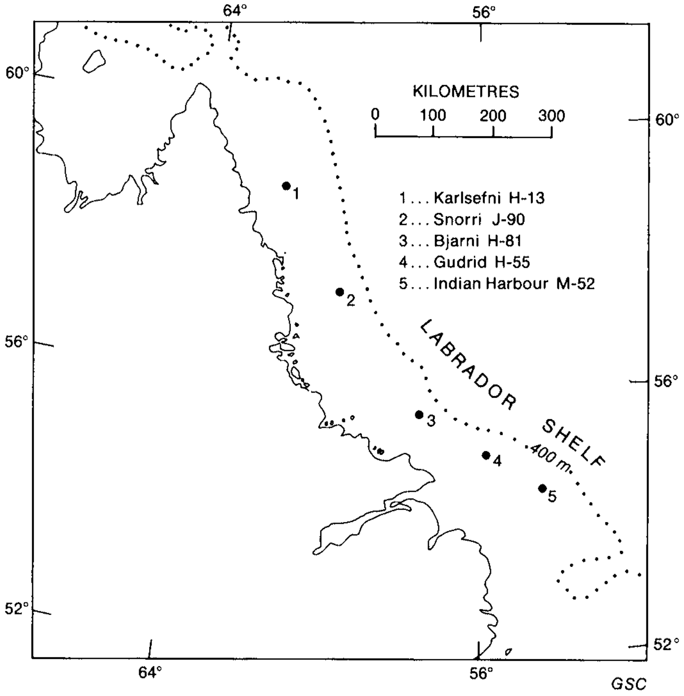


Figure 10.1. *Locations of 5 wells on Labrador Shelf used for examples in this paper.*

This situation arises if A and B are coeval in some wells, and if A is observed to occur about as many times above B as B above A in the wells used for comparison.

Clusters of events with distances which are close in value were defined on the basis of Table 10.1 and can be interpreted as biostratigraphic assemblage zones. these RASC zones can be used to compare and correlate individual wells and display sediment accumulation patterns as shown below.

One of the options of the RASC program is the so-called normality test. It consists of comparing individual well sequences of events with the standard which was computed from the cross-over frequencies for a number of sections in a larger region. Table 10.2 shows results of the normality test applied to the Karlsefni well (Fig. 10.1) in comparison with the standard shown in Table 10.1. The first column of Table 10.2 contains the codes (see Table 10.1 for fossil names) of the 24 Cenozoic microfossil events observed in Karlsefni. If an event is preceded by a hyphen, this indicates that it is coeval to the event situated immediately above it. The 24 events were observed on 16 stratigraphically successive levels down the well here numbered 1 to 16 (see column 2 of Table 10.2). The distances of all 24 events are shown in column 3. If the order of events in Karsefni were the same as that of the events in the standard (Table 10.1), the distance would never decrease in the downward direction. In reality, there is only a general increase in distance and locally events are out of place in comparison with the standard because of various types of uncertainties (Gradstein and Agterberg, 1982). Anomalous events can be identified. In the RASC output these are defined as events which are either too high or too low in a particular section with a probability of 95 or 99 per cent. Events 55 and 43 were identified as out of place in Karlsefni with a probability of 99 per cent and omitted from subsequent calculations. Distances of coeval events were averaged. The resulting unique distance values were related to their 16 stratigraphically successive levels in Karlsefni by using the spline-fitting program ICSSCU from the IMSL Library maintained by the Computer Science Centre of the Department of Energy, Mines and Resources.

