MAGNETIC REVERSALS:
THEIR APPLICATION TO STRATIGRAPHIC PROBLEMS[1]

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ABSTRACT

Paleomagnetic results from Europe and North America show that the Lower Triassic is characterized by mixed polarity, quite in contrast to the long lasting reversed "Kiaman Interval" of the Permian. These pronounced differences emphasize the application possibilities of paleomagnetism to stratigraphical boundary problems, in this case definition of the Paleo-Mesozoic boundary. Furthermore, a paleomagnetic study of the uppermost part of the Middle and Upper Buntsandstein (Scythian), has shown that several magnetic reversals provide the same correlation as do fossil soils over a distance of about 200 km. This example is used to demonstrate the importance of magnetic reversals as stratigraphical auxiliary tool for regional problems.

INTRODUCTION

At the time when the present investigation was started, the question of the origin of reversely magnetized rocks was not settled. It seemed that if one could correlate reversely magnetized sequences in sediments by stratigraphic means (such as fossil soils, etc.) this then would be a rather strong argument in favor of a frequently reversing earth magnetic field. Their lateral distribution and stratigraphic occurrence should allow stratigraphic and paleogeographic conclusions and their number and general occurrence could eventually help in worldwide correlations.[3]

AREA OF INVESTIGATION

The S. W. part of the Triassic basin of Germany was chosen as area of investigation (Figure 1). During the time of deposition of the Buntsandstein (Lower Triassic) a wide trough which deepens slightly toward the north was supplied with clastic sediments from the southwest bordering "Gallic Highlands", as inferred from the directions of the cross-bedding in the sandstone beds. Figure 1 shows that the sedimentation pattern was controlled by a system

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[3] I wish to thank Prof R. BRINKMANN (Bonn) and Prof. H. CLOSS (Hannover) for initiating this work and for their interest and support. I am deeply obliged to Profs. BARTELS (Goettingen), RUNCORN (Newcastle upon Tyne) and G. GJELLESTAD (Bergen) for having the privilege of working in their paleomagnetic laboratories, and to Dr. O. ATZBACH, Prof. E. BECKSMANN and Dr. E. M. MÜELLER for their help in the field. I am indebted to Drs. D. W. COLLINSON, K. M. CREER, K. FROMM, W. A. GOSE, J. W. GRAHAM, A. HAHN, A. L. HALES, C. E. HELSLEY, J. NAGEL, A. E. M. NAIRN, and H. PORATH for interesting discussions and help with the manuscript. The preparation of the manuscript was supported under NSF (GA-1601) and NASA (NSG-269-62, SCAS). The field work was sponsored by Deutsche FORSCHUNGSGEMEINSCHAFT, the laboratory work by a NATO-fellowship. An unknown reviewer helped to update the paleogeographic maps (Figs. 7 and 8)

of epirogenic troughs (Lorraine basin, Upper Rhine depression und Saargemünd - Palatinate trough) and swells (Saarbrücken Carboniferous saddle, Vosges, Black Forest).

The vertical sections investigated in this study were along the margins of the depositional basin where the sedimentation was discontinuous. One consequence of irregular sedimentation in the Triassic basins is that there are numerous discontinuities, some of which may represent long periods of time. The cause of the fluctuating sedimentation is supposed to be climatic. Some of these interruptions in sedimentation lasted long enough for well developed soil zones to be formed. The so-called "Violette Grenzzonen (VG-Zones)" are examples of such fossil soil horizons. Dolomite breccia and dolomite zones are often associated with them and may be explained as caliche zones which formed under arid conditions.

Three major VG- and dolomite zones are recognizable throughout the area studied. As they are found at various stratigraphic levels, they can be used as marker horizons (MUELLER, 1954, 1960; PERRIAUX, 1961; Profile Chart).

MAGNETIC REVERSALS IN THE BUNTSANDSTEIN

Paleomagnetic Results

Along 12 stratigraphically correlated Middle and Upper Buntsandstein sections (Figures 1, 9), covering a distance of more than 200 km, 244 oriented hand samples were taken at about 1 m vertical intervals. From each hand sample a variable amount (up to 30) of specimens was cut and measured. The iron oxide content of the Buntsandstein is generally less than 1% yet the Buntsandstein is sufficiently magnetized to be measurable. Hematite is the main component of the opaque fraction and is thought to be

NRM - DIRECTIONS SHOWN IN CORRELATION CHART

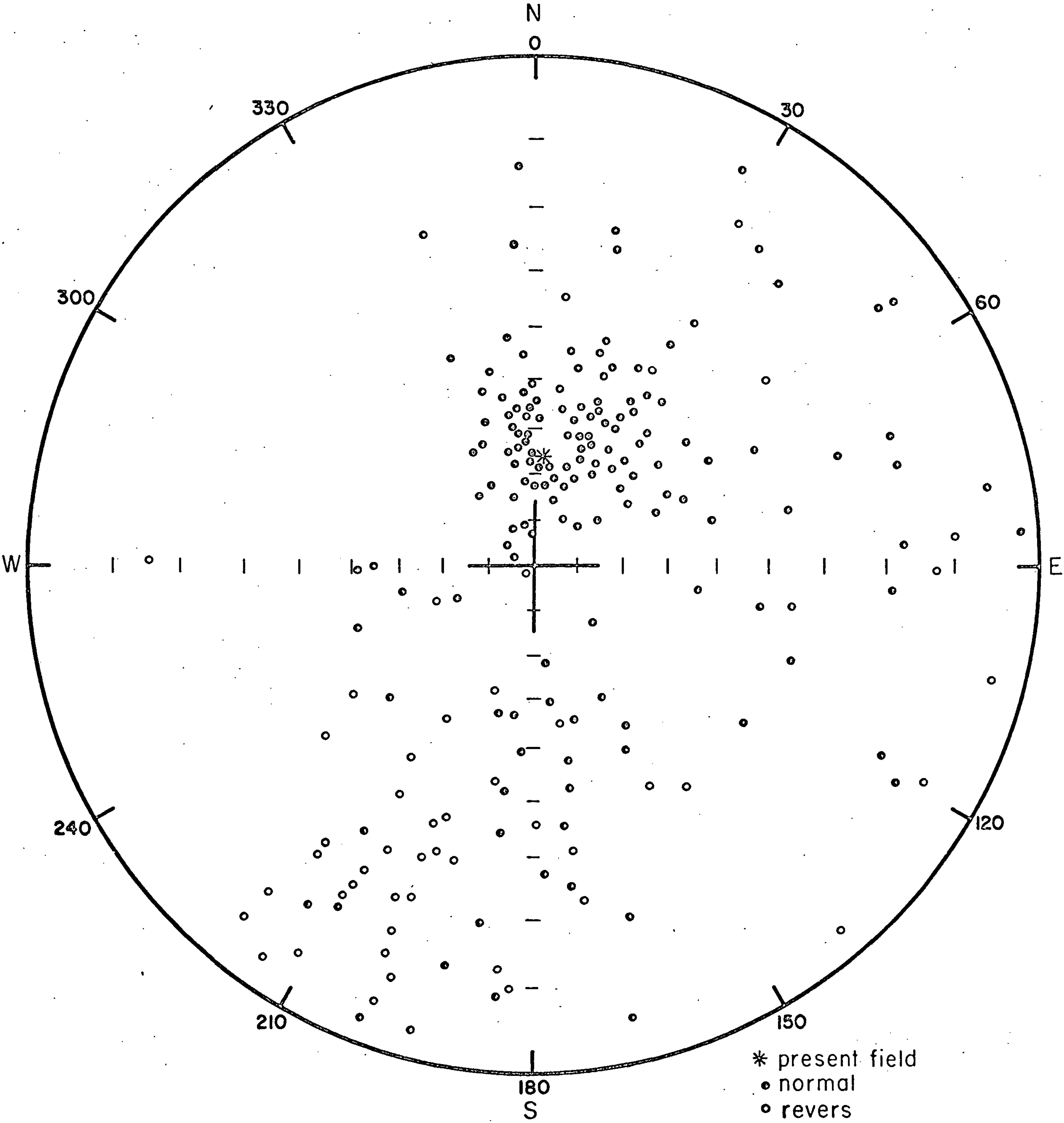

FIGURE 2

the carrier of the natural remanent magnetization. The individual sand grains are enclosed by a red cement, composed of hematite, goethite, carbonates and quartz (HENRICH, 1962 and PERRIAUX, 1961). From these Triassic sandstones the following paleomagnetic results and observations were obtained.

The intensity of magnetization of these Triassic sandstones was between .5 and 5 x 10^{-6} e.m.u./cm^3.

The Natural Remanent Magnetization (NRM) directions of the samples from the Buntsandstein are shown in Figure 2. In spite of the large dispersion in the NRM directions, two clusters of directions can be distinguished which represent approximately the normal and reversed polarity of the same vector. Samples with normal polarities tend to group around the present geomagnetic field.

In order to test the stability of normally and reversely polarized sandstones, 14 samples were tested in alternating fields in steps from 150 Oe to 1080 Oe. No large changes in intensity and direction of the NRM were found (see Figure 3).

