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Vorwort

Das österreichische National-Programm für die Arbeiten im Rahmen des Internationalen Geodynamischen Projektes (IGP) bestand in Untersuchungen, die entsprechend den Empfehlungen der Inter-Union Kommission für Geodynamik (ICG) in Zusammenarbeit von geophysikalischen, geologischen und anderen erdwissenschaftlichen Instituten und zum Teil auch in internationaler Zusammenarbeit durchgeführt worden sind. Zur Koordinierung dieser Untersuchungen ist bei der Österreichischen Akademie der Wissenschaften ein Nationalkomitee eingerichtet worden, das auch das gesamte Arbeitsprogramm entwickelt hat und seine Durchführung zu betreuen hatte.

Die im IGP in Österreich durchgeführten Untersuchungen betrafen die Beteiligung an einem seismischen Längsprofil durch die Alpen von Frankreich bis Ungarn zur Klärung der Struktur der Erdkruste in diesem Bereich (1975) und an weiteren seismischen Profilen in der Folgezeit nach dem katastrophalen Beben im Friaul im Jahre 1976, spezielle seismische Untersuchungen in verschiedenen Teilgebieten und im Zusammenhang damit eine wesentliche Erweiterung des seismischen Stationsnetzes in Österreich, verschiedene geophysikalische Traversen mit gravimetrischen, magnetischen und seismischen Messungen, strukturgeologische und geophysikalische Untersuchungen im Bereich der Periadriatischen Naht und des Tauernfensters sowie an Falt- und Störungszonen, Messungen von Krustenbewegungen, Spannungsmessungen, Messungen von regionalen Massenbewegungen im Zusammenhang mit tektonischen Bewegungen, detaillierte Messungen magnetischer Anomalien, paläomagnetische Messungen, spezielle gravimetrische Untersuchungen, Gezeitenuntersuchungen, geothermische Messungen, gesteinsphysikalische Untersuchungen und petrologische Untersuchungen im Zusammenhang mit Geodynamik.

In den folgenden Berichten wird eine Übersicht über die Ergebnisse der im Rahmen des IGP in Österreich durchgeführten Untersuchungen gegeben. Die jedem Beitrag beigegebenen Publikationsverzeichnisse sollen die Quellen für ausführlichere Darstellungen der Ergebnisse vermitteln. Über die Ergebnisse der ersten Halbzeit des IGP ist bereits früher ein Report of Austria on National Activities in the International Geodynamics Project veröffentlicht und der Tagung der ICG im August 1975 in Grenoble vorgelegt worden.

Die Ermöglichung dieser Untersuchungen im Rahmen des IGP ist der Finanzierung durch das Bundesministerium für Wissenschaft und Forschung zu danken. Dadurch wurde nicht nur die Erarbeitung neuer wertvoller wissenschaftlicher Erkenntnisse ermöglicht, sondern auch die interdisziplinäre Zusammenarbeit gefördert sowie der erdwissenschaftlichen Forschung und darunter im besonderen·der geophysikalischen Forschung in Österreich ein starker Auftrieb gegeben.

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für IGP

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GEOPHYSICAL CONTRIBUTIONS TO THE GEODYNAMICS OF THE EASTERN ALPS

by

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With 13 Figures

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1. Introduction

Geodynamic research activities of the Institut für Meteorologie und Geophysik (IMG) of the University Vienna and the Zentralanstalt für Meteorologie und Geodynamik (ZA) were concentrated onto the Alps and adjacent regions to solve various questions of geodynamics and plate tectonics.

They contribute to the knowledge of the structure of the lithosphere as well as of dynamic processes in the past and present. Methodical questions connected with these research objectives have also been investigated.

Geophysical measurements of areal type and along profiles investigated the structure of the underground on a regional scale. In selected areas local surveys were performed to determine the importance of features like faults for geodynamics and plate tectonics. Mainly refraction seismics, gravimetric and geomagnetic methods were used for these projects.

Paleomagnetism and isostatic investigations were the principal tools for studying geodynamic processes during the orogenesis of the Alps. Earthquake seismology, geodetic levelling and earth tide measurements supplied information concerning the recent geodynamic regime in the Alps.

Great emphasis was laid on the synoptic interpretation of data obtained by different geophysical methods. Theoretical investigations as well as instrumental tests experiments concerning measuring techniques have also been performed in order to improve geophysical techniques and to optimize the procedure of joint interpretation of different geophysical methods respectively.

Because many of these projects required considerable input of manpower, instruments and financial support several investigations were executed in cooperation with other Austrian and foreign geophysical institutions.

2. Regional structural investigations

The determination of the size and the physical characteristics of the rigid plate formed by the crust and the uppermost mantle — known as the lithosphere in terms of plate tectonics — and the underlying weaker layer of the asthenosphere is a major goal for investigating the dynamics of the earth.

In addition the regional structure of the crust can be seen as the result of various geodynamic processes during the Alpine orogenesis. Therefore the knowledge of these structures is a valuable instrument for decovering the geodynamics of the Alps.

2.1 The international seismic experiments ALP 75, ALP 77 and ALP 78 (Publications 3, 62, 90)

Various refraction seismic profiles have greatly enhanced our knowledge of the structure of the crust beneath the Alps during the last decades. However, the coverage of the Alps with seismic profiles was not at all uniform, because most of the profiles in the post had been situated in the Western Alps. In addition, these profiles were oriented preferably perpendicular to the strike of the dominating geological features. With the aid of new powerful interpretational methods like ray tracing procedures it became evident at the beginning of IGP that an unequivocal interpretation of these old profiles is not possible. Because of the wide spacing of profiles and stationsit is not possible to distinguish between lateral and vertical velocity variations. This led to the concept of longitudinal profiles, which are oriented parallel with the strike of the main geologic units of the Alps. Thus one is avoiding strong lateral velocity gradients. As the whole length of the Alps is covered by the refraction line, this allows deeper penetration than on short transverse profiles: information on the structure of the lower lithosphere beneath the crust can be obtained as well. The knowledge of the structure at that depth range should give an essential contribution to the understanding of the geodynamic evolution of the Alps and allows very interesting comparisons with the structures beneath older orogens.

The first Alpine Longitudinal Profile (ALP 75) was carried out in 1975 in international cooperation of institutes from Austria, Federal Republic of Germany, France, Great Britain, Hungary, Italy, Switzerland and Yugoslavia with a total of approximately 200 scientists participating.

Starting at the western end at Mont Revard, France the profile follows the strike of the Western Alps in north-easterly direction up to the Wattener Lizum (Torsee) south of Innsbruck. There it turns almost to the East in order to follow the strike of the Eastern Alps and terminates at Körmend, Hungary. In addition to the main line which is 850 km in length and which rather precisely follows the axis of the negative gravity anomaly several shorter profile segments were observed like Judenburg (Lavantsee)-Deutsch Altenburg, Hochfilzen-Kirchberg a. d. P., Hochkönig-Kötschach, Wattener Lizum-Eschenlohe etc. The longest part of these profiles runs through Austria and contains 4 shot points. Two of them had been placed on the bottom of mountain lakes (shot point Dilake Torsee, Wattener Lizum and shot point E. lake Lavantsee, Judenburg with depths of 6 and 12 meters respectively). To get sufficient seismic energy transmission into the ground, an advanced blast technology had to be developed by distributing the total charge of 1,2 — 2,5 t over a large area of the lake bottom in a carefully dimensioned grid pattern. The generated P-waves reached vibration velocities of 4 cm/s with frequencies of 4—40 Hz at the lake shore and could be recorded along the profile at distances of at least 500 km [3].

In addition at the shotpoint E reflection seismic observations have been carried out in cooperation with the Institut für Erdölgeologie und Angewandte Geophysik, Mining University Leoben. With two 24-trace seismic instruments a reflection profile of approximately 1,5 km length was layed out. Astonishingly clear signals of deep reflections with travel times of 11—12 seconds were recorded although the geology of this area is complex and due to numerous faults high attenuation and multiple reflections as well as complicated refractions have to be expected.

After the severe Friuli earthquakes of May and September 1976 it was decided to arrange additional seismic longitudinal profiles covering the earthquake region. In 1977 a profile extending from Mt. Caninin in the East via Tolmezzo and Salurn to the Sondrio region approximately parallel to ALP 75 was recorded which is known as ALP 77. Further three profiles forming a trident were observed as ALP 78. The central shot point was the lake Obersee at the Stallersattel (Defreggen valley/Eastern Tyrol). The three profile segments were Obersee-Trieste, Obersee-Spielfeld and Obersee-Eschenlohe.

2.2 Seismic profiles (Publications 59, 80, 81, 91)

Using the high seismic activity in northern Italy after the Friuli Earthquakes the project SNEALP (Seismic Network EasternAlpes) has been performed in cooperation with the University of Birmingham. For this project the Friulian aftershocks were observed for a three months period like refraction shots by seismic stations grouped as a profile. The recording stations were situated in Gnesau, Gurk, Stolzalpe, Unzmarkt and Judenburg [59].

In addition the IMG participated in other refraction seismic surveys in Europe during the IGP which were organized by German, Czechoslovakian and Hungarian institutions. Especially the profiles Villach-Eferding-CSSR, Rheinisches Schiefergebirge-France and the Scandinavian long range profile have to be mentioned. The purpose of this participation is to obtain results, which can be compared with Alpine data. While all these profiles as well as the ALP-experiments were investigated by specially designed seismic blasts, shorter profiles up to a length of 70 km were observed by using regular quarry blasts. From the quarries in Froiach and Klaus observations along the profile Linz-Klagenfurt have been carried out in three segments.

Unfortunately in quarry blasts usually the delay technique is used. Therefore it was necessary to study the energy transmission of such delayblasts in detail [80]. This revealed considerable differences in the seismic efficiency of various blasting techniques and showed that different mechanisms exist for causing seismic vibrations in connection with the breakage of rock. Usually the breakage of rocks is performed by the primary shock-wave and secondary tensile loosening. By using a special blast geometry rock breakage can be obtained also by a shear stress mechanism [81]. Also the parameters involved in the propagation of vibrational energy have been discussed [91].

2.3 Seismic models of the Alpine crust (Publications 63, 4, 52, 16, 50)

As a result of the previously described seismic profiles and especially the ALP experiments a detailed crustal model was obtained.

In the Central Alps a troughlike thickening of the earth's crust of approximately 50 km exists, which becomes stepwise thinner towards the East [63]. Whereas in the Pannonian Basin the thickness of the crust is only 27 km.

At a depth of 20 km there is a continuous inversion zone, i. e. a zone of decreased propagation velocity which can be considered as an area either of decreased rigidiy or of abnormal high temperature. In terms of classical earthquake seismology this discontinuity is named after the Austrian geophysicist Conrad Discontinuity, although the original interpretation of this discontinuity was that of an abrupt velocity increase from about 6,2 to 6,8 km/s. An additional inversion zone in the upper crust seems to exist within the Alps at the depth of 8 to 12 km [4]. This inversion zone is traceable as far as 80 km east of Judenburg. A relation to known fault systems and geological structures has not been detected. The disappearance of this upper inversion zone and the special details of the ALP-results in the area of the eastern margin of the Alps point to a complex structure of this transition area.

The complex pattern of seismograms at the eastern end of the Alps can be interpreted only by two-dimensional velocity models, i. e. velocity distributions, being variable in the vertical direction as well as in the horizontal [52]. With the aid of a modeling program allowing the calculation of seismic travel times for arbitrary two-dimensional velocity-distributions it was possible to construct models of the Eastern Alpine margin [16]. However the compatibility with gravity data has not been proved yet. The preliminary model is presented in figure 1. It shows the distribution of the propagation velocities between the shot points E and F Körmend (Hungary) which has been derived by evaluating the refraction seismograms of shotpoint E, with this method. Fig. 2 shows the same profile evaluated for the reverse shot (shotpoint F,). This latter model agrees very well with the seismograms of both shotpoints. It has been derived from the model of fig. 1 by slight modifications of the shape of the inversion zones.

The above mentioned program was also used to test the model for the crustal structure of the Eastern Alps, published by different authors. It shows that the wave groups, which earlier were interpreted as being reflected through alternating layers with velocity inversions can also be interpreted as waves which run in one single channel in a zig-zag path. As a result of this a substantially simplified model of the lower crust is obtained.

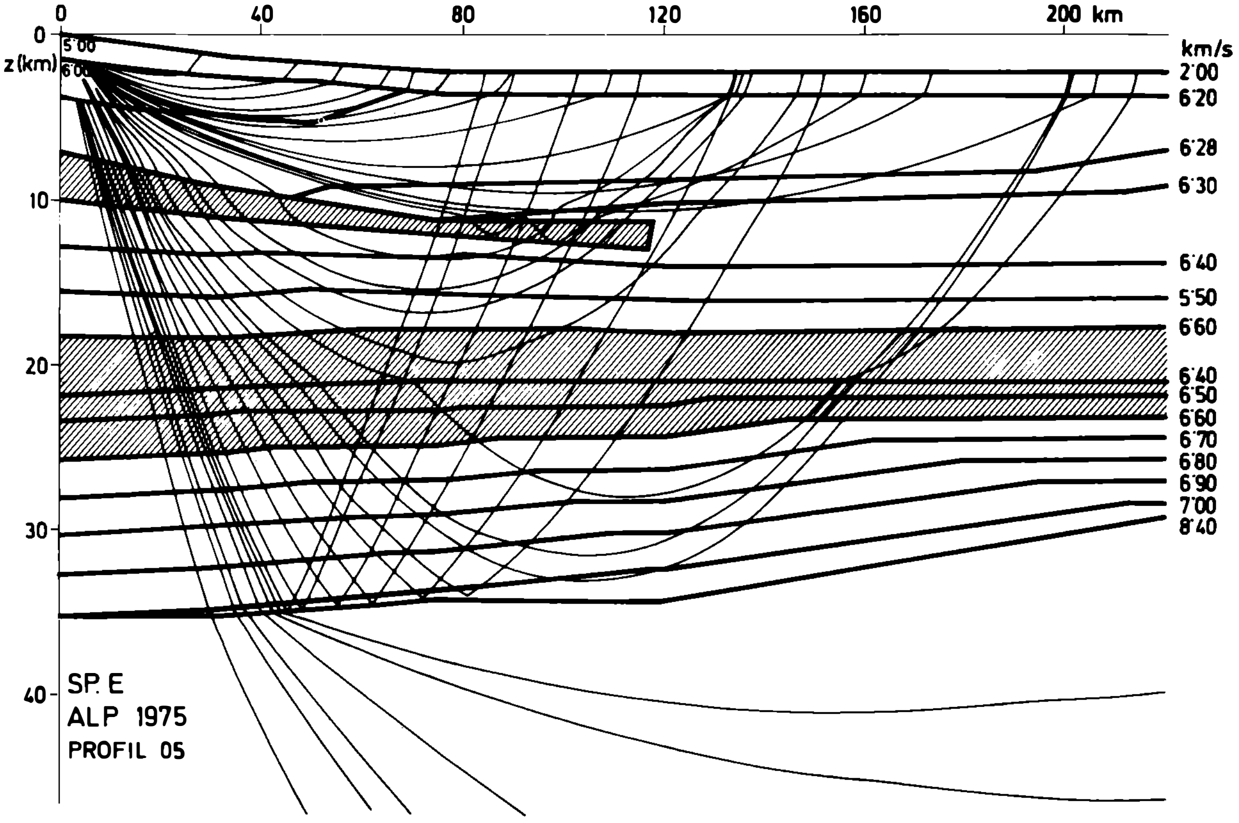

Fig. 1: Model cross section of ALP 75 profile between shot points E and F. The P-velocity distribution of the model has been derived from the seismogram of shotpoint E at lake Lavantsee (14⁰ 34' 21" E, 47⁰ 03' 34" N) near Judenburg by the ray tracing method.

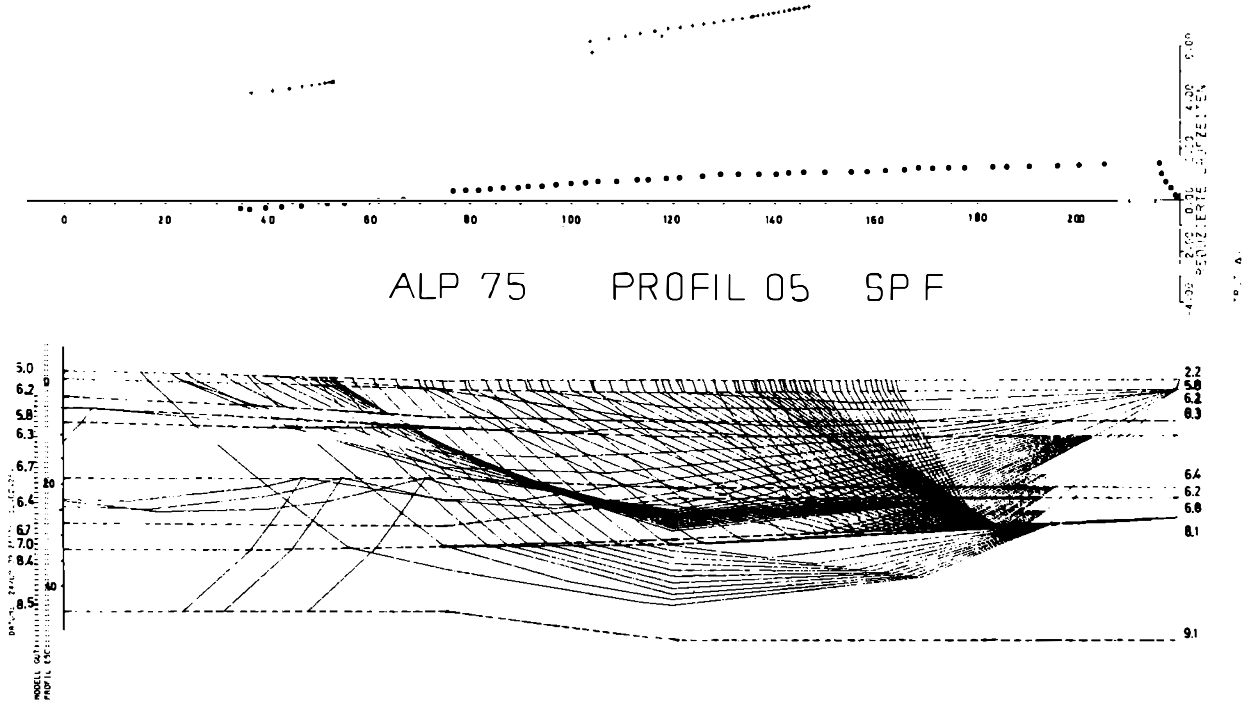

Fig. 2: Model cross section of ALP 75 profile between shot points E and F. The P-velocity distribution of the model has been derived from the seismogram of shotpoint F at Körmend (17⁰ 01' 04" E, 47⁰ 07' 17" N) by the ray tracing method.

2.4 The Periadriatic Lineament (Publications 87, 77, 43, 78, 71)

The Periadriatic Lineament is a very interesting feature of the geology of the Alps which separates the Southern Alps from the Eastern Alps. However the real importance of this feature is still unknown and there are views seeing it as negligeable as well as theories which credit the lineament regional or even continental importance.

Therefore extensive geophysical investigations with different methods have been carried out in the eastern part of the Lineament. Gravimetric and magnetic measurements locally, complemented by refraction seismics and geoelectrics, were performed between the Austro-Yugoslavian border in the South and the line Villach-Wörther See-Völkermarkt-Bleiburg in the North thus covering the mountain chains of the Karawanken and its foreland.

The geology of this area is characterized by crystalline rocks in the North which dips southward. There they are covered by the conglomerates of the Sattnitz in the southward direction. These conglomerates are overthrusted by the calcareous Northern Karawanken in the South. Next the lineament zone and then the Southern Karawanken follow.

Gravity measurements have been carried out in the entire area described above. An aereal distribution of gravity stations has been achieved despite the extremely mountainous character of the region. Together with gravity data provided by the ÖMV-AG (Austrian Mineral Oil Corp.) a total of 795 gravity observations have been carried out within approximately 1500 km². A Bouguer gravity map has been constructed with this data (see Fig. 3). The main feature in this map is a gravity trough along the northern flank of the Karawanken which strikes East-West. Only in the western part the trough bends to a WNW direction thus tending to the Mölltalfault. In the northern slope of the trough secondary gravity minima are formed in the districts of Sabalahöhe, Rottenstein and Eberndorf. North of this trough one east-west striking gravity high extends from the Pyramidenkogel to Klagenfurt. The southern slope of the trough is characterized by a disturbed pattern of isolines in the region of the Periadriatic Lineament, probably caused by locally occuring volcanites and other rocks of higher density. The main features of the Bouguer gravity map have been interpreted by two-dimensional models. The trough in the gravity map is explained by the low density of the Sattnitz-conglomerates, which forms a wedge between the crystalline rocks and the calcareous formations of the Karawanken having higher densities. The conglomerates end approximately below the ridge of the northern Karawanken in depths of approximately 1000 m. Fig. 4 represents model cross sections at the Obir [87].