The program ICSSCU is based on an algorithm originally written in ALGOL by Reinsch (1967). A FORTRAN version of this same algorithm has been published by De Boor (1978, p. 240-242). The input consists of N values X_i for the independent variable and corresponding values Y_i, $i = 1, ..., N$ for the dependent variable. These values have the property $X_i < X_{i+1}$, $i = 1, ..., N - 1$. Also part of the input is a set of values D_i which are estimates of the standard deviations $(Y_i - S_{ti})$ where S_{ti} represent the true (population) values of the dependent variable which are to be estimated. Another input parameter is SM representing the sum of squares of standardized residuals of Y_i. As a guideline, Reinsch (1967) suggested that SM should lie within $N \pm (2N)^{\frac{1}{2}}$ which represents a 68 per cent confidence interval. If the values of D_i are unknown they can all be set equal to 1.0 as was done in our applications. Then the parameter SM can be considered as a knob which can be regulated. It is desirable to work with a parameter which is independent of the sample size N. For this reason, we have defined a smoothing factor SF = SM/N. This parameter merely serves to rescale the residuals. Suppose that the values D_i were set equal to a constant C instead of 1.0, then SF/C^2 will yield identical estimates of S_{ti}. The latter estimates can be written as S_i. They are part of the output, as well as (N - 1) sets of 3 coefficients for the (N - 1) cubic polynomials fitted to the data. The fitted spline function has the properties that it is continuous everywhere (also at the "knots" X_i), and that its first and second derivative are also continuous everywhere. The latter two variables assume zero values at the points where $i = 1$ and $i = N$. In our applications, the first derivative can be interpreted as the inverse of the rate of sedimentation.

Table 10.2

Events observed in Karlsefni H-13 well
(No. 1 in Fig. 10.1) compared to standard in Table 10.1

Event Code	Level Number	RASC Distance	Cluster Code
228	1	0.0000	1
22	2	1.0498	2
67	3	1.2286	2
25	4	2.9783	4
41	5	4.6659	
-118	(4.5858)	4.5056	5
69	6	3.8122	5
29	7	4.1183	5
57	8	5.9541	7
53	9	5.3359	6
86	10	5.2734	6
-30	(4.5318)	4.8792	6
-31		3.6985	5
-34		4.2761	5
42	11	5.0914	6
-46	(5.6814)	6.2714	7
36	12	5.8642	6
50	13	6.7377	7
52	14	7.0435	7
45	15	5.9587	6
-54	(6.1478)	6.3368	7
55	16	(8.0324)	8
-43	(7.6279)	(5.7850)	6
-56		7.6279	

Hyphens in column 1 indicate coeval events for which RASC distances were averaged (see values in brackets in column 2).

The 16 pairs of values that remain after averaging and omitting two anomalies (see text) are plotted in Fig. 10.2.

Figure 10.2a shows the ordinary cubic spline function fit which is obtained for smoothing factor SF = 0. In this situation, the fitted curve passes exactly through the 16 distance values used as input. Figures 10.2b to 10.2e show fits for larger values of SF. The amount of smoothing increases as a function of SF until the best-fitting least-squares straight line is obtained for SF = 1, 2, and all greater values. This straight line forms the upper limit of smoothing. Figures 10.2a to 10.2e were redrawn from displays generated on the screen of a Tektronix 4014-1. Because the RASC scale is related to geologic time, distances should in reality never decrease in the down-well direction (event scale). A decrease would violate the law of superposition of sedimentary strata. The fact that the observed distances do show local downward decreases is due to various types of uncertainties.

The pattern of Figure 10.2d (SF = 0.4) might be selected for further work because it satisfies the condition of no down-well decrease. It is noted that Figure 10.2c represents a border-line situation with approximately no decrease. However, from levels 9 to 11, the fitted RASC curve remains constant in Figure 10.2c. This would represent an infinitely large rate of sedimentation which is physically impossible. Consequently, the pattern of Figure 10.2d can be considered as the more realistic one. Similar sequences of displays where generated for 4 other wells. Non-decreasing curves were obtained for SM = 0.04 (Snorri and Bjarni) and SM = 0.2 (Herjolf and Gudrid).

Specific values along the horizontal distance scale of Figure 10.2d for Karlsefni can be selected for correlation with other wells. Use of the values 1 to 7 resulted in the pattern of Figure 10.3. The event scale in Figure 10.3 is the same as the vertical scale in Figure 10.2. The levels 1 to 7 were plotted along the event scale at values corresponding to the values 1-7 along the horizontal (RASC distance) scale using the spline-curve of Figure 10.2d. These levels were connected between adjacent wells in Figure 10.3. Although a pattern of the type shown in Figure 10.3 may be useful as an intermediate step in an interactive session for the quantitative stratigraphic correlation of a number of wells, it cannot be readily interpreted from a stratigraphic point of view. For this reason, the following additional steps should also be performed.

