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Palaeomagnetic Data From the Central Part of the Northern Calcareous Alps, Austria

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Abstract. Palaeomagnetic data from the Osterhorngruppe in the Northern Calcareous Alps (NCA) southeast of Salzburg are presented. The investigations were concentrated on the red nodular Adneter Kalk (limestone) of Liassic age which carries a stable natural remanent magnetisation. Rockmagnetic investigations revealed magnetite as the carrier of the remanent magnetization.

The obtained palaeomagnetic results do not contradict a northward shift of the NCA of the order of several hundred kilometres and indicate a clockwise rotation of about 45° of the Northern Calcareous Alps with respect to Eurasia, since the Jurassic. Time of possible shift and rotation are briefly discussed.

Key words: Palaeomagnetism – Rockmagnetism – Adriatic plate – Northern Calcareous Alps – Jurassic – Adneter Kalk.

Introduction

In the last few years, a series of palaeomagnetic data has been published which show an anticlockwise rotation of the Adriatic plate in the Tertiary. The data are based on measurements in several places throughout the Apennine peninsula and the Southern Alps and show rotation angles between 23° and 55° (Hargraves and Fischer, 1959; Van Hilten, 1960; Manzoni, 1970; Soffel, 1972; Zijderveld and Van der Voo, 1973; Lowrie and Alvarez, 1974; Channell and Tarling, 1975; Channell and Horvath, 1976; Vandenberg and Wonders, 1976; Van der Voo and Zijderveld, 1969).

The Austroalpine nappe system of the Eastern Alps is considered to have been part of the Adriatic plate which split off from the Eurasian continent due to the opening of the South Penninic ocean. The question arises whether the Austroalpine region rotated with the main part of the Adriatic plate, or whether there was differential movement between these areas during the Alpidic orogeny.

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To date very few palaeomagnetic data have been published from the Austroalpine region, and only from the Northern Calcareous Alps (NCA). Hargraves and Fischer (1959) established a 20° clockwise rotation for the Lofer area west of Salzburg.

By far the greatest part of the Mesozoic cover of the Austroalpine basement is found in a large décollement nappe, the Northern Calcareous Alps (NCA), which has been thrusted over the Rhenodanubian flysch by gravity gliding in the late Eocene. For geometric reasons, the Northern Calcareous Alps, considered as a whole, cannot have suffered major rotation relative to their basement, during the downgliding process. However, they are dissected into several smaller nappes, slices and blocks (see Tollmann, 1976) which may have rotated individually through larger angles.

Our investigations were carried out in the Osterhorn mountain group which is a flat-lying stable block within the central part of the NCA. Our results, obtained for Jurassic rocks, are in accordance with the Jurassic magnetic direction of Hargraves and Fischer (1959) and the Triassic directions of Soffel (pers. comm.) from other areas of the NCA. Therefore the conclusion seems justified that the data are representative for the NCA throughout their length.

The samples were drilled in the field and oriented in situ with an orientation table and compass. 6 to 8 cores were collected at each site across an area of less than 1 m^2.

Geological Review of the Osterhorn Mountains

Tectonic Relations

The Osterhorn mountain group is situated in the central part of the Northern Calcareous Alps (Salzkammergut) southeast of Salzburg (Fig. 1). This flat-lying, only marginally distorted block belongs to the "Tirolicum" (Tyrolian nappe).

The borders of the Osterhorn block are tectonic ones (Fig. 1) (Plöchinger, 1953, 1973; Tollmann, 1976). To the northeast, it has been thrusted some distance onto the Schafberg unit which is also attributed to the Tyrolian nappe; along the thrust fault, the Wolfgangsee fault, there are the windows of St. Gilgen and Strobl containing members of the Rhenodanubian flysch and the Ultrahelvetic nappes. To the north, the Tyrolian nappe has been thrusted over a very thin nappe slice, the "Bajuvaricum" (Bavarian nappes), which represents the northern margin of the NCA and in turn has been thrusted over the Rhenodanubian flysch. To the west, the Salzachtal fault separates the Osterhorn block from the tectonically more complicated Berchtesgaden Alps. To the south, a complex normal and high angle slip fault separates the tectonically highly contorted zone of the Lammer valley. To the east, the tectonically higher Gamsfeld nappe ("Juvavicum" Unit), borders against the Osterhorn block by a normal fault.