As a further check, an additional 43 normal and reversed samples were heated stepwise from 100°C or 150°C to 650°C and remeasured after cooling to room temperature in zero field. Most of the samples proved to be stable, while a few others showed changes in the directions and intensity of the NRM.

The high stability of the Buntsandstein samples in alternating field and thermal demagnetization experiments confirms the presence of hematite [which is characterized by high coercitive forces and high Curie temperatures] in the samples.

EXAMPLE OF STEPWISE ALTERNATING CURRENT DEMAGNETISATION

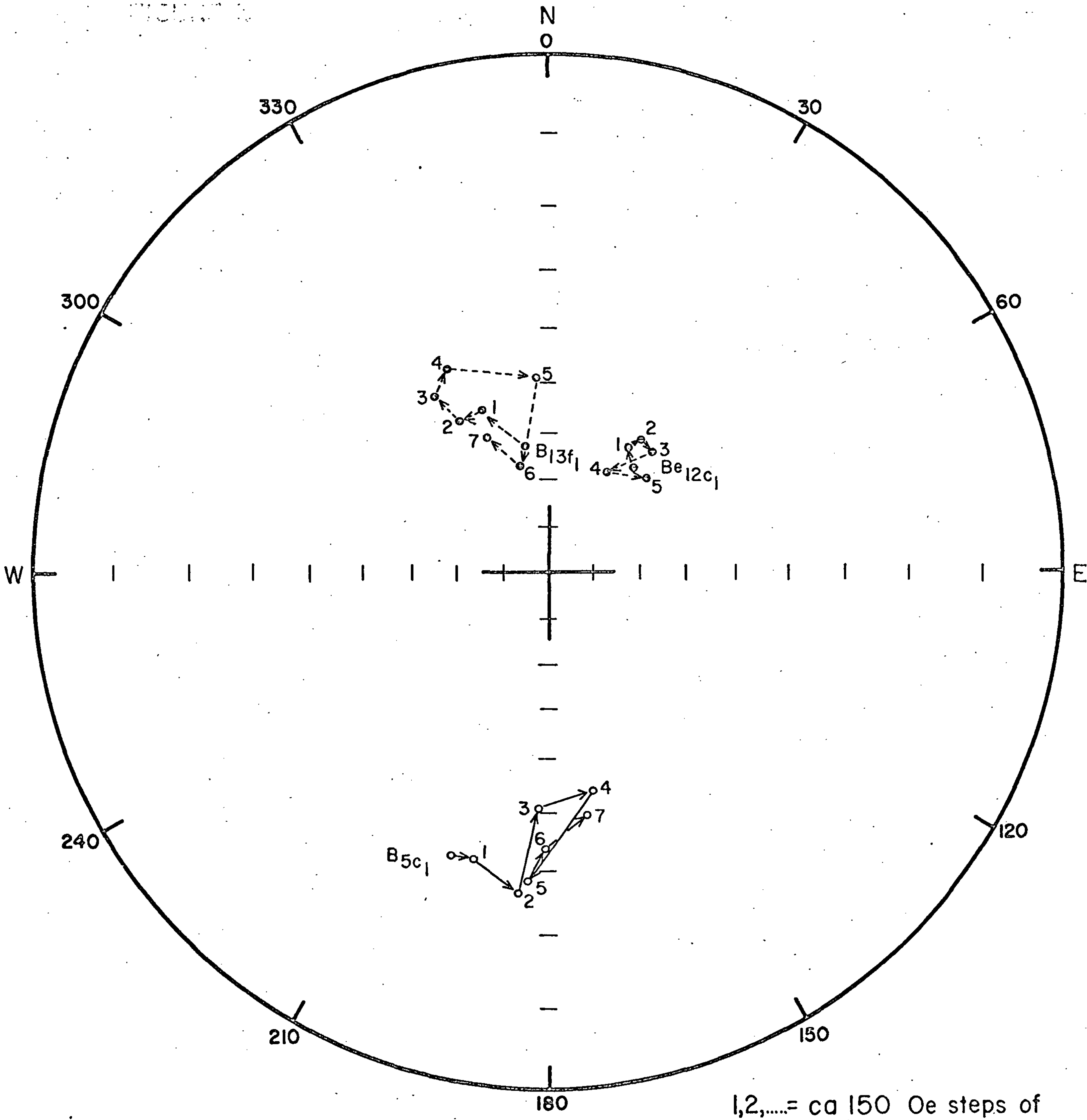

FIGURE 3

1,2,.....= ca 150 Oe steps of AC-field increase.

✳ present field

◉ lower hemisphere

o upper hemisphere

Bleached sandstones, in which the hematite within the cement has been dissolved and removed, are frequently found in the Buntsandstein, especially in the Voltziensandstein. In some cases the intensity of their NRM is comparable to that of red sandstone. Generally, however, it is somewhat less, but the directions of the NRM are in agreement with those of the unbleached sandstone. The weaker magnetization can be attributed to the fact that not only has the iron oxide content of the cement been decreased but that the opaque heavy minerals have also been partially removed during the bleaching. Similar results have been discussed by GRAHAM (1955) and are supported by bleaching experiments reported by COLLINSON (1964) and BUREK (1969).

In light of the above observations it is believed that during sedimentation and before consolidation of the Buntsandstein, the detrital magnetic particles of hematite were able to be influenced and aligned by the earth's magnetic field. This magnetization process is generally called Depositional Remanent Magnetization (DRM) and is treated theoretically and experimentally by KING (1955), GRIFFITHS, et al., (1957), IRVING (1957), COLLINSON (1964).

As the magnetization of hematite is often rather weak, good alignment of the magnetic particle during deposition is only likely under especially favorable conditions. Apparently these did not exist for much of the Buntsandstein period, at least

VECTOR DIAGRAM OF COARSE GRAINED SAMPLE: Be 4
(UNT. ZWISCHENSCHICHTEN)

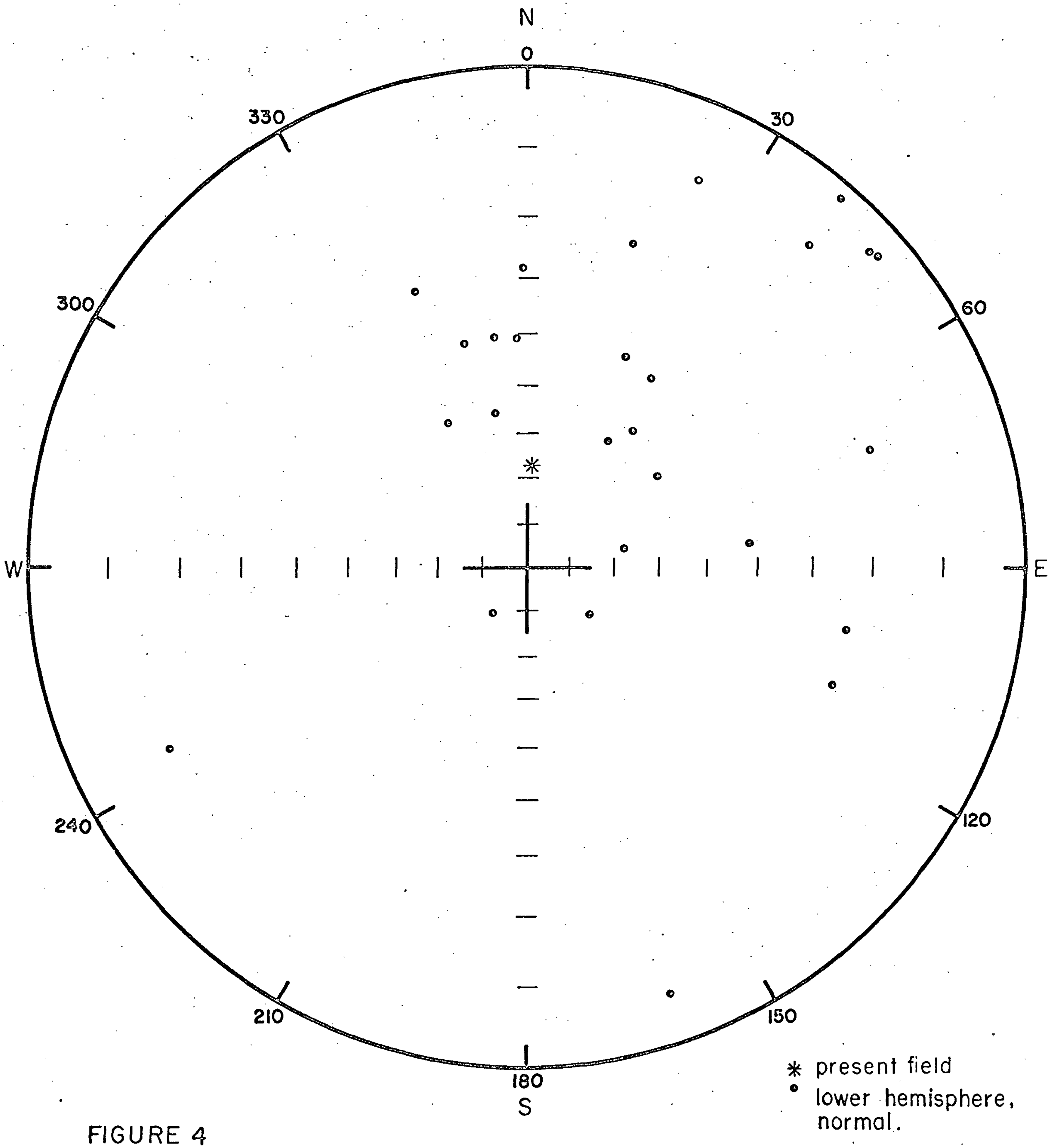

FIGURE 4

VECTOR DIAGRAM OF FINE GRAINED, REVERSELY MAGNETISED
SAMPLE: B8
(VOLTZIENSANDSTEIN)

