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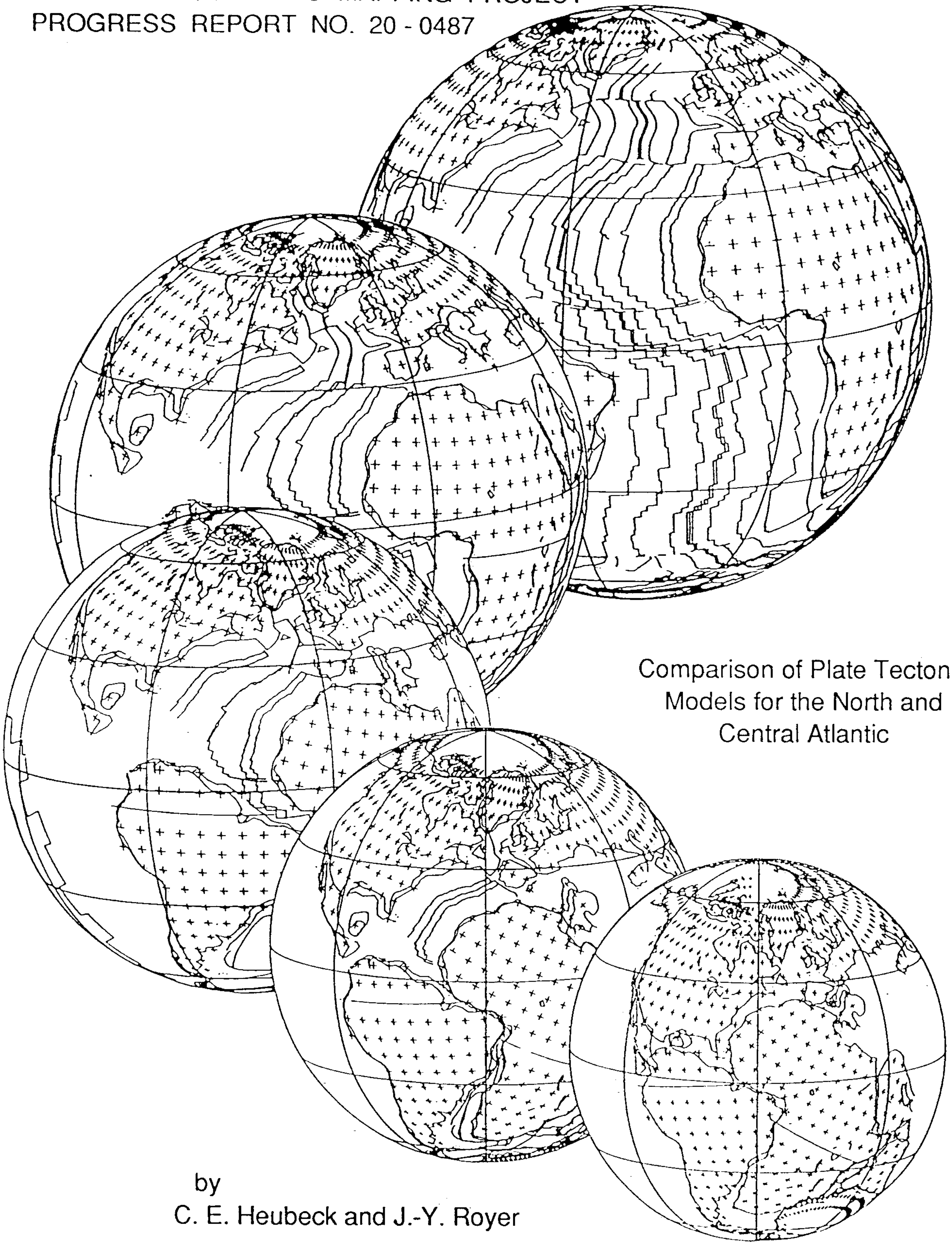

Comparison of Plate Tectonic Models for the North and Central Atlantic

by
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Introduction

Numerous models describing the tectonic evolution of the North and Central Atlantic Ocean have been proposed. However, it is often difficult to quickly evaluate how these models differ. In this study, we have modified a computer program, originally written by Philippe Patriat, that graphically displays spreading rates and spreading directions for any pair of plates.

Using this program we have analyzed the plate tectonic models proposed by Pitman and Talwani (1972), Sclater et al. (1977), Olivet et al. (1984), Savostin et al. (1986), Klitgord and Schouten (1986), and Srivastava and Tapscott (1986). In addition, we have included the unpublished models of Francheteau (1970), Phillips and Tapscott (1981), Molnar and Stork (1983), Rowley et al. (1985), Gahagan et al. (1987), and Müller (1987).

In order to produce the graphs illustrated in Figures 5-22, the user must supply 1) a list of finite rotations describing the fit of magnetic anomalies between any pair of plates, and 2) the latitude and longitude of one or several points along the spreading axis. The program then generates a list of stage poles and two graphs which illustrate the changes in spreading rate and direction at the specified locations. Sample input parameters are illustrated in Figure 1, and sample output is given in Figures 2 and 3.

This technique is useful because 1) it permits a quick comparison of different plate models and 2) allows us to look for patterns between ocean basins that may be evidence for global synchroneity in plate tectonic interactions (such as major plate reorganizations due to plate collision or due to the opening of ocean basins).

Method

The program requires the following input:

1. A file containing the following data on each line (Figure 1)
   - ID number of moving plate (in our study: Europe = 301, Africa = 701
   - time for which rate and direction of spreading is to be calculated (usually the age of a magnetic anomaly)
   - latitude, longitude, and angle of the pole of finite rotation for this time
   - ID number of reference plate (in our study: North America = 101)
   - anomaly number

   (- optional comment field)

2. The program permits the user to specify the location of up to five points (in latitude and longitude) on the plate boundary for which the rates and directions of relative movement will be calculated. In our study, two points on the spreading ridge were used. The user also must specify the plate ID for which the stage poles of motion and spreading directions should be calculated.

Conventions*:
- Plate ID's are three-digit numbers
- time is in Millions of years
- geographical coordinates are positive to the north and east, negative to the south and west.

- the angle of rotation is counted positive clockwise
- anomaly numbers are one-, two- or three-digit numbers

*All these conventions are standard features of the POMP datafiles.

Special care should be taken concerning the following points:
- The first line of the input file must be a dummy line with an arbitrary pole for the present-day situation (time = 0.0 and angle = 0.00).
- Time must be consecutive and increasing. Two lines with identical time data will cause a fatal "division by zero"- error. To obtain meaningful comparisons between alternative models, the time scale used in these models should be identical (Kent and Gradstein, 1986; Table 3).
- Anomaly numbers may not be identical, since a different age is associated to each anomaly number. We code the M-Anomalies adding 34 to their M-series number except for M0 which is coded as "35" and mark this change in the comment line (M4 = 38, M16 = 50, ...) .
- If the number of points on the ridge axis is zero, the graphical output will be blank, and the program will calculate stage poles only.

Using the input data, the program then calculates stage poles, azimuths and rates of spreading using several subroutines which were modified from Patriat (unpublished). Two menus offer selective calculations of specific stages as well as options to modify the graphical representation of the data. The results are stored in a data file (Figs. 3, 4) and a plot file will be produced if the graphics option is chosen.

Discussion

Plots of spreading rate and direction versus crustal age may be subject to several errors, all of which affect the input parameters (Vogt et al. 1982). These errors include: misidentification of magnetic anomalies, incorrect radiometric age dating, and non-symmetrical spreading.

Based on the idea that the spreading history of an ocean basin is likely to record an evolutionary, gradual process rather than a revolutionary development, we assume that the ideal graphs of spreading rate and spreading direction versus time will be smooth curves. Maxima, minima, and steep gradients may reflect: episodes of major worldwide plate reorganization, events at one of the ocean's margins (initiation of subduction, rifting or collisional events, the abandonment of a triple junction), or may be the result of a change in the configuration of the spreading ridge itself.

Extreme changes in the graph, however, are more likely to be an artifact of plate reconstruction. The nature of these changes can be tested by comparing models of different authors.

Ten models of the Central Atlantic (North America / Africa, Table 1) and nine models of the North Atlantic (North America / Europe, Table 2) were compared. This was done the following way.

- All the ages based on magnetic anomalies were standardized to the DNAG timescale (Table 3). Where authors had based ages on tectonic events such as rifting stages, their ages were used.

- We calculated spreading rates and directions at the following locations along the mid-Atlantic spreading ridge for all models. These were

	Latitude	Longitude
1) for the Central Atlantic:	Latitude	Longitude
	24.60	-46.20
	38.40	-30.60
2) for the North Atlantic:	Latitude	Longitude
	42.10	-29.20
	56.90	-34.00

The publication dates span 15 years and the increasing resolution of the models (Figure 5 -14, 15-23) reflects the acquisition of new data and the progressive refinement in the plate tectonic models.