Probably the margin of the southward dip of the crystalline has to be interpreted as a fault, which extends mainly along the Rosental. The northern flank of the gravimetric trough corresponds to this Rosental fault and the southern most part of the southern flank is associated with the Periadriatic Lineament. This seems to indicate that both features have to be seen geologically in context with one another.

Further it is of interest that the Karawanken show no gravimetric indication of a mountain root which has to be expected for an independent mountain range with isostatic behaviour [77].

Detailed refraction seismic and geoelectric measurements investigated the structure of the conglomerates in the area Plöschenberg-Köttmannsdorf and could trace the southward dipping crystalline rocks underneath the overlying conglomerate. The measurements yield representative values of propagation velocities and the subsurface topography of the crystalline basement below the sediments [43]. P-velocities measured at the surface of the crystalline rocks (4350 m/s) are low in comparison to limestone or fresh crystalline formations.

Also magnetic measurements were carried out along the Lineament and in the Karawanken [78]. At approximately 3800 stations the geomagnetic total intensity (T) was measured with proton magnetometers. The area

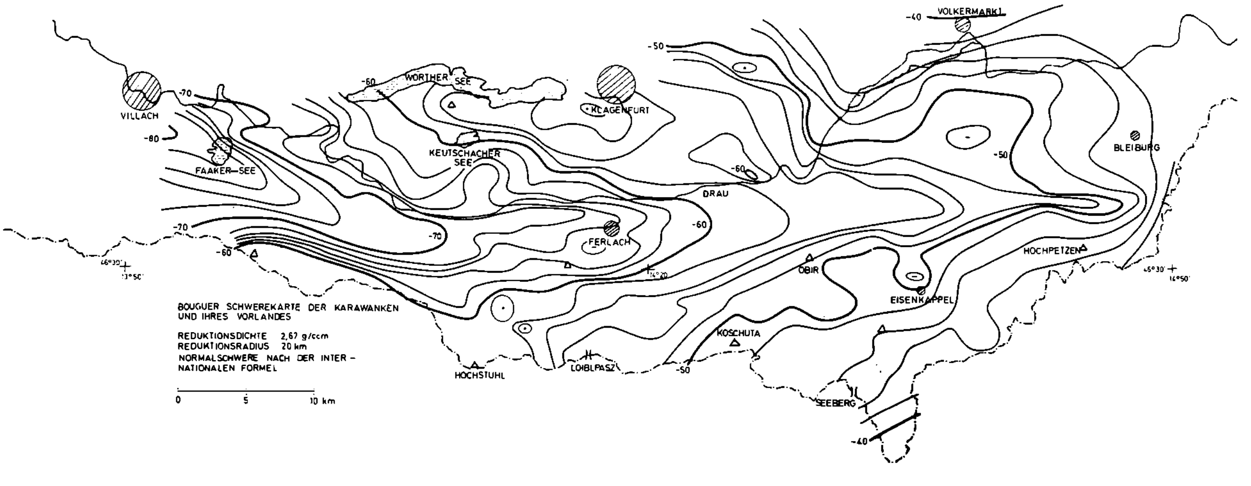

Fig. 3: Map of Bouguer-Anomalies of the Karawanken and their northern foreland [87].

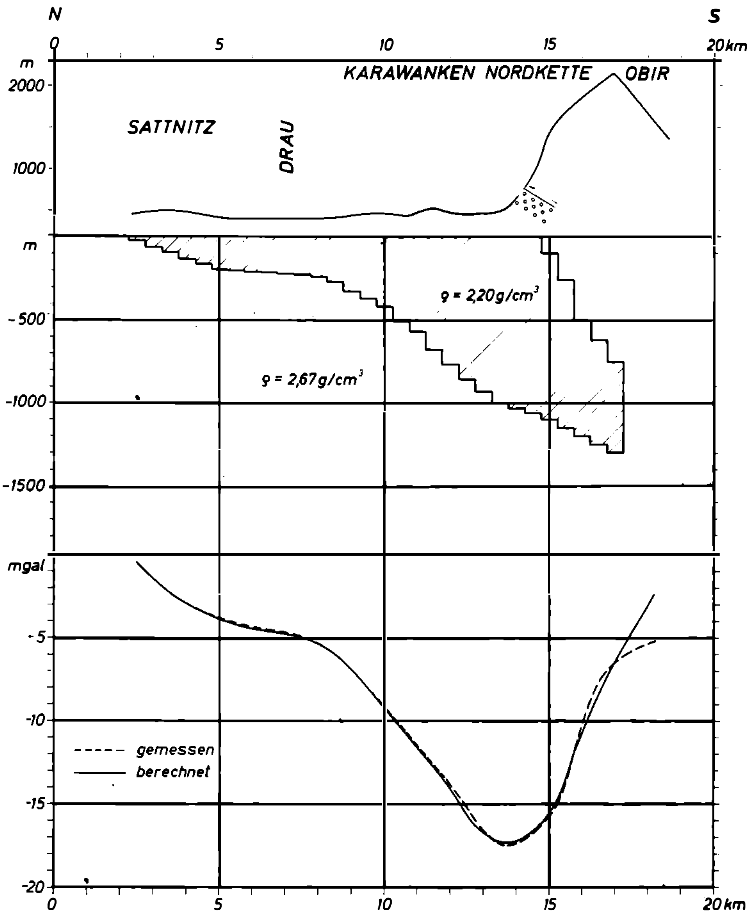

Fig. 4: Results of the gravimetric survey in the Karawanken top: topography on N-S profiles (the overthrust of the Karawanken over the conglomerates is indicated); centre: two-dimensional gravity models (density contrast: — 0,47 g/cm^3); bottom: comparison of observed and model gravity anomalies.

under investigation was 860 km^2 in size. All measurements were reduced to the epoch 1975.0. The rather large height variations necessitated an altitude correction in using the vertical gradient of T (~22 nT km^{-1}). The main field was calculated with a least square second order polynomial fit in order to determine the residual field ($\triangle$T).

In the investigated area three different zones of magnetic anomalies have been observed. The southernmost zone is characterized by long and narrow anomalies. In the north-western part of the investigated area a broad zone of short and mainly negative anomalies exists. In the North East an extensive positive anomaly is situated.

The first zone is correlated to the Periadriatic Lineament. In the west the anomalies are tied to lamellae of tonalitegneisses. The pattern of anomalies indicate that these lamellae have a greater extension than local outcrops suggested. The greatest anomalies have been observed along the eastern part of the Lineament. They are connected to the diabase of Eisenkappel. Two-dimensional model calculations reveal diabase dimensions of 300 m in width and a depth range of approximately 700 m, dipping steeply to the south. To obtain a good fit between the model calculations and the observed data the rather small inclination of I = 25° had to be used. This indicates either a tilt of the diabase by tectonic forces or a dominant remanent magnetization gained in low magnetic latitudes. In this context it is also interesting that in the carboniferous rocks at Nötsch also very small inclination values have been observed thus indicating a former position in low geomagnetic latitudes (Heinz, personal communication, 1979).

The second zone of anomalies in the northwestern part of the investigated area is limited in the south by the southern rim of the Sattnitz thus indicating that this rim marks a major fault zone.

A broad and elongated anomaly with an amplitude of approximately 30 nT constitutes the third zone. Its strike length is at least 35 km. According to two-dimensional model calculation the anomaly can be explained by crystalline rocks dipping under the northern chain of the Karawanken. It seems that this dip is increasing to the south while approaching the Lineament. Beneath the Drau-valley the crystalline formations are in a depth of 300 m to 400 m.

For performing these model calculations systematic in situ measurements of susceptibility of rocks have been carried out in the entire area. With the exception of the diabase of Eisenkappel the susceptibility shows only small but systematic variations [71].

The magnetic map of southern Carinthia was also interpreted qualitatively with regard to faults and other tectonic features. Two main faultdirections can be proved: The first is parallel to the Periadriatic Lineament, whereas the other one strikes SSW-NNE.

Finally it has to be pointed out that the geomagnetic model calculations are in accordance with the gravimetric ones, both showing a uniform picture of the northern part of thc Periadriatic Lineament.

2.5 Geomagnetic survey of Austria (Publications 65, 70, 69, 56, 53, 54)

The geomagnetic survey of Austria has been revised and updated for the epoch 1975.0. The aim was to get a better idea about the main field in the Eastern Alpine area and to pick up large scale geomagnetic anomalies, which could be correlated with the Alpine orogenesis [65; 70].

This investigation is based upon observations of D, H, and Z at 227 stations.

In the residual maps two large anomalies, the Berchtesgaden anomaly and the Moravian anomaly, can be recognized. Only parts of both anomalies are situated on Austrian territory. Most likely these anomalies are caused by magnetized bodies in the upper crust between 10 km and 20 km below surface. As their strike-direction is almost parallel with the axis of Alpine-Carpathic orogene both anomalies have to be considered as an overall geophysical feature of the Alpine-type mountain system.

On the eastern rim of the Tauern Window at a number of stations the total intensity of the earth's magnetic field was observed. Aditionally, at selected sites in-situ measurements of the rock susceptibilities were carried out [69].

It is evident that in an area like the Alps, where often rather inaccessible regions occur, airborne measurements could speed up the survey considerably. Therefore the IMG tried to perform an aeromagnetic survey at least in the central and northwestern parts of the Eeastern Alps. It soon became evident that this project by far exceeded the frame of the national program for the IGP. Consequently soon after the start of preparations for these investigations the aeromagnetic survey was seperated from the IGP-project and installed as an own national project. Nevertheless, the aeromagnetic investigation of the Alps is of great importance for geodynamics too. Fig. 5 shows the aeromagnetic map of Western Austria. Magnetic anomalies are concentrated in the regions west and east of the Unterengadin-window, in the western part as well as in the centre of the Tauern-window, in the area south of Kufstein and in the western part of Graywacke-zone. A dominating feature of this aeromagnetic map is the wellknown Berchtesgaden anomaly.

Of great geodynamic interest are the anomalies in the area of Matrei, geologically connected with the upper schist cover. These anomalies seem to indicate that the causing ultrabasites are fairly deep-rooted and this affects the importance of the Matrei-zone for the geodynamic evolution of the Eastern Alps. It will be necessary to test this hypothesis by model calculations [56].

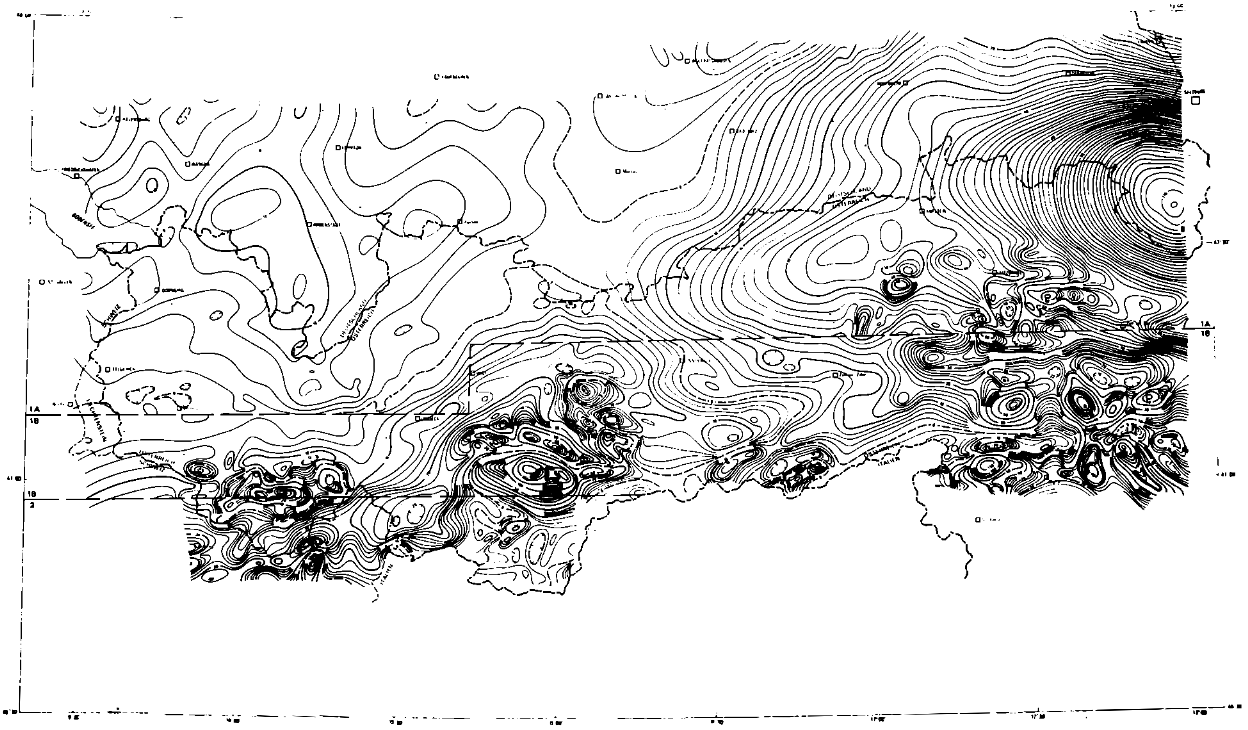

Fig. 5: Aeromagnetic Map of the western and central part ot the Eastern Alps.

Some of these anomalies are already interpreted quantitatively by two- or three-dimensional model calculations. This was done mainly in view of the physical parameters and the dimensions of the involved bodies but neglecting questions of the real shape of these bodies. Thus it was possible to use only simple models as the sphere and the rectangular prism, even in cases where it is evident from surface geology that more complicated models would be necessary for a realistic approximation of the shape of the magnetic bodies.

In the case of the Ötztal-anomaly, which is caused by amphibolites, gravimetric measurements are available in addition. A positive Bouger-anomaly of approximately 10 mgal coincides with the aeromagnetic anomaly. Also gravimetric and magnetic model calculations are in good correspondence [53].

2.6 The Gravimetric Alpine Traverse (GAT). (Publications 66, 18)

The Geodetic Survey of Austria (Bundesamt für Eich- und Vermessungswesen) has established a basic network of gravity measurements in Austria which is oriented strictly towards the purpose of the national geodetic survey. Therefore the gravity stations are exclusively tied to bench marks of level lines. Since level lines are organized mainly for the needs of the population and the economy within the Alps, they are concentrated to the densely populated valleys. As a result of this, in the Alpine part of Austria between different levellines, areas of 2000 km² and evenmore are left without any gravity stations. Bouguer anomalies based upon these data represent only regional trends in greater areas and therefore have limited importance for geodynamical questions.

Therefore the GAT project was started for IGP. Within this traverse the gravity stations are distributed on a grid pattern thus giving areal coverage of the traverse. The traverse extends North-South with a width of one degree longitude between 13°20' E and 14°20' E from the southern to the northern border of Austria. Limited in the East by the line Loiblpass — Klagenfurt — Froiach — Rottenmanner Tauern — Sengsengebirge — Linz — Bad Leonfelden and in the West by the line Naßfeldpass — Sachsenburg — Hochalmspitz — Radstädter Tauern — Tennengebirge Hausruck — Passau,the traverse cuts through all important Alpine geological units. Beginning in the South with the Southern Alps, the Austroalpine layers, the Tauern Window, the Graywacke-zone, the Northern Calcareous Alps, the Flysch-zone and the Molasse it ends in the North at the Bohemian Massif. In addition several faults, fracture zones and other tectonic features are situated in this traverse: the Periadriatic Lineament and the faults of Mölltal. The Malta-Gegendtal and the Ennstal are other examples for these features.

Besides the gravimetric investigation in the surroundings of the Periadriatic Lineament which has been discussed already, approximately 1100 gravity stations have been measured in this traverse with a mean station density of one point per 10 km². In addition at 40 stations the vertical gradient of gravity has been determined as well. Thus it was possible to show the areal distribution of the gravimetric vertical gradient after applying topographic corrections. In consequence it was possible to calculate free air corrections with the real gradient instead of using the normal gradient.

Evaluation and interpretation of these gravimetric data has first been concentrated to an area between the Hochalmspitz in the WNW and the Nock mountains in the ESE. The area under investigation is oriented almost perpendicular to the strike of the Bouguer isolines and extends from the easternmost part of the Tauern window to the western part of the Upper Austroalpine Gurktal nappes. Two Bouguer maps have been drawn, one using the conventional free air correction and one applying the actual vertical gradient in the free air correction term [66]. The latter one agrees very well with surface geology. There is a Bouguer minimum between Gößgraben and Malta valley which corresponds to the updoming gneisses of the Gößgrabenkern being part of the Taueranticline. At the rim of the Tauern Window the Bouguer gravity increases. In the small region of the schist cover and Lower Austroalpine a fairly high horizontal gradient of approximately 2 mgal/km can be observed while most of the middle Austroalpine units are characterized by nearly flat gravity gradient. The Permo Mesozoic Middle Austroalpine unit is indicated by a gravity trough while afterwards the increase of Bouguer values continues within the Upper Austroalpine Gurktal-nappe. The ore bearing Triassic of the Innerkrems as well as the magnesite bearing crystalline at the northeastern Millstätter Alpe are marked by positive Bouguer anomalies.

The Bouguer map based upon the conventional algorithm of corrections is by far less interpretable in terms of surface geology. The use of the actual vertical gradient thus enables an isolation of the residual part of the Bouguer field which has to be explained by the uppermost layers of the crust.

The conventional Bouguer map containing information from all layers of the earth crust is dominated by the pronounced gravity contrast of the Tauern window and the Gurktal nappe which results in an intense horizontal gradient up to 5 mgal/km. Gravity troughs mark the faults of the Malta- and the Möllvalley. It is interesting to note that the continuation of the Malta fault to the southeast the Gegendtal fault — is gravimetrically not detectable, at least between Gmünd and Radenthein. On the other hand there is a gravimetric indication for the continuation of the Feldkirchen-Patergassen fault to the Northwest. It seems it is traceable as far as north of Radenthein. Quantitatively these data are interpreted by three-dimensional model calculations (Ruess, personal communication 1979).

2.7 Magnetotelluric sounding (Publication 1)

Magnetotelluric measurements have been started 1978 in the transition zone between the Eastern Alps and the Pannonian Basin in cooperation with the Hungarian Geodetical and Geophysical Research Institute, Sopron. The sounding localities were situated along the ALP 75 profile and allow a comparison of the electric and the seismic crystal parameters yielded from the magnetotelluric and refraction seismic measurements respectively. Two conductive zones have been detected in depths of 7 and 32 km which correspond fairly well with the low velocity layers observed at the ALP 75 profile [1].

2.8 Geothermic measurements (Publication 55)

The ZA and the Niedersächsisches Landesamt für Bodenforschung, Hannover, have carried out temperature measurements in Alpine lakes for the purpose of heat flow determination as a cooperative project. The measurements were successful in six shallow lakes situated in Tyrol (Wachsee, Hechtsee) and in Trentino. Together with 26 heat flow values which have been published previously it is possible to distinguish schematically four different zones in the Alps:

	mean heat flow
northern Alpine foreland:	78 mWm^{-2}
northern Alpine margin:	125 mWm^{-2}
main Alpine area:	65 mWm^{-2}
southern Alpine margin:	125 mWm^{-2}

Different possible interpretations have been tested by model calculations [55].

3. Investigations of local structures

Detailed investigations of local size have been performed because of two reasons. On one hand areas were selected according to special tectonic questions which are of main structural importance for the geodynamics of the Eastern Alps (e. g. faults). On the other hand such investigations were started to gain detailed information (e. g. velocity distribution) which form the necessary background for studies of regional size. Simultaneously such measurements revealed the efficiency and applicability of various geophysical methods for treating Alpine geodynamics.

Some results of general interest are reported here.

3.1 Local gravimetric investigations in the Hohe Tauern Großvenediger and Felbertauern (Publications 34, 33, 46)

The Tauern Window consists of granitic rock formations surrounded by schists. One of the basic petrographic questions is to determine the origin of the metamorphism which is evident in all rocks of the window. The usual explanation is that of a regional metamorphism caused by thick layers of overburden. The alternative hypothesis is that huge magmatic granite-bodies intruded the Tauern area at the end of cretaceous times thus causing thermal metamorphism. Since a considerable size of these young granitic bodies (tonalites) is the necessary requirement for the latter hypothesis, gravimetric measurements were performed for testing this hypothesis in cooperation with the TU Clausthal [34].

Three-dimensional model calculations reveal that these young rock bodies end at a depth of approximately 1,5 km below the sea-level [33].

It has to be emphasized that these models are very schematic ones intending only to indicate the magnitude of the different bodies. These results demonstrate that it makes sense to divide the „Venediger-Kern“ complex into two different rock units as well as they are in favour of a regional metamorphism of the Tauern Window because of the fairly small dimensions of the tonalites.

Similar gravimetric measurements have been performed in the Felbertauern area where it was possible to put gravity stations in three different levels: into two tunnels and on the surface. Model calculations at all three levels reveal that the Bouguer anomalies are caused by different bodies of gneisses, schists and amphibolites [46].