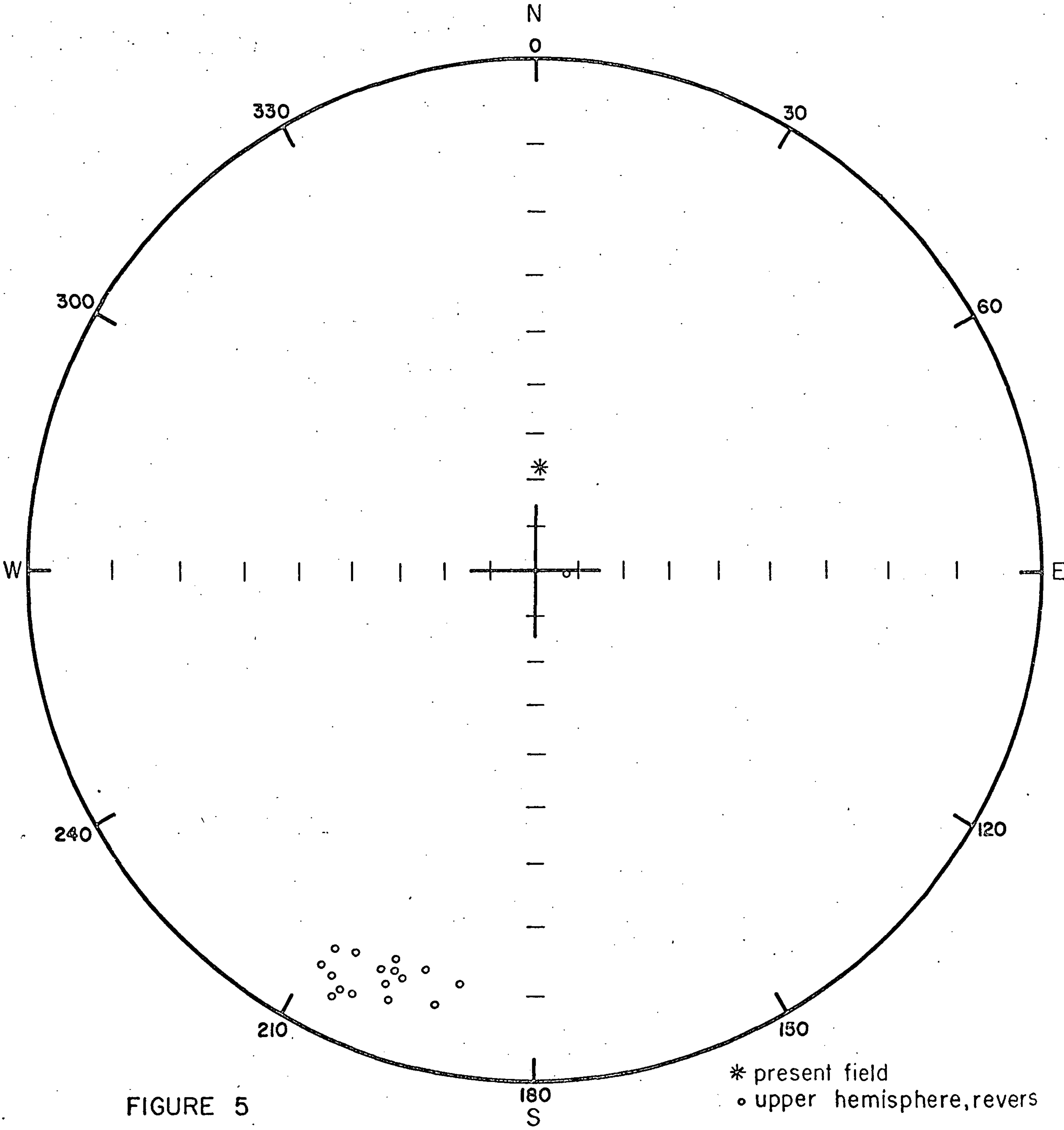

FIGURE 5

not in the lower part of the sedimentation cycles. The turbulent sedimentation conditions in the Zwischenschichten in which cross-bedded, coarse-grained to conglomeratic sandstones were deposited, were apparently unsuitable for good alignment (see Figure 4). Somewhat less turbulent conditions seem to have prevailed at the time of the Voltziensandstein. In this case the sandstones are finer-grained and were deposited in a more settled, limnitic environment and consequently the dispersion of the magnetic directions is not as great (see Figure 5).

Due to the poor grouping of the magnetic directions, no attempt was made to calculate the magnetic pole positions for the Buntsandstein. Nevertheless, the occurrence of reversely magnetized zone suggests that the sandstones of the Buntsandstein probably reflect the polarity of the Triassic geomagnetic field (see Figures 2, 5 and Correlation Chart). Rock samples are considered normal if their magnetization directions lie in the following range: declination between 300° and 90°, inclination downward (+). They are considered reversed if their declination varies between 130° and 250° and their inclination is either upward (-) or only slightly downward (up to ca. 20°). Some intermediate directions occur either just below or above the normally or reversely magnetized zones.

Stratigraphic Occurrence of the Reversely Magnetized Horizons

The reversals: R_1, R_3, R_5, R_6 and R_7 in the Upper Buntsandstone (see Correlation Chart)[4] can be traced from the Tierer Bay through the Saarland to Lorraine and through the Palatinate into the S. Odenwald, i.e. over a distance of more than 200 km (see Figure 1).

They stay within certain stratigraphic levels: R_1 and R_3 (reported by NAIRN, 1960) in the Lower Zwischenschichten, R_5 in the Upper Zwischenschichten, R_6 in the bordering region of Upper Zwischenschichten/Voltziensandstein, and R_7 in the Voltziensandstein. The horizontal consistency in reversals R_5 and R_7 is particularly clear.

The thin, reversely magnetized horizons, R_4, R_8 and R_9 cannot be safely correlated on the basis of the presently available evidence. This might be explained by assuming that these horizons coincide with a time of slow or no deposition However, it is also probable that the vertical (i.e. stratigraphic) interval between consecutive samples was too large.

The polarity of the samples is independent of the petrographic state e.g.: grain size, carbonate content, bleaching or Triassic weathering. The reversed and normal horizons occur in sandstones of broadly similar and variable lithology.

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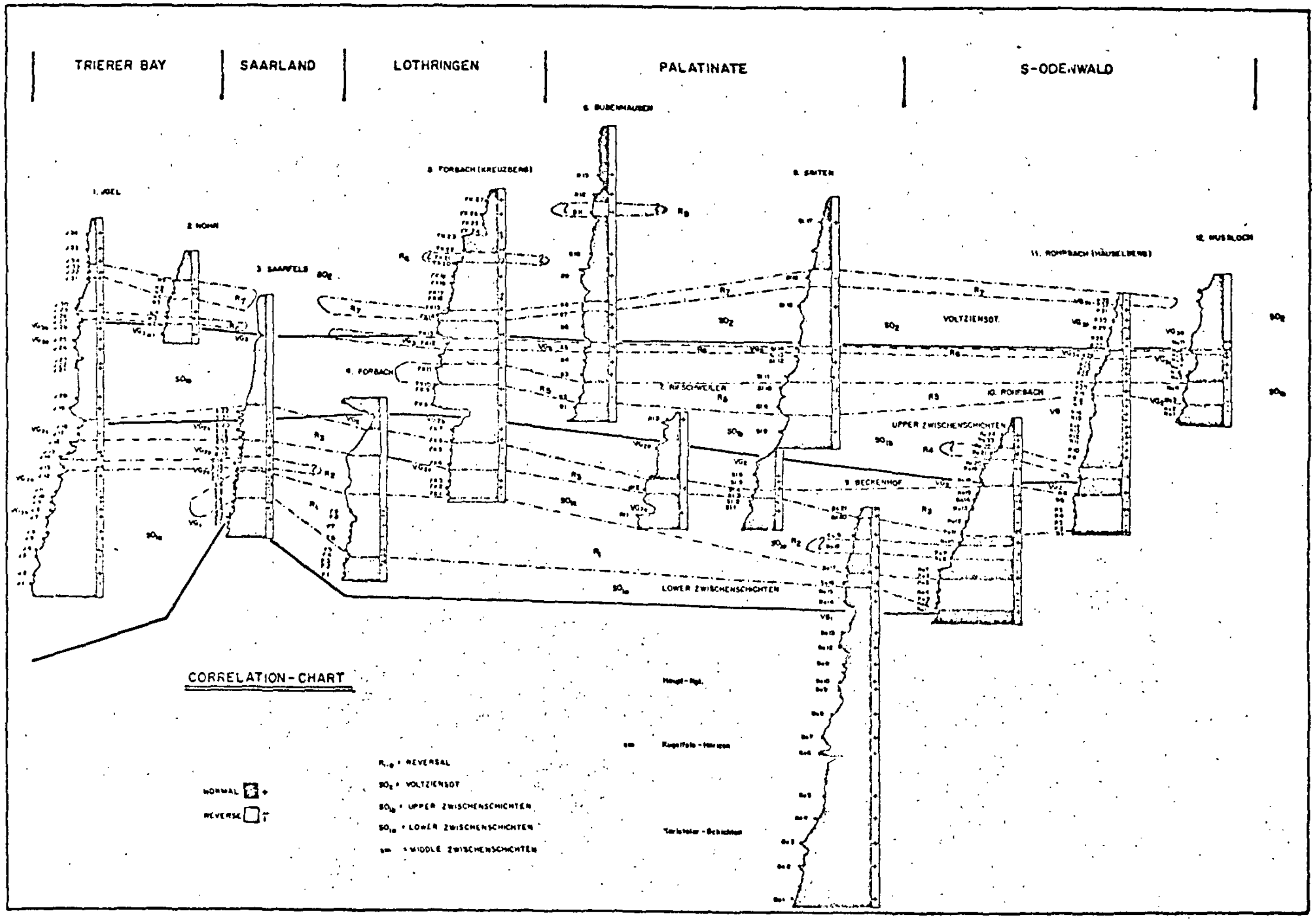
[4] The author knows of at least one certain reversal in the higher parts of the Middle Buntsandstone (close to profile Simten). More Middle Buntsandstone reversals are described in the literature (CLEGG et al., 1954; NAIRN, 1960).


