A Deviating Permian Pole From Rocks in Northern Italy

D. van Hilten

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Summary

A palaeomagnetic investigation of effusives near Bolzano (southern Alps, Northern Italy) produced a Lower Permian pole situated at 118°·6 W and 51°·4 N. This position diverges strongly from other European Permian poles found up till now. The ordinary explanations failed to account for this divergence, and alpine orogenic displacements of the Bolzano region are held responsible.

By means of a new method for presenting palaeomagnetic data—the method of isoclines—the divergent character of this north-Italian magnetization is visualized.

Abstract of data

Formation investigated

Rock type: Basic and acid volcanics
Age: Lower half of the Permian

Sampling

Location: 11° 25' E, 46° 27' N.
Number: 39 samples; 33 used for determination of pole
Thickness of strata: 500-1000 m
Horizontal spread: 30 km

Stability: Unstable magnetizations of recent age were removed during progressive demagnetization (room temperature)

Mean direction of magnetization:

Declination: N 150° E
Inclination: -31°
α (95 per cent): 4°

Pole position:

magnetic south-pole at 118°·6 W, and 51°·4 N
δ m 95 5°
δ p 95 2·5°

1. Some field and laboratory data

1.1. Introduction.—As part of a thesis by the author (van Hilten 1960) a palaeomagnetic survey has been made of the Lower Permian effusive series near Bolzano, in northern Italy. The results of this survey are briefly reported here.
The lower part of the formation is composed of basaltic tuffs and some mela-
phric lava flows; locally intercalations of conglomerates are found. The upper part
is formed by a mighty complex of more acid, rhyolitic ignimbrites, the thickness of
which ranges from 500 to 1000 m.

This volcanic series has a large extension (some 2500 km²) and it is found at
many places in the south-alpine Dolomites. In the Austrian literature it is known
as the "Bozener Quarzporphyr Platte".

1.2. Sampling.—A total of 39 samples was collected from different stratigraphic
levels of the effusive series. The sampling sites are situated south of Bolzano in the
Adige valley, and north-east of this town in the Isarco valley, covering a horizontal
distance of 30 km. These sampling sites, and the distribution of the samples over
the stratigraphy of the volcanic series are described more fully in the thesis men-
tioned above.

Three of the samples were taken near Lugano (200 km west of Bolzano) but
they have not been used for the determination of the Lower Permian pole as a
tectonic correction for these three samples is not known.

Tectonic deformation of the effusive series in the region around Bolzano is of
minor importance; the series is gently (10°-15°) dipping to the S or SSW.

Much attention was paid to the collection of fresh unweathered samples.

1.3. Age of the formation.—Near Bolzano the Permian consists of
Bellerophon Series—transition to the Triassic
Gardena Sandstones
Tregiowo Series—occurring locally
Effusive Series—acid near the top
—basaltic at its base, with intercalated conglomeratic layers
Metamorphic basement of quartz-phyllites, folded during the Hercynian
orogenesis.

The Bellerophon Series announces the marine transgression of the Triassic.
Its date is accurately known from its fossil content. The Gardena Sandstones often
carry fossil plant remains. They make an Upper-Middle Permian age of this
formation probable.

Off-shoots of the Volcanic Series occur in the Collio Series, a formation which
is found south-west of the investigated region in the Bergamasco Alps. On analogy
of facies this Collio Series is considered contemporaneous with the German Unter
Rotliegendes (Lower Permian). Finally, the conglomerates at the base of the
Effusive Series are composed of reworked metamorphic quartz-phyllites of the
basement. After the Hercynian Orogeny (Upper Carboniferous) these folded
rocks were buried at great depth and metamorphosed there. After their elevation
to the surface and after some peneplanation, the effusion of the volcanic series
began. On account of this lengthy process—burial, metamorphism, peneplana-
tion—an older age than Lower Permian for the volcanic series seems unlikely.
The synchronism with the neighbouring Collio Series affirms the Lower- to Middle
Permian age of the palaeomagnetically investigated Effusive Series.

1.4. Measurement of the remanent magnetization.—The measurements of the
samples were carried out in collaboration with the Geophysical Department of
the Royal Netherlands Meteorological Institute in De Bilt, Holland, under the
supervision of Professor Dr. J. Veldkamp and were made with an astatic magnetometer. Details of this apparatus, and the method of measurement are given by As & Zijderveld (1958) and by As (1961).

From these measurements the directions of magnetization of the samples are derived, expressed as a declination and an inclination. The declination is taken from north to east, and the inclination is considered positive when the direction of magnetization points downwards. The directions of magnetization of the 39 samples are presented in stereographic projection in diagram A of Figure 1. It is seen that the majority of these directions is situated in the upper hemisphere of the south-eastern quadrant of the stereographic projection.