3.2 The basement of the Inn valley (Publication 17)

A cross-section of the Inn valley was investigated east of Innsbruck. Reflection- and refraction seismic methods as well as gravimetry were used for these measurements. The thickness of the Inn valley sediments is 340 m. Reflection seismic data show two horizons within the sediments which are interpreted as water tables. At the northern margin of the valley an intermediate wedge between sediments and basement has been detected which is up to 300 m thick (see fig. 6). This wedge could be the geophysical indication of a mylonite zone or fault marking the boundary between the Northern Calcareous Alps and the crystalline rock formations. Fig. 6 shows the gravimetric model of the cross sections. The corresponding seismic V_p velocities are 2000 m/s, 3000 m/s and 4900 m/s for the sediments, intermediate wedge and basement respectively.

For fitting the gravity model to the observed Bouguer-values an iterative algorithm has been developed. Based on the gravitational attraction of rectangular prisms the theoretical gravity anomalies of an initial model are calculated. The differences to the observed gravity values are used for proportional changes of the prism dimensions. Consecutively the gravity calculations is repeated and usually after four iterative repetitions there is sufficient coincidence of the gravitational anomalies of the model with the observed ones [17].

One consequence of this investigation is of importance for the entire Alps and has to be pointed out especially.

The Bouguer gravity data show a difference of approximately 10 mgal between stations in the middle of the valley and marginal ones. It has to be concluded that the results of gravity profiles extending purely through mountain valleys have to be considered with great reservation. Due to the fact, that the basement of many valleys consists of a fault and due to the often unknown thickness of young sediments in the bottom of a valley, measured gravity values may be systematically erroneous, i. e. to low. Therefore it was inferred that profile oriented gravity measurements will not be of great help and that an areal distribution of gravity stations has to be achieved for obtaining a realistic picture of the Alpine gravity field. This was consequently followed in all gravimetric investigations of the IMG, like the Periadriatic Lineament survey and the GAT-project.

3.3 The Diendorf-fault near Melk (Publication 45)

In the area where the Danube joins a variscian transform fault — the socalled „Diendorfer Störung" — near Melk detailed geophysical investigations have been applied to trace this fault underneath the flat lying gravel and river sediments of the Danube valley. Mainly refraction seismic and gravimetric measurements were performed in a dense network of profiles and gravity stations respectively and revealed the deeply intended surface of the crystalline basement. In evaluating the gravimetric data the regional field was determined by a least square third order polynomial fit. The residual field is presented in fig. 7. It shows that two faults meet each

Inntal-Untergrund bei Thaur

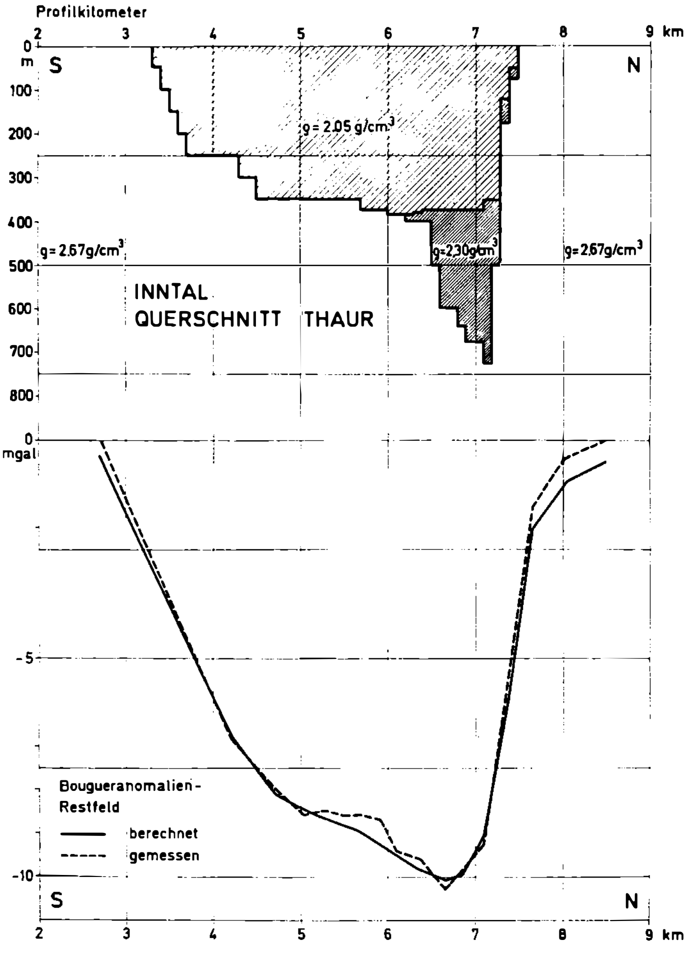

Fig. 6: Cross section of the two-dimensional gravimetric model of the Inn-valley basement [17]; top: model cross section; bottom: comparison of observed and calculated residual Bouguer anomalies.

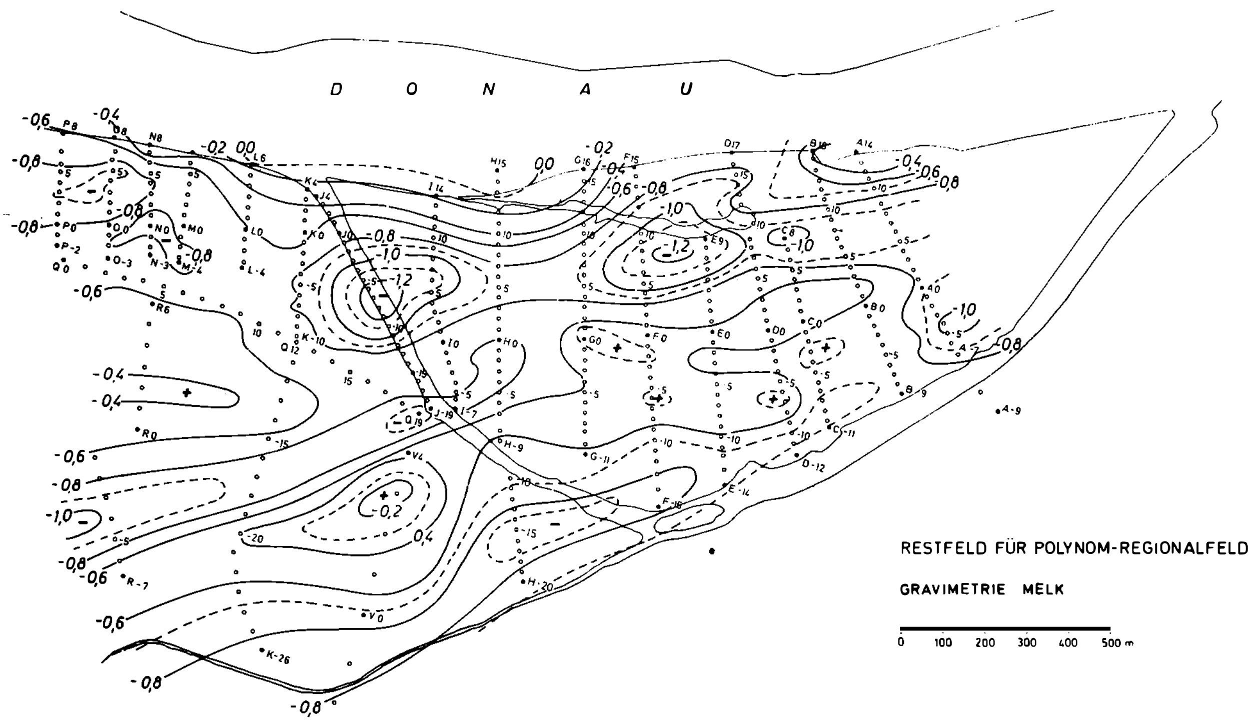

Fig. 7: Residual Bouguer anomalies of the fault system near Melk [45]. (Units in mgal.)

other in this area. One fault extends east-west just south of the Danube and is marked by a series of Bouguer minima. The second one is the Diendorf fault striking WSW-ENE which has a complicated structure consisting of two parallel troughs of Bouguer minima seperated by a ridge formed by a series of Bouguer maxima. Three-dimensional model calculations explain this as the deeply indented surface of the crystalline, where nearly vertical fault throws up to 80 m exist [45].

3.4 Seismic propagation velocities near the margin of the Tauern Window (Publication 2)

Refraction seismic measurements have been carried out in the easternmost part of the Tauern Window in the Malta valley and Gößgraben and outside the window at the Nöringsattel. The Penninic granitic gneisses of the Gößgraben show a velocity of $V_p = 4700$ m/s while the schists of the middle Austroalpine formation at the Nöringsattel have a V_p-velocity of 5500 m/s [2]. As the Penninic gneisses and schists are supposed to dip underneath the Austroalpine unit at the entire length of the Eastern Alps the resulting velocity inversion is of great importance for any refraction seismological investigation of the Alpine crust. Only advanced refraction seismic methods can untie such velocity distributions. Joint interpretation of refraction seismic data together with other geophysical results will improve the significance remarkably. In this case the GAT project, as it has been discussed already above, will serve for this purpose.

3.5 Interpretation of macroseismic data with regard to a velocity inversion (Publication 28)

A model seismic experiment has been carried out to explain the anomalous wide extension of the isanomals of East Alpine earthquakes to the north. This model consists of an outcropping low velocity-channel representing the Molasse layer over a half space with high P-velocity The latter represents the Bohemian Massif. The Nor thern Calcareous Alps lying on top of the Molasse layer are simulated in the model by a thin layer of high P-wave velocity. The model seismic experiments deduced that the low velocity channel acts as a wave guide if the seismic source is located close to that channel [28].

This explains the existence of a shadow zone for seismic energy in the Calcareous Alps and why in the northern foreland relatively greater earthquake intensities can be observed.

3.6 Seismic transmission function of the crustal structure in the Vienna area (Publication 64)

The fine structure of the earth's crust has been studied by means of far distant earthquake seismograms. The transmission function of the crust near Vienna using records of P-phases from long period seismographs at Wien-Kobenzl has been studied [64]. Calculations result in a thickness of the crust of **31 km**. The best approximations have been obtained by a 4-layer model, determined with a trial end error method. However, the results are very sensitive to the choice of the initial model for this procedure. Therefore it has to be concluded that optimum benefit can be derived from this method in areas where no other source of geophysical information is available than a seismographic station.

3.7 Marginal basin of the Bohemian Massif (Publication 67)

Seismic and gravimetric measurements have been carried out in the basin of Horn with the aim to localize the Bohemian crystalline basement below the sediments [67].

The survey in the center of the basin between the two villages of Wörtersdorf and Karnegg yielded a thickness of sediments of about 100 m. The P-velocity of the basement of 4400 m/s represents a typical value for weathered and tectonically stressed crystalline Phyllites.

4. Geophysical indications of geodynamic processes

Two different methods have been used to detect geodynamic processes which caused the orogenesis of the Alps. On one hand the isostatic behaviour of the Alpine system was compared with recent crustal vertical movements and on the other hand paleomagnetic investigations were started to study movements of different Alpine units as well as global geodynamic processes like plate tectonic movements and the mechanism of geomagnetic field reversals.

4.1 Recent crustal movements and isostasy in the Hohe Tauern (Publication 86)

Recent crustal movements have been observed in the area of the Hohe Tauern indicating an uplift of about 1 mm/year of the southern part of the Tauern Window in comparison to the Salzach valley. Uplift caused by isostasy requires a mass deficit in the uplifting crust. On the base of a crustal model of the approviate Alpine cross section it can be demonstrated, that the crustal uplift of the southern Tauern Window is not in accordance with an isostatic compensational movement. In fig. 8 on top the mass balance for this cross section is shown which indicates that the masses within a crustal column increase continously from north to south.

Below the mass balance the uplift rates are presented which are positively correlated to the mass balance curve (instead of having a strong negative correlation as it is demanded by isostasy). As mean topographic heights are considerably greater in the South than in the North it can be concluded that this process is continuing already since a longer period. The overall conclusion is that lateral forces acting from the South could be the cause for this uplift [86].

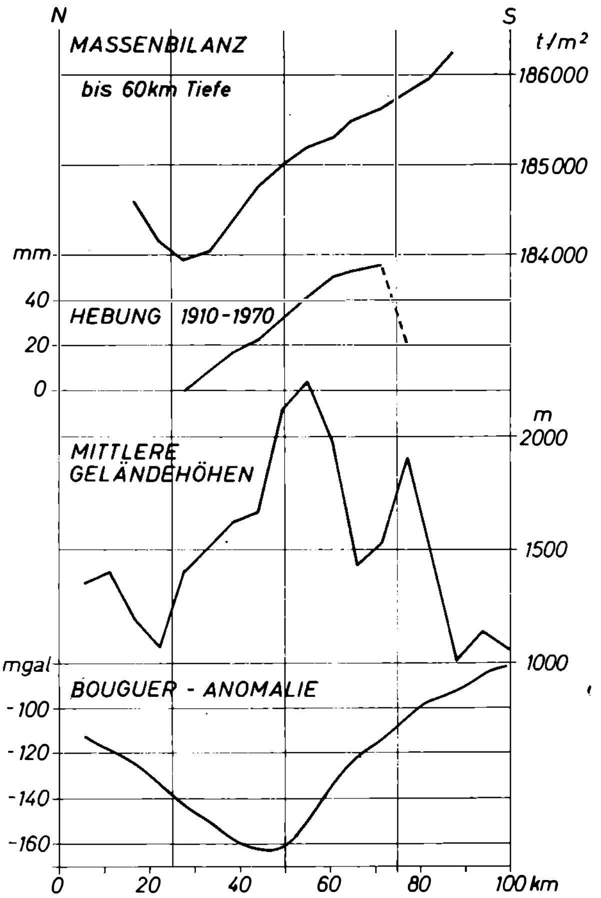

Fig. 8: Hohe Tauern cross section showing from top of bottom mass balance, uplift 1910—1970, mean topographic heights and Bouguer anomaly [86].

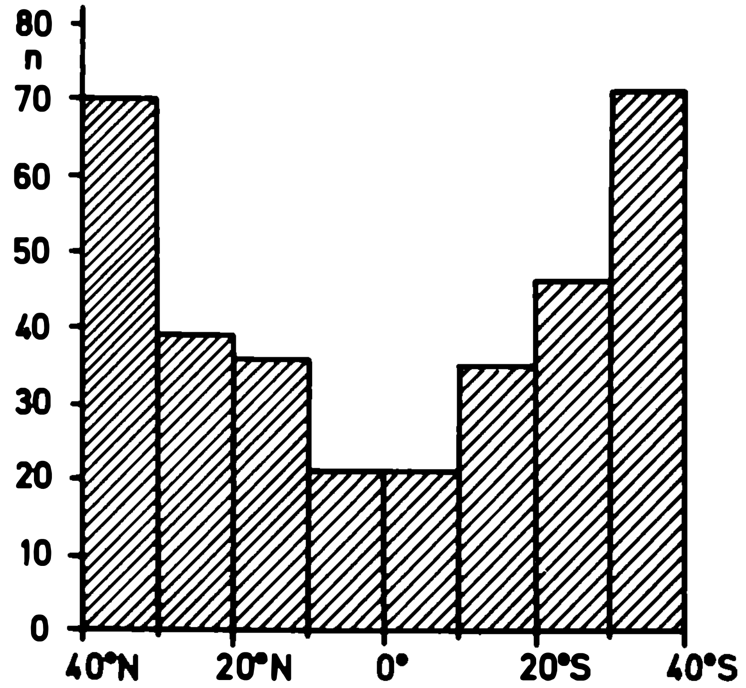

Fig. 9: Latitudinal frequency distribution of paleopoles during polarity transitions [88].

4.2 Behaviour of the geomagnetic field during polarity transitions (Publication 88)

Since paleomagnetic interpretation regarding tectonophysical questions is always conducted using the hypothesis that the geomagnetic field behaves dipolar and is oriented in average parallel to the earth's axis of rotation. As polarity reversals are a wellknown fact it is interesting to investigate the behaviour of the geomagnetic field during these transition periods when deviations from the above described hypothesis have to be expected.

Data of 23 field reversals of recent, Tertiary and Upper Mesozoic age containing approximately 350 paleopole positions between latitudes of 40° N and 40° S were examined in cooperation with St. Louis University. The result is a latitudinal frequency distribution of paleopoles of a U-shape type (Fig. 9). This can be interpreted as a flip over of the geomagnetic field which gains speed when its axis approaches the equator. Paleointensity studies reveal that the moment of the transitional field becomes progressively weaker when its axis advance towards the equator but retains still comparatively high values during the greater part (ca. 90%) of the transition time interval. Only for a very short period when its axis is within the latitudes of 10° N and 10° S the geomagnetic moment becomes very weak.

Quantitatively the following table summarizes the properties of geomagnetic transitional periods:

Latitudinal interval of paleopoles	40°—30°	30°—20°	20°—10°	10°—0°
Mean magnetic moment in arbitrary units (axial dipole field = 100)	60	45	27	10
Mean transitional velocity in arbitrary units	30	49	59	100
Average time of transition in percent	42	25	21	12

The results discussed so far are valid whether the geomagnetic field remains dipolar or become multipolar during the transition. Nevertheless, some statistical hints have been detected suggesting that at least in some cases the geomagnetic field keeps its dipolar character during the reversal [88].

4.3 Plate tectonics investigations by paleomagnetic methods (Publications 93, 94, 89)

The evolution of the Alps is a very complex one in terms of plate tectonics and can be seen in connection with differential movements of the faster African and the slower European Plate and the Mediterranean region in between which contains some microplates. It has to be expected that comparative studies in regions with a less complicated tectonic history might be helpful in solving geodynamic questions of the Alpine orogenesis. As region for this comparative investigation the Carribean was chosen. The Carribean is situated between the North American and the South American Plate with the latter one moving faster. It is, of course, evident that the comparability between Carribean and Mediterranean is a limited one. Anyway, some similarities in the tectonic situation between the Alps and the mountain ranges of the Greater Antilles situated at the northern margin of the Carribean are of interest. Therefore together with St. Louis University paleomagnetic investigations have been performed in Jamaica [93] and Hispaniola [94.]

The results can be interpreted in terms of plate tectonics and yield an anticlockwise rotational movement of the Carribean plate over a distance of approximately 1000 km to the Northeast since Lower Cretaceous [89]. relative to North America. Some Paleopoles in equatorial latitudes suggest additional local rotations of the islands as marginal blocks of the Carribean plate probably caused by the differential movement of the adjacent plates. Similar rotations have been observed in the Mediterranean as well.

4.4 Paleomagnetic studies in the Alps (Publications 82, 79)

Systematic paleomagnetic investigations in the Eastern Alps have to be directed to several problems. One basic question is to examine how far the curve of apparent polar wandering for stable Europe can be used as reference for the interpretation of paleomagnetic results from the Eastern Alps. This will enable the systematic paleomagnetic study of the different Alpine rock units, structural geological features and their geodynamic behavior. Especially the Northern Calcareous Alps and the Periadriatic Lineament are of great interest with regard to this objective. Also the importance of metamorphism for the rock magnetic properties has to be investigated. This requires cumbersone studies because the orientation of the original remanent magnetization will be changed not only by the metamorphic VRM but also by anisotropy effects caused by the high stressrates of the metamorphism process.

It was necessary to furnish the new paleomagnetic laboratory with instruments especially suitable for the research objectives described above. Sedimentary rocks, which are measured primarily, are usually characterized by an extremly weak magnetization. The Medium NRM of rock samples from the Northern Calcareous Alps is approximately in the range of 7.10^{-7} emu which is only a little bit more than the sensitivity of modern spinner magnetometers. Therefore only small possibilities are left for demagnetization experiments. A superconducting SQUID-magnetometer was installed, which allows the detection even of diamagnetic rock samples (e. g. occassionally observed in marbles) and enables the investigation of considerably lower magnetized rock samples with higher accuracy. Great care is also necessary for avoiding viscous remanent magnetization effects during measuring and demagnetization procedures of weakly magnetized samples. Therefore mumetal shields are used for all instruments and storage boxes for protection against the earth's field and its variations. Within the shielding typical values of the residual field are for instance ±1 nT in the oven of the thermal demagnetization apparatus. To avoid rotational remament magnetization effects (RRM) a shielded static alternating field demagnetization system was chosen instead of a thumber [82].

Paleomagnetic investigations of the basalts of the Pauliberg/Burgenland contribute to the polar wandering studies. Rock samples from this volcano of Upper Tertiary age have been treated with the usual paleomagnetic methods. The mean direction obtained after applying „cleaning" procedures are the declination $D = 10{,}0^{\circ}$ and inclination $I = 63{,}1^{\circ}$. This direction agrees very well with results from Styrian vulcanites indicating a Dacian age of the Pauliberg basalts. The paleopole position obtained from this direction fits to the European polar wander curve [79].