TRIERER BAY
SAARLAND
LOTHRINGEN
PALATINATE
S-ODENWALD
1. IGEL
2. NOHN
3. SAARFELS
4. FORBACH
5. FORBACH (KREUZBERG)
6. BUBENHAUSEN
7. RIESCHWEILER
8. SIMTEN
9. BECKENHOF
10. ROHRBACH
11. ROHRBACH (HÄUSELBERG)
12. NUSSLOCH
VOLTZIENSOT
UPPER ZWISCHENSCHICHTEN
LOWER ZWISCHENSCHICHTEN
Haupt-Kgl.
Kugelfels-Horizon
Karlstaler-Schichten
CORRELATION-CHART
NORMAL +
REVERSE −
R1-8 = REVERSAL
SO2 = VOLTZIENSOT
SO1b = UPPER ZWISCHENSCHICHTEN
SO1a = LOWER ZWISCHENSCHICHTEN
sm = MIDDLE ZWISCHENSCHICHTEN

Individually the facies of the reversely magnetized rocks can be very diverse. For instance, horizon R_1 at Heidelberg-Rohrbach (see Correlation Chart) is a bright, quarzitic and dolomitic sandstone; at Simten and Rohrbach, this horizon is a loosely cemented, intensely reddish-brown, coarse sandstone and conglomerate; at Saarfels the it consists of medium-grained partially bleached sandstones.

The stratigraphic consistency of reversely polarized zones, the independence of lithology, and the rock magnetic characteristics indicate that the reversed magnetizations in the Upper Buntsandstein are not local matters, or the result of self-reversal, but rather are evidence of several reversals of the geomagnetic field at the time of the deposition.

The occurrence of five reliable and even more probable reversely polarized horizons of small thickness shows that the geomagnetic field in Upper Skythian time was extremely variable and that the polarity changed frequently. Thus it seems possible to use reversals for fine stratigraphic correlations in the Upper Buntsandstein and perhaps in other red sediments.

STRATIGRAPHIC USE OF OBSERVED REVERSALS FOR LOCAL PROBLEMS

Correlation of the stratigraphic positions of polarity reversals provides a means of determining "time lines" within a stratigraphic sequence. Determination of these reversals thus can provide more information regarding relative time of deposition than can the lithology of the sediments alone. Examples of the usefulness of these additional data are:

A. R_1 is situated a few meters above the VG_1 zone in Saarland, Lorraine and the Palatinate; in the S. Odenwald, however, it occurs directly above the VG_1 zone. This shows that the debris coming from the Gallic highlands reached the S. Odenwald later than the more western areas (Figure 1). The normaly magnetized sandstone sequences between VG_1 and R_1 are thickest at Forsthaus Beckenhof/Palatinate and R_1 is restricted here to a relatively thin horizon. This section is found in the center of the Palatimate basin, where the thickness and conglomerate content of the Lower Zwischenschichten is greater than in the Lorraine section and those of the Saarland and S. Odenwald. This explains the later occurrence of R_1 in the Palatinate because of faster sedimentation at the beginning of the Lower Zwischenschichten. Erosion and redeposition also could be responsible in part for the decrease in thickness of R_1.

B. R_6 shows small deviations. It is found in the B-horizon of the VG_3-zone at Heidelberg-Rohrbach, Bubenhausen and Forbach-Kreuzberg; in a dolomite-breccia of VG_3 at Simten; in the Trierer Bay, as well as at Nohn and Igel it is above VG_3, i.e. it is already in the basal layer of the Werkstein. There is no consistent relationship between the soil zones and their sense of magnetization. However, the occurrence of reversals below, in and above VG_3, can be explained as follows:

the formation of the VG_3 soil in S. Odenwald, Palatinate and Lorraine was penecontemporaneous with the polarity change of the earth's magnetic field, whereas, in the Trierer Bay, the Voltziensandstein had already been deposited.

STRATIGRAPHIC USE OF POLARITY EPOCHS FOR WORLDWIDE CORRELATION PROBLEMS

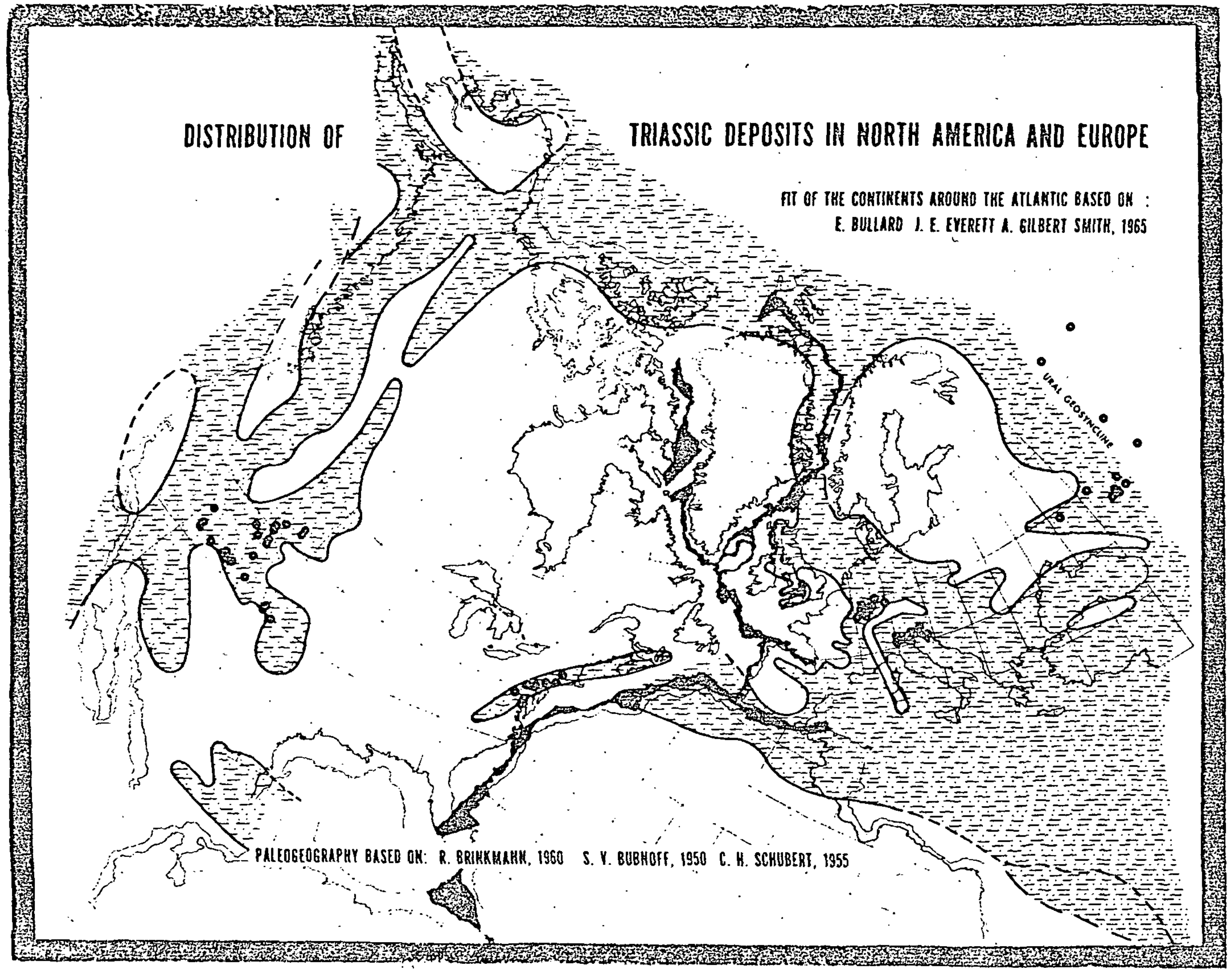
A. The Lower Triassic Buntsandstein of Germany indicates mixed polarity. A comparison with other results is given in Figure 9. It is of particular interest that Picard (1964), McMahon and Strangway, (1967) and Helsley (1968) and others (Figure 9) have found clear evidence for mixed polarity in the Chugwater Formation of West Central Wyoming, the Upper Maroon Formation of Western Colorado, and in the Moenkopi Formation of Utah and W. Colorado, USA.