Central Atlantic Comparisons

In the following section, the Central Atlantic models under discussion will be identified by the following code numbers:

(1) Francheteau, 1970 (Figure 5)
(2) Pitman and Talwani, 1972 (Figure 6)
(3) Sclater et al., 1977 (Figure 7)
(4) Molnar and Stork, 1983 (Figure 8)
(5) Olivet et al., 1984 (Figure 9)
(6) Rowley et al., 1987 (Figure 10)
(7) Savostin et al., 1986 (Figure 11)
(8) Klitgord and Schouten, 1986 (Figure 12)
(9) Gahagan et al., 1987 (Figure 13)
(10) Müller, 1987 (Figure 14)

In general, all the models are in good agreement with each other. It appears that in nearly all models southeasterly directed spreading during the Jurassic and Early Cretaceous (represented by a peak on the graph illustrating spreading direction) corresponds to a "low" in spreading rate, and that a more easterly direction of spreading during the Cretaceous/Tertiary (represented by a trough on the graph illustrating spreading directions) corresponds to a "high" in spreading rate. This means that E-W directed spreading was faster than NW-SE oriented spreading. The reason, however, for this is not clear.

Models 1, 2, 3 and 9 have too few control points to permit detailed comparison with the other models. Models 1-3 are from the early seventies. Model 9 is intended to be a test of the isochrons of Larson et al. (1985).

Models 4, 6, 8 and 10 are in good to very good agreement. This is partly due to the fact that they are based on essentially the same data. They also agree fairly well to models 5 and 7 (7 is a modification of 5).

In general, the most recent models (6, 7, 8, 10) have the fewest number of anomalous peaks and, we feel, are the best approximations of the actual spreading history.

North Atlantic Comparison

In the following section, the North Atlantic models under discussion will be identified by the following code numbers:

(11)	Francheteau, 1970	(Figure 15)
(12)	Pitman and Talwani, 1972	(Figure 16)
(13)	Sclater et al., 1977	(Figure 17)
(14)	Phillips and Tapscott, 1981	(Figure 18)
(15)	Molnar and Stork, 1983	(Figure 19)
(16)	Rowley et al., 1985	(Figure 20)
(17)	Savostin et al., 1986	(Figure 21)
(18)	Srivastava and Tapscott, 1986	(Figure 22)
(19)	Gahagan et al., 1987	(Figure 23)

The models 11, 12, 13, 14, 15, 16, and 18 are in general agreement. All show a discontinuity in spreading rate and spreading direction during the early Tertiary (50-60 Ma). However, the sharp discontinuity on model 14 points out more likely an error on one of the finite rotations involved. At anomaly 21 time (50 Ma), a steep decline in spreading rates is observed.

Spreading directions are commonly confined between 65 and 105 degrees from north (on the North American plate), without any major changes.

Study 19 (same as 9) does not show a good correlation with any of the other models. Study 11 is not detailed enough to permit meaningful comparisons. Study 17 surprisingly does not show the slow-down in spreading rates at 50 Ma, but rather records a fairly smooth decline in spreading rates from the beginning of the Tertiary to the present.

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001	0.00	0.50	0.50	0.00	002	0	hypothetical input
001	10.00	85.00	80.00	5.00	002	2	
001	20.00	80.00	80.00	10.00	002	3	
001	30.00	75.00	80.00	15.00	002	4	
001	40.00	70.00	80.00	20.00	002	5	
001	50.00	65.00	80.00	25.00	002	6	
001	60.00	60.00	80.00	30.00	002	7	
001	70.00	55.00	80.00	35.00	002	8	total opening

Fig. 1 - Input rotation file describing the movement of a hypothetical plate pair in the format required by the program. The pole of rotation moves progressively south along the meridian 80° E as the plates move apart.

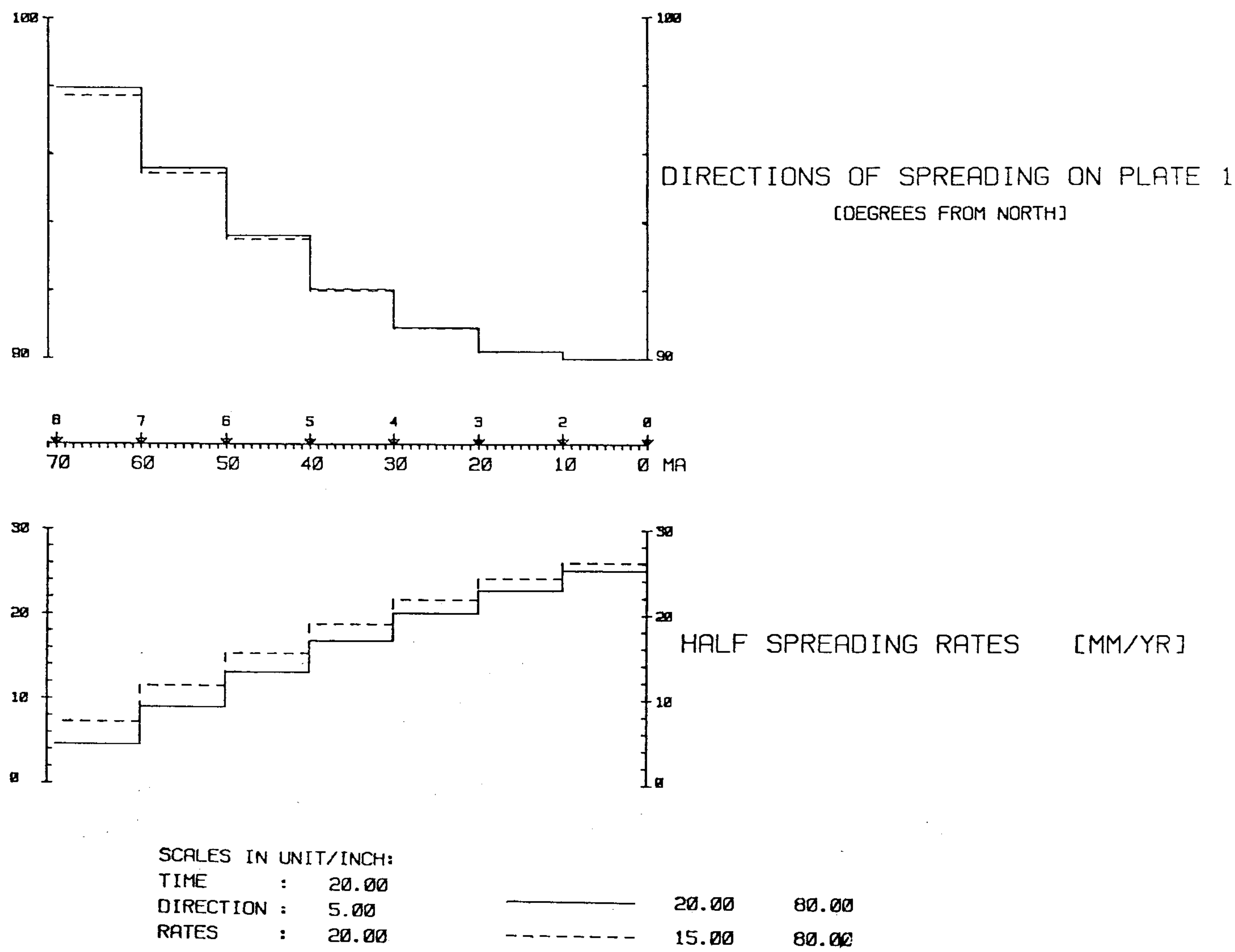


Fig. 2 - Output plot file illustrating the plate movements of Fig. 1.

Table 3 - DNAG timescale used in this study.

Anomaly number	Age (Ma)
1	.9
2	1.9
2a	3.2
3	4.8
3a	5.9
4	7.4
5	10.6
6	20.5
6b	23.0
7	26.0
8	27.7
9	29.2
10	30.3
11	32.1
12	32.9
13	35.9
14	
15	37.7
16	39.2
17	41.1
18	42.7
19	44.1
20	46.2
21	50.3
22	52.6
23	54.7
24	56.1
25	59.2
26	60.8
27	63.5
28	65.1
29	66.2
30	68.4
31	69.4
32	71.7
33y	74.3
33o	80.2
34	84.0

Anomaly number	Age (Ma)
0	118.7
1	122.3
2	123.0
3	125.4
4	126.5
5	127.1
6	127.3
7	128.0
8	128.6
9	129.4
10	130.2
11	133.5
12	135.6
13	137.1
14	138.3
15	139.6
16	141.9
17	143.8
18	144.8
19	146.4
20	148.3
21	149.9
22	152.2
23	154.2
24	155.5
25	156.6
26	158.0
27	158.4
28	158.9
29	160.3

MOB. plate: 1, REF. plate: 2

Data points where directions & rates of spreading are calculated :

2 20.00 60.00 15.00 80.00

Finite rotations :

0	0.00	0.50	0.50	0.00	HYPOTHETICAL INPUT
2	10.00	85.00	80.00	5.00	
3	20.00	80.00	80.00	10.00	
4	30.00	75.00	80.00	15.00	
5	40.00	70.00	80.00	20.00	
6	50.00	65.00	80.00	25.00	
7	60.00	60.00	80.00	30.00	
8	70.00	55.00	80.00	35.00	TOTAL OPENING

Stage poles for plate 1

A1	A2	T1	DT	Lat	Lon	Angle	Dist	V	Dir	Dist	V	Dir
0	2	0.00	10.00	85.0	80.0	5.00	65.	50.	90.	70.	52.	90.
2	3	10.00	10.00	75.1	78.3	5.04	55.	46.	90.	60.	49.	90.
3	4	20.00	10.00	65.2	77.0	5.11	45.	40.	91.	50.	44.	91.
4	5	30.00	10.00	55.7	75.6	5.22	36.	34.	92.	41.	38.	92.
5	6	40.00	10.00	46.4	74.2	5.36	26.	26.	94.	31.	31.	94.
6	7	50.00	10.00	37.5	72.7	5.53	17.	18.	96.	22.	23.	95.
7	8	60.00	10.00	28.9	71.1	5.73	8.	9.	98.	13.	15.	98.