Construction of Age-Depth Diagrams

In Figure 10.4, the RASC distance of Table 10.1 is related to the numerical time scale as follows. The approximate age in millions of years is known for a number of the biostratigraphic events used. These dates are shown as circles in Figure 10.4. Distances for the same age were averaged and a spline-function was fitted by means of the ICSSCU program with SM = 1.0. For this purpose, age was used as the dependent variable. The curve of Figure 10.4 served to replace all distances of Tables 10.1 and 10.2 by ages (in Ma).

Only the relative order of events in wells is used in the RASC computer program for constructing standards such as Table 10.1 because rates of sedimentation differed significantly from well to well during geologic time. However, for purposes of correlation, the actual depth of the biostratigraphic events should be employed instead of relative levels along the event scale. Figure 10.5 for Karlsefni is equivalent to Figure 10.2 with distance replaced by age along the horizontal scale, and relative level of events replaced by actual depth along the vertical scale. Spline-fits for SF = 0.4 and 40.0 are also shown. In this type of diagram, a hiatus would be represented by a horizontal line. The pattern for SF = 0.4 suggests the existence of a long hiatus at about 6700 ft. Although the curve for SF = 40 is non-decreasing with depth, this spline function is not sufficiently flexible to show discontinuation in the rate of sedimentation such as hiatuses. Similar displays (all for SM = 0.4) were generated for the other four wells (Fig. 10.5). The SM = 0.4 spline-curves were intersected by vertical lines for multiples of 10 Ma. (The SF = 40 curve in Figure 10.5a was used for 50 Ma only.) The corresponding depth values can then be used for correlation.

Figure 10.6 is equivalent to Figure 10.3 with the RASC distance replaced by absolute age for 6 levels, and using depth instead of relative events order in the vertical direction. This pattern readily displays the conclusion of Gradstein and Srivastava (1980) that a broad shelf regression occurred in the Oligocene (37.5-23 Ma) probably accentuated by eustatic sea-level lowering.

Figure 10.7 (from Gradstein and Srivastava) illustrates depositional history at the site of the Karlsefni well. Cumulative sediment accumulation is plotted relative to the paleoseafloor through time. It is noted that the accumulated thickness was assumed to remain constant at about 6700 ft during the Oligocene in Figure 10.7 and this is in agreement with the pattern of Figure 10.5.