The interior of the Osterhorn block is characterized by the horizontally lying Upper Triassic to Upper Jurassic sequence (Fig. 2). Only the margins

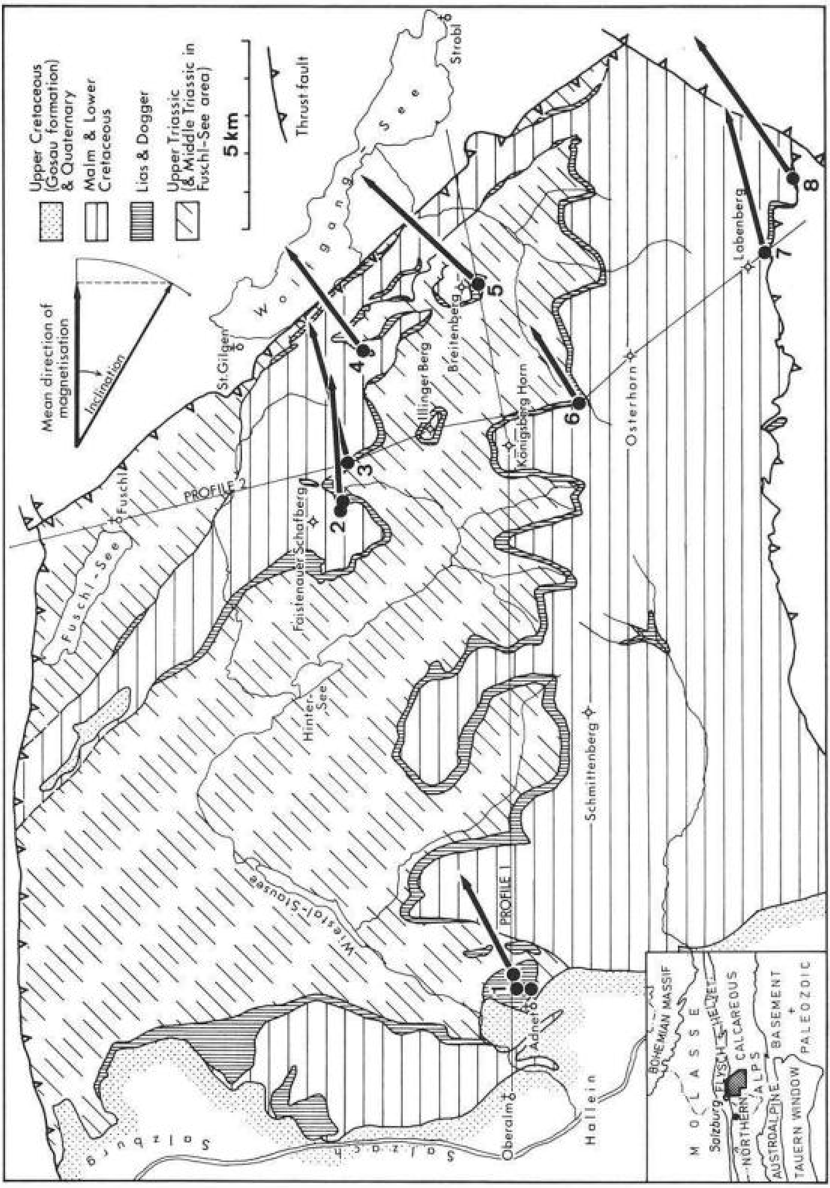

Fig. 1. Geological sketch of the Osterhorn mountains, sample localities and mean directions of magnetisation. Geology after Bittner and Fugger (1907), Mojsisovics and Bittner (1905), Plöchinger (1953, 1972), and Prey (1969)

have been subjected to stronger deformation: this is in particular true along the northeastern border where accompanying faults to the Wolfgangsee thrust fault are responsible for tectonic complications, and along the southern margin. The interior of the block is only slightly folded; in the sampling areas of the Faistenauer Schafberg (no. 2 and 3) there are north-south trending folds dying out towards the south; approaching the NW-SE striking Wolfgangsee

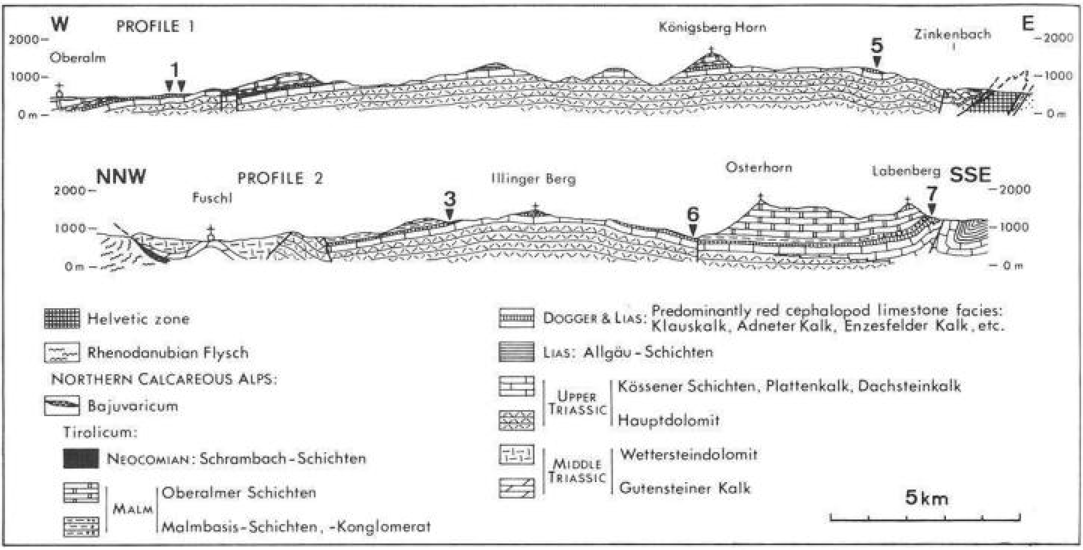

Fig. 2. Geological profiles through the Osterhorn mountains. For location of profiles, see Figure 1

fault, these structures bend parallel to it (Plöchinger, 1973). At the western and eastern margins of the Osterhorn block the rock sequences are downwarped.