Fig. 3 - Summary statistics for Figure 2, listing finite and stage poles and indicating rates and direction of movement.

A1, A2 = stage boundaries
T1 = age of A1
DT = age difference between A1 and A2
Lat, Long, Angle = position of the stage pole and its angle of opening
Dist = distance of the point from the stage pole in degrees
V = total rate of opening at the point in mm/yr
Dir = direction of movement of the point in degrees from north

MOB. plate: 101, REF. plate: 701

Data points where directions & rates of spreading are calculated :

2 37.40 -32.30 24.60 -46.20

Finite rotations :

0	0.00	79.07	77.94	0.00	
5	10.60	79.08	77.95	2.41	KLITGORD & SCHOUTEN 1986
6	20.50	79.57	37.84	5.29	DNAG
13	35.90	76.41	7.12	9.81	
21	50.30	74.51	-4.83	15.32	
25	59.20	80.60	-0.50	18.07	
30	68.40	82.51	-0.63	20.96	
32	71.70	81.35	-9.15	22.87	
33	74.30	80.76	-11.76	23.91	=33 YOUNG
33	80.20	78.30	-18.35	27.06	=33 OLD
34	84.00	76.55	-20.73	29.60	
35	91.00	73.82	-19.48	34.28	=CEN/TUR BOUNDARY
35	118.70	66.30	-19.90	54.25	M0
38	126.50	66.13	-19.00	56.39	M4
45	131.70	65.95	-18.50	57.40	M10N
50	141.90	66.10	-18.40	59.79	M16
55	149.90	66.50	-18.10	61.92	M21
59	156.60	67.15	-16.00	64.70	M25
60	170.00	67.02	-13.17	72.10	BSMA
61	175.00	66.97	-12.34	74.57	CLOSURE, MIN FIT
62	176.00	66.95	-12.02	75.55	CLOSURE, MAX FIT

Stage poles for plate 101

A1	A2	T1	DT	Lat	Lon	Angle	Dist	V	Dir	Dist	V	Dir
0	5	0.00	10.60	79.1	77.9	2.41	57.	21.	102.	72.	24.	99.
5	6	10.60	9.90	76.8	11.3	2.92	44.	23.	103.	59.	28.	103.
6	13	20.50	15.40	70.6	-12.9	4.61	35.	19.	103.	50.	25.	105.
13	21	35.90	14.40	70.6	-21.3	5.56	33.	24.	99.	48.	32.	103.
21	25	50.30	8.90	68.6	151.7	3.28	73.	39.	86.	84.	41.	81.
25	30	59.20	9.20	85.5	153.1	2.96	56.	30.	89.	68.	33.	88.
30	32	68.40	3.30	66.3	-45.9	2.01	28.	32.	87.	41.	45.	96.
32	33	71.70	2.60	67.2	-40.7	1.08	29.	22.	91.	43.	31.	99.
33	33	74.30	5.90	60.2	-41.9	3.37	22.	24.	91.	36.	37.	103.
33	34	80.20	3.80	59.2	-38.8	2.69	21.	28.	97.	36.	46.	107.
34	35	84.00	7.00	57.4	-25.3	4.92	23.	30.	117.	39.	49.	118.
35	35	91.00	27.70	54.9	-30.0	20.72	19.	27.	118.	36.	48.	120.
35	38	118.70	7.80	57.8	-8.2	2.17	30.	16.	133.	47.	23.	128.
38	45	126.50	5.20	52.2	-10.8	1.04	28.	10.	145.	45.	16.	136.
45	50	131.70	10.20	68.5	-11.5	2.39	33.	14.	114.	48.	20.	114.
50	55	141.90	8.00	72.0	9.4	2.17	41.	20.	114.	56.	25.	111.
55	59	149.90	6.70	60.6	31.2	2.99	51.	38.	129.	67.	46.	122.
59	60	156.60	13.40	60.0	0.0	7.50	36.	36.	133.	53.	49.	127.
60	61	170.00	5.00	59.9	-0.1	2.50	36.	33.	135.	53.	44.	127.
61	62	175.00	1.00	59.8	0.1	0.99	36.	65.	135.	53.	88.	128.

Fig. 4 - Output data file for Klitgord and Schouten's (1986) model of the opening of the Central Atlantic. For explanation, see Fig. 3.