Within the Northern Calcareous Alps the situation of the „Weyrer Bögen" an arcuate structure of nappes has been investigated in cooperation with the Institut für Geologie of the University of Vienna. Conflicting hypotheses exist concerning the primordial orientation of the sedimentary basin. One suggests an arcuate shape of the basin while the other assumes sedimentation in a straight shaped basin and a later rotation of the nappes. Paleomagnetic studies can test these hypotheses by calculating angles of rotation for rock samples of appropriate sites within the „Weyrer Bögen" and outside the questionable area. Sites of comparable age and bedding yield the following preliminary data. (Site names describe only approximate location).

site location related to Weyrer Bögen		predicted angle of rotation	paleomagnetic determined angle of rotation
outside	inside		
Frankenfels	Brunnbach	86°	70°
Losenstein	Unterlaussa	97°	105°
Reichraminger Hintergebirge	Palfau	38°	45°

Correspondence between predicted and calculated rotations is good enough to support the rotational hypothesis of the origin of the Weyrer Bögen.

5. Recent tectonic processes and movements

Earthquake seismology is the principal tool for studying recent geodynamics of the Alps.

In addition recent crustal movement and earthtide measurements delivered information concerning recent geodynamics.

5.1 Earthquake studies

Seismic activity in Austria is from low to moderate. The yearly rate of 15—25 perceptible earthquakes is comperably small, and this reduces its statistical value as information source about plate tectonics. The fact that catastrophic earthquakes occured in Friuli 1976 has changed this somewhat as these earthquakes were accompanied by many fore- and aftershocks. This activity continues still today. Untill summer 1979 more than 3000 seismic events of Friuli have been recorded by Austrian seismographic stations. Fortunately from the beginning of IGP the seismological station network of Austria has been improved and expanded continuously by IMG and ZA. This was a necessary condition for a more distinct and accurate study of earthquake zones in Austria. Also the evaluation and geodynamic interpretation of macro- and microseismic data has been improved and extended.

5.1.1 Evaluation of macro- and microseismic data (Publications 92, 24, 39, 40, 48, 57, 47, 26, 27, 68, 51, 35, 25, 23, 38, 41)

The earthquake catalogue of Austria has been revised and updated to gain full information on Austrian seismicity [92].

In the beginning of IGP the severe earthquake of April 1972 at Seebenstein gave evidence for the necessity of enhanced seismological activity in Austria. This earthquake has a maximum intensity of $7{,}75^{0}$ of the MS-scale and a fairly large magnitude of 5,4. Besides the epicentral region also heavy damages occurred in the northern part of Vienna in a distance of approximately 60 km north of the epicenter. This unusual pattern of damages can be explained by resonance effects of the uppermost Quarternary layer [24].

The macroseismic data of the great earthquake at Namlos 1933 collected by the Bavarian seismological service and the ZA was studied [39]. They used this data to prove a new method for determing the focal depth H and the extinction coefficient a of seismic waves. The same method has been applied to 72 East Alpine earthquakes [40]. It is shown that 72% of the hypocenters are situated in the upper crust. An increase of the extinction coefficient for deeper foci indicates a zone with low shear resistivity.

The geographical distribution of East Alpine earthquakes was investigated by using material of the ZA and from other sources [48]. The epicenters are correlated with the areas where great geological fault systems cross each other, i. e. the Mur- and the Lavantfaults.

The macroseismic data of the Friuli earthquake (May 1976) obtained by the ZA and other European institutions have been compiled by an international group resulting in a map [57].

The „relative intensity" represents a correction term δI applied to the expected intensity I observed at a location at a distance Δ to the epicenter of an earthquake with the maximum intensity I_o, the azimuth ϕ and the focal depth H [47]. The "relative intensity" can be estimated empirically. It depends on the local geological conditions in a complex manner.

The catastrophic Friuli earthquarkes of May and September 1976 affected also Austria. A short description of the three strongest earthquakes was given and macroseismic maps of all important aftershocks for the territory of Austria were presented [26]. In addition a historical summary as well as a selection of isoeismal maps of historic shocks are shown.

Macroseismic investigations of the severe earthquake of September 1978 in the western Swabian Alb revealed a better perceptibility of the earthquakes north of the Alpine main crest than south of it [27]. An improvement of the P_G- and S_G-traveltime curve of near earthquakes has been proposed for the seismographic station Vienna [68]. An empirical relation of the sensitivity of the station Vienna to earthquakes of different distances and magnitudes has been proved [51]. Empirical P_n- and S_n-traveltime curves for 3 different classes of focal depths are presented.

An international working group with participation of he IMG has determined focal parameters of 18 selected major aftershocks of Friuli, which occured between May 6 and September 15, 1976 [35]. Observations from many European seismic stations and also from mobile stations in the epicentral area were used for this purpose. For deriving more quantitative information from macroseismic observations the relation between maximum acceleration and the local intensity on the MSK-scale has been determined for Vienna [25].

A formula on the assessment of maximum earthquakes in the Alps and adjacent areas was developed [23]. This formula is based on the relation between fault length and magnitude M of an earthquake. This is possible because the magnitude is a function of the seismic energy which is proportional to the focal volume and consequently related to the focal length. Assuming that the entire fault length is involved in the earthquake process the maximum earthquake can be estimated, so far as $M < 7$ is valid.

Recurrence periods for strong earthquakes are investigated for Central Europe. Earthquakes with an epicentral intensity of at least 8° MS are followed by a fairly strong aftershock after an average period of 130 days. A second recurrence period of about 40 days seems to exist too [38].

5.1.2 Improvement and extension of the Austrian seismographic station network (Publications 58, 19)

In the beginning of the IGP the seismological service of the ZA operated 5 stations in Vienna, Wien-Kobenzl, Innsbruck, Molln and Kremsmünster with recording speeds of 30 or 120mm/min. For studying the East Alpine seismicity between the Carpathians and Friuli a higher time resolution of the recordings is as necessary as are additional stations located in the active seismic zones. At selected sites, where suitable conditions were indicated by noise level measurements, 6 new seismographic stations have been put into service, located in Pitten, Mariazell, Glashütten, Klagenfurt, Bleiberg and Malta. Fig. 10 shows the station network and the distribution of epicenters 1903 to 1973.

The stations are equipped with short-period seismographs (Geotech S 13). The total transmission characteristic of the system is tuned to a frequency range of 0.25—20 Hz. High time resolution is gained by a recording speed of 300 mm/min, which allows distinct seperation of different seismogram onsets.

The instruments of these stations have been standardized in their transmission characteristics [58].

5.1.3 Determination of focal coordinates and earthquake magnitudes (Publications 48, 49, 10, 29, 21, 36, 37, 30, 6, 20, 22)

The resolving power of this network with regard to focal coordinates has been studied [48], showing that the geographical distribution of the stations is best for the localization of earthquakes in the area of the Mur-Mürz fault system.

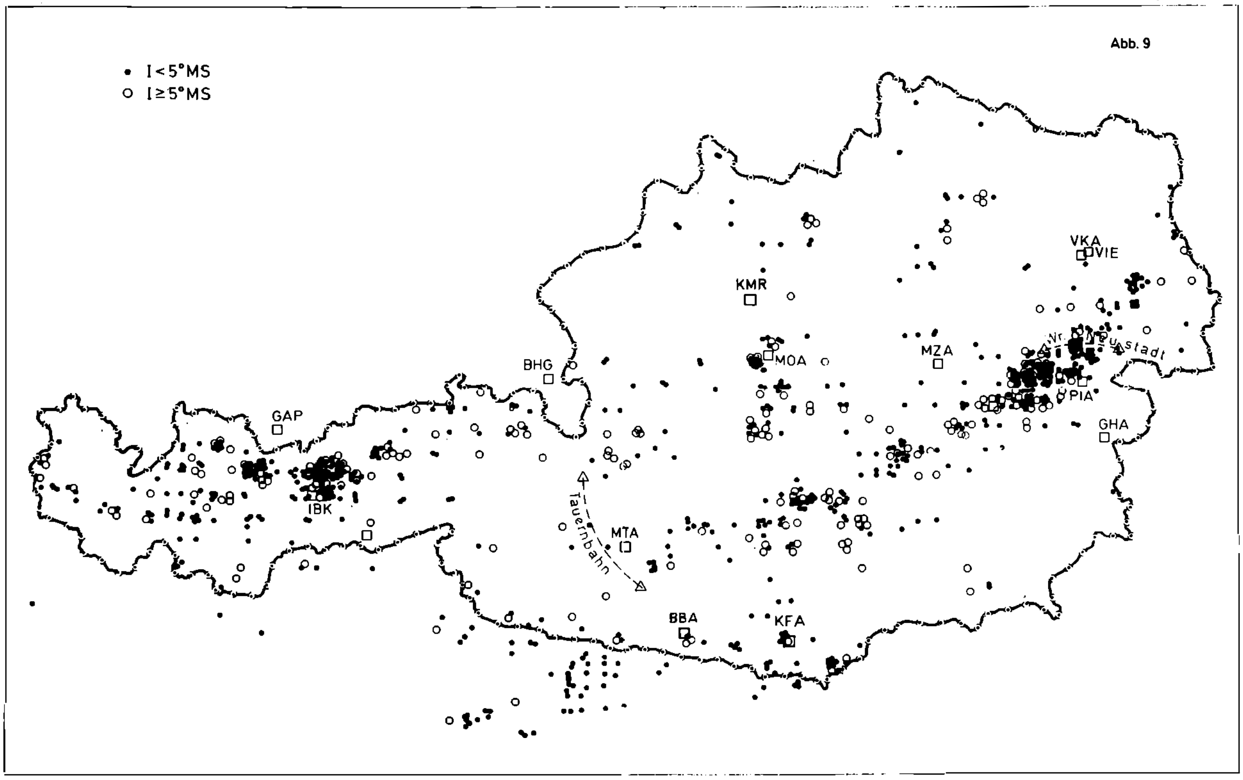

Fig. 10: Distribution of epicentres 1903—1973 and seismographic stations

VKA	Vienna-Kobenzl	BBA	Bleiberg
VIE	Vienna-Hohe Warte	MOA	Molln
PIA	Pitten	KMR	Kremsmünster
MZA	Mariazell	IBK	Innsbruck
GHA	Glashütten	GAP	Garmisch-Partenkirchen
KFA	Klagenfurt	BHG	Berchtesgaden
MTA	Malta		

A new computentional method using P_n- and P_G-arrval times of near earthquakes has been developed to determine focal coordinates, focal time, P_n- and P_G-velocity and the Moho-depth by a least square-fit of time errors [49]. With this method new hypocenter determinations of some earthquakes were performed showing that the foci in the Tauern are situated in the lower crust and those in the foreland of the Alps in the upper crust [10, 29].

Studies concerning the determination of earthquake magnitudes within a wide range of distances and periods have been carried out. One goal was to develop procedures for determining body wave and surface wave magnitudes by means of one seismograph with broad band recording characteristics [21].

The relation between the frequency and the magnitude of microshocks in the area of Molln is investigated [36]. It is shown, that the seismicity there is below the average of Austria. The great number of the Friuli aftershock enables a direct correlation between the signal duration, observed in Molln and the magnitude [37].

An empirical formula connecting the magnitude M, the amplitude A and the t_s-t_p-arrival time difference is developed. The knowledge of the epicentral distance is not necessary for using this formula. This advantage has been applied to another computational program for determining East Alpine epicenters. Observations of the dominant frequency of shear waves (Δ = 30 km to 500 km) indicate a clear dependence on the maximum intensity [30].

An empirical formula relating the magnitude, maximum intensity and focal depth h has been deduced from records of many Friuli aftershocks [6]. This formula is $\log h\ (\mathrm{km}) = 0{,}45\ M - 0{,}28\ I_0 + 0{,}80$.

The Leoganger Steinberge [20] and the neighboring Steinernes Meer area [22] were exposed to minor but unusual earthquake activity. Focal depths for these earthquakes were scattered around 10 km, thus indicating an origin within the crystalline basement, which has been overthrusted by the Northern Calcareous Alps. The magnitudes of these earthquakes, ranging from 1,6 to 3,5 have been estimated by an empirical formula based on macroseismic determinations of maximum intensity and focal depth:

$M = (2/3)\ I_0 + (8/3)\ \lg h - 2{,}57.$

Both formulas agree quite well, although they have been derived from earthquake observations in the Southern and the Eastern Alps respectively.

5.1.4 Fault plane solutions (Publications 44, 42, 14, 15, 29)

A comparative investigation of focal mechanisms of earthquakes in the Eastern Alps and the Dinarides reveals the dominance of horizontal motions of earthquakes and consequently their strike slip character within the investigated area. Further it is shown that the axis of maximum pressure is always oriented towards the Adriatic Sea [44].

GEORG GANGL

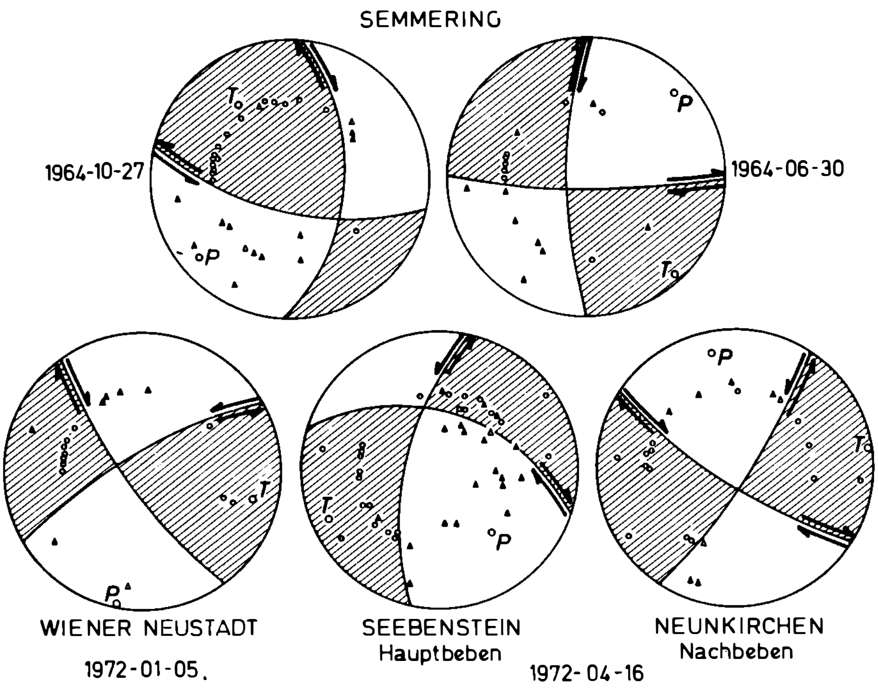

Fig. 11: Distribution of compression (circles) and dilatations (triangles) of the first motion of P-waves shown on the lower half of the focal sphere [42].

Within the Eastern Alps i. e. the eastern margin of the Alps the earthquakes belong to a NNE-SSW striking zone of increased seismic activity. The earthquake foci are situated in the upper crust (average depth: 9,9 km). The fault plane solutions obtained from the direction of first arrivals show predominantly horizontal motion.

Fig. 11 presents fault plane solutions for five typical earthquakes. Both Semmering earthquakes of fig. 11 are characterized by stress relaxation perpendicular to the strike of the Alps. The other three investigated earthquakes show focal mechanisms with maximum compression in N-S direction and maximum tension in E-W direction [42].

Twelve of 14 greater earthquakes in the area east of Judenburg indicate a tensional stress field oriented perpendicular to the alpine strike, i. e. more in E-W direction [14]. Probably this area is influenced by the forces initiated by the subsiding Pannonian Basin. According to this assumption the Viennese Basin, the Semmering and the eastern part of the Mur-Mürz Valley can be interpreted as a marginal fault system of the subsiding Pannonian block [15]. This conclusion fits into the concept of mantle diapirs below of the Pannonian Basin.

The earthquake of Molln (1967-01-29) has been investigated in detail [29]. This earthquake has a dipslip (compressional) fault plane solution with the B-axis oriented N 68°E. As far as macroseismic observations are concerned similarities with the earthquakes of Scheibbs (1876) and Neulengbach (1873) are evident.

5.1.5 Seismicity studies in Carinthia (Publications 8, 5, 12, 31, 7, 9, 13)

The series of Friuli aftershocks 1977—1978 indicate a correlation with the local seismicity in the lead mine of Bleiberg sofar only the mean activity in time intervals greater than 30 days is regarded. Single aftershocks of Friuli do not correlate with single local shocks in the mine [8]. Very small shocks occurring in the mine or nearby can be partially interpreted as man-made earthquakes (mine bumps), since blasts have been excluded.

The correlation of various earthquake events recorded at the seismographic station Bleiberg with the radon content of the nearby hot spring in Villach has been investigated. Corrections for changes of ground-water level, atmospheric pressure and precipitation have been applied [5]. This investigation has the goal to seperate tectonically and meteorologically induced changes of radon content, as this could be the basis for a tentative physical earthquake prediction.

Traveltimes of seismic waves from Friuli earthquakes recorded at Austrian seismographic stations have been used to construct a P-wave velocity model of the crust. Improvements concerning lateral veriations are still necessary [12].

The focal volumes of the main shocks of Friuli have been deduced from the area of aftershock activity which surrounds the main foci. The results agree well with those of other authors [31]. Using the t_s-t_p records of Bleiberg (Austria) and Trieste a value of $V = 10^4$ km^3 was determined for the main earthquake of May 6, 1976.

5.2 Recent crustal movements and earthquakes (Publications 42, 84)

Repeated precision levelling surveys of various level lines performed by the Bundesamt für Eich- und Vermessungswesen (Geodetic Survey of Austria) provide data concerning recent vertical movements in Austria. Some of these movements seem to be in connection with earthquakes.

After the earthquakes of Wr. Neustadt 1972 and Seebenstein 1972 repetition levelling of two lines (measured previously 1956—1961) indicated subsidence of the Wr. Neustadt basin. Maximum subsidence of 16 mm has been measured close the village Neudörfl east of Wr. Neustadt. This agrees very well with the fault plane solutions of the above mentioned earthquakes (see fig. 11), indicating tensile stress in this direction [42].

The level line Villach-Thörl Maglern has been measured in 1952 and 1964. After the Friuli earthquakes 1976 an additional survey of this line was performed in October 1976. From 1952 to 1964 a southward oriented uplift of 12 mm occured, while from 1964 to 1976 a downward movement of 4 mm was observed. This change of direction of recent crustal movements can be explained by the rebound mechanism of the Friuli earthquakes.

These earthquakes have a focal mechanism of the underthrusting type. For those earthquakes the rebound mechanism predicts in medium distances to the epicenter a preseismic uplift of the underthrusted block and subsidence due to the seismic rebound. As the geodetic observations are consistent with the mode described here, the recent movements may be interpreted as rebound effect of the Friuli earthquakes [84].

5.3 Earth tide investigations (Publications 61, 32, 60)

The La Coste & Romberg microgal gravimeter D-9 has been used for earth tide recordings. Three stations on a profile extending from the center of the Eastern Alps to the Pannonian Basin have been measured so far, namely Innsbruck, Vienna and Tihany (Lake Balaton). The purpose of this investigation is to determine whether the changing crustal structure between Alps and Pannonian Basin is of importance for the tidal parameters. In addition the deformation coefficient for tidal corrections of gravity measurements in this area has to be evaluated and information concerning the non-elastic behavior of the crust shall be gained.

At each station recordings have been performed for time intervals of more than 70 days. The analysis of records is performed by standard procedures of T. Chojnicki and ICET respectively which are in worldwide use [61].

As example for the analysis according to Chojniki observations at Vienna — Hohe Warte are presented.

Recording period: 71 days	group symbol	amplitude factor
	S_2K_2	1,180 ± 0,004
	M_2	1,184 ± 0,002
	$K_1P_1S_1$	1,154 ± 0,003
	O_1	1,171 ± 0,004

Comparisons with Tihany observations indicate systematic differences

group symbol	ratio of amplitude factors Vienna/Tihany
S_2K_2	99,5%
M_2	99,7%
K_1	101,2%
O_1	100,1%

(Meurers, personal communication, 1979).

Further the hypothesis is tested, whether the horizontal component of the earth tides can trigger earthquakes. Approximately 450 Austrian and Friulian earthquakes of the period 1900—1977 have been used for a statistical investigation. For the time of origin of each earthquake the azimuth of the tidal vector has been calculated. For these azimuth angles the frequency distribution shows two maxima in a distance of approximately 90°. In different earthquake zone of Austria the orientation of fault zones coincides with the maxima of the distribution. This correlation of fault orientation and earth tide azimuth points to a triggering effect, which is of interest for questions of earthquake prediction [32].

6. Contributions to potential field investigations

Potential methods have been applied to gravimetric and geomagnetic data as well as theoretical and methodological questions connected with geodynamic research objectives have been treated during IGP.

6.1 Geomagnetic field transformations (Publication 73)

Various transformations of the total intensity data (T) of the earth's magnetic field have been investigated. The reduction to the pole, which is a very important transformation, was applied to the T-residuals of the Eastern Alps. Because of this, almost all T-anomalies with a strike direction W-E are shifted to the North by approximately 15—20 km and are now situated just above the disturbing bodies. Also the transformation of the anomalous T-vector into its components (x, y, z) have been used for transforming the T-residuals of the Eastern Alps into Z-residuals [73].