Stratigraphy

A synoptical description of the stratigraphic sequence of the Osterhorn mountains is given by Plöchinger (1973, 1975) to whom the reader is referred.

The most prominent members of the Osterhorn mountains are the Upper Triassic Hauptdolomit and the Upper Jurassic Oberalmer Schichten. Middle Triassic carbonates are exposed only in the tectonically disturbed Fuschlsee area (Figs. 1 and 2).

The thick Upper Triassic Hauptdolomit sequence indicates a basement steadily subsiding at a rate of 150–200 m/m.y. Towards its top, it gives way to the Plattenkalk and the Rhaetian Kössener Schichten with intercalations of reef buildings.

In the Liassic, the subsidence process continues but becomes inhomogeneous; the Upper Triassic platform decomposes, and becomes faulted and differentiated in basins and swells by tensional processes which are palaeogeographically characteristic throughout the southern domain of the Eastern Alps in the Jurassic.

The Liassic sequence consists of grey and red limestones and marls. The grey facies changes vertically and laterally into the red which is characterized by low sedimentation rates and subsolution (Jurgan, 1969). The Liassic of the Osterhorn mountains does not exceed a few tens of metres. The grey facies includes partly siliceous marls ("Fleckenmergel") and skeletal and nodular limestones, which contain flints in places. The red facies is mainly represented by the nodular cephalopod limestones (Adneter Kalk), also flint-bearing in

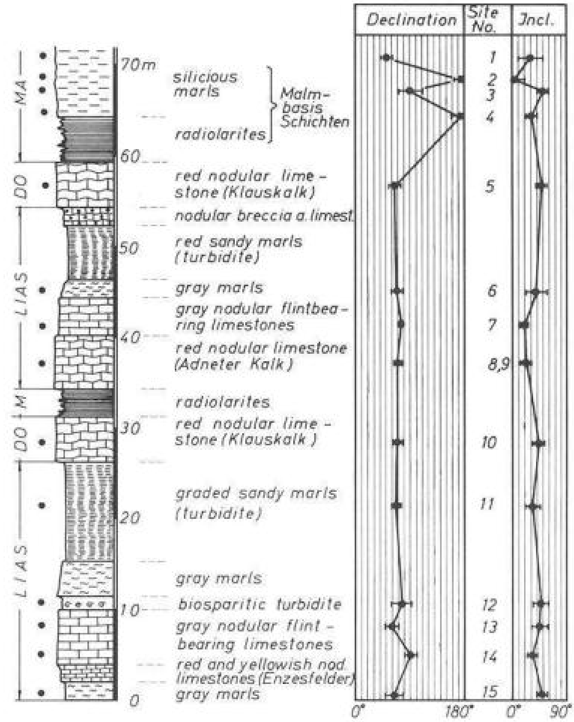

Fig. 3. Geological sequence in the Saubachgraben (sampling locality no. 3) after Plöchinger (1973, 1975) and palaeomagnetic results. Note the consistency of the palaeomagnetic results through the olistolite repetition

places. In the Saubachgraben (locality 3; Fig. 1) turbidites occur in two horizons (Plöchinger, 1973, 1975) (Fig. 3). The relationships in the are of Lofer (black spot in inset of Fig. 1) are well comparable (Hargraves and Fischer, 1959) with the NCA.

Dogger has recently been proved by fossils in the Saubachgraben (loc. 3) by Plöchinger (1975) in the form of red nodular cephalopod limestone rich in Mn-Fe-oxides (Klauskalk). This member is only a few metres thick.

The Malm starts with red radiolarite (Ruhpoldinger Radiolarit) which changes into variegated siliceous marls ("Malmbasis-Schichten" of Plöchinger, (1973)). This facies already reflects a deep-water environment although no absolute figures for the water depth can be given. In the "Malmbasis-Schichten" there are repetitions in the sequence (Fig. 3) which are explained by Plöchinger (1973, 1975) as synsedimentary gliding masses (olistolites) (cf. Vortisch, 1937). In the southern Osterhorn mountain group, the "Malmbasis-Schichten" grade laterally into a clastic facies, the Tauglboden-Schichten. These consist of coarse local breccias transported by olistostromes, fluxoturbidites, and turbidity currents from a southerly direction (Schlager and Schlager, 1973).

The "Malmbasis-Schichten" are topped by the mighty Oberalmer Schichten (Kimmeridgian to Portlandian), flint-bearing micritic limestones which dominate in the southern Osterhorn group.

In the Neocomian, the sequence continues with deep-water marls (the Schrambach Schichten) preserved in synclines of the Osterhorn mountains.