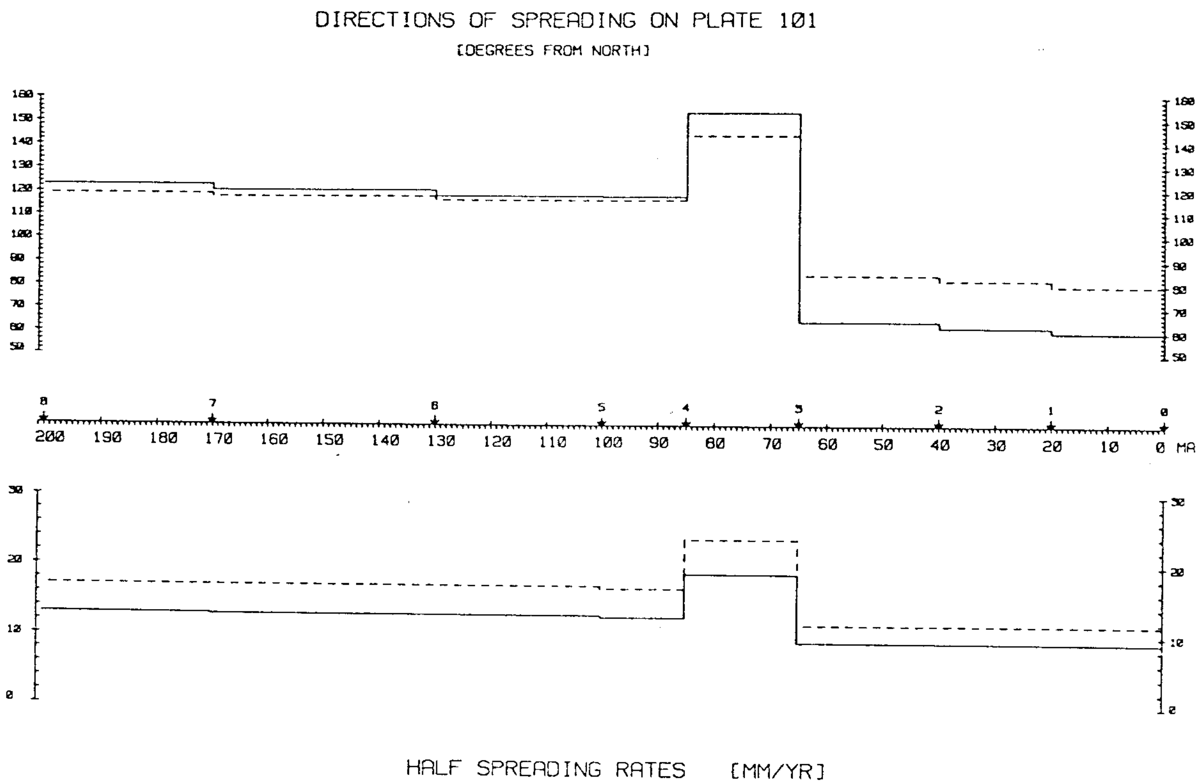


Fig. 5 Francheteau 1970

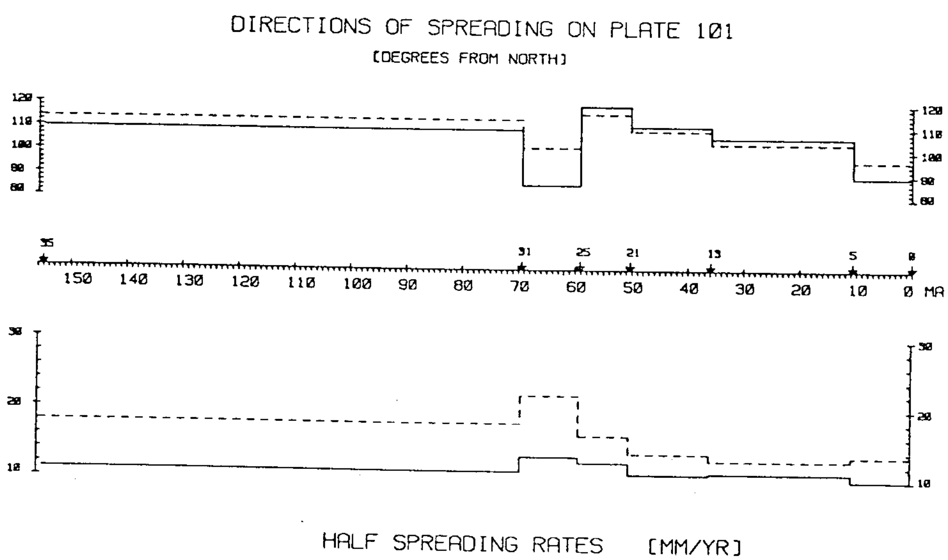


Fig. 6 Pitman and Talwani 1972

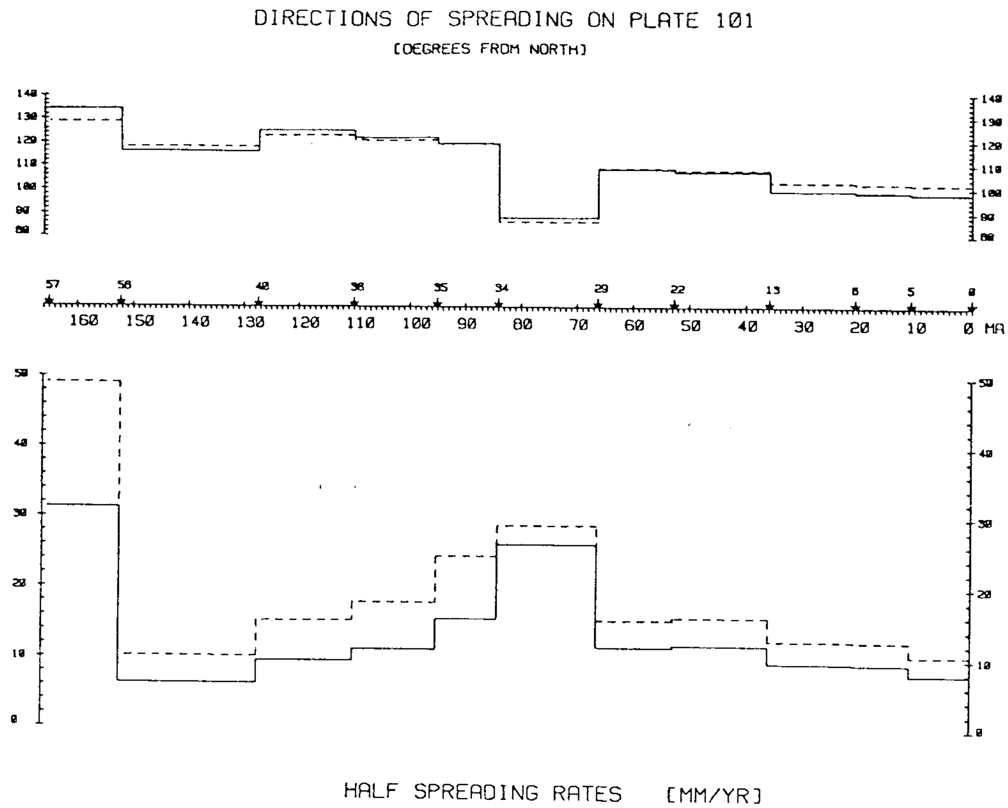


Fig. 7 Sclater et al. 1977

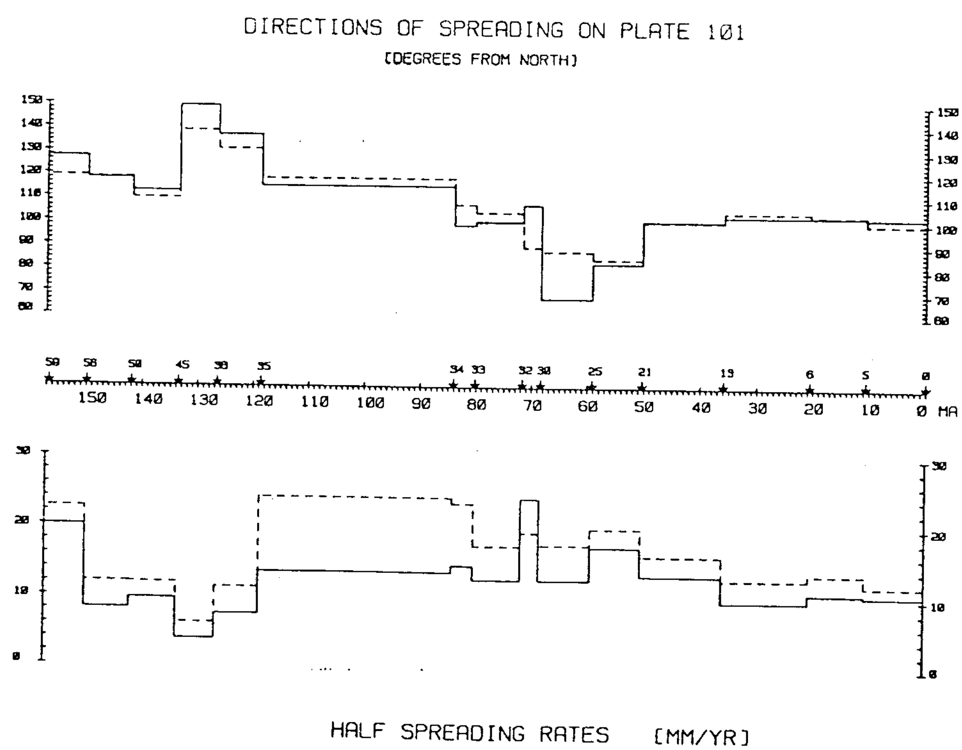


Fig. 8 Molnar and Stock 1983