For instance, the Red Peak Member of the Chugwater Formation is underlain by the Dinwoody Formation which is of Lower Skythian age. It is overlain by the Alcova Limestone Member and the Popo Agie Formation which contains a reptile fauna of lower Middle Keuper (J. B. Reeside, Jr. et al., 1957), but is separated from the Alcova by a hiatus which seems to comprise most of the Middle Triassic. There might be thus a certain probability that the Red Peak Member of the Chugwater Formation is stratigraphically equivalent to the Upper Skythian, i.e. the upper part of the Buntsandstein (this study).

Furthermore, McMahon and Strangway (1968) quote a Skythian age for the Upper Maroon Formation and state that it is time

DISTRIBUTION OF PALEOMAGNETIC SAMPLING LOCATIONS FOR TRIASSIC ROCKS

1. BECK, 1965
2. BIDGOOD, HARLAND, 1961
3. BLACK, 1964
4. BOWKER, 1960
5. BRIDEN, 1966
6. COLLINSON, 1965
7. COLLINSON, RUNCORN, 1960
8. DE BOER, 1967, 1968
9. DOELL, 1955a, 1955b
10. DU BOIS, 1957, 1958
11. DU BOIS, IRVING, OPDYKE, RUNCORN, BANKS, 1957
12. GRAHAM, 1955
13. HELSLEY, 1965, 1968
14. IRVING, BANKS, 1961
15. KINTZINGER, 1957
16. KOBAYASHI, SCHWARTZ, 1966
17. KOBAYASHI, TASHBROOK, NAGATA, 1963
18. KHRAMOV, 1958
19. LAROCHELLE, WANLESS, 1966
20. MC LAUGHLIN, 1950
21. MC MAHON, STRANGWAY, 1968
22. OPDYKE, 1961
23. PICARD, 1964
24. ROY, 1963
25. RUNCORN, 1956, 1962



DISTRIBUTION OF TRIASSIC DEPOSITS IN NORTH AMERICA AND EUROPE

FIT OF THE CONTINENTS AROUND THE ATLANTIC BASED ON :
E. BULLARD J. E. EVERETT A. GILBERT SMITH, 1965

PALEOGEOGRAPHY BASED ON: R. BRINKMANN, 1960 S. V. BUBNOFF, 1950 C. H. SCHUBERT, 1955

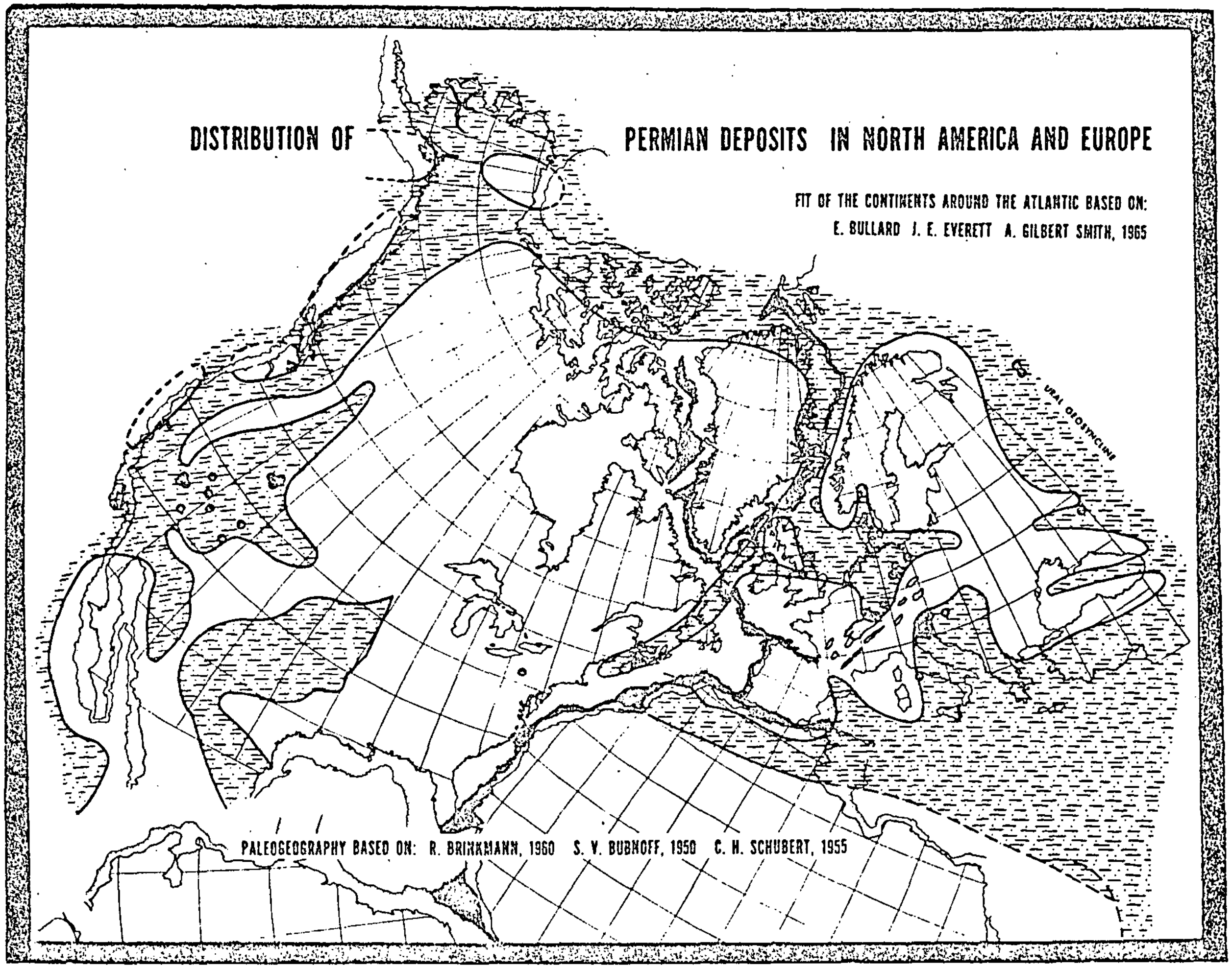
1. ARMSTRONG, 1957
2. AS, ZIJDERVELD, 1958
3. BIDGOOD, HARLAND, 1961
4. BIRKEMAJER, NAIRN, 1964
5. CREER, 1957
6. CREER, IRVING, NAIRN, 1959
7. DE BOER, 1963, 1965
8. DIETZEL, 1960
9. DU BOIS, 1957
10. EVERDINGEN, 1960
11. FINDHAMMER, DE BOER, 1965
12. GUICHERIT, 1964
13. GUSEV, 1959
14. KALASHNIKOV, 1961
15. KHRAMOV, 1958, 1961
16. LOOKEREN, DE BOER, 1965
17. NAIRN, 1957, 1960, 1963
18. NIJENHUIS, 1961
19. NIJENHUIS, DE BOER, 1965
20. POPOVA, 1963
21. ROCHE, 1957
22. RUTTEN, et al.
23. SCHWARTZ, 1964
24. SCHMUCKER, 1959
25. VAN DER LINGEN, 1960
26. VAN HILTON, 1960, 1962

equivalent to the Moenkopi Formation (Helsley, 1968). These ages are compatible with the general magnetic pattern (Burek, 1964; Helsley, 1968; McMahon and Strangway, 1968 and Picard, 1964) observed on both continents, all of which indicates mixed polarity for Lower Triassic (Skythian) times. We suspect that the reversals seen in this study may represent some of the same events described from Triassic rocks in North America. But for the time being (i.e. without further stratigraphieal evidence) no definite correlations are attempted.

However, as soon as the number and stratigraphical occurrences of Triassic polarity changes are as well known as they are now for the Tertiary (Cox et al., 1967; Opdyke et al., 1967; Heirtzler et al., 1968), it should be possible to use reversals for stratigraphic and paleogeographic conclusions or at least as auxiliary information in the cases in which time indicators [fossils etc.] are present.