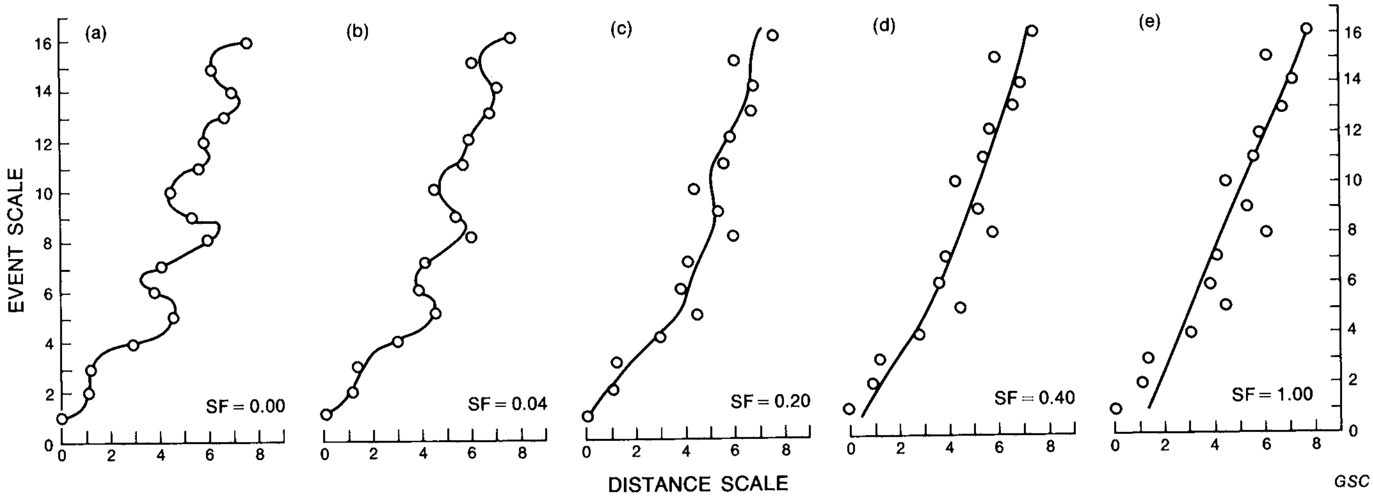


Figure 10.2. Succession of spline curves fitted to Karlsefni data of Table 10.2 using different smoothing factors (SF). Figure 10.2d was selected for correlation in Figure 10.3.

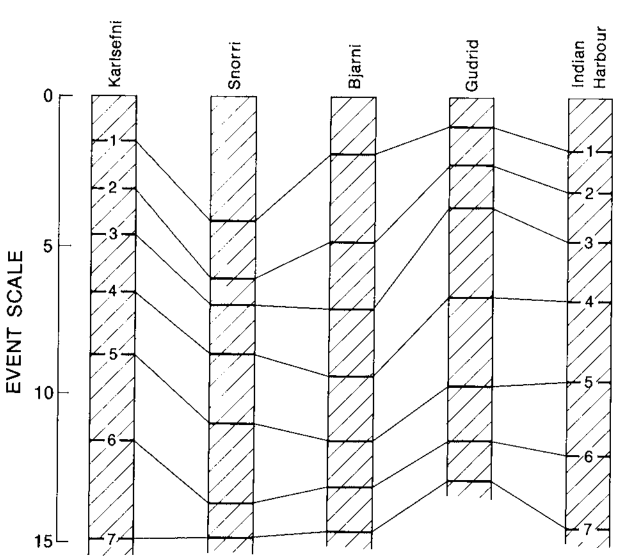


Figure 10.3. *Correlation of 5 wells shown in Figure 10.1. Levels 1-7 plotted along event scale represent RASC distances, e.g. those for Karlsefni were taken from Figure 10.2d.*

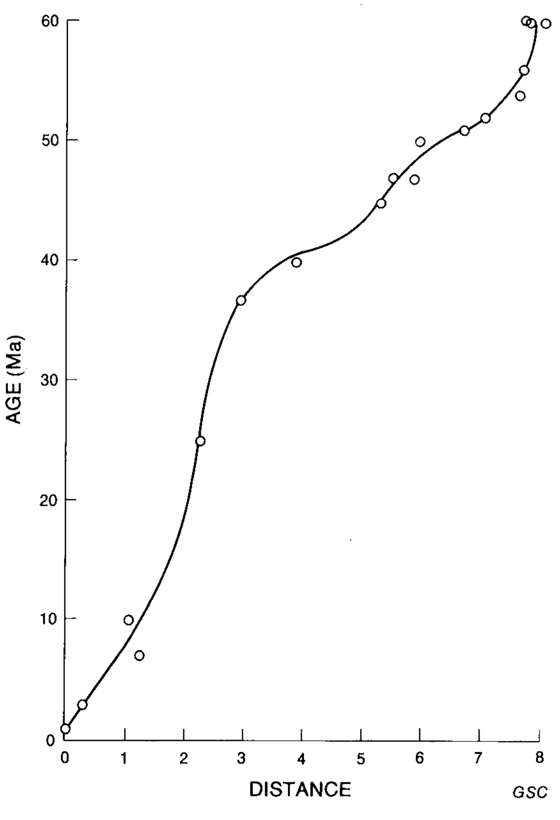


Figure 10.4. *Relation between age in Ma and RASC distance. Spline-curve with SF = 1.0 was fitted to crosses representing biostratigraphic events. Distances for events with same age were averaged.*