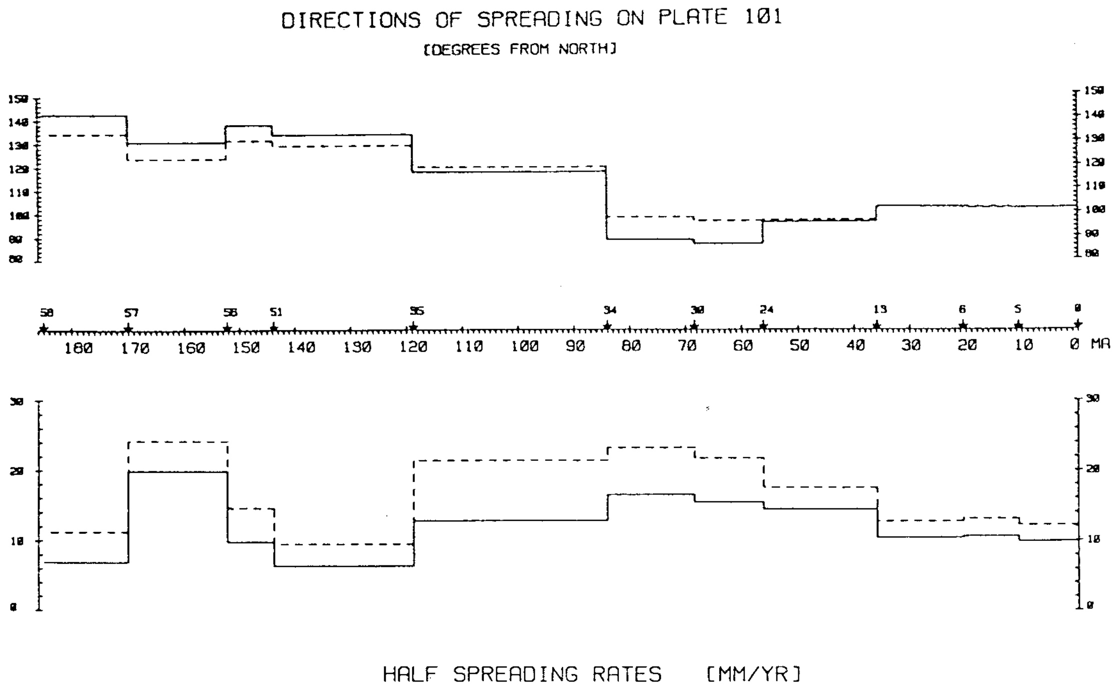


Fig. 9 Olivet et al. 1984

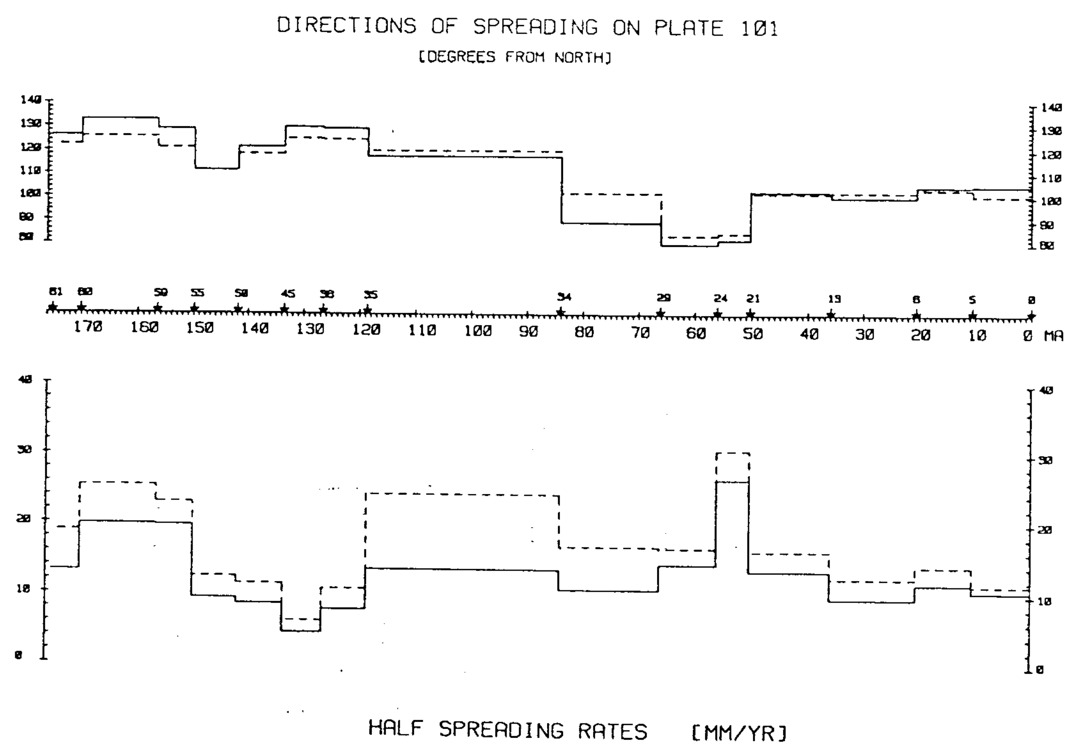


Fig. 10 Rowley et al. 1985

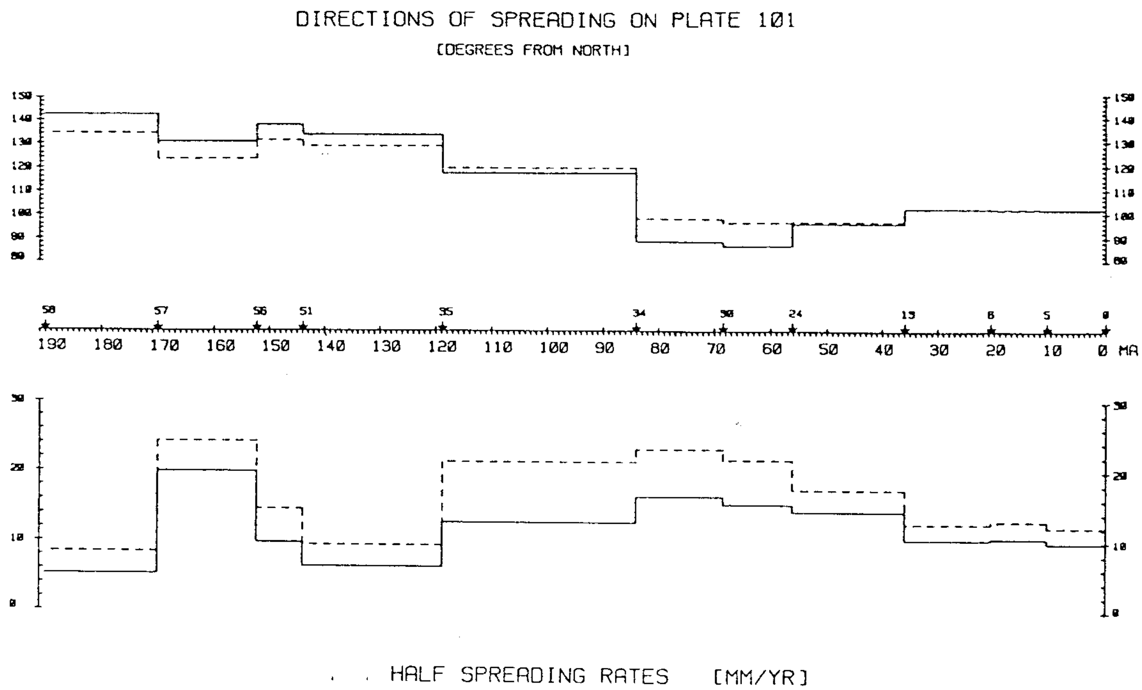


Fig. 11 Savostin et al. 1986

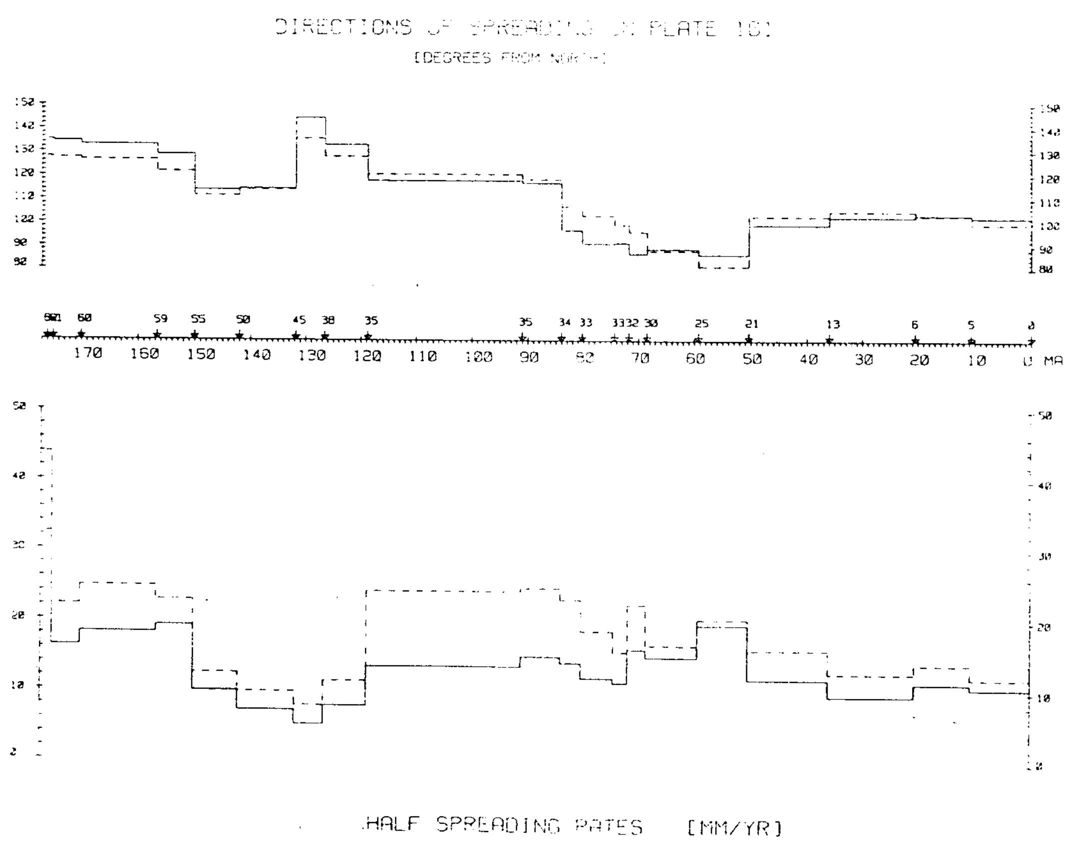


Fig. 12 Klitgord and Schouten 1986