1.5. Removal of soft magnetization.—The samples were exposed to alternating magnetic fields (50 c/s) of stepwise increasing intensity. This progressive demagnetization showed that in many instances the remanent magnetization is composed of two components, a soft magnetization with low coercive force, and a hard magnetization with a higher coercive force.

The graph and diagram of Figure 2 show a curve of demagnetization of one of the samples, which is representative of the rock specimens studied. It demonstrates that the soft magnetization was removed completely during the demagnetization when the intensity of the alternating magnetic fields exceeded a value of 500 oersted. The direction of the vector of the remaining hard magnetization is not affected by still stronger fields; they only decrease the length of this vector.

In general we are only interested in the thermo-remanent magnetization of a sample as it represents the declination and inclination of the magnetic field which was active during the cooling down of the volcanics. Judging from its high coercive force, the hard magnetization is the desired thermo-remanent magnetization; its direction may be reconstructed from the presented graph (full line in Figure 2) and from the diagram. The soft magnetization with low coercive force entered the rock in later times, for its direction (dotted line in the graph of Figure 2) coincides with the direction of the present-day geocentric axial dipole field of northern Italy.

Similar results were reached by this method by As & Zijderveld (1958) and by Van Everdingen (1960).

It is emphasized that only from a curve of demagnetization may it be decided whether a thermo-remanent magnetization is present and reliable. Three of the samples did not produce a reliable direction of magnetization, as judged from their curves of demagnetization, and, consequently, they have not been used for the determination of the mean direction of magnetization.

1.6. Correction for geological dip of the flows.—In the entire region covered by the sampling, the formation is dipping uniformly 10°–15° to the S or SSW. In Figure 1b the directions of the thermo-remanent magnetizations have been brought together, after the required tectonic correction to eliminate the present-day geological dip of the strata has been made.

For the three samples taken near Lugano the geological dip of the volcanic flow was not known, and these samples are therefore not shown in Figure 1b.

As compared to diagram A of Figure 1, the concentration of the data in diagram B has notably increased. This is due to the removal of the soft magnetization from the original measurements of diagram A. As the direction of this soft magnetization was parallel to the direction of the present-day magnetic field in northern Italy, the directions of magnetization have moved away from the direction of this present-
FIG. 1.—Directions of magnetization, plotted in stereographic projection.

A Primary measurements, before demagnetization and tectonic correction
B Stable Permian directions, after demagnetization and tectonic correction
  • Upper hemisphere (negative inclination)
  ○ Lower hemisphere (positive inclination)
  + Mean direction of magnetization, with cone of confidence.
day magnetic field. In the diagram of Figure 2 this movement was observed also, during the stepwise demagnetization of one of the samples, which appeared to withdraw gradually from this direction (G.A.D. in Figure 2). However, part of the movement in diagram B must be attributed to the tectonic correction, which is accidentally almost parallel to it.

1.7. Mean direction of magnetization.—The mean value was calculated of the 33 tectonically corrected directions of hard (thermo-remanent) magnetization, as shown in diagram B of Figure 1. This mean direction is: declination N 150° E; inclination -31°.

The of the cone of confidence ($P = 0.05$) comes to 4°.

This direction of magnetization differs notably from the value obtained from another investigation of this rock series, by Dietzel (1960). For he found a declination of N 164° E, and an inclination of -10°5. This difference is most remarkable, for the rock investigated by him is the same effusive series of the Lower Permian; sampling was carried out by Dietzel in an adjacent area, the Merano region, where the tectonic position of the formation is identical. Furthermore, the same methods of measurement and the same instruments were used by him.

A comparison of the primary measurements of both authors (Figure 1a of the present paper, and Figure 29 of Dietzel 1960) shows that a difference is already observable in the initial stages of the surveys. For in our Figure 1a the directions are found in the upper hemisphere of the south-eastern quadrant, whereas in Dietzel's Figure 29 the majority occupy positions in the lower hemisphere; their scatter is also notably greater than in our Figure 1a.

This difference is encountered through all stages of the investigations, and it leads finally to the different result (direction of magnetization and Permian pole position) obtained by both authors. It is, therefore, not caused by a different method of measurement, but it must be imputed to a difference in the initial material with which the investigations started.