B. The definition of the Permian-Triassic boundary presents a major problem especially in continental deposits that are all too often characterized by unfossiliferous red beds. Permian (Figure 8) and Triassic (Figure 7) paleomagnetic collection sites from Europe and North America are plotted on maps which show the Permian and Triassic sedimentation areas. These somewhat unusual paleogeographic reconstructions of the continents around the Atlantic are based on a computed reconstruction by Bullard, et al. (1965) and paleomagnetic evidence that indicated continental fit for

1. BECK, 1965
2. BIDGOOD, HARLAND, 1961
3. BLACK, 1964
4. BOWKER, 1960
5. BRIDEN, 1966
6. COLLINSON, 1965
7. COLLINSON, RUNCORN, 1960
8. DE BOER, 1967, 1968
9. DOELL, 1955a, 1955b
10. DU BOIS, 1957, 1958
11. DU BOIS, IRVING, OPDYKE, RUNCORN, BANKS, 1957
12. GRAHAM, 1955
13. HELSLEY, 1965, 1968
14. IRVING, BANKS, 1961
15. KINTZINGER, 1957
16. KOBAYASHI, SCHWARTZ, 1966
17. KOBAYASHI, TASHBROOK, NAGATA, 1963
18. KHRAMOV, 1958
19. LAROCHELLE, WANLESS, 1966
20. MC LAUGHLIN, 1950
21. MC MAHON, STRANGWAY, 1968
22. OPDYKE, 1961
23. PICARD, 1964
24. ROY, 1963
25. RUNCORN, 1956, 1962


DISTRIBUTION OF PERMIAN DEPOSITS IN NORTH AMERICA AND EUROPE

FIT OF THE CONTINENTS AROUND THE ATLANTIC BASED ON: E. BULLARD J. E. EVERETT A. GILBERT SMITH, 1965

PALEOGEOGRAPHY BASED ON: R. BRINKMANN, 1960 S. V. BUBNOFF, 1950 C. H. SCHUBERT, 1955

1. ARMSTRONG, 1957
2. AS, ZIJDERVELD, 1958
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6. CREER, IRVING, NAIRN, 1959
7. DE BOER, 1963, 1965
8. DIETZEL, 1960
9. DU BOIS, 1957
10. EVERDINGEN, 1960
11. FINDHAMMER, DE BOER, 1965
12. GUICHERIT, 1964
13. GUSEV, 1959
14. KALASHNIKOV, 1961
15. KHRAMOV, 1958, 1961
16. LOOKEREN, DE BOER, 1965
17. NAIRN, 1957, 1960, 1963
18. NIJENHUIS, 1961
19. NIJENHUIS, DE BOER, 1965
20. POPOVA, 1963
21. ROCHE, 1957
22. RUTTEN, et al.
23. SCHWARTZ, 1964
24. SCHMUCKER, 1959
25. VAN DER LINGEN, 1960
26. VAN HILTON, 1960, 1962

Permo-Triassic times. The Permo-Triassic paleomagnetic results are summarized in Table 9. This summary of Permian paleomagnetic results from North America and Europe, as well as previous ones (McMahon and Strangway, 1967) show that during the Permian the earth's magnetic field was consistently reversed. However, in the uppermost Permian (Post-Kupfer Schiefer) a brief normally magnetized epoch is reported from the Upper Tartarian Sandstones, Russia (Khramov, 1960) and the Groedener Sandstone, Alps, (Guicherit, 1966). There is good reason to assume that both authors are describing the same magnetic event. The Upper Carboniferous-Permian reversed magnetic interval was named by Irving (1966) as Kiaman Interval.

The pronounced contrast between the long lasting reversed Kiaman interval of Late Paleozoic time and the frequent polarity change of Early Mesozoic times should provide a valuable tool for defining the Paleozoic-Mesozoic boundary.

CONCLUSION

The stratigraphic consistency of reversely polarized zones, the independence of lithology, and the rock magnetic characteristics indicate that the reversed magnetizations in the Upper Buntsandstein (Lower Triassic) are not due to a local effect, but represent reversals of the geomagnetic field at the time of the deposition.

PERMO-TRIASSIC PALEOMAGNETIC DATA

TRIASSIC - NORTH AMERICA

Reference List of Paleomagnetic Directions and Pole
Positions of the Triassic from North America

Location	Rock Units Studied Name	Age	D_m, I_m	Polarity	
Utah 37N, 113W	Springdale Sandstone	Tru(205-180)	338+16		Runcorn, 1956
Arizona 36N, 111W	Chinle Formation	Tru(205-180)	335+43	M?	Graham, 1955
Nevada 35N, 105W	Chinle Formation	Tru(205-180)	33+47	N	Graham, 1955
Colorado 39N, 109W	Chinle Formation	Tru(205-180)	356+66	N	Collinson, Runcorn, 1960
Colorado 39N, 109W	Chinle Formation	Tru(205-180)	34+60	N	Collinson, Runcorn, 1960
New Mexico 35N, 105W	Chinle Formation	Tru(205-180)	16+09	M	Graham, 1955
Utah 39N, 109W	Chinle Formation	Tru(205-180)	156-07	R	Graham, 1955
Utah 39N, 109W	Chinle Formation	Tru(205-180)	160-10	M?	Graham, 1955
Maryland 40N, 77W	New Oxford Formation	Tru(205-180)	334+48	N	Graham, 1955
New Mexico 35.4N, 104.9W	Chinle Formation	Tru(205-180)	33+47	N	Graham, 1955
New Mexico 35.5N, 105.2W	Chinle Formation	Tru(205-180)	16+9	N	Graham, 1955
Arizona 36.8N, 113W	Moenave Fm.(Dinosaur Canyon)	Tru(205-180)	339+30	N	Kintzenger, 1957
Utah 37N, 113W	Moenave Fm.(Dinosaur Canyon)	Tru(205-180)	338+16	N	du Bois, et al., 1957
Utah 37.2N, 113W	Springdale	Tru(205-180)	350.2+38.8	N	Runcorn, 1956
Connecticut 42N, 73W	Lavas and sediments	Tru(205-180)	12+14	N	du Bois, et al., 1957
Massachusetts 42N, 73W	Lavas near Holyoke	Tru(205-180)	10+14	N	du Bois, et al., 1957
Connecticut 42N, 72.6W	Conn. Valley Flows and Dike	Tru(205-180)	8+27	N	de Boer, 1968
Massachusetts 42.5N, 72.6W	Deerfield Flow	Tru(205-180)	26+14	N	Bowker, 1960, de Boer, 1968
Connecticut 42N, 72.6W	Conn. Valley Flows	Tru(205-180)	12+14	N	Bowker, 1960, de Boer, 1968
Pennsylvania 40N, 76.5W	Newark Group Diabase	Tru(205-180)	359.5+23	N	Beck, 1965
Connecticut 42N, 72.6W	East Berlin Fm. Hamden Basalt	Tru(205-180)		N,R?	Kobayashi, Schwartz, 1966
Nova Scotia 43.5N, 66.3W	Lava	Tru(197+32my)	7+41	N	Larochell, Warless, 1966
Nova Scotia 40.5N, 74.5W	Neward group Sediments	Tru(205-180)	357.2+23.5	N	Opdyke, 1961
Nova Scotia 40.5N, 74.5	Neward group Dolerite Intr.	Tru(205-180)	355.8+27.7	N	Opdyke, 1961
Nova Scotia 40.5N, 74.5	Newark group Watchung flows(190my)	Tru(205-180)	8.6+23.5	N	Opdyke, 1961
Massachusetts 42.5N, 72.6W	Meridan Fm., Lava in Granby Tuff Holyoke lava	Tru(205-180)	10+76	N	Irving, Banks, 1961
Greenland 72N, 23W	Kapp Biot Sediments	Trm-u(215-180)	358+68	M	Bidgood, Harland, 1961
Maryland 39.5N, 77.4W	Newark group, New Oxford Fm.	Trm(230-195)	330+35	N	Graham, 1955
New Jersey 41N, 75N	Brunswick Fm. (Basal)	Trm(230-195)	6+28	N	McLaughlin, 1950
Connecticut Valley 42N, 73W	Sediments and lavas	Trl(230-195)	12+14	N&R	du Bois, 1957
Utah 38N, 111W	Moenkopi Formation	Trl(230-195)	139+23	R?	
			151-6	R	Collinson, Runcorn, 1960
Colorado 40N, 109W	Moenkopi Formation	Trl(230-195)	148-7,156-4	R,R	Collinson, Runcorn, 1960
Utah 41N, 109W	Moenkopi Formation	Trl(230-195)	158-4	R	Collinson, Runcorn, 1960
Arizona 36N, 111W	Moenkopi Formation	Trl(230-195)	337+36	N	Collinson, Runcorn, 1960
Arizona 37N, 112W	Moenkopi Formation	Trl(230-195)	349+28	N	Collinson, Runcorn, 1960
Arizona 36.8N, 111.4W	Moenkopi Formation	Trl(230-195)	325+35	N	Kintzinger, 1957
Colorado 38.6N, 108.9W	Moenkopi Formation	Trl(230-195)	154.6+3.0	R_6	Helsley, 1968
			337.1+20.0	N_5	unpublished data
			174.7+6.4	R_5	
			352.1+18.6	N_4	
			177.9+13.3	R_4	
			339.4+16.2	N_3	
			166.4+5.2	R_3	
			40.9+68.8	PF	
			166.4+5.2	R_3	
			343.7+27.8	N_2	
			165.8+6.9	N_2	
			344.1+24.0	N_1	
			158.8+14.4	R_1	
			128.9+52.4	R?	
Arizona, Utah 36-41N 109,112W	Moenkopi Formation	Trl(230-195)	0.2+27.4	N	Runcorn, 1956
Wyoming 42-43,5N 107.5-111W	Red Peak member of Chugwater Fm.	Tlm	120.5+66	I	Picard, 1964
			160-17.5	R	
			348+39	N	
			131.5-54.5	R	
			131.5-54.5	M	
			339+51.5	M	
			150-16	R	
			310+65.5	N	
			127.5-44.5	R	