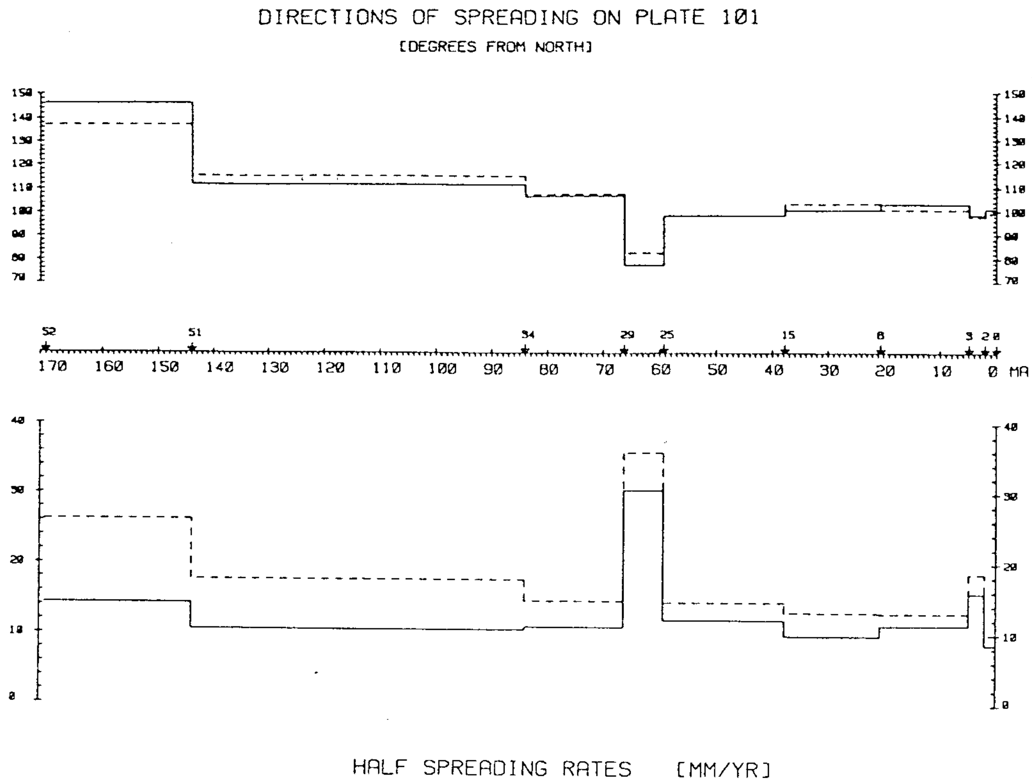


Fig. 13 Gahagan et al. 1987

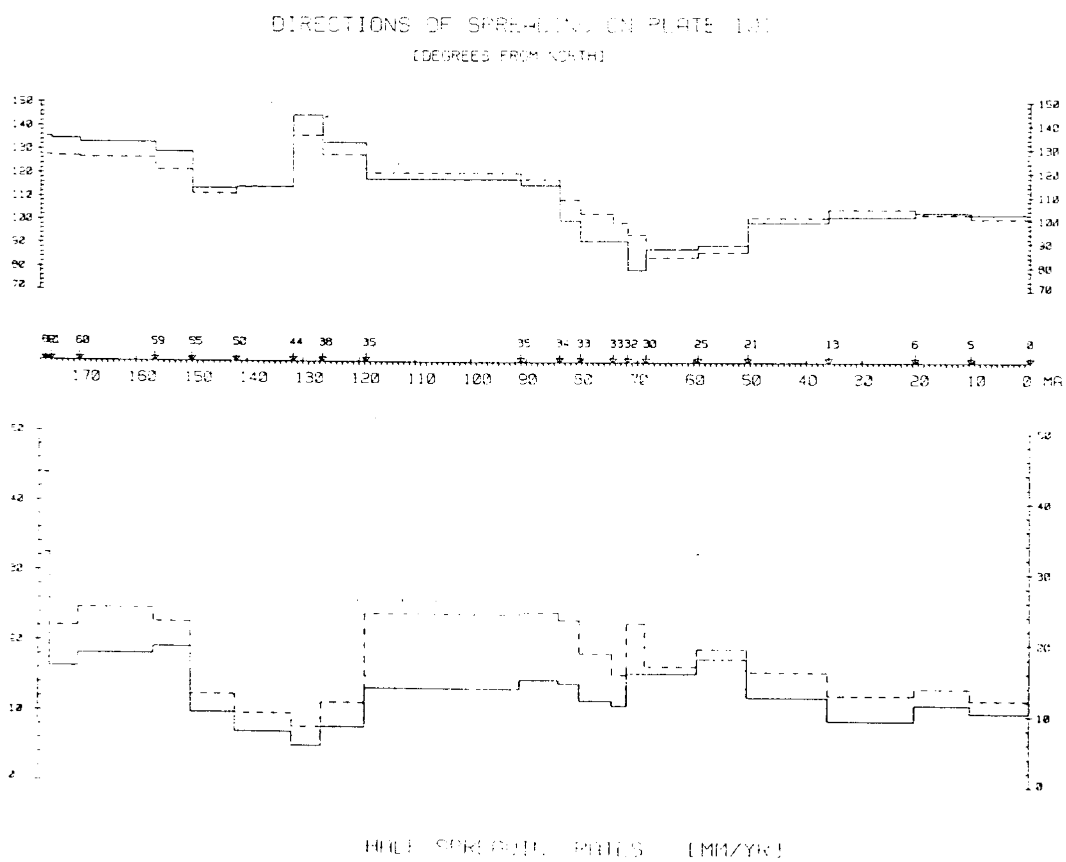


Fig. 14 Müller 1987

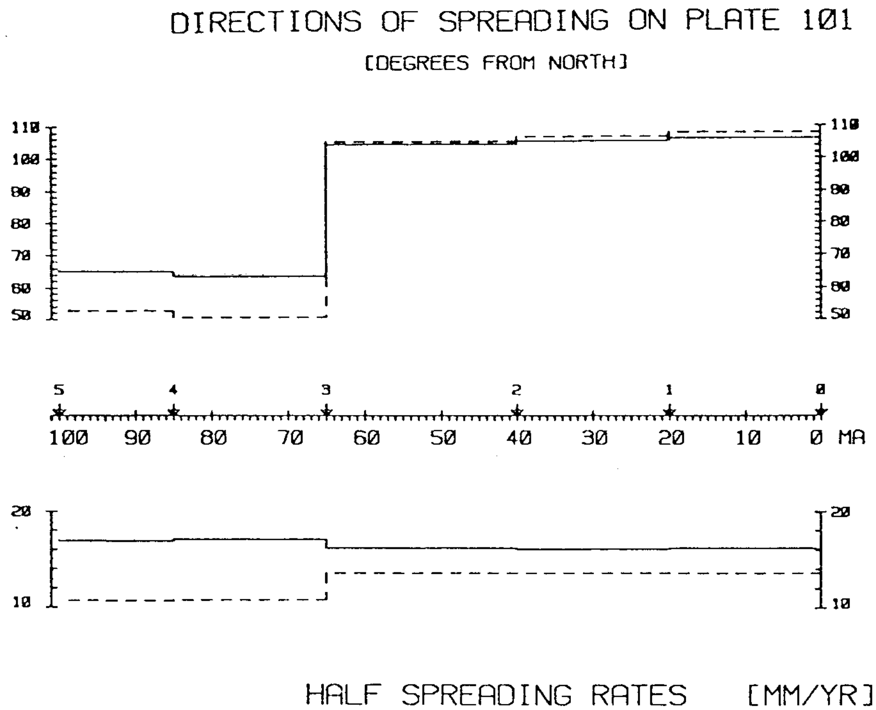


Fig. 15 Francheteau 1970

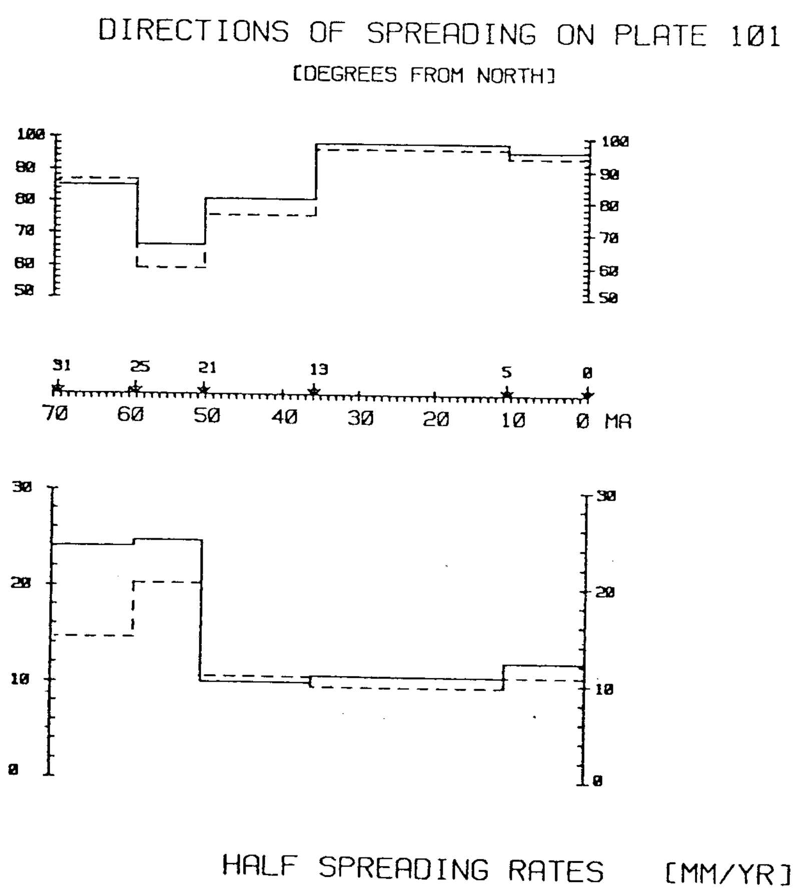


Fig. 16 Pitman and Talwani 1972