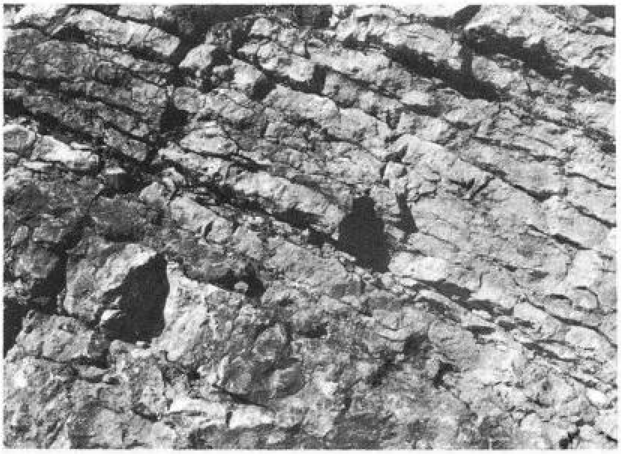

Fig. 4. Typical outcrop of red nodular Adneter Kalk. Königsbachtal (loc. No. 6)

Selection of Rock Types for Palaeomagnetic Measurements

Due to its thickness, the Hauptdolomit crops out over a large area in the central, western and northwestern parts of the Osterhorn mountain group. Because the magnetisation is very weak ($<5\times10^{-8}$ G) no reliable measurements and interpretation can be made.

The other prominent member of the Osterhorn mountains, the Oberalmer Schichten, is also weakly magnetised, and outcrops are not easily accessible (with the drilling equipment) as they form the upper parts of the mountain group.

Thus, our investigations were concentrated in the Liassic beds, and there predominantly in the red Adneter Kalk facies which, in general, does not exceed a few metres in thickness. The Adneter Kalk has been preferred for the following reasons: (a) it is the only member between the Triassic and the Ruhpoldinger Radiolarit that is persistent throughout the Osterhorn mountain group; (b) its NRM shows stable components during progressive thermal demagnetization; (c) it is possible to get good drill cores out of these limestones. Disadvantages are errors with the measuring of the bedding plane due to its nodular development (Fig. 4), poor and limited outcrops and landslips at several localities.

At localities 2, 3, and 4 (Fig. 1), siliceous marls of the Lower Malm, Dogger limestone (Klauskalk) and different members of the Liassic were also sampled.

The Lower Malm radiolarites possess satisfying rockmagnetic properties but it was impossible to attain suitable specimens because of the hardness of the rock, and its subsequent disintegration upon drilling.

Depositional Environment of the Red Nodular Limestones

The red nodular limestones of Liassic (Adneter Kalk, Fig. 4; pale yellowish variety: Enzesfelder Kalk) and Dogger (Klauskalk) age are rich in cephalopods which are largely responsible for the nodular appearance of the rock. The

Adneter Kalk is worked in quarries near Adnet (locality 1) as decorative plate "marble". An abandoned quarry is situated near the top of Breitenberg (locality 5).

The red limestones are characterized by low rates of sedimentation (in the order of less than 1 m/m.y.), subsolution and rearrangement of particles and fossil skeletons. In places, the limestone is developed as an intraclastic breccia.

Some of these properties would suggest that the red limestones are not well suited for a palaeomagnetic investigation. However, the directions of stable remanence are fairly consistent (Fig. 3). The tight clustering of stable NRM directions is possibly caused by the low sedimentation rate which allowed concentration and tight orientation of the magnetic particles. If, however, the magnetite, which is definitely the carrier of the characteristic remanent magnetisation (ChRM), was formed by reduction of the primary haematite in a diagenetic stage, good groupings of the directions of the ChRM could also be explained.

The depositional environment of the red limestones is considered to be that of a swell facies rich in bottom currents in an oxygen-rich water; the corresponding basin facies are the grey marls ("Fleckenmergel" or Allgäu Schichten) which are poorly developed in the Osterhorn mountains.

The alternation of the prevailing red and the grey limestone facies, thin marl beds and turbidite layers reflects the unsteady and changing conditions during the Liassic between swells, slopes and local basins. The water depth will have been that of a deeper littoral (50–100 m) for the condensed red limestones according to Wendt (1970) who based his results on the fauna, and a few hundred metres at most for the small local basins.

The Middle Jurassic Klauskalk is extremely condensed (missing in parts?) which is considered to be possibly due to bottom currents. The water depth will have been increasingly deeper thus approaching the deep water environment of the Oxfordian (Ruhpoldinger Radiolarit).

Palaeomagnetic Investigations

The palaeomagnetic investigations started in 1974 with the sampling of two profiles in the Schafbachgraben (locality 2 in Fig. 1, 20 sites) and Saubachgraben (locality 3, 14 sites). The results are presented in Figure 3. The profiles covered the Lias, Dogger and lower Malm, and detailed rockmagnetic studies were carried out to find the carrier of the remanence. For this purpose, high temperature, low temperature and saturation magnetisation experiments were carried out (Fig. 5). As shown in Figure 5a and b, the high temperature experiments establish magnetite (Fe_3O_4) with a maximum blocking remperature of about 540–550° C as the carrier of the NRM.