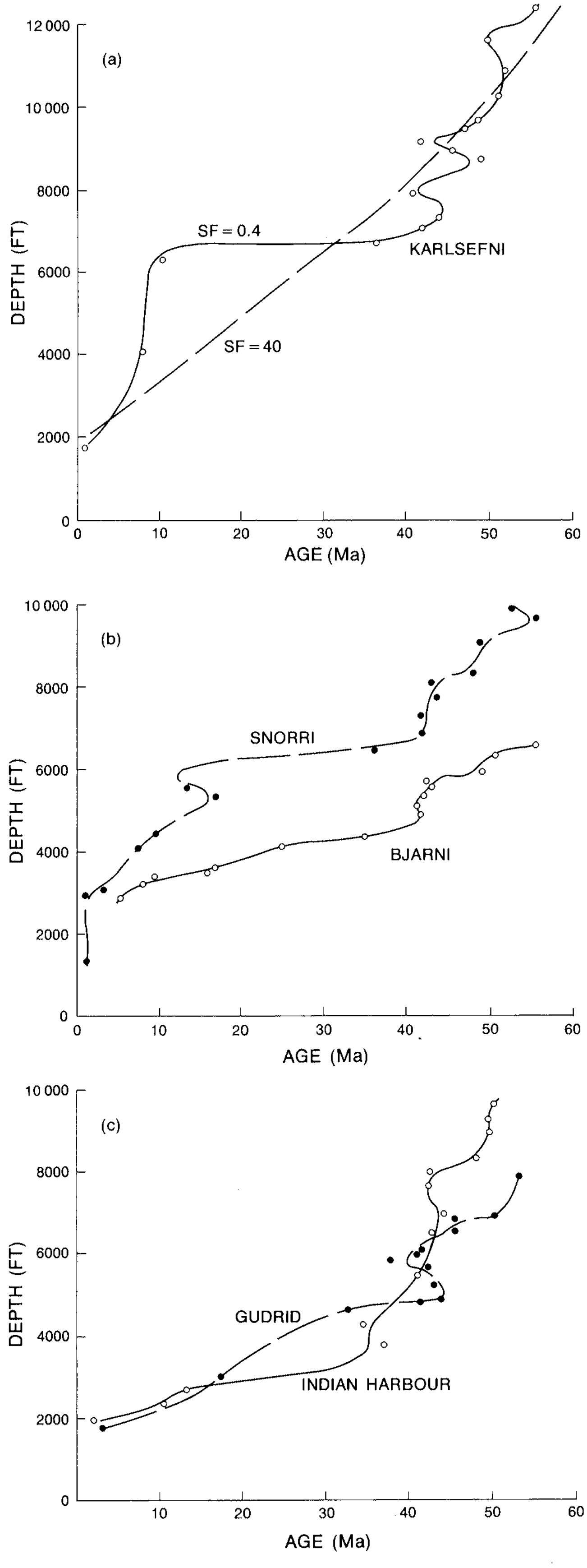


Figure 10.5. *Age-Depth diagrams of 5 wells. For Karlsefni, Figure 10.5a is equivalent to Figure 10.2 with replacement of horizontal distance scale by age (using relation shown in Fig. 10.4), and vertical event scale by depth.*