Dietzel's cluster of measurements (Figure 29, op. cit.) has an elongated shape of roughly elliptical outline. In the stereographic projection the length and direction of the longer axis of this ellipse coincide with the great circle between two special points: the direction of the present-day magnetic field in northern Italy (N 0° E, incl. 65°) and the direction of magnetization as found by the present author (N 150° E, incl. -31°). This shape of Dietzel's cluster indicates strongly that his samples contained a larger additional component parallel to the present-day magnetic field. This component seemed also to have a higher coercive force, as Dietzel's directions of magnetization after demagnetization occupy still a lower position in the stereographic projection, that is they are nearer to the direction of the present-day magnetic field than in our case. This opinion is supported by the curves of demagnetization given by Dietzel: his samples do not seem to be cleaned completely of additional components, as his curves are not heading for the origin of the ordinate system, as in the presented curve of Figure 2.

It is suggested that Dietzel's samples were taken from a more weathered rock. By the chemical changes accompanying weathering, a new remanent magnetization may originate (chemical magnetization) parallel to the present-day magnetic field (Cox & Doell 1960). The stability of this newly acquired magnetization is great (high coercive force), and it is affected in a similar way by alternating demagnetizing fields as the thermo-remanent magnetization; this implies that the two magnetizations cannot completely be separated.
Fig. 2.—Representative example of progressive demagnetization, using alternating fields of 0-25-50-75-100-150-200-250-300-400-500-700 to 900 (peak value) oersted.
(For details see opposite page.)
1.8. The Lower Permian pole.—From the mean direction of magnetization the position of the geocentric axial dipole field during the Lower Permian may be calculated. Its magnetic south-pole was situated at

118°-6 west of Greenwich,
51°-4 northern latitude,

and it indicates a reversed magnetic field at that time. The semi-major and semi-minor axes (δm and δp respectively) of the 95 per cent confidence oval around this pole position amount to 5° and 2°-5 (see Figure 3).

2. Review of explanations for the divergence of the Bolzano pole

The position of the Lower Permian pole of Bolzano differs notably (50° over a great circle) from the average of Permian poles obtained so far from other European sampling sites. The latter form a cluster, the centre of which is situated at 169°-5 E and 43° N. Rather divergent pole positions are occupied also by poles derived from the volcanic and sedimentary rocks of the Estérel (southern France; Nos. 5, 6 and 7 in Figure 3) and of the Spanish Pyrenees (No. 4 in Figure 3).

At least two, essentially different, explanations for the divergent position of the Lower Permian pole of Bolzano may be advanced:

1. The direction of magnetization is not representative of the Permian geocentric axial dipole field.
2. The tectonic unit to which the investigated rocks belong has undergone a post-Permian displacement.

First we shall review the factors which might have caused the rocks to acquire a direction of magnetization divergent from the Permian geocentric axial dipole field.

2.1. Influence of secular variation on the ultimate result.—The sampling of the rock series covers a stratigraphic thickness of over 1000 m. The chemistry of the series develops from basaltic near its base, towards rhyolitic near the top of the formation. In many instances we could observe periods of reworking and re-sedimentation between the individual flows. Any of these three facts apart suggests that a considerable lapse of time (i.e. much more than the period of a secular variation) is required for the laying-down of the entire volcanic series.

GRAPH:
The a (vertical) and c (E–W) components plotted against the b (N–S) component.
Dashed line: Course of progressive demagnetization
Full line: Stable Permian direction of magnetization (higher coercive force)
Dotted line: Additional magnetization (lower coercive force). Its reconstruction in the upper part of the graph produces a vector dipping 65° to the north, which is the direction of the present-day geocentric axial dipole field in northern Italy.
Scale unit in e.m.u.

DIAGRAM:
In the lower hemisphere of the stereographic projection the direction of magnetization moves away from the present-day geocentric axial dipole field (G.A.D.) along a great circle through this point.
The mean direction of magnetization therefore, averaged over the thickness of the sampled formation, will be free of influences of secular variation and its divergent character cannot be attributed to this factor.

2.2. Special magnetic minerals.—The changing chemistry displayed by the formation makes it unlikely that the magnetic minerals are of one special Fe/Ti ratio. Such a special ratio may be considered responsible for divergent magnetizations, though up till now it is known only to have caused a change of polarity, not intermediate aberrant values as in the present case.

2.3. Magnetostriction.—No great tectonic stresses have been active on the investigated formation, neither during nor after its cooling. Over an extension of more than 2 500 km² the volcanic series forms a flat, thick, and rigid plate, slightly saucer-shaped, in which no folding took place. Only near its borders—carefully avoided when sampling—this plate is locally intensely faulted. During the final stage of the alpine orogeny the formation was tilted some 10–15° towards the south, which caused only the overlying sedimentary formations to be folded under gravity on the south-inclined slope.