However there is a remarkable difference in the behaviour of the samples shown in Figure 5a (representing the Malmian) and Figure 5b (representing the Liassic Adneter limestones). Whereas Figure 5a establishes only magnetite with one blocking temperature at about 540° C, Figure 5b shows two blocking temperatures at about 320° C and 540° C. Using the susceptibility curves as an indication of chemical changes we can see that in the Malmian material

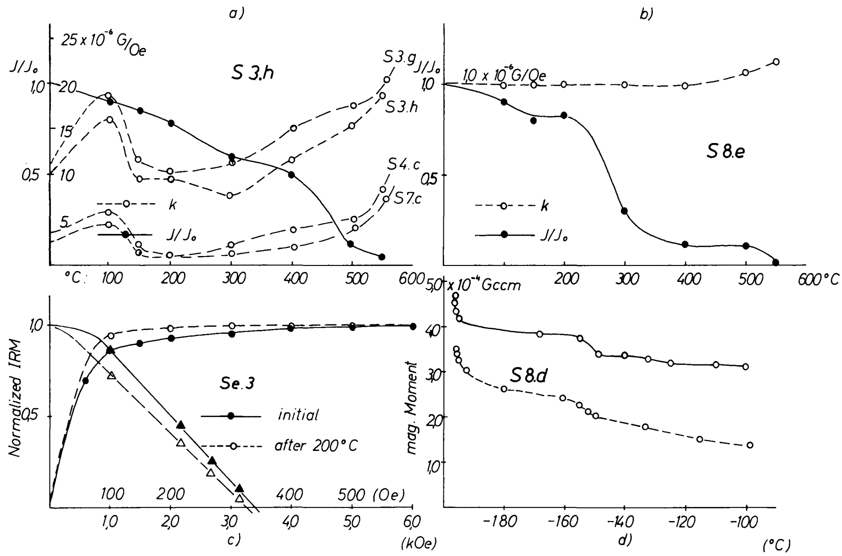

Fig. 5a–d. Results of the rockmagnetic investigations. (**a**) and (**b**) show the high temperature behaviour (normalized intensity and volume susceptibility versus temperature) of typical members of the investigated sequence; note in (**a**) that the characteristic change in susceptibility at 100° C occurs in the majority of the samples. (**c**) saturation magnetisation and coercive force versus field strength, and (**d**) low temperature-transition for Fe_3O_4 at −143° C

in Figure 5a there seems to be ironhydroxide (FeOOH) as a second mineralisation. Limonite is prooved by microscope analysis but there is no evidence if it is a mixture of α and γ ironhydroxide in the sence of Millot (1970, p. 22) or if it is pure α-FeOOH or γ-FeOOH. In Figure 5b the susceptibility curve shows clearly that no chemical change occurs in the red sediments at about 320° C which shows that there is no other mineralisation besides magnetite. This means that both blocking temperatures are due to magnetite and that the reduced blocking temperature at about 320° C is caused by yet unknown changes in the chemical composition.

In Figure 5c the saturation magnetisation behaviour is presented. It can be seen that in the initial stage the material was saturated at 4 kOe which is a bit high but nevertheless typical for magnetite. Therefore, and for the fact that the susceptibility curve (Fig. 5a) indicates some additional effect from another mineralisation, the samples were heated up to 200° C and the saturation magnetisation behaviour was again tested. The dotted line clearly shows saturation at 2 kOe. This effect is in good agreement with the susceptibility curve in Figure 5a which shows some chemical changes in this temperature range.

In Figure 5d a typical curve for low temperature experiments is presented. The curve shows two remarkable anomalies, one at −195° C and the other at around −148° C. The first is due to the fact that a large sample has to be used to get a strong signal, and the temperature gradient between the surface of the sample and the centered thermo couple causes a decrease of the magnetic

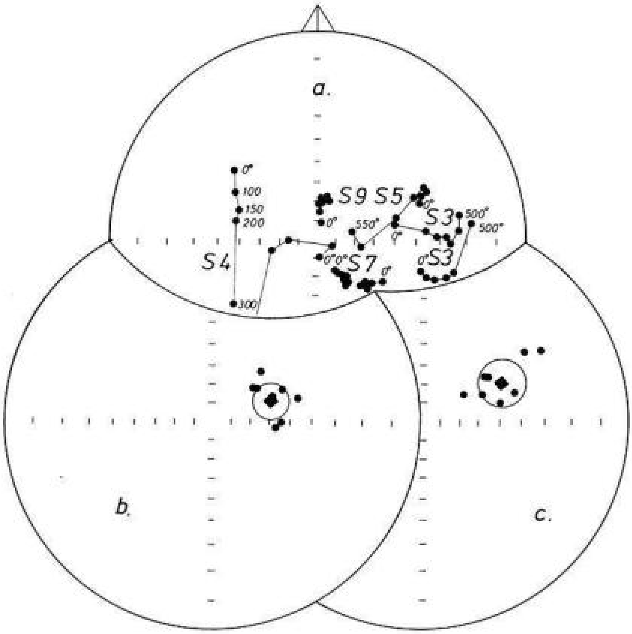

Fig. 6a–c. Stability results. (**a**) Stability of the direction of NRM during thermal demagnetisation. (**b**) Mean of the site mean values before and (**c**) mean of the site mean values after bedding correction

moment(Mauritsch and Turner, 1975). The second is is the true low temperature magnetic transition for magnetite.