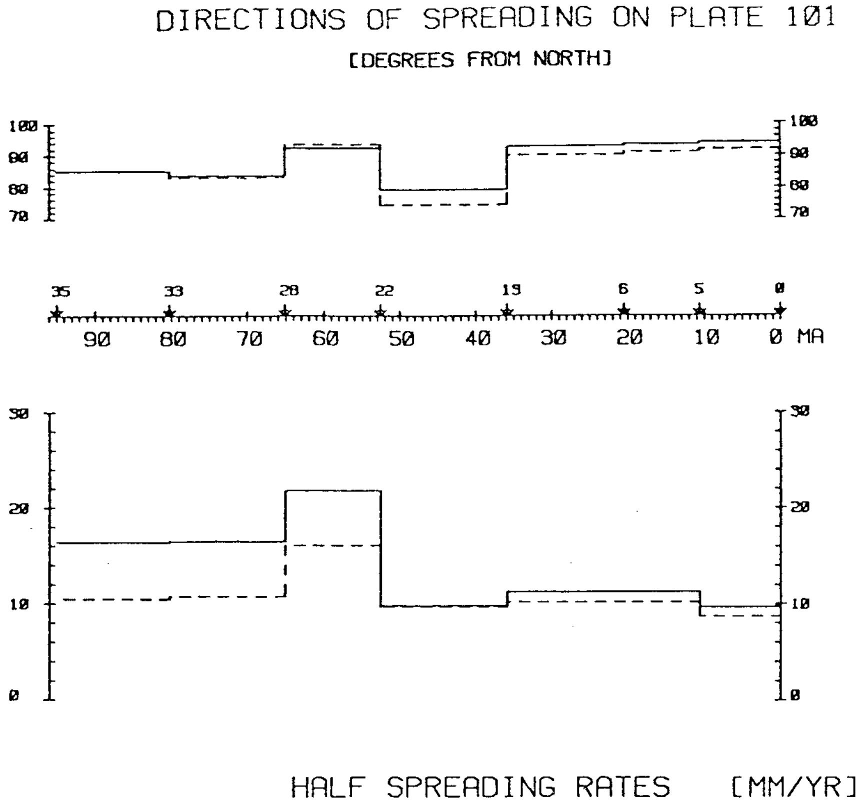


Fig. 17 Sclater et al. 1977

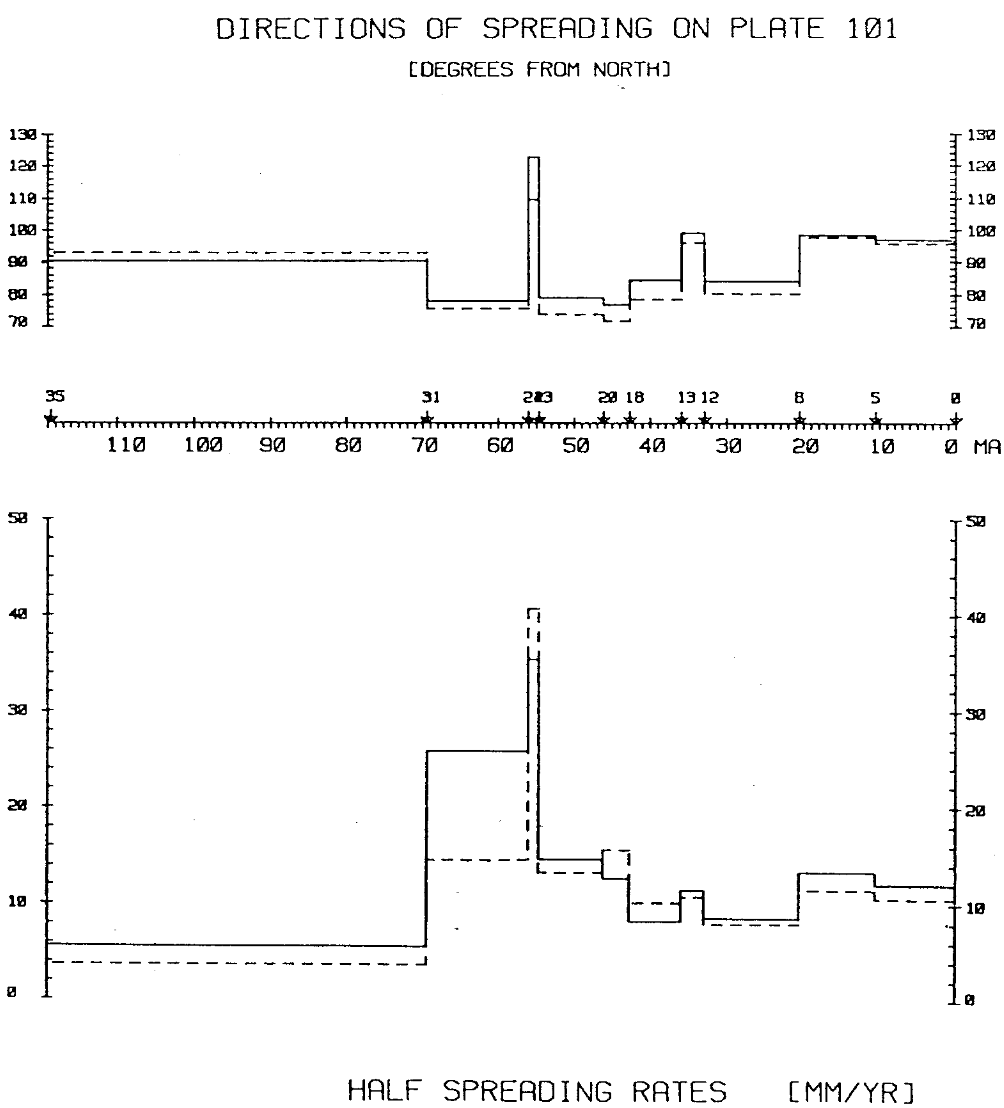


Fig. 18 Phillips and Tapscott 1981

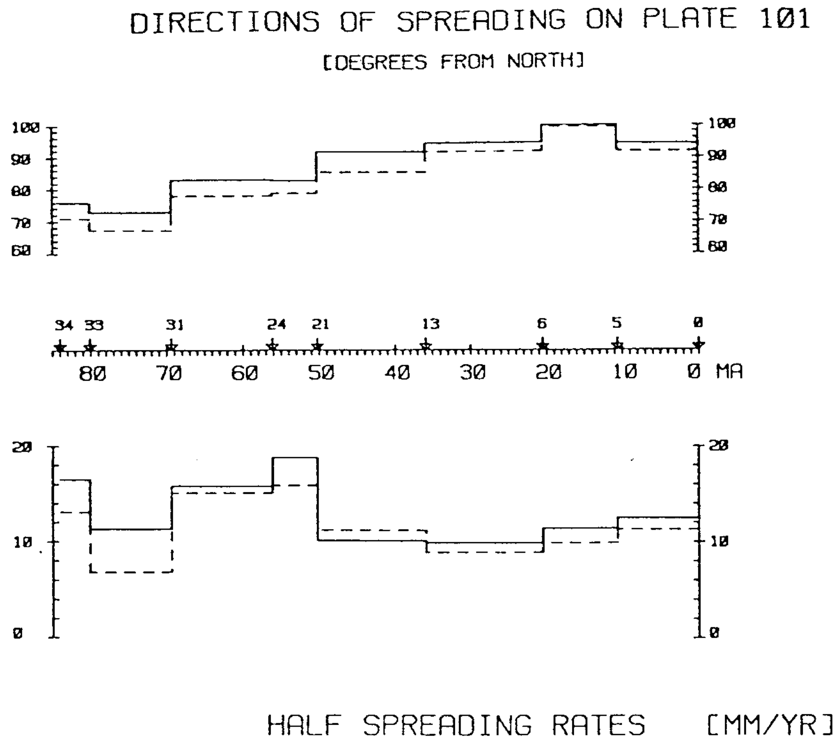


Fig. 19 Molnar and Stork 1983

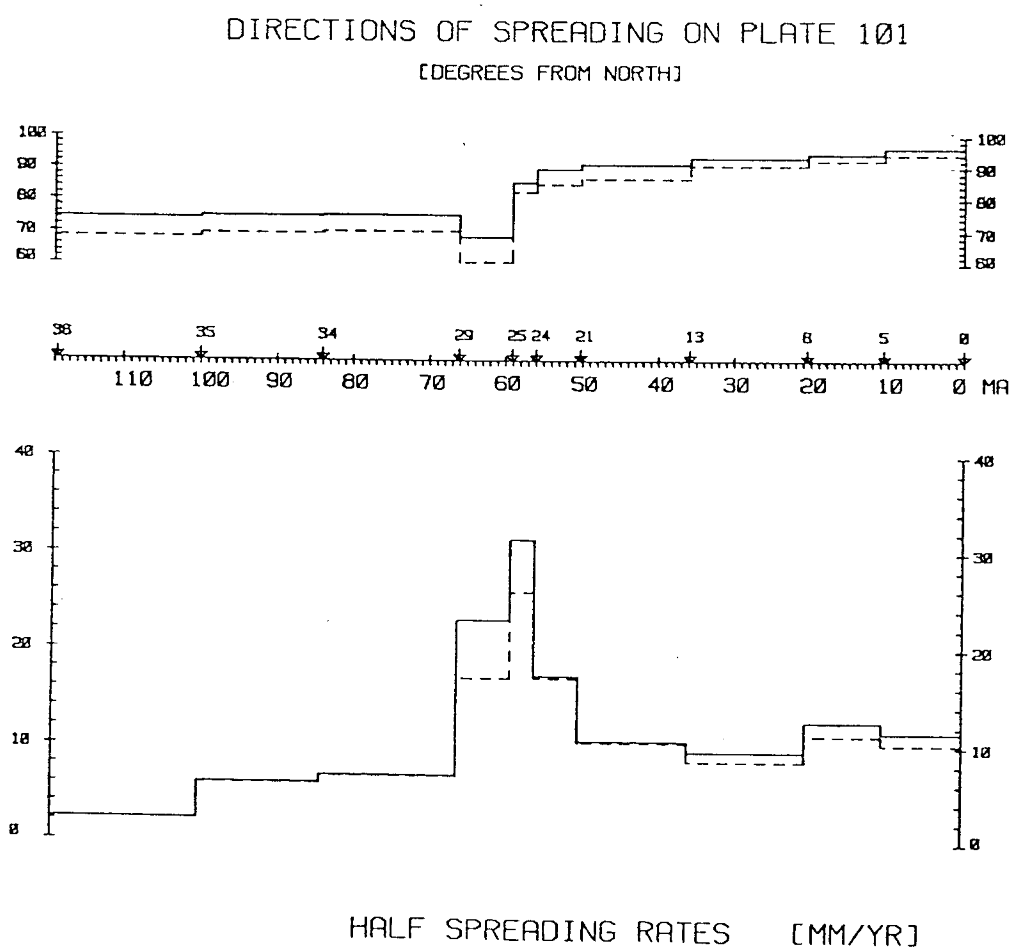


Fig. 20 Rowley et al 1985