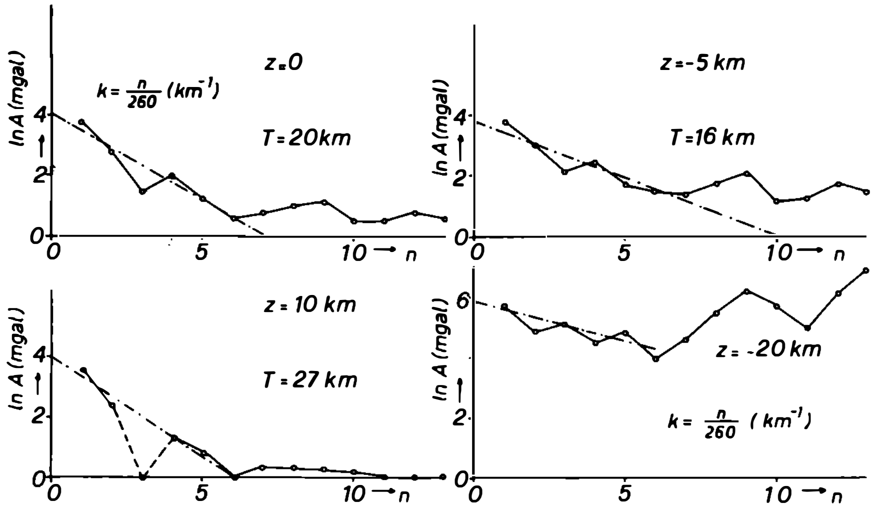

Fig. 12: Depth estimation of the gravimetric source by means of harmonic analysis for a N-S profile in the Hohe Tauern [73].

6.2 Gravity field investigations (Publications 73, 74, 66, 83, 85)

Upward and downward continuations of the gravity field of the Eastern Alps have been calculated as well. The field was projected upward to the elevations 10, 30 and 100 km and downward to —5 km. A depth estimation of the gravimetric source has been performed by means of harmonic analysis for the conspicious Bouguer gravity minimum of the Hohe Tauern area. Fig. 12 shows the amplitude spectra of a N-S profile for projection elevations 0, 10, —5 and —20 km and the depth estimation T from the projection height to the theoretical layer of origin. This depth estimation — giving a maximum depth — is derived from the slope low frequency Fourier amplitudes, which becomes zero if the layer of origin itself is chosen as projection height.

According to fig. 12 the causing body of the Bouguer minimum of the Hohe Tauern is situated in the upper crust in a maximum depth of 17 to 21 km [73].

A comparison of the power of the two-dimensional harmonic analysis and the convolution method in potential field transformation has been performed. Harmonic analysis yields slightly better results for greater continuation heights, while the influence of the periphery of the measuring plane to the frequency response of the actual field data has to be considered as a minor shortcoming of this method [74].

As it is not possible to determine the vertical gradient of the gravity field directly, experimental and mathematical approaches have been tested in the area of the GAT-project. Experimental determinations were performed by measuring gravity differences at two positions one upon another. The upper position is measured on a tripod, which causes some problems concerning stability. The LaCoste & Romberg microgal-gravimeter D-9 has sufficient sensitivity to reduce the height dimension of the tripod to approximately 1,6 m. This enhances the accuracy of the measurement considerabely. In addition the vertical gradient was computed for the same area with Bhattacharyya's formula out of the Bouguer anomalies. The comparison was carried out for 22 stations and resulted in a significant correlation. The correlation coefficient $r = 0{,}73$ is acceptable at the 99,9% level [66].

For performing such high precision measurements the calibration of the gravimeter has to be done very carefully and nonlinearities of the calibration factor have to be considered [83].

Additional problems arise from the high vibrational noise level of the European Calibration Line and minor inaccuracies in the gravity datum of the European Calibration Line. The latter one is caused by measuring errors as well as by the change from the International Gravity Formula 1930 to the Geodetic Reference System 1967 [85].

However, absolute gravity determinations in Austria should overcome these difficulties in the near future.

6.3 Relation between gravitational and magnetic field (Publications 72, 79, 75)

Because of Poisson's theorem there exists a simple relationship between the gradient of gravity potential and the geomagnetic potential. This relationship can be of great help for interpretation especially if ultrabasites have to be discriminated from other types of rock.

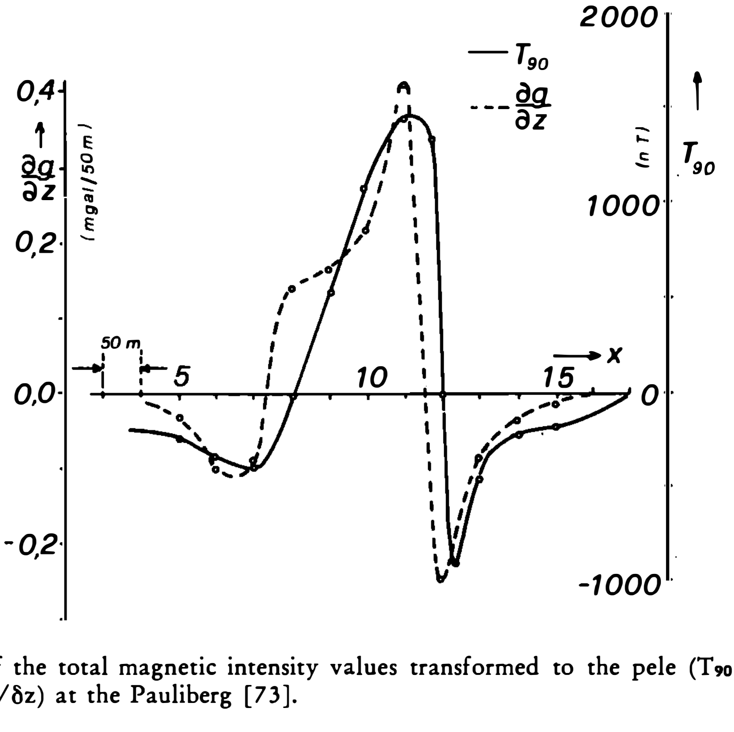

Fig. 13: Comparison of the total magnetic intensity values transformed to the pele (T_{90}) and of the vertikal gradient of gravity ($\delta g/\delta z$) at the Pauliberg [73].

This relationship has been applied to the gravimetric and magnetic data measured at the basalt outcrop of the Pauliberg near Landsee, Burgenland. It has been shown already that these basalts are part of the young volcanic activity of the Alpine orogenesis. They consist mainly of alkaline olivine basalts. Magnetic ($\triangle T$), rock magnetic and gravimetric measurements ($\triangle g$) were carried out over the Pauliberg in 1976. From two-dimensional model calculations the maximum thickness of approximately 60 m was deduced for the basalts [72].

After the transforming the $\triangle T$-values to the pole and calculating the vertical gradient of $\triangle g$ (see fig. 13) Poisson's theorem was used in an attempt to obtain quantitative data on the density contrast of the Pauliberg basalts to the basement: calculated and measured density values are coincident [79].

Poisson's theorem has also been applied on a regional scale. There is some visual evidence of a correlation between the Bouguer anomaly δg and the residual δZ of the earth's magnetic field in the Eastern Alpine area. If this correlation is real, it should be caused by the same structure in the crust of the earth. To examine this, the gravimetric and magnetic data of parts of Central Europe were interpolated on a square grid with a grid spacing of $\triangle s = 10$ km. In the next stage the two horizontal gradients and the vertical gradient were estimated by means of approximation formulas. The correlation between these gradients and δZ was performed by evaluating the multiple correlation coefficient. Only in the eastern part of Austria a good correlation was found. To explain this result a test profile has been evaluated. Two-dimensional model calculations along a N-S profile in Central Austria indicate that the δZ-anomaly is caused by the upper boundary of the weakly magnetized crystalline basement. This has also a positive density contrast to neighboring formations, and contributions therefore to the Bouguer anomaly. But the total amount of the Bouguer anomaly contains also the effects of rock formations situated in greater depths, thus having temperatures well above the Curie point. Therefore these formations cannot contribute to the geomagnetic isanomalies [75].

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Appendix

Geographical coordinates of localities

Locality	Longitude East	Latitude North
Bad Deutsch Altenburg	16° 55’	48° 08’
Bad Leonfelden	14° 18’	48° 31’
Bleiburg	14° 48’	46° 35’
Brunnbach	14° 31’	47° 50’
Eberndorf	14° 39’	46° 35’
Fluela Paß	9° 57’	46° 46’
Frojach	14° 19’	47° 08’
Gmünd (Kärnten)	13° 33’	46° 55’
Gnesau	13° 58’	46° 55’
Gurk	14° 18’	46° 53’
Hechtsee	12° 10’	47° 37’
Hochalmspitz	13° 19’	47° 01’
Hochfilzen	12° 34’	47° 26’
Horn	15° 40’	48° 40’
Innsbruck	11° 24’	47° 16’
Judenburg	14° 40’	47° 10’
Klagenfurt	14° 19’	46° 37’
Köttmannsdorf	14° 14’	46° 34’
Körmend	17° 01’	47° 07’
Lavantsee (Judenburg)	14° 34’	47° 04’
Leoben	15° 06’	47° 23’
Linz	14° 17’	48° 03’
Loibl Paß	14° 16’	46° 26’
Losenstein	14° 26’	47° 56’
Matrei	12° 32’	47° 00’
Melk	15° 20’	48° 14’
Mont Revard	5° 59’	45° 40’
Naßfeld Paß	13° 17’	46° 33,5’
Nöring Sattel	13° 38’	46° 51’
Nufenen Paß	8° 23’	46° 29’
Obersee (Staller Sattel)	12° 12’	46° 54’
Orgiano	11° 57’	45° 21’
Palfau	14° 48’	47° 43’
Passau	13° 28’	48° 34’
Plöschenberg	14° 14’	46° 34’
Pyramidenkogel	14° 09’	46° 37’
Radenthein	13° 43’	46° 48’
Sabalahöhe	14° 10’	46° 34’
Sachsenburg	13° 21’	46° 50’
Sebenstein	16° 09’	47° 42’
Semmering	15° 50’	47° 38’
Stolzalpe	14° 11’	47° 07’
Unterlaussa	14° 27’	47° 57’
Unzmarkt	14° 25’	47° 12’
Villach	13° 51’	46° 37’
Völkermarkt	14° 38’	46° 40’
Walchsee	12° 20’	47° 39’
Wattener Lizum	11° 41’	47° 10’
Wiener Neustadt	16° 15’	47° 49’

Institut für Geophysik der Montan-Universität Leoben

Institute for Geophysics of the Mining University Leoben

ACTIVITIES OF THE INSTITUTE OF GEOPHYSICS OF THE MINING UNIVERSITY LEOBEN IN THE INTERNATIONAL GEODYNAMIC PROJECT

by

F. Weber, H. Janschek, H. Mauritsch, M. Oberladstätter, R. Schmöller and G. Walach

With 18 Figures

The investigations of the Leoben working group refer to the following research projects:

1. Geophysical geotraverses in the easternmost part of the Eastern Alps and the Alpine-Pannonic boundary region (gravimetry, magnetics, seismics).
2. Petrophysical measurements (density, magnetic susceptibilitiy, longitudinal velocity) in the same area.
3. Geothermal measurements in the area of Styria and Burgenland.
4. Paleomagnetic investigations on Miocene and Pliocene volcanites in the area of eastern Styria.

1. Introduction

Geological investigations in the easternmost part of the Alps yield new and very important results which change the structures of this region. The proven existence of extended penninic windows in the area have far reaching consequences for the clarification of nappe structures. These observations demonstrate the necessity of our project and the validity of the chosen geophysical program. With regard to the latest geological and geophysical evidence a broad geotraverse was planned reaching from the Wechsel area to the Hungarian border, which crosses all the important geological units, in order to obtain further information. Furthermore the data was connected to the Hungarian net of measurements where the results are proven by deep seismic sounding and deep wells.

In 1975 a strong impuls was given by the Alpine Longitudinal Profile sponsored also by the Geodynamic Project organisation. We obtained information down to the Moho discontinuity in the immidiate southern neighbourhood of our project area. Following this, the geotraverse 3 was planned to supplement the seismic data with results from other methods.

In the last year of the project we attempted in part to fill the area between the traverses with a net of magnetic and gravemetric measurements.

The density of measuring points in the area is such that the results contributed to the regional geophysical survey of Austria. This forms a basis for the continuation of geophysical research in selected areas and selected topics where interdisciplinary cooperation exists.

2. Magnetics

Measurements of the magnetic vertical component on three regional traverses have been carried out, in the easternmost part of the Central Alps and the adjoining Tertiary regions, to study the deep structure and nappe systems on the eastern border of the Alps. A map of the surveyed area is presented in figure 1. About 8000 readings in an area of approximately 1000 km². Normally the average stadion density was 4/km² but in areas of important anomalies station density was increased to 10/km². Additional micromagnetic studies (grid 5 x 5 or 10 x 10 m) were most helpful in determining main tectonic directions.

Susceptibility determinations, discussed in the later chapter „Petrophysics“ show significant key rocks in the different Penninic and East Alpine geologic-tectonics units. For most of the Miocene and Pliocene volcanic rocks in the Styrian Tertiary basin high susceptibilities were observed, where the Tertiary sediments show very small values.

The results of N-S magnetic traverse 1 have been published in Austrian IGP-report 1975 (short note) and later by WALACH [9]. Isanomalic maps of the W-E traverse 2, connected to traverse 1 near Waldbach, show characteristic anomalies indicating a continuation of the Penninic Rechnitz Series under Lower East Alpine nappes (Wechsel- und Grobgneiss Series) about 40 km to the west. Figure 2 is a cross section of the western part of traverse 2, showing the above mentioned geological situation deduced from geophysical model calculations. As an example the model calculation of the NNE striking anomaly near Schäffern is shown in figure 3.

In the eastern part of magnetic traverse 2, W of Lutzmannsburg the main strike direction of anomalies is ENE, corresponding well to the general striking of the adjoining Penninic Series.

The nearly 100 km long magnetic traverse 3 covers the „Alpine Longitudinal Profile“ (Alp 75), section 5, from E of Graz to the Hungarian border. Isanomalic maps and the model calculation shown in figure 4, reflect extension and depth of buried Miocene volcanics within Tertiary layers near Ilz and show two parallel, NNE striking, W dipping, prism-shaped disturbing bodies along the Hungarian border near Eberau, whose exact geological meaning up till now is unknown.

The comprehensive results, including all previous magnetic investigations in this area, has presented OBERLADSTÄTTER, WALACH and WEBER in EGS-meeting, Vienna 1979 [6].

3. Gravimetry

The gravimetric measurements were started in 1977 in the area between 47° 15'—47° 30' N, 15° 50'—16° 50' E and fieldwork was finished in August 1979. A location map is shown in figure 5. Till now 540 stations over an area of approximately 1600 km² have been measured.

In a montainous country the topographic corrections are a very important factor in gravity interpretation. Therefore, to enhance the accuracy of results a digital terrain model of the surveyed area on a grid of $\Delta \phi = 0{,}1975'$ and $\Lambda = 0{,}3125'$ (approximately 350 x 380 m) on base of the Austrian topographic maps 1 : 25.000 and 1 : 50.000 was developed. In connection, with a detailed density model on an equal grid, high precision position- and elevation controls for the field stations and specific computer techniques, it will be possible, to reduce the errors in Bouguer anomalies to very small magnitudes. Computer programs for correcting and analyzing gravimetric data have been prepared. Initial results as a Bouguer map calculated with standard density 2,67 g/cm³ will be published in the last quarter of 1979.