The tests carried out establish that the main carrier of the NRM is magnetite and there is no clear evidence that any other mineralisation is of importance. Even in the red coloured limestones of the Adnet type there was no magnetic effect caused by haematite. Haematite seems to occur in a superparamagnetic stage at room temperature (Fig. 5d).

We cannot decide whether the remanence (NRM) has been formed by depositional or chemical processes. To test the stability of the direction of NRM, a large number of pilot samples were heated stepwise (0–550° C). The direction was measured after each step with a spinner magnetometer (digico, Molyneux, 1971) and afterwards plotted on a stereogram (Fig. 6a). In this figure the pilots S3 and S4 represent the Malmbasis Schichten. They are extremely unstable. The sample S5 covers the Dogger, S7 (grey, nodular flint bearing limestone) and S9 (Adneter Kalk) the lower Lias and it can be noticed, that the sample S5 remains stable up to 300°C. Above this temperature and up to 550° the direction moves and no other stable direction has been found. Above 550°C the intensity was too low ($<2\times10^{-8}$ G) so that further demagnetisations became impossible. The samples S7 and S9 are very stable over the whole range of thermal cleaning, making it easier to decide which material should be used for further work.

Concluding the rockmagnetic investigations, one observes that above 100° C of thermal cleaning, the suitable material (Liassic members) remains stable up to 500° C. The Malmbasis Schichten were found to be extremly unstable and were rejected.

Palaeomagnetic Results

At localities 2 and 3, the Jurassic sequence was sampled including various Liassic members, Klauskalk (Dogger), and the Malmbasis Schichten (lower Malm). Figure 3 shows the profile of the Saubachgraben which has been described geologically in detail by Plöchinger (1973, 1975).

The upper half of the profile (Fig. 3) cuts an olistolite (Plöchinger, 1973, 1975) and it is remarkable that the directions of the ChRM are quite uniform throughout the profile, independent of the rock type.

Major disturbance occurs in the Malmbasis-Schichten at the top of the profile. This is probably the top part of the olistolite, and therefore the disturbance is considered to be due to perturbation during the gliding process. The good correspondence of the data of the lower part of the profile and the olistolite suggests that the gliding occurred without any rotation.

Members of the Dogger were sampled only in the Saubachgraben (loc. 3).

Malmbasis Schichten were sampled at localities 2, 3 and 4. At all localities, except loc. 4 because of landslips, the red Adneter Kalk was sampled. In addition at loc. 2 and 3 various Liassic members were also sampled, even turbiditic layers (Fig. 3).

The local mean directions are shown in Figure 1, Figure 7 and Table 1 show the mean directions with the α_{95} cones of confidence for the Liassic members only.

The magnetic intensity (NRM) for the Adneter Kalk varies between 1×10^{-5} and 5×10^{-7} G.

The α_{95} cones of confidence for individual sites vary between 5° and 20°. The relatively large angels are attributable to the inaccuracy of the measurement of the nodulous bedding planes of certain members.

In the locality Breitenberg the results within a site are very consistent (COFC < 10°) but the local mean direction is (more or less) unsuitable. The reason is that sometimes even a statistical determination of the bedding parameters does not give satisfying results as in these sediments. Furthermore, we

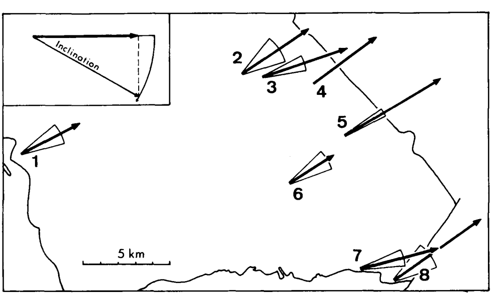

Fig. 7. Distribution of the direction of the characteristic remanent magnetisation for the Liassic sites of the Osterhorn mountain group with the cones of confidence. Loc. 4 shows vector for Malmbasis Schichten, because Liassic members could not be sampled there

Table 1. Palaeomagnetic results from the northern calcareous alps (austria)