PERMIAN - NORTH AMERICA

Reference List of Paleomagnetic Directions and Pole
Positions of the Permian from North America

Location	Rock Units Studied Name	Age	D_m, I_m	Polarity	
Colorado 39.6N, 107.4W	Cutler Formation (1)	P(280-230)	140+06	R	Graham, 1955
Utah 37.0N, 110.0W	Cutler Formation (2)	P(280-230)	161+33	R	Graham, 1955
Greenland	Red Sandstone	P	175-37	R	Bidgood, Harland, 1961
Colorado 40N, 105W	Lykins Formation (lower)	Pm-u	170-14		
			138-21	R	McMahon, Strangway, 1968
Colorado 40N, 105W	Lyons-SS	Pm	Unstable	R	McMahon, Strangway, 1968
New Mexico 35.5N, 105.2W	Yeso Formation	Pl-m	143-01	R	Graham, 1955
New Mexico 34.4N, 106.4W	Abo Formation (1)	Pl(280-260)	149+08	R	Graham, 1955
New Mexico 35.3N, 108.4W	Abo Formation (2)	Pl(280-260)	160+55	R	Graham, 1955
Arizona,35N,11.6W;34N,110.4W	Supai Formation	Pl	140+20-40		
			165+15	R	Graham, 1955
Arizona	Supai Formation	Pl	137+22.9	R	Graham, 1956
Utah	Cutler Formation	Pl	54.5+65	N?	Graham, 1956
Arizona	Supai Formation	Pl	146+8	R	Graham, 1955
West Virginia 39.4N, 81W	Dunkard Series	Pl	163+8.4	R(&1N)	Helsley, 1965
Colorado 40N, 105W	Fountain Formation (upper)	Pl	169-24		
			136+6		
			148-6	R	McMahon, Strangway, 1968
Colorado 35.4N, 105.3W	Sangre de Cristo Formation	Cu-Pl(290-250)	175+31	R	Graham, 1955
New Foundland 46.2N, 63.5W	Red Beds (unnamed)	P-C	174+7	R	Roy, 1963, Black, 1964

Tu = Upper Triassic
Tl-m = Lower to Middle Triassic
P-T = Permo- Triassic
P = Permian
Pl = Lower Permian

T = Triassic undifferentiated
Tl = Lower Triassic
Pu = Upper Permian
Pl-m = Lower to Middle Permian
Cu-Pl = Upper Carboniferous to Lower Permian

TRIASSIC EUROPE

Reference List of Paleomagnetic Directions and Pole
Positions of the Triassic from Europe

Location	Rock Units Studied Name	Age	D_m, I_m	Polarity	
England 53N, 2W	Keuper Marls	Tru(200-180)	33+27	M	Clegg, et al., 1954
England 50.7N, 3.2W	Keuper Marls (Sidmouth)	Tru(200-180)	30+23	M	Creer, 1959
Alps 45N, 11E	Acid Intrusives	Tru(200-180)	26+29	N	Guicherit, 1964
Alps 45N, 13E	Acid Intrusives	Tru(200-180)	18+50	N	Lookeren, 1966
Alps 45N, 11E	Limestone	Tru(200-180)	330+40	N	de Boer, 1963
Alps 46N, 13E	Granite	Tru(200-180)	28,43	N	Guicherit, 1964
Alps 45N, 13E	Sandstone	Tru(200-180)	15,48	N	de Boer, 1963
Spain 43N, 5W	Sandstone	Tr(220-180)	353+57	N	Blackett, et al., 1960
Scotland 55.6N, 5.3W	New Red Sandstone, Arran	Tr(230-180)	214-48	R	Leng, 1955
U.S.S.R. 75N, 108E	Taimyr Peninsula, Red Sandstone	Tr(230-180)	130+68	N	Gusev, 1961
U.S.S.R. 71N, 101E	Siberian Platform, Dolerites(1)	Tr(230-180)	286-59	R	Gusev, 1961
U.S.S.R. 71N, 101E	Siberian Platform, Dolerites(2)	Tr(230-180)	117+64	N	Gusev, 1961
U.S.S.R. 71N, 101E	Siberian Platform, Dikes	Tr(230-180)	303-64	R	Gusev, 1961
U.S.S.R. 71N, 101E	Siberian Platform combined	Tr(230-180)	115+63	M	Irving, 1964
Alps	Acid Intrusives	Trl-m(230-195)	331+40	N	de Boer, 1963
France 49N, 7E	Vosge Sandstone, negative	Trl(230-210)	10+40	N	Nairn, 1960
France 48N, 7E	Vosge Sandstone, positive	Trl(230-210)	218+09	R	Clegg, et al., 1957
France 48.5N, 7E	Vosge Sandstone Combined	Trl(230-210)	25+16	M	Irving, 1964
Germany 45.5-50N, 7.5-9E	Buntsandstein	Trl(230-210)	17+29	M	Nairn, 1960
Germany 50N, 7-8E	Buntsandstein	Trl(230-210)		M	Burek, 1964
Poland	Buntsandstein	Trl(230-210)		M	Birkenmajer, Nairn, 1964
Alps 45N, 11E	Clastics	Trl(230-210)	149-35	R	de Boer, 1963
Alps 45N, 11E	Porphyry	Trl(230-210)	149-39	R	de Boer, 1963
Alps 45N, 11E	Porphyry	Trl(230-210)	333+40	N	de Boer, 1963
U.S.S.R. 59N, 50E	Vitloosian Sediments	Trl(230-210)	222-19	R	Khramov, 1961
U.S.S.R. 48N, 38E	Serebryansk Suite	Trl(230-210)	39+57	M	Khramov, 1961
U.S.S.R. 48N, 47E	Bashunchak Suite	Trl(230-210)	42+56	N	Khramov, 1961
U.S.S.R. 49N, 52E	Tananyk Suite	Trl(230-210)	45+46	M	Khramov, 1961
U.S.S.R. 53N, 52E	Buzuluk Suite	Trl(230-210)	220-51	R	Khramov, 1961
U.S.S.R.	Lower Triassic combined	Trl(230-210)		M	Irving, 1964
U.S.S.R.	Siberian Traps (1)	Trl(230-195)	67+84	M	Feinberg, et al., 1961
U.S.S.R. 66N, 88E	Siberian Traps (2)	Trl-m(230-195)	90+71	N	Feinberg, et al., 1961
U.S.S.R. 67.0N, 88.8E	Siberian Traps (3)	Trl(230-195)	62+76	N	Feinberg, et al., 1961
U.S.S.R. 67N, 92E	Siberian Traps (4)	Trl(230-195)	92+80	M	Feinberg, et al., 1961
U.S.S.R. 63N, 114E	Siberian Traps (5)	Trl(230-195)	179+87	N	Feinberg, et al., 1961
U.S.S.R.	Siberian Traps combined	Trl(230-195)		M	Irving, 1964

PERMIAN EUROPE

Reference List of Paleomagnetic Directions and Pole
Positions of the Permian of Europe