2.4. Tectonic correction for dip of the volcanic flows.—This leads us to the uniformly 10–15° south-dipping inclination of the volcanic series in the area covered by the sampling. Besides, from my elementary field observations, this uniform inclination can be deduced also from the line of outcrop of the formation from geological maps of the region.

2.5. Stability of the Permian magnetization.—The progressive demagnetization procedure, as developed by the Geophysical Department of the Royal Netherlands
Meteorological Institute at De Bilt allowed two magnetizations of different stability (coercive force) to be distinguished. As shown in Figure 2 the two directions of magnetization of each sample can be reconstructed from the demagnetization curves. The magnetization with the higher coercive force is most likely to be a thermo-remanent magnetization, and therefore of Permian age. The direction of magnetization with the lower coercive force appeared to coincide with the direction of the recent geocentric axial magnetic dipole field of northern Italy. For all samples treated in the paper similar curves were drawn. For three samples only, the curve of demagnetization did not run towards the zero-point of the ordinate system, and

<table>
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<th>Sampling site</th>
<th>Age*</th>
<th>Pole position</th>
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<tr>
<td>ENGLAND</td>
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<td>Exeter volcanics</td>
<td>?</td>
<td>E 164</td>
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<td>?</td>
<td>E 175</td>
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<td>?</td>
<td>W 153·5</td>
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<td>sedim.</td>
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<td>51·5 N</td>
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<td>Estérel, R4</td>
<td>L?</td>
<td>E 142</td>
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<td>E 144</td>
<td>As &amp; Zijderveld, 1958</td>
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<td>M?</td>
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<td>E 157</td>
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<td>E 174</td>
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<td>E 165</td>
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<td>U</td>
<td>E 178</td>
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<td>sedim.</td>
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<td>L</td>
<td>W 146</td>
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<td>Bolzano porphyries</td>
<td>L</td>
<td>W 118·5</td>
<td>van Hilten, 1960</td>
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<tr>
<td>M Mean pole of Europe</td>
<td>L</td>
<td>E 169·5</td>
<td>from poles 1, 2, 3, 8, 9, 10, 11, 12, 13, 14 and 15.</td>
</tr>
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* U: Upper Permian
L: Lower Permian
M: Middle Permian
? : not differentiated
these three directions have been eliminated from the calculation of the mean direction of magnetization.

After the removal of the unstable, soft magnetization, with its lower coercive force, the remaining vectors of the stable, hard magnetizations displayed a better concentration than before the demagnetization tests.

2.6. A deviation of the Permian magnetic field from the geocentric axial dipole field does not seem probable in view of the other nearby central European sampling sites (see Figure 4) which provide a regular series of measurements conforming to the assumptions of a geocentric axial dipole field. They indicate in no way the abrupt change in declination (about 45°) and in inclination (some 30°), as shown by the North Italian measurements.

2.7. Displacement of the tectonic unit of Bolzano.—The divergency of the North Italian pole is not satisfactorily explained by any of these mentioned factors. We are forced, therefore, to accept the other type of explanation: a post-Permian displacement of the tectonic unit of which the investigated formation forms part. Bolzano is situated in an orogenic region, so displacements are not altogether impossible. As we are considering an alpine orogenic region, a displacement is most likely to be linked to some stage of the alpine orogenesis.

3. The Permian magnetic field of Europe, presented by isoclines.

The conventional procedure for estimating the displacement of an area from which a divergent pole position has been derived, is to shift this aberrant pole towards a well-established cluster of poles. In the present case a shift of our pole 17 (of Figure 3) towards the cluster of European poles would reveal the displacement of the Bolzano region with respect to the European continent. A serious handicap of this method is the difficulty of visualizing the relation between the shift of the pole and the corresponding displacements of the considered area, which is often situated at the opposite side of the globe.

The construction of the path described by the pole is comparatively easy if the Bolzano area is rotated on the spot around a vertical axis. The path corresponding to a dextral rotation of the Bolzano region is depicted in Figure 3; it by no means passes through the cluster of other European poles, but it comes quite close to the virtual poles of the Estérel (5, 6 and 7 in Figure 3). The problem offered by our North Italian pole is not solved by a simple rotation of the Bolzano area.

A better method for reconstructing such displacements is highly desirable for this and other problems in palaeomagnetism.