	Palaeo Data (Bedding corrected)						
Sampling area	LOC.	DEC	INC	N(Sites)	k	COFC.	Sampled members
Lofer[a]		47.9	50.6	30 cores	70.7	6.5	Radiolarites, Lias
Adnet	1	63.7	56.1	6	26.8	13.1	Adneter Kalk
Schafbachgraben	2	56.4	48.9	6	15.3	17.6	Lias
Saubachgraben	3	71.1	42.3	8	34.1	9.6	Lias
Breitenberg	5	59.3	24.1	6 cores	255.73	4.2	Adneter Kalk
Königsbachtal	6	57.9	63.8	2	417.3	12.2	Adneter Kalk
Ausserlimbach	7	75.7	49.1	2	688.6	9.5	Adneter Kalk
Moosbergalm	8	55.2	30.0	2	228.0	16.6	Adneter Kalk
Mean values Osterhorn Gruppe (7 locations)		62.5	45.1		29.1	11.3	

	Palaeopoloposition for Lofer and Osterhorngruppe			
	Sampling area position		Palaeopoleposition	
Lofer[a]	47,37°N;	12,34°E	LAT.: 53°N;	LONG. = 112°E
Osterhorngruppe:	47,7°N;	13,3°E	LAT.: 37,5°N;	LONG. = 103,4°E

[a] After Hargraves and Fischer (1959)

get the same effect but with lower perturbation for the mean result of the whole area investigated. Figure 6b and c show the mean direction for the Osterhorn mountain group before and after the bedding correction.

Summarizing these details we have found in the area investigated a stable Jurassic magnetisation direction, which is suitable for attempting a geotectonic reconstruction of this part of the NCA.

Conclusions

Our results from Jurassic rocks of the Osterhorn mountain group, which is a stable block within the Northern Calcareous Alps (NCA), are in accordance with those obtained by Hargraves and Fischer (1959) for Jurassic, and Soffel (pers. comm) for Triassic rocks in other areas of the NCA. Therefore, the results are considered to be representative for the NCA throughout their length. To attain coincidence of the computed palaeopole for the Osterhorn mountains with the palaeopoles obtained by Van der Voo and French (1974) for the Jurassic of the European and African continents, it is necessary to rotate and laterally shift the NCA.

Figure 8 shows the Jurassic poles for stable Europe and Africa in their present position, as well as the computed palaeopole (with its cone of confidence) for the Jurassic rocks of the Osterhorn mountains, within the present geographi-

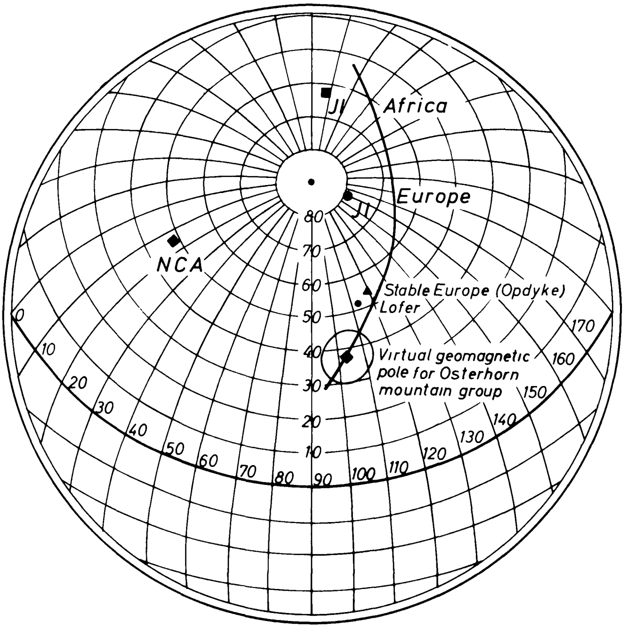

Fig. 8. Positions of lower (Jl) Jurassic magnetic poles for Africa and Europe after Van der Voo and French (1974) within the present geographical grid. Abandoned Jurassic pole for Europe after Opdyke (1960), as well as poles for the Lofer area after Hargraves and Fischer (1959) and for the Osterhorn mountains are shown. NCA: present position of the Northern Calcareous Alps. (Polar error: $dm = 13{,}9$; $dp = 9{,}04$)

cal grid. A major clockwise rotation is evident. The magnetic palaeopoles for Africa and Europe on the one hand and for the Osterhorn mountains on the other do not lie on a small circle centered at the present position of the Osterhorn mountains. Therefore the Osterhorn mountains seem to have not only rotated but also moved laterally since the Jurassic. The lateral shift is necessary to attain coincidence in the inclination of the palaeomagnetic vectors.

Coincidence in the inclination for the Jurassic rocks of the Osterhorn mountains on the one hand and of stable Europe and Africa on the other is realized along a small circle (palaeolatitude) around the Jurassic magnetic pole. Figure 9 shows the position of Europe relative to Africa in the middle Jurassic after Channel and Horvath (1976), based on the results of Van der Voo and French (1974). Palaeolatitudes are shown for the Liassic rocks of localities 1, 2, 3, and 7, and for the lower Malmian rocks of loc. 4. The average of these values is the 30° magnetic palaeolatitude (corresponding to 49,5° inclination) which is shown as a broken line. The palaeolatitudes for localities 5, 6, and 8 are situated too far to the north and south and are therefore impossible palaeopositions for the NCA. The reason for this lies in difficulties with the measurements of the bedding plane at these localities. This does not significantly influence the declination and therefore all values were taken into account in Figure 8.