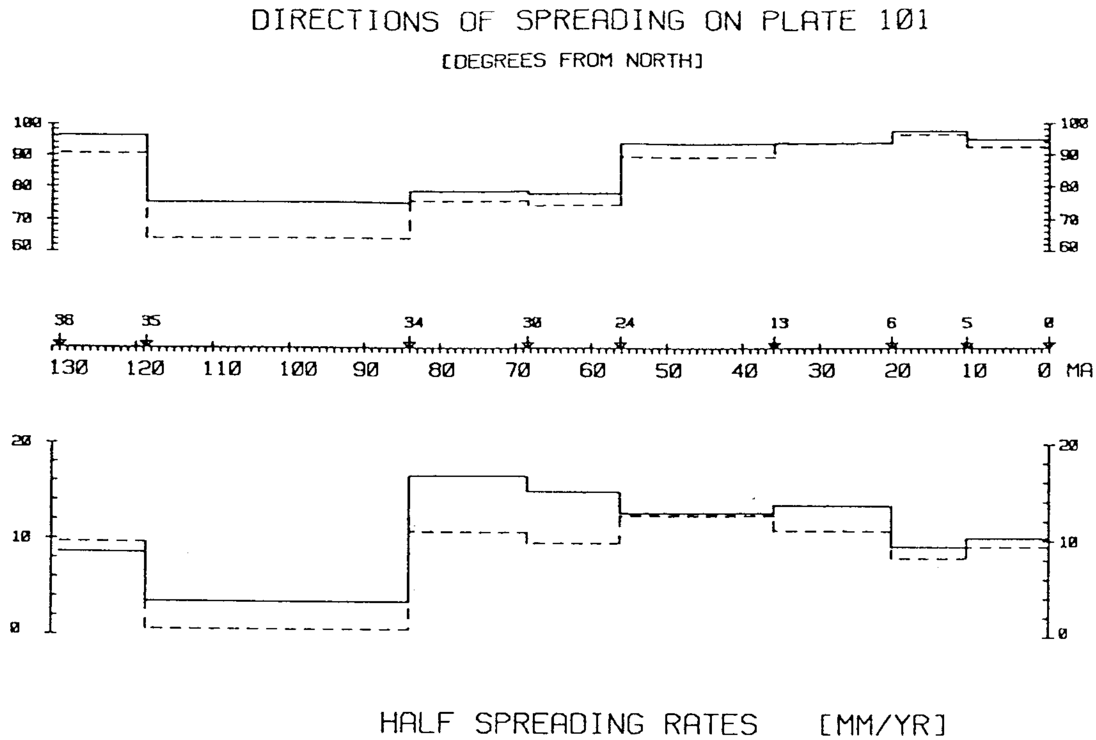


Fig. 21 Savostin et al. 1986

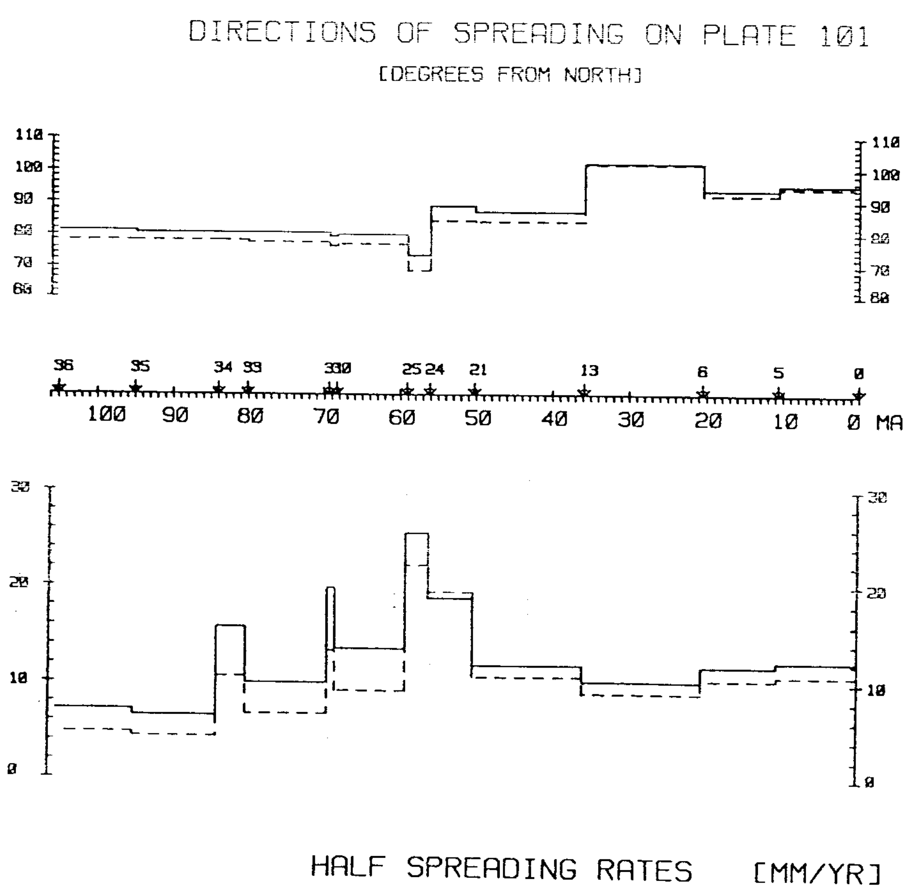
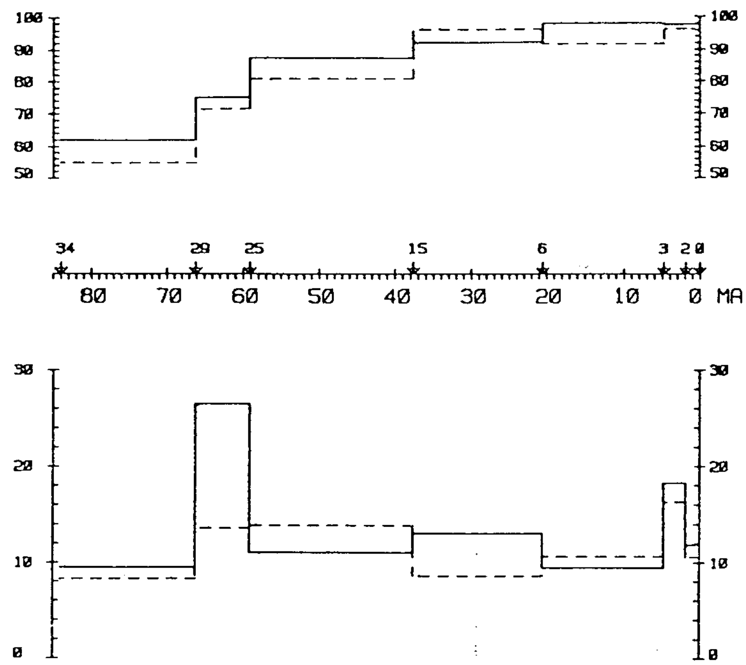


Fig. 22 Srivastava and Tapscott 1986

DIRECTIONS OF SPREADING ON PLATE 1Ø1

[DEGREES FROM NORTH]



HALF SPREADING RATES [MM/YR]

Fig. 23 Gahagan et al 1987