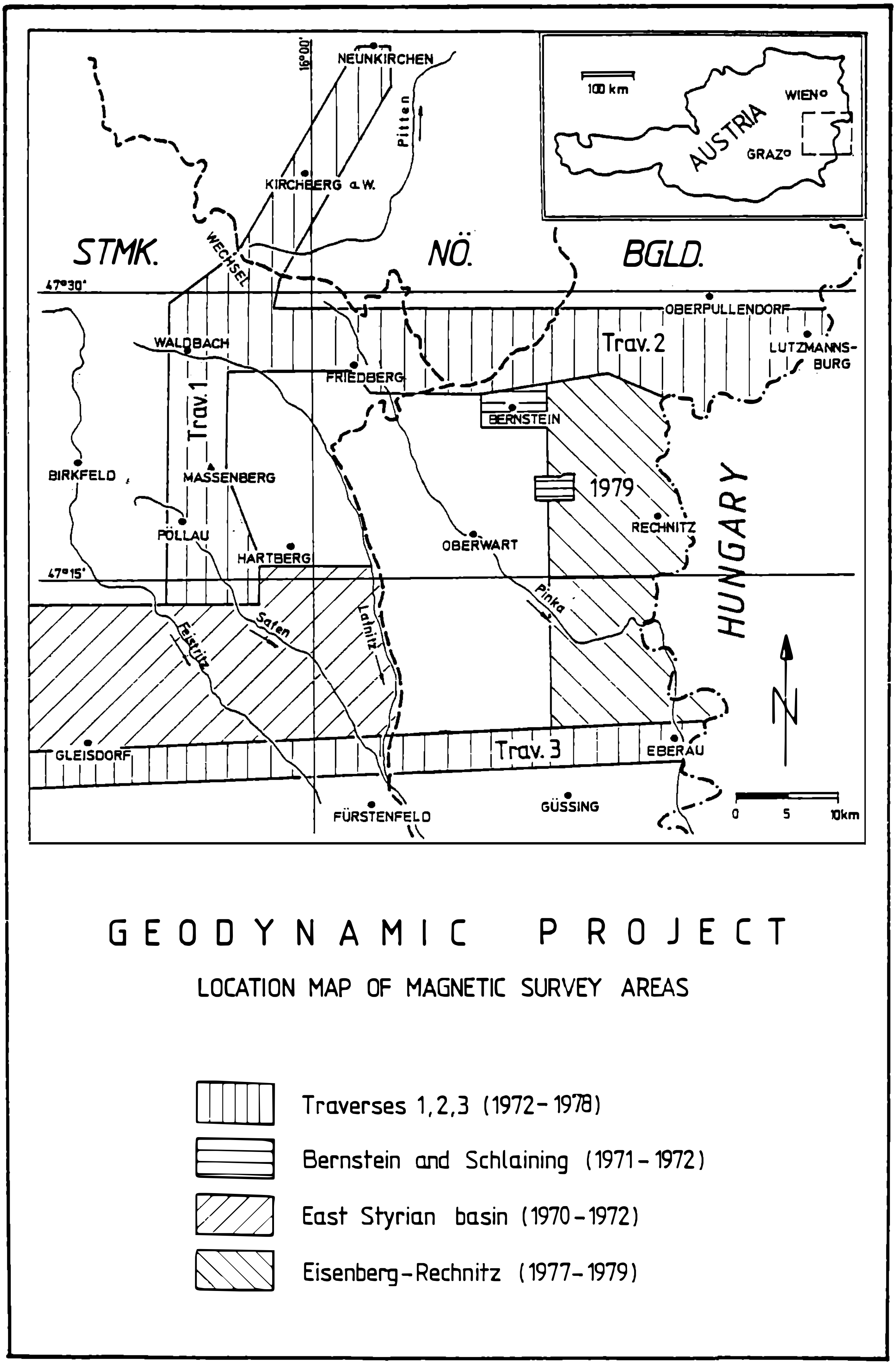


Fig. 1: Location map of magnetic survey areas

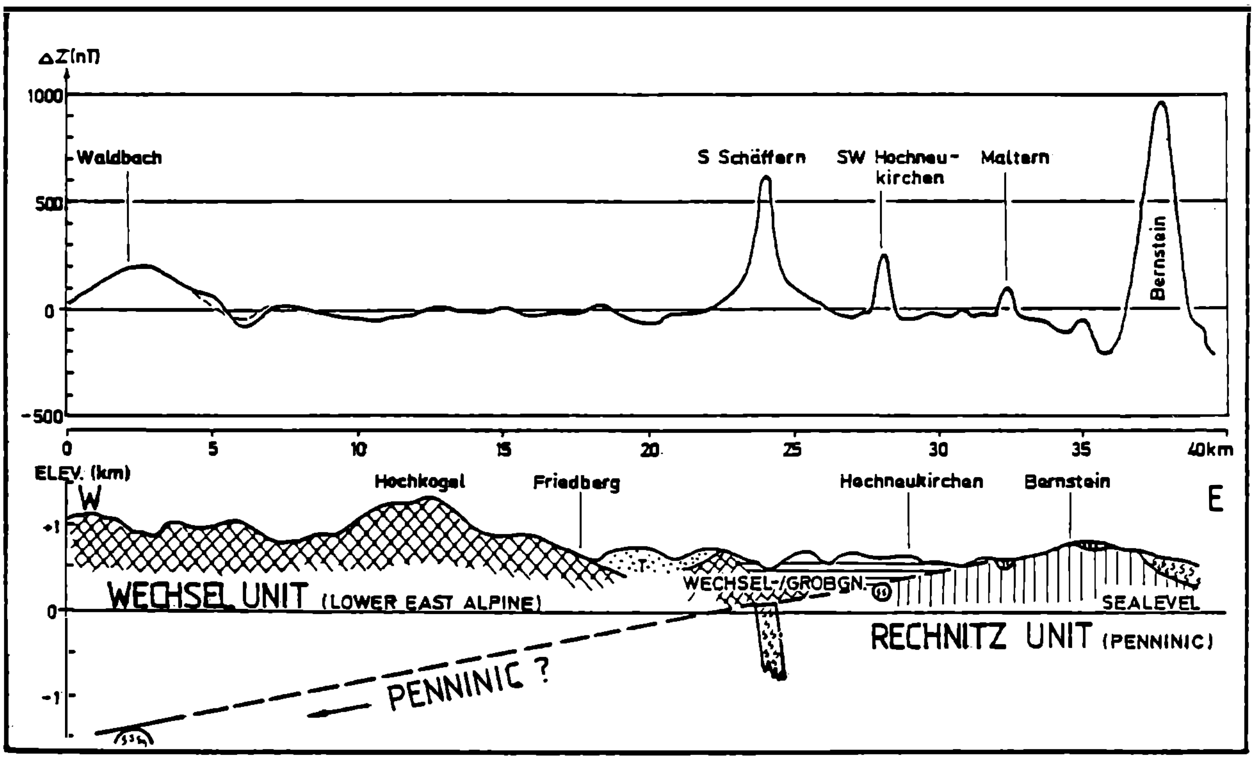


Fig. 2: Magnetic profil and interpretation of traverse 2

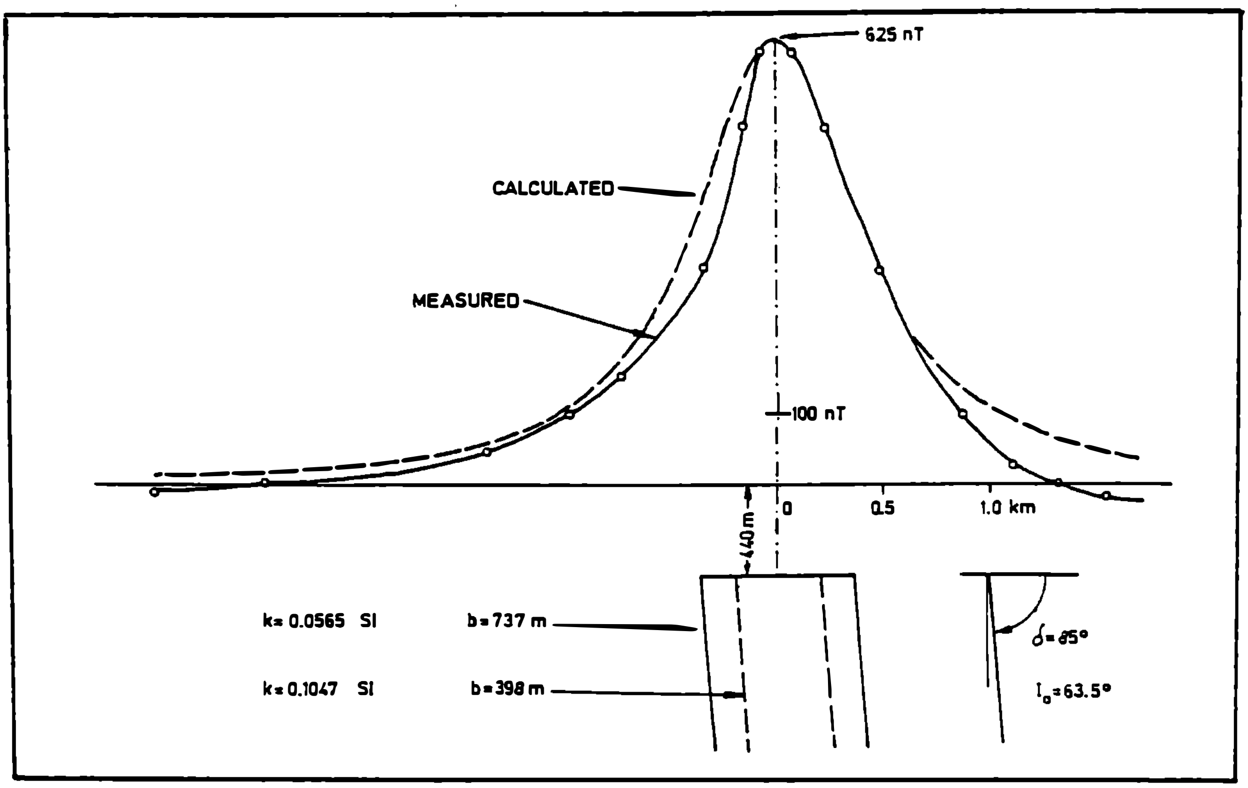


Fig. 3: Model calculation of the Schäffern anomaly (Magnetic traverse 2)

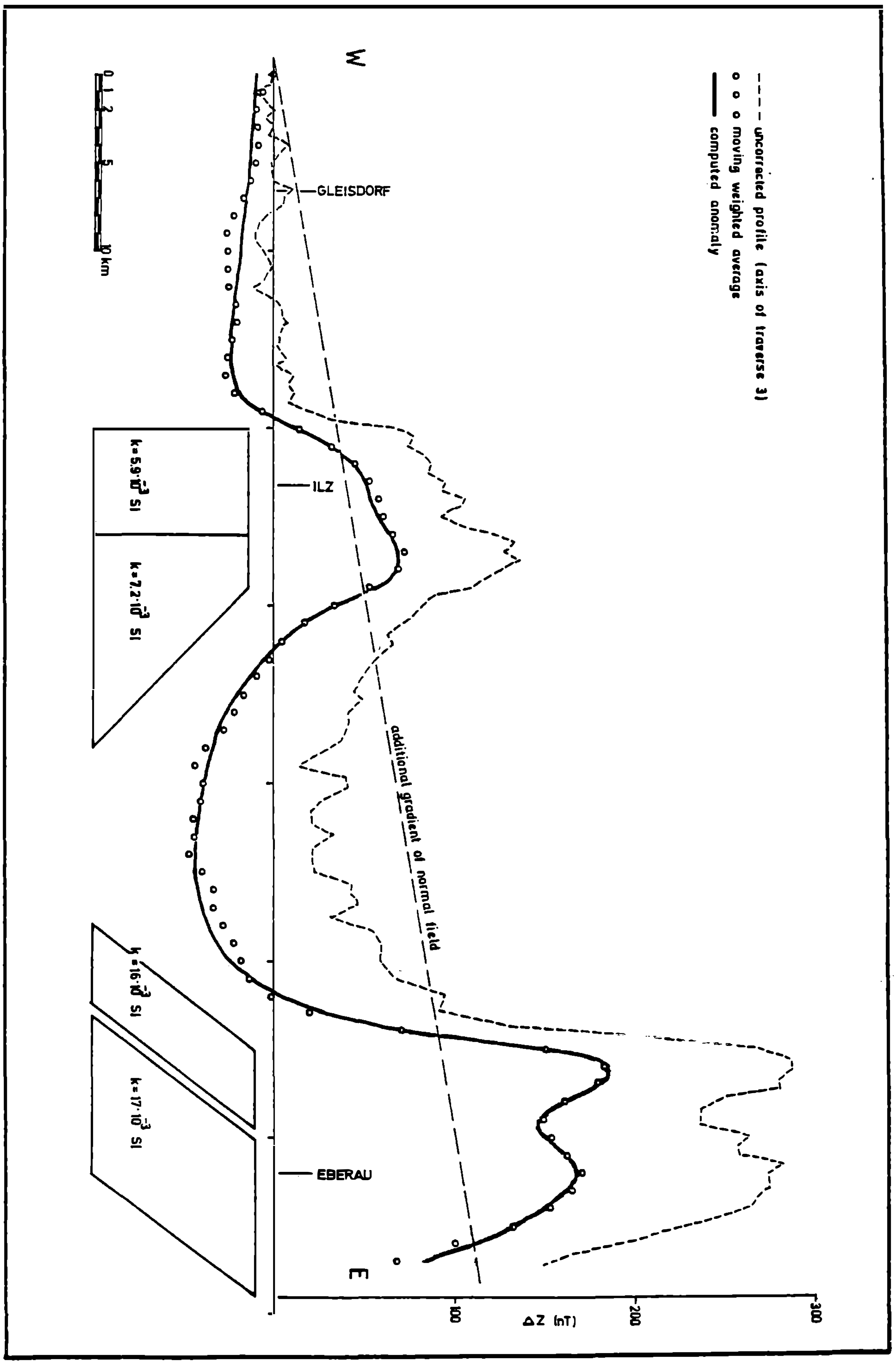
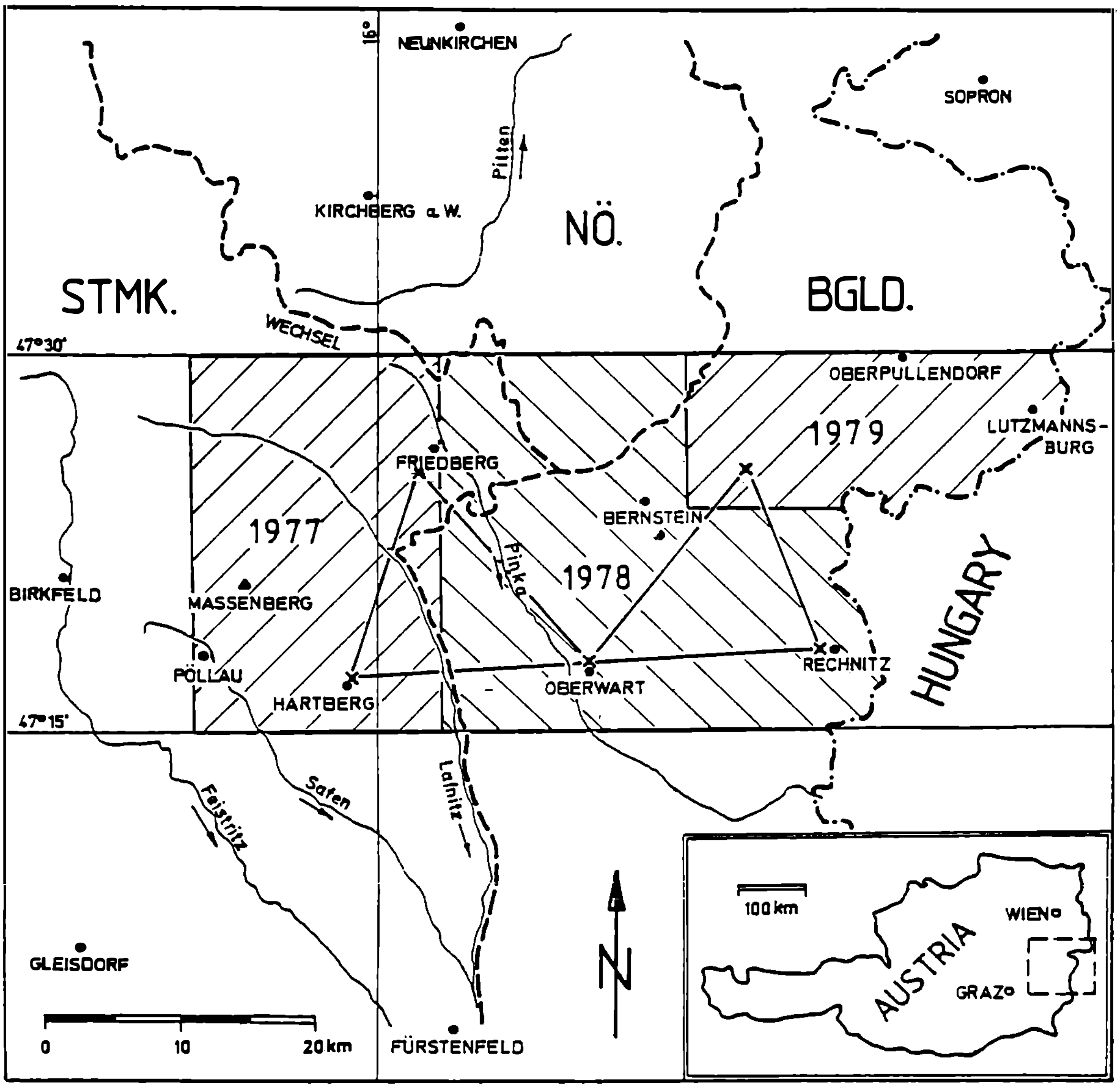


Fig. 4: Model calculation for magnetic traverse 3



GEODYNAMIC PROJECT

LOCATION MAP OF GRAVIMETRIC SURVEY AREA

× Base stations connected to the Austrian gravity network

Survey area approx. 1600 km^2, 540 stations

Fig. 5: Location map of gravimetric furvey area

4. Petrophysics

Contemporaneous to the geophysical investigations, a study of petrophysical parameters was performed. Measurements of magnetic susceptibility, density and longitudinal velocity on nearly 1500 rock specimes were made, additionally supported by a high number of "in situ" measurements of susceptibility and longitudinal velocity. Measurements of remanent magnetisation will be made in near future.

The present available data have been statistically analyzed and grouped, according to variations of the above mentioned parameters, to give reliable petrophysical models of the surveyed area. Tables 1 and 2 give a general review of the results.

Table 1: Densities (g/cm³) and susceptibilities (10^{-3} SI)

Series	Rocks	Density	Susceptibility
Rechnitz (Penninic)	Carbonateschists	2,72	0,2
	Carbonatephyllites	2,70	0,2
	Quartzphyllites	2,66	0,1
	Marbles	2,72	<0,1
	Sericitephyllites	2,67	1
	Ophicalcites	2,78	5
	Greenschists	2,96	0,7
	Serpentinites	2,61	36
	Serpentinites (with magnetite blasts)	2,98	160
	Conglomerate (Cak)	2,75	<0,1
Wechsel (Lower E. A.)	Albitegneisses	2,70	0,6
	Micaschists	2,68	0,6
	Amphibolites (diaphtoritic)	2,92	0,7
	Greenschists	2,87	50
Grobgneiss (Lower E. A.)	Micaschists	2,70	0,2
	Aplitegneisses	2,62	0,3
	Granitgneisses	2,68	0,3
	Metagabbros	2,95	0,6
(Permomesozoic)	Quartzites	2,66	<0,1
Sieggrabner (Middle E. A.)	Paragneisses	2,63	0,3
	Amphibolites	2,88	24
	Eclogites	3,36	2
	Serpentinites	2,53	32
Hannersdorf (Upper E. A.)	Dolomites	2,76	<0,1
	Rauhwacke	2,28	<0,1
	Greenschists (a, b)	2,86	0,6 35
	Miocene volcanites (andesitic)	2,64	2 . . . 40
	Pliocene volcanites (basaltic)	2,80	12

Table 2: Longitudinal velocities in m/sec (Maltern and Friedberg area)

Series	Rocks	in situ-measurements (shotpoint-distance >200 m)	ultrasonic measurements
Rechnitz	Carbonateschists	3300 — 3800	5040
	Carbonatephyllites	3300 — 3800	6270
	Sericitephyllites	3000 — 3800	6000
	Greenschists	2600 — 3600	5290, 6270
	Dolomites	—	5290
	Gabbro-Amphibolites	—	7350
	Antigorit-Serpentines	4800 — 5000	6070
	Breunerit-Serpentines	—	4060
Wechsel	Albitegneisses	4100 — 5000	—
	Albitegneisses, cracked	—	2940
	Micaschists	4100 — 4500	5600
	Plagioglasamphibolites	—	5200
	Amphibolites, diaphtoritic	4800 — 5400	4890
	deeper horizons (?)	5500	—
Grobgneiss	Micaschists	3500 — 4500	—
	Aplitegneisses	4500 — 5000	4290
	Granitegneisses	4800 — 5000	—

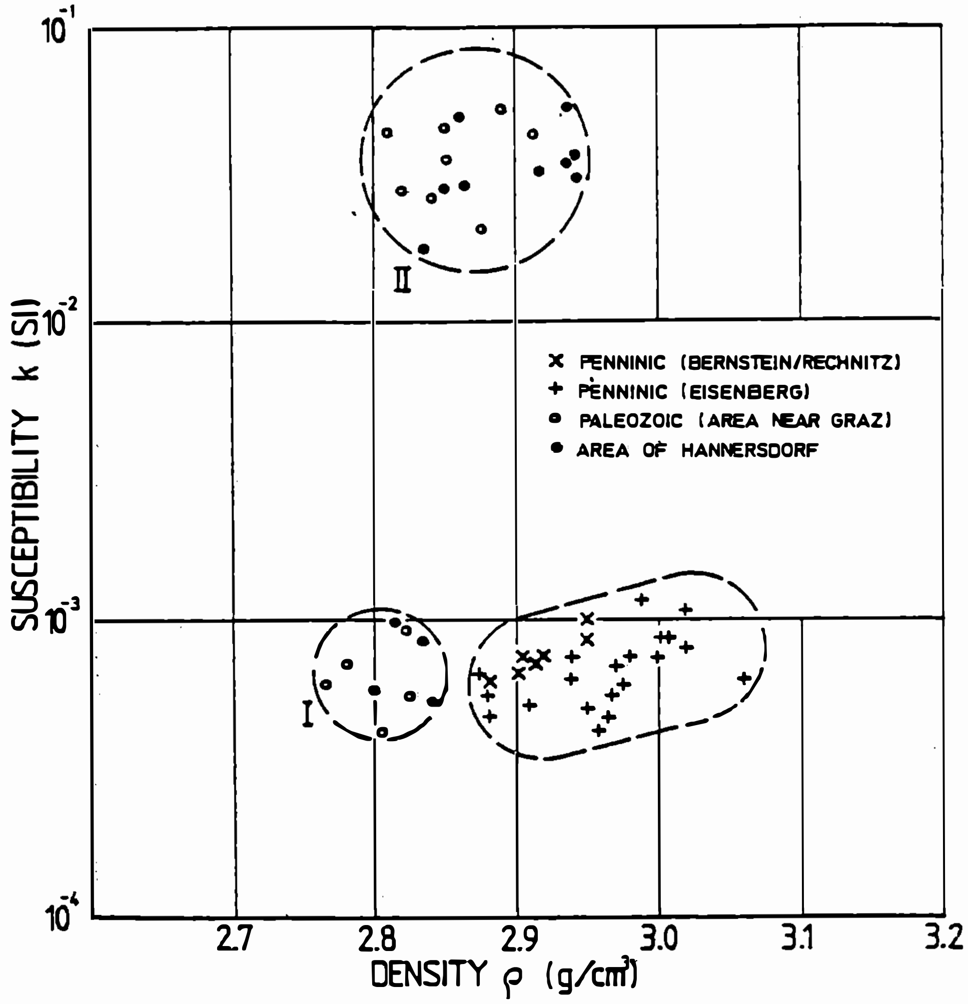


Fig. 6: Crossplot susceptibility versus density of several greenschists

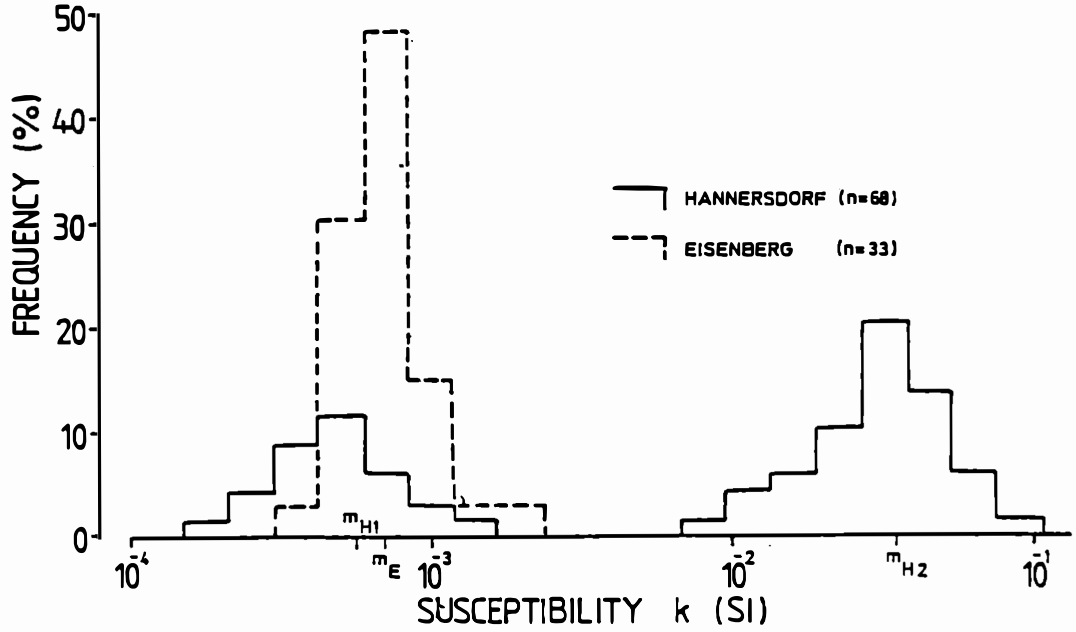


Fig. 7: Frequency distributions of susceptibilities from greenschists of Eisenberg and Hannersdorf

Susceptibility observations show significant variations in the rocks of different Penninic and East Alpine geologic-tectonic units. In the Penninic Rechnitz Series different ophiolites, mainly serpentinites show high susceptibilities up to 240.10^{-3} SI-units (mean value 35.10^{-3}). In the Wechsel Series greenschists are marked by high values up to 60.10^{-3} (mean 50.10^{-3}), but the gneisses and micaschists of the Grobgneiss Series have uniformly very low susceptibilities (mean 0,3—10^{-3} SI-units). Most of the Miocene and Pliocene volcanic rocks within the Styrian Tertiary basin have also high susceptibilities [2, 3, 8]

Density measurements on rock specimens of the Wechsel- and Grobgneiss Series show only small density variations and confirm the assumption, that the standard density of 2,67 g/cm^3 is a good estimate for the gravimetric corrections. In the Rechnitz Series marbles, carbonateschists, ophicalcites, greenschists and partly serpentinites (due to the content of magnetite) have higher densities up to 3,05 g/cm^3. The mean value for all Penninic rocks is in the range of 2,75 g/cm^3.