Location	Rock Units Studied Name	Age	D_m, I_m	Polarity	
PERMIAN (280-230 m.y.)					
NE-Spain 43N, 3E	Andesites, Huesca Province	P-Tr	152-22	R	Schwartz, 1964
NE-Spain 43N, 3E	Red Sediments, Huesca Province	P-Tr	250-+51	R	Schwartz, 1964
NE-Spain 42N, 3E	Andesites, Cantrand	P-Tr	163-14	R	van der Lingen, 1960
U.S.S.R. 57N, 54E	Lower Tartarian Sediments (3)	Pu(245-230)	226-44	R	Khramov, 1961
U.S.S.R.	Lower Tartarian combined	Pu(245-230)	223-39	R	Khramov, 1961
U.S.S.R. 61N, 46E	Upper Tartarian Sediments (1)	Pu(245-230)	42+48	M	Khramov, 1961
U.S.S.R. 59N, 51E	Upper Tartarian Sediments (2)	Pu(245-230)	42+48	M	Khramov, 1961
U.S.S.R. 53N, 52E	Upper Tartarian Sediments (3)	Pu(245-230)	46+46	M	Khramov, 1961
U.S.S.R.	Upper Tartarian combined	Pu(245-230)	43+47	M	Khramov, 1961
U.S.S.R. 57.5N, 55E	Kazanian Red Sediments (1)	Pu(255-235)	222-42	R	Kalashnikov, 1961
U.S.S.R. 57N, 55E	Kazanian Red Sediments (2)	Pu(255-235)	229-44	R	Kalashnikov, 1961
U.S.S.R. 57N, 55E	Kazanian combined	Pu(255-235)	227-43	R	Kalashnikov, 1961
U.S.S.R. 57.5N, 56E	Ufimian Red Sediments (1)	Pu(260-245)	220-38	R	Khramov, 1958
U.S.S.R. 56N, 55E	Ufimian Red Sediments (2)	Pu(260-245)	228-40	R	Khramov, 1958
U.S.S.R. 57N, 55.5E	Ufimian combined	Pu(260-245)	224-39	R	Khramov, 1958
U.S.S.R. 54N, 52E	Lower Tartarian Sediments (1)	Pu(245-230)	222-39	R	Khramov, 1961
U.S.S.R. 61N, 45E	Lower Tartarian Sediments (2)	Pu(245-230)	220-35	R	Khramov, 1961
Alps 45N, 11E	Bolzano Porphyry	Pu(260-245)	150-22	R	de Boer, 1965
Alps 45N, 11E	Bolzano Porphyry	Pu(260-245)	151-29	R	de Boer, 1965
Alps 45N, 11E	Bolzano Porphyry	Pu(260-245)	158-31	R	de Boer, 1965
Alps 46N, 12E	Grodenes Sandstein	Pu(260-245)	332+26	M	Guicherit, 1964
Alps 46N, 14E	Grodenes Sandstein	Pu(260-245)	35+24	M	Guicherit, 1964
Alps 45N, 11E	Bolzano Porphyry	Pu(260-245)	330+37	M	de Boer, 1963
Alps 45N, 11E	Bolzano Porphyry	Pu(260-245)	327+29	M	de Boer, 1963
France 46.5N, 4.5E	Montcenis Sandstone	Pm(265-240)	197+06	R	Nairn, 1957
U.S.S.R. 72N, 102E	Ultrabasics of Maymecha-Kotuy	Pm-u(250)	295-68	R	Gusev, 1959
France 48N, 6E	Nideck Porphyry (1)	P(m?)(265-230)	193-07	R	Nairn, 1957
France 43.5N, 6.8E	Esterel Pyromeride R4	P(280-230)	210-16	R	Roche, 1957
France 43.5N, 6.8E	Esterel Rhyolite R3	P(280-230)	217-23	R	Rutten, v. Everdingen, 1957
France 43.5N, 6.8E	Esterel Dolerite	P(280-230)	175-13	R	Rutten, v. Everdingen, 1957
France 43.5N, 6.8E	Esterel Igneous Rocks combined	P(280-230)	201-18	R	Rutten, v. Everdingen, 1957
France 43.5N, 6.8E	Esterel Igneous & Sedimentary Rocks	P(280-230)	207-16	R	As, Zijderveld, 1958
Scotland 55.4N, 4.5W	Mauchline Lavas	P(280-230)	180-04	R	du Bois, 1957
Scotland 55.4N, 4.5W	Mauchline Sediments	P(280-230)	187-06	R	du Bois, 1957
Scotland 55.4N, 4.5W	Ayrshire Kylites	P(280-230)	190+02	R	Armstrong, 1957
West Germany 50N, 8E	Nahe Igneous Rocks (1)	P(280-230)	195-04	R	Schmucker, 1959
West Germany 50N, 8E	Nahe Igneous Rocks (2)	P(280-230)	195-15	R	Nijenhuis, 1961
France 53.9N, 5.7E	Volcanics, Nideck-Donon (2)	P(280-230)	193-13	R	Nairn, 1957
Greenland 72.5N, 23.5W	Sediments	P(280-230)	175-37	R	Bidgood, Harland, 1961
Spain 42.7N, 0.5W	Pyrenean Rocks	P(280-230)	159-14	R	Van Hilten, 1962
Corsica 42N, 8E	Porphyry	P(281)	141+8	R	Nairn, 1963
Corsica 42N, 8E	Porphyry	P(281)	141-8	R	Nairn, 1963
Italy 46.6N, 11.2E	Bolzano Quartz-Porphyry (1)	Pl(280-255)	164-11	R	Van Hilten, 1960
Italy 46.5N, 11.4E	Bolzano Quartz-Porphyry (2)	Pl(280-255)	150-31	R	Dietzel, 1960
W. Germany 49.5N, 7E	St. Wendel Sandstone	Pl(280-255)	181-09	R	Nairn, 1957
W. Germany 48-49N 7-8E	Rotliegende Sediments and Lavas	Pl(280-255)	177+01	R	Nairn, 1960
Norway 59.7N, 10.4E	Igneous Complex of Oslo	Pl(270)	204-36	R	Everdingen, 1960
England 51N, 4W	Exeter Traps	Pl(279)	189-09	R	Creer, 1957
U.S.S.R. 48N, 38E	Donbas Red Sediments	Pl(280-255)	225-09	R	Khramov, 1961
England 55N, 2W	Great Whin Sill	Cu-Pl(281)	188-05	R	Creer, et al., 1959
Poland	Krakow Porphyry, etc.	Cu-Pl(281)	205-16	R	Birkemajer, Nairn, 1964
Alps 46N, 11E	Bolzano Porphyry	Cu-Pl(281)	173-8	R	Nijenhuis in de Boer, 1965
Alps 46N, 11E	Bolzano Porphyry	Cu-Pl(281)	137-8	R	Findhammer in de Boer, 1965
Alps 45N, 11E	Bolzano Porphyry	Cu-Pl(281)	148-29	R	de Boer, 1963
Alps 46N, 11E	Bolzano Porphyry	Cu-Pl(281)	163-23	R	Lookeren in de Boer, 1965

The occurrence of five certain, and probably even more reversely polarized horizons of small thickness in the Middle and Upper Buntsandstone of SW-Germany and the comparison with roughly time equivalent (Skythian) paleomagnetic results obtained in North America show that the geomagnetic field in Lower Triassic times was extremely variable and that its polarity changed frequently. Correlation of the stratigraphic positions of polarity reversals provides a means of determining "time lines" within a stratigraphic sequence. Thus, it is possible to use reversals for local fine stratigraphic studies. Determination of these reversals thus can provide more information regarding relative time of deposition than can facies changes in unfossiliferous sediments alone.

The pronounced contrast between the long lasting reversed Kiaman Interval of Late Paleozoic time and the frequent polarity changes of Early Mesozoic times provides useful data for defining the Paleo-Mesozoic boundary on a worldwide scale.

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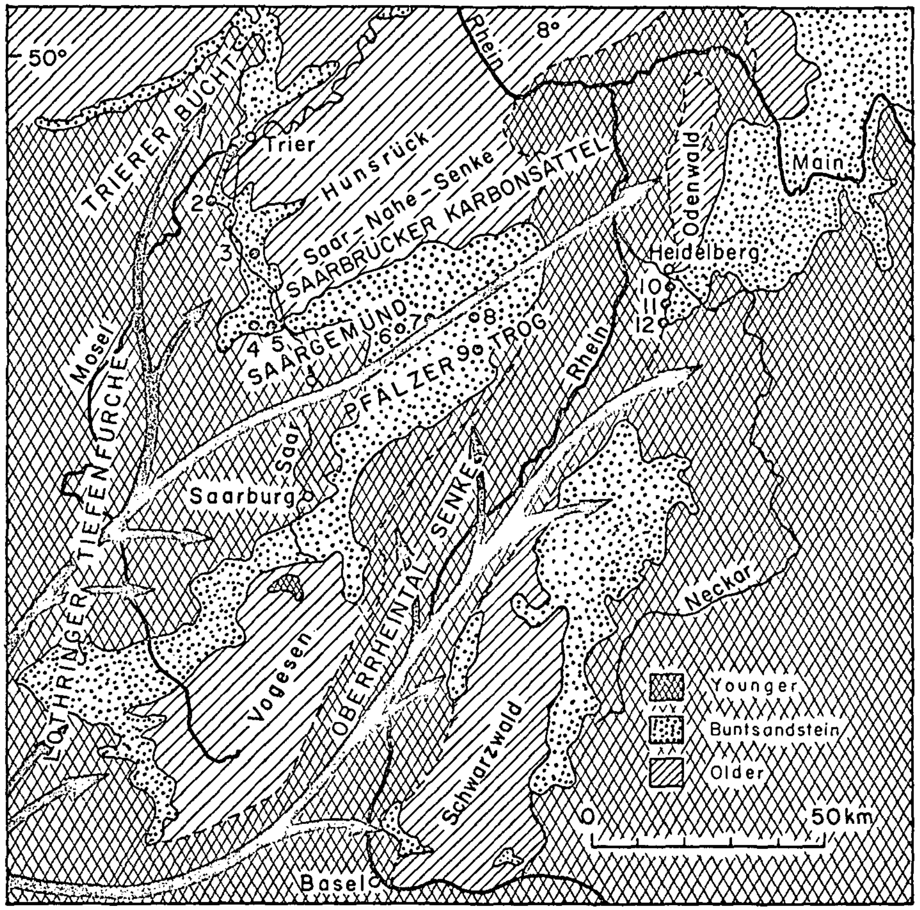

FIG.1: DIRECTIONS OF SEDIMENTTRANSPORT IN THE SW-GERMAN AND LORRAINESE BUNTSANDSTEIN (compiled from PERRIAUX, 1961 and MULLER, 1954)
NUMBERS REFER TO LOCATION OF PROFILES SHOWN IN FIG.10 (CORRELATION-CHART)