The mean palaeolatitude (Fig. 9) is computed omitting localities 5, 6, and 8 and is in very good accord with the mean inclination obtained by Hargraves

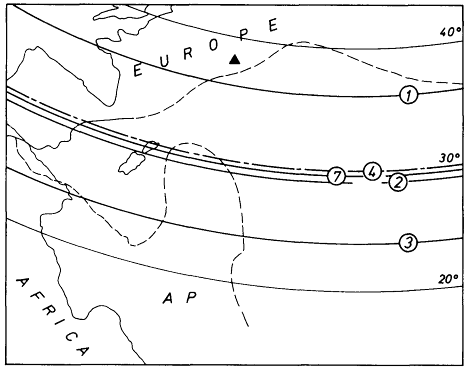

Fig. 9. Reconstruction of the palaeolatitudes for the different sampling areas in the Osterhorn mountain group with the mean latitude of about 30°N which represents also the mean latitude for Lofer area after Hargraves and Fischer (1959). Black triangle indicates the present position of NCA. A.P.· Adriatic plate in the position of Channell and Horvath (1976)

and Fischer (1959) for the Lofer area. The palaeolatitude for this area also is on the broken line, Figure 9.

Theoretically, the NCA could have been placed at any point along the palaeolatitudes whose mean value runs through the wedge of the western Tethys formed by the Eurasian and African continents in the Jurassic.

The authors consider the NCA as a part of the Adriatic "plate" or "promontory" in the Jurassic comprising the autochthonous Apennines, the Southern Alps, and the Austroalpine domain. The Adriatic region has been separated from the Eurasian continent by the opening of the South Penninic ocean (Frisch, 1977). Tensional faulting of the NCA in the early Jurassic reflects this event. The Adriatic plate may have been separated from the African plate by a transform fault or a small ocean whose period of activity is unknown. Channel and Horvath (1976) considered the Adriatic region as a promontory of northern Africa. Our results are consistent with this interpretation although a slightly different position of the Adriatic region is preferred by Frisch (1977). Evidence for the timing of the separation of the Adriatic region from the African plate is poor; Biju-Duval et al. (1977) put this event near the beginning of the Jurassic implying that the Adriatic plate existed from this time on as a separate plate. Channel and Horvath (1976) let the Adriatic region remain as an African promontory up to the late Tertiary. Frisch (1977) presents evidence for the separation of the Adriatic plate from Africa in the Cretaceous.

The palaeoposition of the NCA (Fig. 9) implies lateral shift of the order of several hundred kilometres with respect to Eurasia. The magnetic vectors show clockwise rotation of about 45° relative to the Eurasian plate, and of about 90–100° relative to the African plate (Fig. 8). Progressively easterly palaeopositions of the NCA would enlarge the rotation angle.

If the Adriatic plate formed a coherent unit from the Jurassic on up to the present, the measured magnetisation directions of the autochthonous Apennine, the Southern Alps and the Northern Alps should correlate. This is definitely not the case. The Apennines and the Southern Alps show anticlockwise rotation of 23° to 55° (depending on the paper and the age of the rocks) relative to Europe. This anticlockwise rotation is in course agreement with the movement of Africa since the Jurassic (Channel and Horvath, 1976). The significant deviation in the magnetic orientation of the Austroalpine realm (NCA) from the major part of the Adriatic plate implies decomposition of the plate at some time. Several theoretical possibilities are discussed:

(a) The separation of the NCA from the major part of the Adriatic region occurred earlier than the separation of the Adriatic plate from Africa. This is not supported geologically.

(b) The separation occurred after a common clockwise rotation of the Adriatic plate; while or after overthrusting welded the Austroalpine domain onto the Eurasian continent, (a process which has been finished by the late Eocene), the southern and major part of the Adriatic plate split off and rotated anticlockwise through an angle enlarged for the amount of the preceding clockwise rotation.

(c) The Adriatic plate remained as a unit without significant anticlockwise rotation up to the Upper Cretaceous. The breakoff of the NCA occurred at some time when the Austroalpine realm first came in contact with microcontinents to the north (Middle Penninic zone; Frisch, 1977). The clockwise rotation commenced at this moment and continued during the consequent overthrusting.

(d) The separation of the NCA from the Adriatic plate occurred at some time during the north- or northwestward drift of the Adriatic plate, prior to the collision to the north.

From our results, we are not able to decide whether the rotation of the NCA occurred at the beginning, during, or at the end of the drift. The decision as to which possibility preference should be given, is therefore delayed until more palaeomagnetic data, in particular for variously aged sequences from both sides of the Periadriatic lineament, are available. Drift and rotation of the NCA, however, can be limited to the period between the middle Jurassic and the collision and overthrust of the Austroalpine realm to the north. Frisch (1977) presents a plate tectonics reconstruction which makes decomposition of the Adriatic plate during the Upper Cretaceous most probable; according to this model, preference should be given to possibility (c).

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