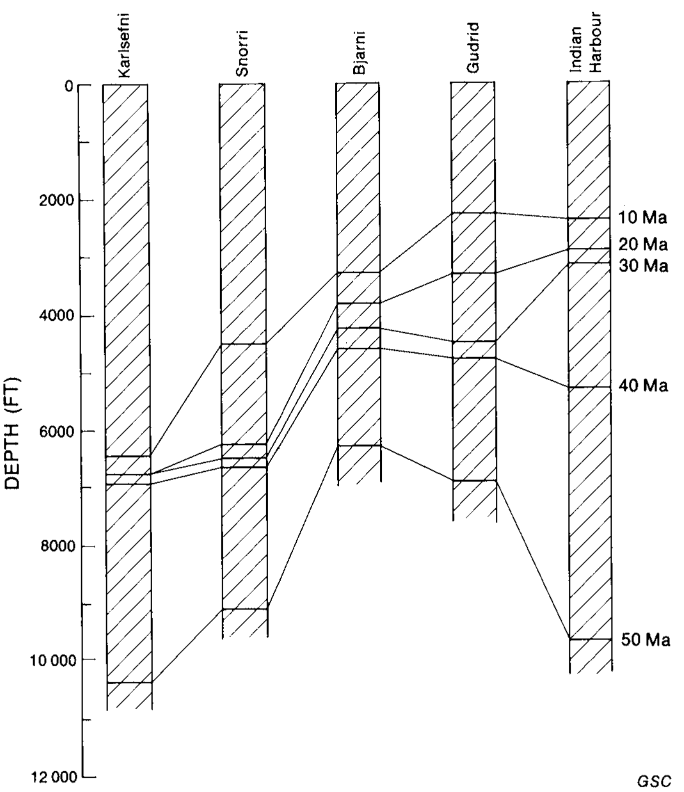
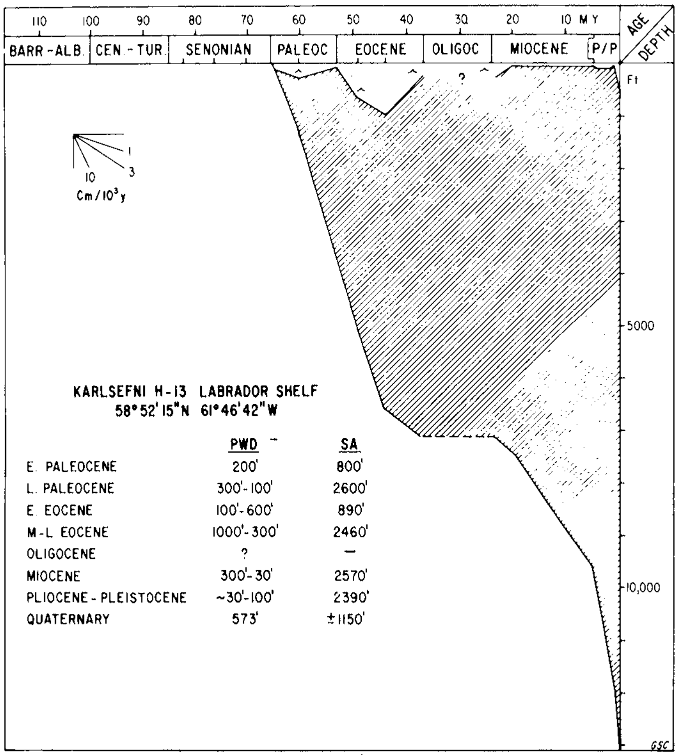


Figure 10.6. Correlation of 5 wells shown in Figure 10.1. Levels for multiples of 10 Ma were taken from Figure 10.5a to 10.5c.



KARLSEFNI H-13 LABRADOR SHELF
58°52'15"N 61°46'42"W

	PWD	SA
E. PALEOCENE	200'	800'
L. PALEOCENE	300'-100'	2600'
E. EOCENE	100'-600'	890'
M-L EOCENE	1000'-300'	2460'
OLIGOCENE	?	–
MIOCENE	300'-30'	2570'
PLIOCENE-PLEISTOCENE	~30'-100'	2390'
QUATERNARY	573'	±1150'

Figure 10.7. Cumulative sediment accumulation (SA) is plotted relative to paleoseafloor through time, as derived from paleowaterdepth (PWD) interpretations to illustrate subsidence and depositional history. Well site is Karlsefni H-13 (from Gradstein and Srivastava, 1980, Fig. 10.4d, p. 274). Note similarity with Fig. 10.5a if age scale is reversed.

Concluding Remarks

A system of interactive computer programs for quantitative stratigraphic correlation is under development. Upon completion this system should generate the types of displays shown as Figures 10.2 to 10.7 of this paper. The development and application of algorithms in addition to the subroutine ICSSCU for spline-fitting is being considered.

Additional factors including estimated paleoseafloor depth and compaction should be used to perform more refined geohistory analysis. For this purpose, information on lithology and actual depth of samples along the wells will have to become part of the input for the RASC computer program. Special attention should be paid to the problem of relating observed stratigraphic events and their average positions along the RASC distance scale to the numerical time scale in order to arrive at the best possible RASC biochronology.

By means of this interactive system, it should not only be possible to perform quantitative stratigraphic correlation and geohistory analysis but also to evaluate the propagation of errors due to uncertainties in the original data and the assumptions made.

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