A two-dimensional frequency plot of susceptibility versus density (figure 6) often give important informations on the rocks in question. In the Eisenberg/Hannersdorf area (see figure 1) two types of greenschists occur. The greenschists of Eisenberg show identical petrophysical properties to the Penninic Rechnitz greenschists-mean density 2,96 g/cm^3 and a unimodal susceptibility distribution (mean $0,7.10^{-3}$). However, the greenschists of Hannersdorf have a mean density of 2,86 g/cm^3 and a significant bimodal susceptibility distribution with partial mean values of $0,6.10^{-3}$ and 35.10^{-3} SI-units (figure 7). This difference could be an indication, that the greenschists of Hannersdorf are a part of the adjoining Upper East Alpine nappe relics. A comparison of this data with data from the greenschists of the Upper East Alpine area near Graz ("Grazer Paläozoikum") in figure 6, confirms this assumption.

Refraction seismic surveys in some parts of traverse 2 (Maltern 1971, 1977; Pinggau-Friedberg 1976), completed by ultrasonic measurements in the laboratory, were performed to get informations about the longitudinal velocity and about the distribution of the different rock members to a depth of about 300 m. After PAHR (1972) the Penninic Rechnitz Series is the deepest tectonic unit in the surveyed area, overthrusted by the Lower East Alpine units Wechsel- and Grobgneiss Series.

As shown in table 2 maximum values of 4000 m/sec and more may be due to either rocks of Grobgneiss- and Wechsel Series or dense limestones and serpentinites of the Rechnitz Serie. Great variations of longitudinal velocity were observed in the Rechnitz Serie but generally the velocities are smaller than in the overlaying tectonic units. This fact may give a "blind zone" in seismic refraction measurements.

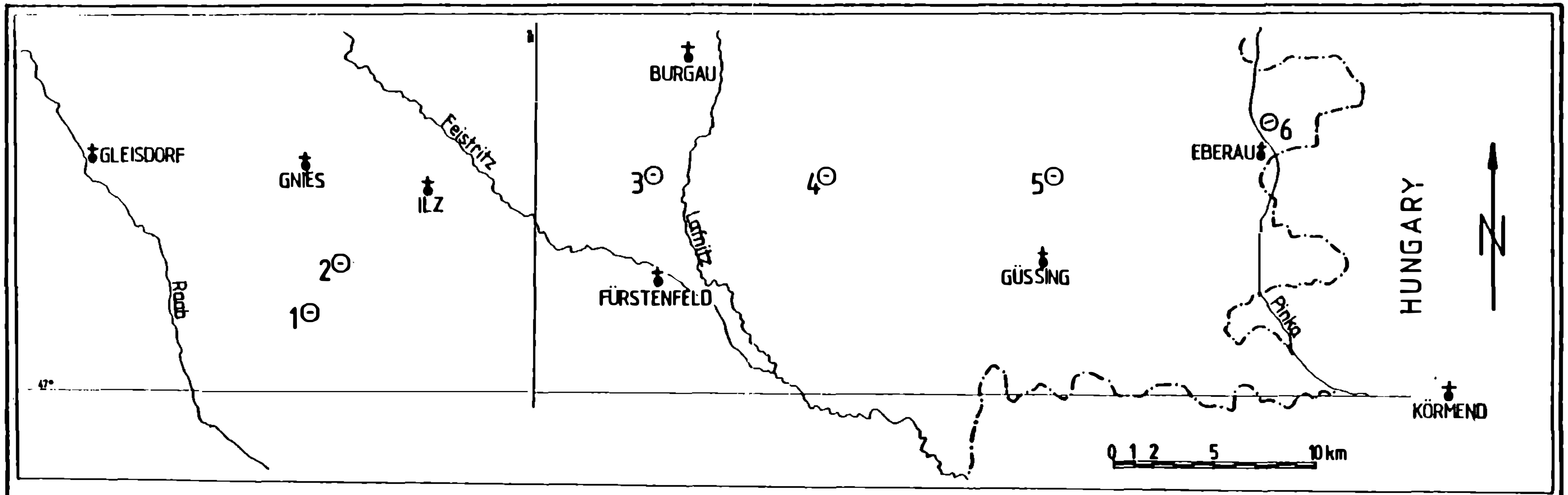
5. Reflection Seismogramms from Shotpoint F (Hungary) Recorded in Eastern Austria.

Three shots from shotpoint F (32 km NE Körmend, Hungary) were recorded by reflection seismic stations on six locations in the eastern most part of the Alpine Longitudinal Profil 1975 (Fig. 8). Besides the analog seismic stations of the Institutes of Geophysics of the universities in Leoben and Vienna a digital reflection seismic station of PRAKLA-SEISMOS GmbH. (working for RAG, Vienna) was also available in 1977.

Date	Time	Charge (tons)	Refl. seism. Station	Location
17. 9. 1975	09 : 01 : 01.95	4	4 (Inst. Leoben)	Eisenhüttel
21. 6. 1977	05 : 00 : 00.57	1	1 (PRAKLA-SEISMOS)	Hartmannsdorf
21. 6. 1977	05 : 00 : 00.57	1	3 (Inst. Leoben)	Commende Wald
24. 6. 1977	05 : 59 : 58.55	2	2 (PRAKLA-SEISMOS)	Eichberg
			5 (Inst. Leoben)	Punitzer Wald
			6 (Inst. Vienna)	Eberau

One of the presented records was taken in 1975 near Eisenhüttel (station 4). The result of a preliminary interpretation was presented in Salzburg (Geodynamic and Geotraverses around the Alps, meeting 28. 2. — 1. 3. 1977). A good agreement between the recorded and theoretical traveltimes was reached by using a compressed and somewhat simplified velocity depth distribution proposed by H. MILLER (1977) for the Tauern Window-area (shotpoint D).

This velocity depth function — further simplified — was used again for the reinterpretation in connection with the 1977 measurements. To fit the theoretical and measured travel times of the headwave M 1 travelling along the bedrock of the Tertiary basins in Austria and Hungary and to simplify the calculations a mean basement depth H 1 was chosen individually for each seismic station. Deriving from this conception the presumable basement depths at the seismic stations an agreement with the so far known topography of the bedrock at least in the Styrian basin has been found. So the computation procedure regarding the individual mean basement depths seemed to be an acceptable interpretation method and it was used also for the later arrivals of reflection and refraction waves.

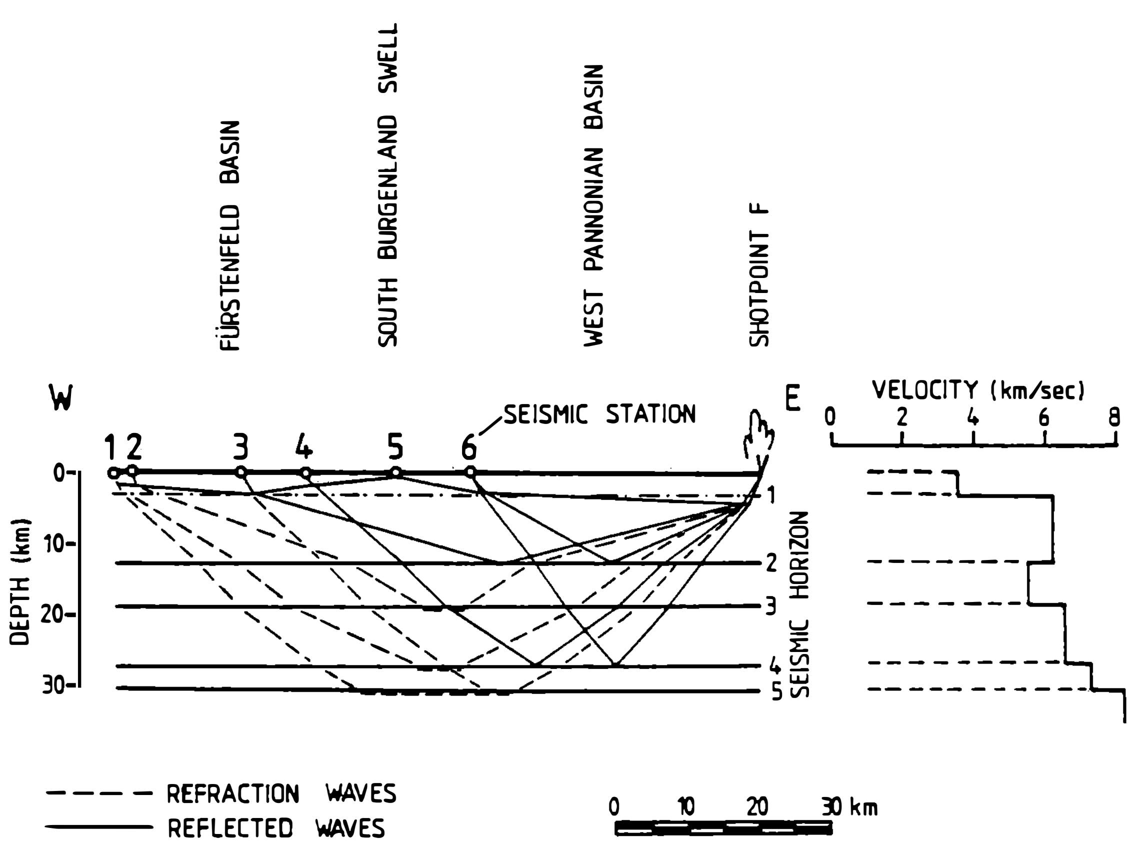


GEODYNAMIC PROJECT

POSITION MAP OF THE REFLECTION SEISMIC STATIONS IN AUSTRIA FOR SHOTPOINT F
(~32 km NE KÖRMEND, HUNGARY)

Stations	Spread length
1 Hartmannsdorf	1380 m
2 Eichberg	1380 m
3 Commende Wald	690 m
4 Eisenhüttl	690 m
5 Punitzer Wald	690 m
6 Eberau	460 m

Fig. 8: Position map of the reflection seismic stations in Austria for shotpoint F (32 km NE Körmend, Hungary)



REFLECTION SEISMIC STATION

1 HARTMANNSDORF
2 EICHBERG
3 COMMENDE WALD
4 EISENHÜTTL
5 PUNITZER WALD
6 EBERAU

GEODYNAMIC PROJECT

SELECTED RAYPATHS BETWEEN SHOTPOINT F (NE KÖRMEND) AND THE REFLECTION SEISMIC STATIONS ON THE ALPINE LOGITUDINAL PROFILE IN THE MOST EASTERN PART OF AUSTRIA

Fig. 9: Selected raypaths between shotpoint F (NE Körmend) and the reflection seismic stations of the Alpine Longitudinal Profile in the most Eastern part of Austria

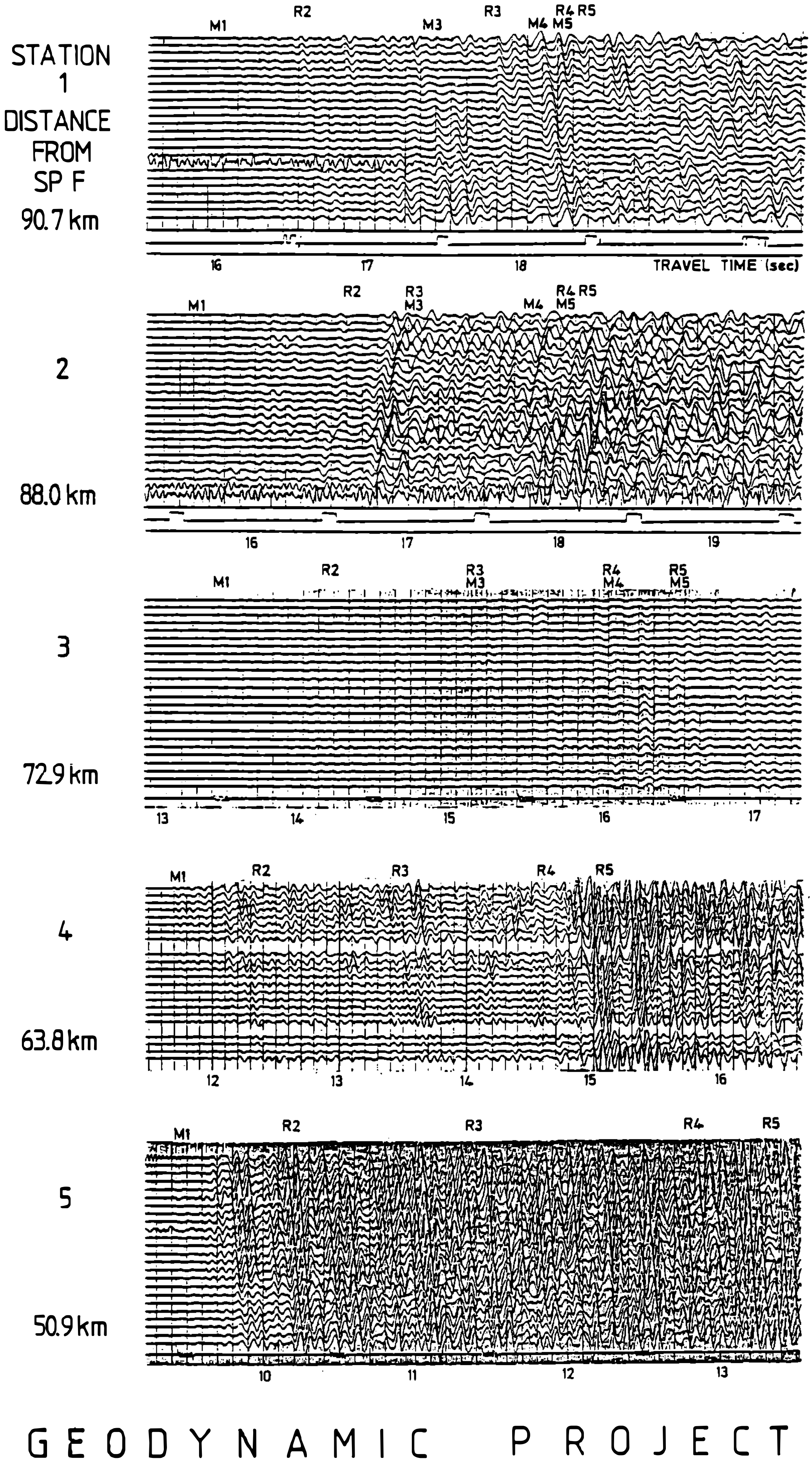


Fig. 10: Reflection seismic records of station 1 to 5 from shotpoint F

Fig. 9 shows the model and some of the theoretically calculated P-wave rays (solid lines for the reflected waves, dashed lines for the refraction waves). The records of station 1 to 5 are presented in Fig. 10. The calculated arrival times of the refraction waves (or Mintrop waves) are marked by M 1, M 2 etc. and the reflection waves are marked by R 2 etc. The position of H 5 on the record indicates for example the arrival time of the refraction wave travelling along discontinuity 5 of Fig. 9 and the position of R 4 shows the calculated arrival time of the reflection from discontinuity 4.

The points of critical reflection lie between 35 and 41 km for the discontinuities 3, 4 and 5 of the model so that critical reflected waves should be expected on stations 1 to 3. A critical reflection should be recognicable by identical travel times of refracted and reflected waves as e. g. of H 3 and R 3 on station 2. Although R 5 is subcritical with regard to the used velocity distribution it actually has the appearence of a critical Moho-reflection.

We were very much obliged to PRAKLA-SEISMOS GmbH, to the party chief E. PFEIFFER and his operators for their spontaneous cooperation. We are also indebted to RAG Vienna for having taken an interest in this extra activity of the PRAKLA-SEISMOS seismic party.

6. Geophysics Maltern area.

The area around Maltern has been chosen for refraction and reflexion seismic experiments.

The main reason for taking this region was the fact that in this area three tectonic units are situated within a short distance: the Rechnitz Nappe, the Wechsel Nappe and the Grobgneiss-series. Former refraction seismic measurements and the result from a deep well (Maltern I) have been used as a base for the research program