A number of European virtual poles (1, 2, 3, 8–15 in Figure 3) form a distinct cluster. The centre of this cluster is situated at 169°·5 E, and 43° N (M in Figure 3). It represents the mean European virtual south pole during the Permian. At 90° from this mean pole position we may reconstruct the European Permian magnetic equator, a great circle over the globe. This equator may be looked upon as an isocline, on which the inclination is constantly 0°. On both sides of this equator we can construct two small circles parallel to this equator, representing isoclines on which the inclination will be + 10° and −10°. From the general formula

\[ \tan \phi = \frac{1}{2} \tan I \]

the distance (\( \phi \)) of these small circles from the equator is known. This construction
Location 6 (see Table 1)

-22° Direction of magnetization: declination SW, inclination -22°

FIG. 4.—Reconstruction of the reversed Permian magnetic field in Europe, by means of isoclines of equal magnetic inclination, based on the mean European pole 169.5° E, and 43° N. Directions of magnetization are also plotted on the map, showing their declination and amount of inclination. The locations (underlined) 4, 5, 6, 7 and 17 do not fit in the network of isoclines. The outlines of the landmasses around the Mediterranean have been dashed, illustrating thus their unknown position before the alpine orogenesis.

Further explanation in text.
may be repeated for other values of \( I \) (inclination). The mean European pole position then, is the centre of a number of concentric small circles, and one great circle (the equator).

In Figure 4 part of these isoclines are shown on a map of Europe. The European palaeomagnetic measurements have been plotted also on this map by giving their declination (direction of arrows) and their inclination. The central and northern European measurements are in good agreement with the network of isoclines, and this is not surprising because the isoclines have been derived indirectly from these palaeomagnetic data.

Agreement between isoclines and measurements exists when the declination is perpendicular to the isoclines, and when the inclination corresponds with the interpolated value between two isoclines.

Not in agreement with the isoclines are the palaeomagnetic measurements from the Pyrenees, from the Estérel and from northern Italy. Of course, in Figure 3 these sites produced there also pole positions divergent from the distinct cluster.

A remarkable fact is that these three sampling sites are all situated in—or in the direct neighbourhood of—regions influenced by the alpine orogenesis. We remember that also from other areas outside Europe divergent pole positions were found from rocks in the alpine chains: the Cretaceous—Late Tertiary poles from Japan (Nagata & others 1959), and the Eocene pole from the Rocky Mountains (Cox 1957). Furthermore, investigations in the Pyrenees and the Alps by students of the Utrecht State University are revealing a still increasing number of similar aberrant pole positions. In view of these facts, the occurrence of deviating Permian—Tertiary directions of magnetization in alpine influenced areas seems rather a rule than an exception. An obvious idea is to attempt to explain these deviations by the mechanism which seems to connect them mutually: alpine orogenic movements.

The advantage of the presented method of isoclines is that we do not have to work with virtual pole positions at the other side of the globe, but that we can displace directly the region with the aberrant measurement towards any place where it is in agreement with the isoclines. For if the region has been moved there, its virtual pole position will automatically coincide with the cluster of poles, from which the isoclines have been derived.

From Figure 4 we might try now to find a suitable position for the Bolzano region, where it is in agreement with the European network of isoclines. The \(-31^\circ\) isocline is situated in Norway and Sweden. On geological grounds we can discard this possibility because alpine orogenic movements did not reach so far northward. By assuming a reversal of the (reversed) Permian magnetic field, i.e. a normal Permian magnetic field, we see that the \(+31^\circ\) isocline (running over North Africa) is turned into a \(-31^\circ\) isocline.

Now a southern origin of the Bolzano region is geologically speaking most probable. The majority of alpine geologists favour a northward movement of the south-alpine tectonic unit during some stage of the alpine orogeny, because these movements are clearly indicated by the alpine palaeogeography. Opinions however differ considerably on the magnitude of these displacements and on the mechanism by which they are produced. In general the displacements as advocated by alpine geologists are too small to explain our divergent pole position of northern Italy. Only the estimate given by Carey (1958) approaches the values as suggested by the palaeomagnetic observations from Bolzano. His palaeogeographic and megatectonic considerations predict that the south-alpine sedimentary basin
was situated far from its present-day position. In Figure 4 the relative position
with respect to Europe of the spot favoured by Carey is indicated by a circle, east of
the present-day position of Gibraltar. The arrow indicates the direction of the
decllination there, for a normal Permian magnetic field.

4. Conclusion

The notion that palaeomagnetic data from alpine influenced areas are in general
divergent, suggests that palaeomagnetism may successfully be used for a better
understanding of orogenic displacements and processes.

In the example of northern Italy some qualitative agreement with orogenic
theories was found; quantitatively most estimates offered by orogenic hypotheses
appeared to be too small to explain satisfactorily the palaeomagnetic divergency.

Further systematic investigation of the alpine chains and their surroundings is a
first condition for proving the validity of the proposed relation between orogenic
movements and the deviating poles derived from these regions.

5. Acknowledgment

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