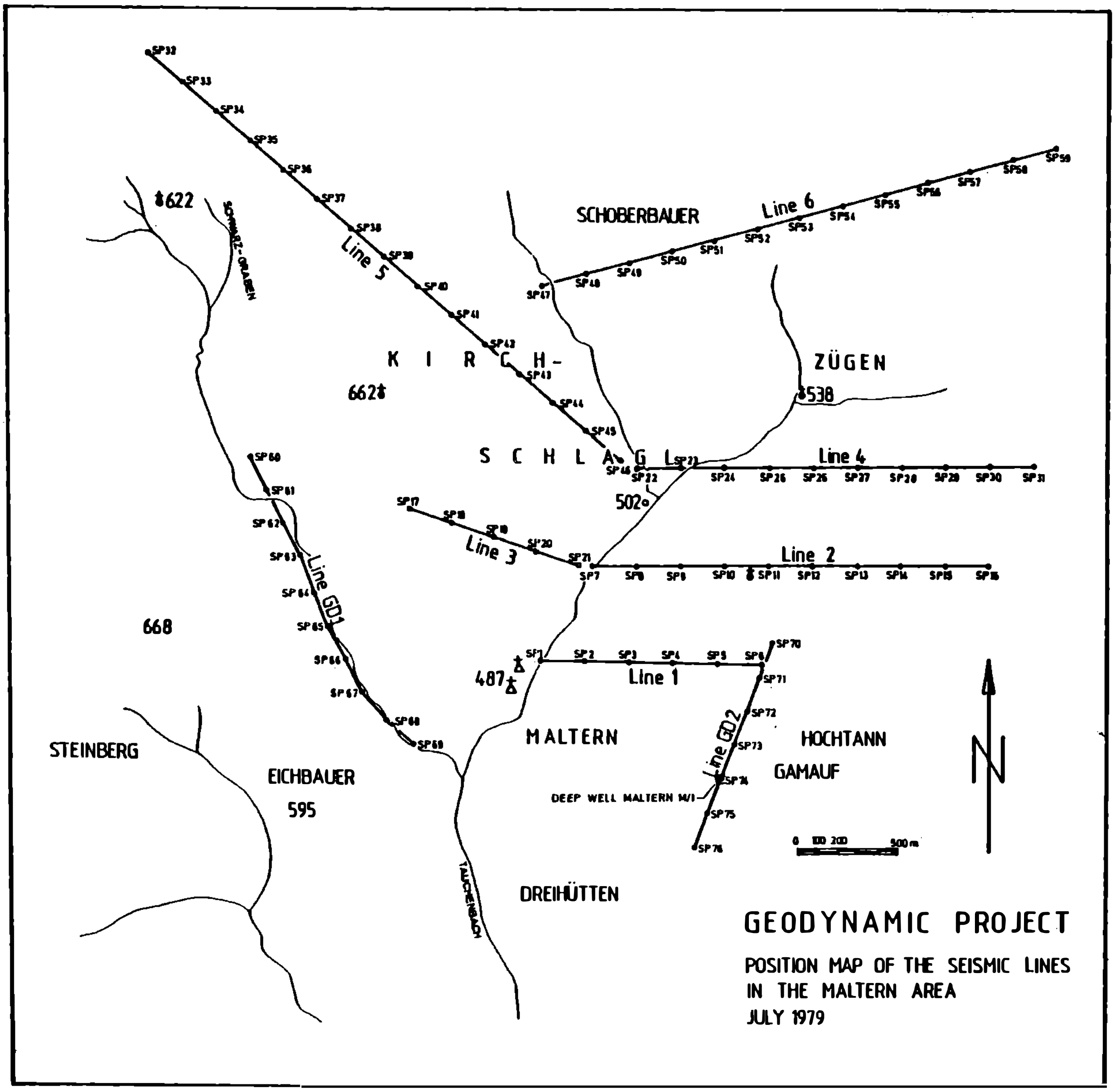


Fig. 11: Position map of the seismic lines in the Maltern area

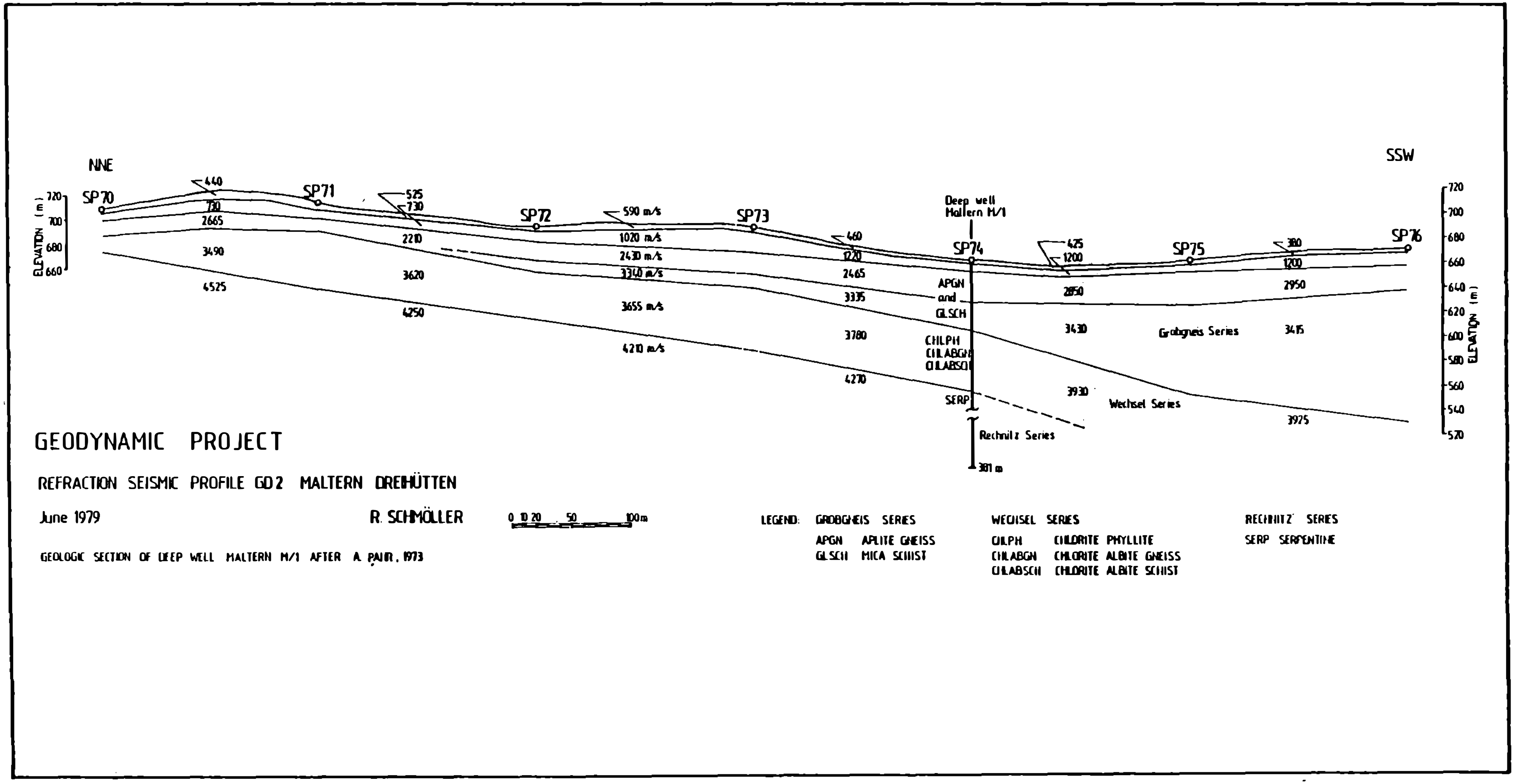


Fig. 12: Refraction seismic profile GD2 Maltern-Dreihütten

of the geodynamic project. A new geological map (A. PAHR) was available for the correlation of the geophysical facts. An area of 20 km² was investigated with 8 refraction seismic lines of 14,1 km length (fig. 11). On two of these lines (line GD 1 and GD 2) additional reflection seismic measurements have been carried out.

The seismic methods are normally used in sedimentary areas and research works in crystalline areas are rare, due to the difficulty in analyses of the data. One basic problem is the determination of marker horizons. Despite these difficulties some positive aspects were found from an older investigation in the metamorphic rocks near Schlaining (15 km in the SE). The seismic data gave indication to the trends of tectonic features and relatively flat lying structures, in agreement with the geological evidence that the Grobgneiss-series is a relatively thin, flat lying cover.

Interpretation problems and results.

Severe problems often arise from the weathering layer, and its influences must be correctly eliminated. This is especially important for finding smaller structures (faults, tectonic lines) in crystalline areas combined with decreasing velocities. Multiple coverage is a necessity and gives a better velocity control.

Computation methods based on a successive reduction of the multiple-layer case are appropriate. Since they give a good insight into each step of the interpretation. A trial and error procedure is often useful in complicated cases. Nevertheless depth control is not as good as in sedimentary areas.

The southern part of the area is of particular importance for the interpretation because there is a connection of the seismic lines with the well Maltern 1. The line GD 2 gave a good insight into the problems of analyses and interpretation (fig. 12). This line confirms the experience, that velocities of rocks measured in situ are often much lower than the laboratory determinations of ultrasonic velocities. Generally there are up to 6 layers on this profile. The most important result is that the Grobgneiss-series, the Wechsel-series and the serpentinite of the

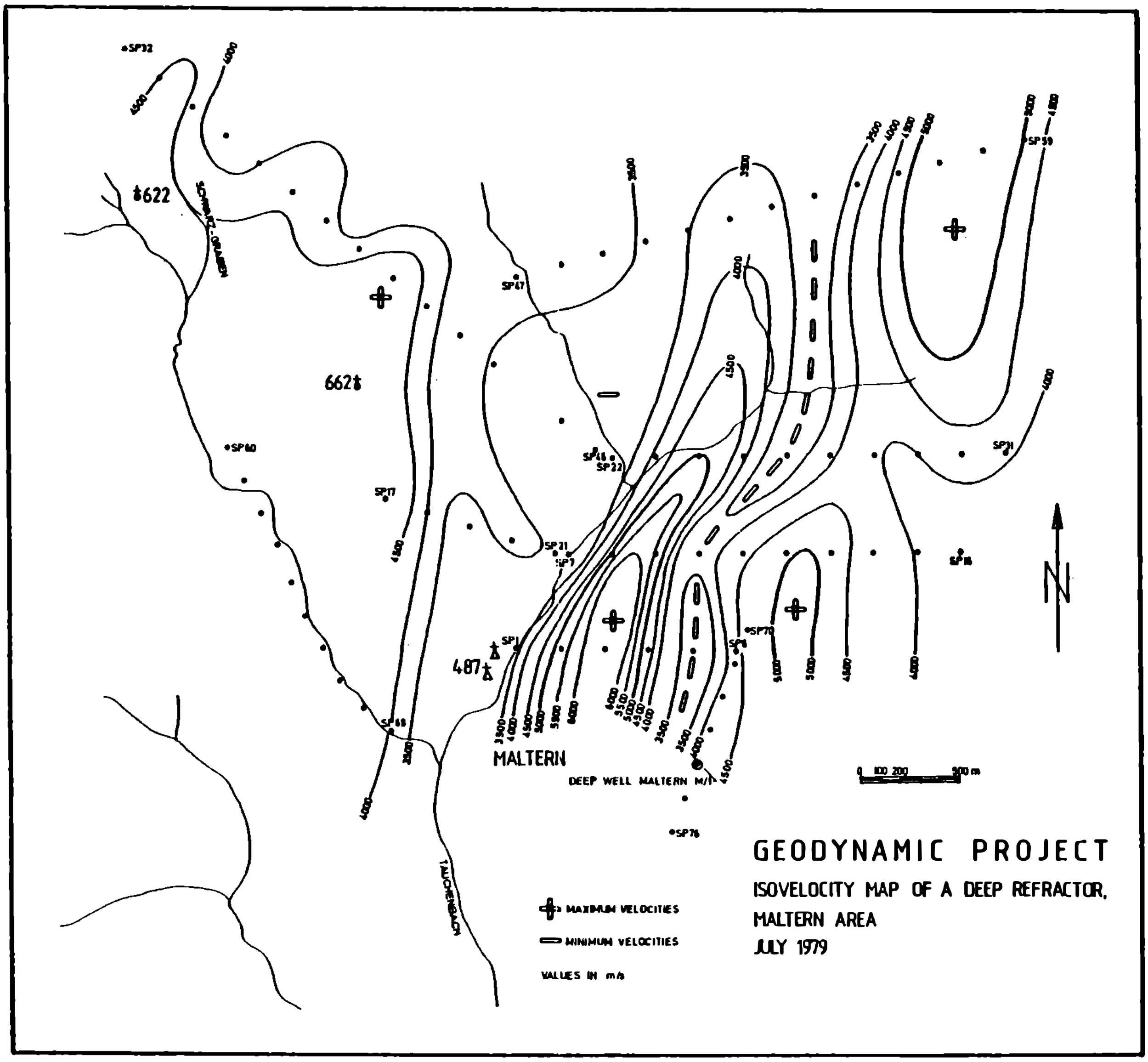
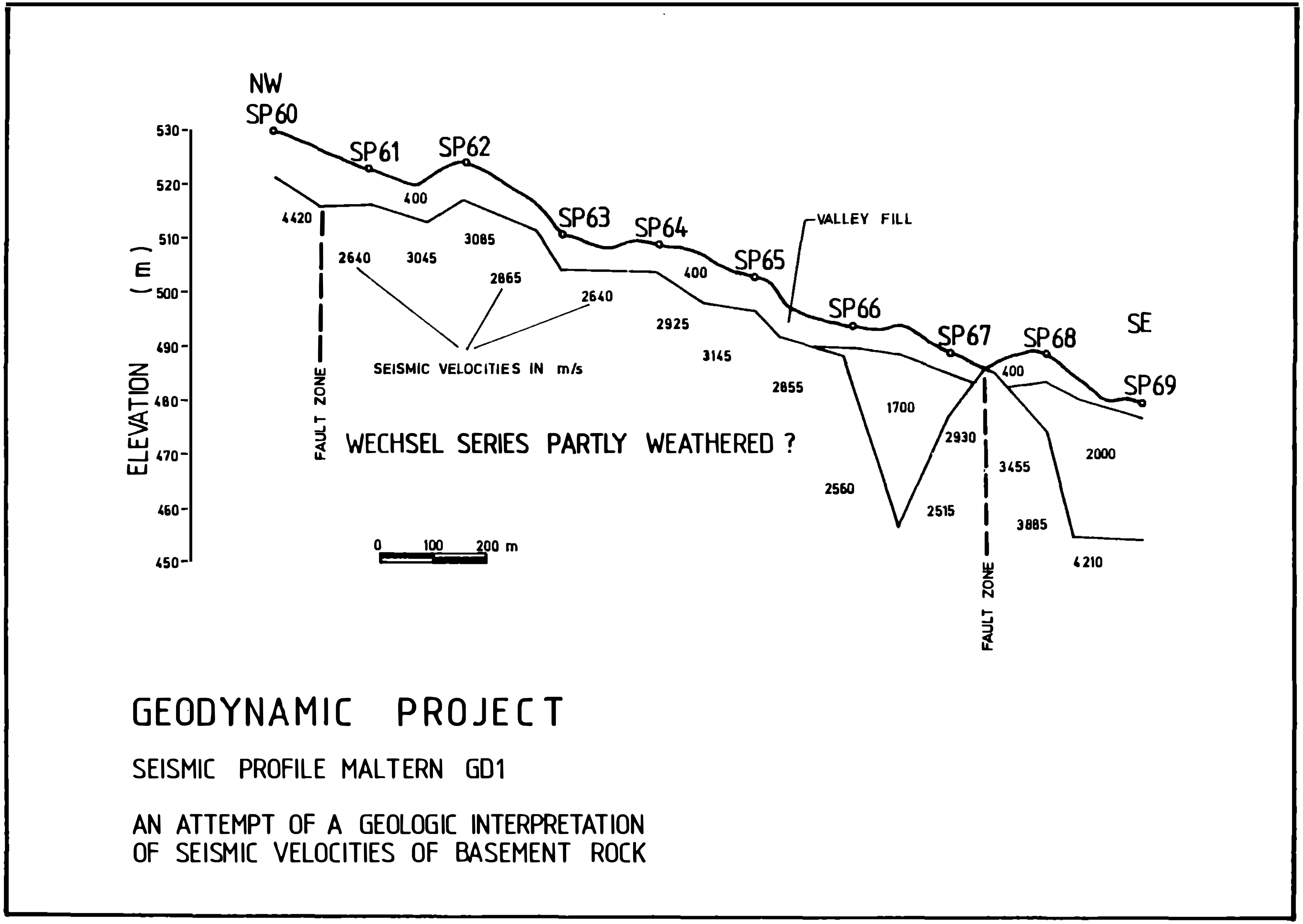


Fig. 13: Isovelocity map of a deep refractor, Maltern area



GEODYNAMIC PROJECT

SEISMIC PROFILE MALTERN GD1

AN ATTEMPT OF A GEOLOGIC INTERPRETATION
OF SEISMIC VELOCITIES OF BASEMENT ROCK

Fig. 14: Seismic Profile Maltern GD 1

Rechnitz-series could be recognized by special marker horizons. The nappe structure of this area is proven by the well and the profile indicates flat lying overthrusting.

The gneisses and micaschists of the uppermost Grobgneiss series have relatively low velocities (up to 3430 m/sec) which is partly due loosening of the rock structure. The velocities of the Wechsel-series are between 3500—3930 m/sec and there is a clear velocity decrease to the north. The deepest refractor has velocities between 4210—4520 m/sec and is correlated with the top of the serpentinite body. All the refractors show a flat rise in the northern direction which leads to the conclusion that the geological horizons and discontinuities have the same tendency. The deepest refractor — the serpentinite — could be found on most seismic lines and be correlated in the S and E part of the investigation area. Velocities of this marker horizon are up to 6000 m/sec.

An attempt was also made to construct an isovelocity map of the deepest refractor (fig. 13). This map shows 4 maximum areas (velocities > 4500 m/sec.). These structures are situated in the serpentinite of the Rechnitz-series and in the Wechsel-series. A pronounced minimum zone in the eastern part has a N-NNE strike direction and may indicate a tectonic feature. The Tauchen valley near Maltern seems also to be a fault zone charactericed by a zone of minimum velocities. The exact proof of a fault and its displacement is more difficult as in an area with sedimentary horizons. Often a combination of different facts can be used to locate such tectonic elements (fig.14). A detailled correlation of these elements gives a picture whereby a probable solution is a series of generally N-NNE striking fault zones (fig. 15). The serpentinite body seems to culminate south of line 2 and may be bounded by faults to the east and west. In the Tauchenbach area a graben like structure is assumed.

The corrected travel time of refraction time-distance curves often show small anomalies caused by irregularities of the weathering layer and the relief of the crystalline horizons. The velocity-depth distribution shows normally a 4-layer case. The V₁-horizon (600—700 m/sec) is due to the top soil and the V₂-horizon (1500—2000 m/sec)

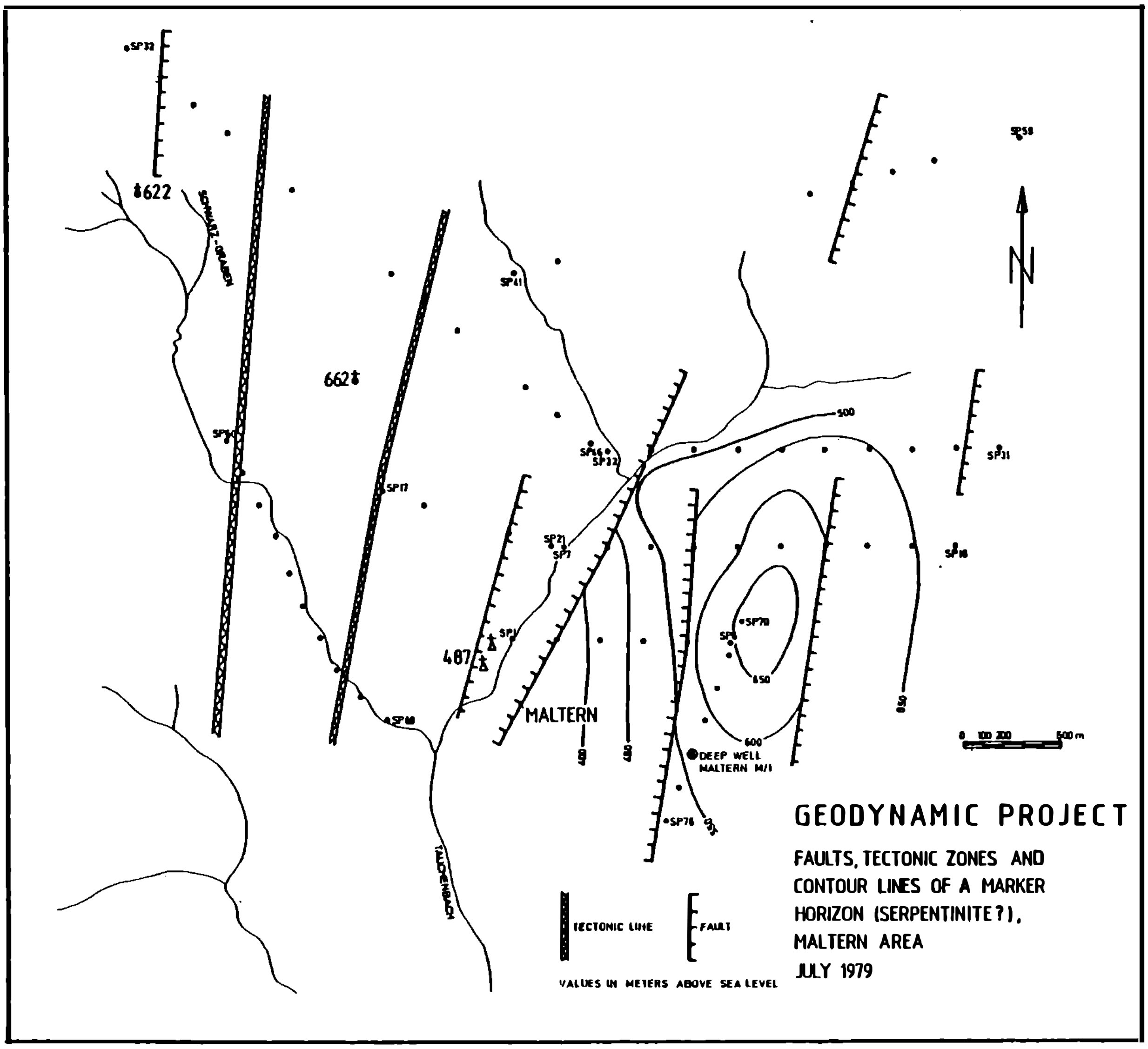


Fig. 15: Faults, tectonic zones and contour lines of a marker horizon (Serpentinite?), Maltern area

corresponds to the weathered crystalline rock. The V_3-horizon with velocities > 3000 m/sec reflects the normal velocities of the various metamorphic series. The V_4-horizon is characericed by high velocities (>4000 m/sec) and may be due to serpentinites or gneisses (Table 2).

In connection with a refraction seismic survey in the Maltern area in 1977 experimental reflection seismic measurements were carried out to see if the reflection seismic method could give additional informations about the complicated layering of the various geological units.

From geological considerations and refraction seismic measurements a rather flat and shallow layering of the Rechnitz-, Wechsel- and Grobgneiss-series are evident. Therefore reflection seismic travel times between 200 and 300 msec were expected from the interfaces of these tectonic units. Small charges had to be used to prevent making these shallow reflection signals by ground roll energy. Hence only shallow holes were necessary which was also of an economic importance.

The velocities obtained from the refraction seismic measurements and the reflection arrivals observed at approx. 300 msec on seismic line GD 1 indicate some major discontinuity at a depth of 550 to 600 m, which is possibly the interface between the Rechnitz- and Wechsel-series.

On seismic line GD 2 reflection arrivals at 200 msec apparently come from the base of the serpentine rock. In this area the serpentine represents the top of the Rechnitz-series (350—400 m).

A clarification of the layering of the various geological units by the reflection seismic method seems questionable, especially with the available equipment and realizable fieldtechniques. However using sophisticated outfit and operation techniques in combination with adequate data processing is beyond the scope of realistic exspectations at the present time, due mainly to the high costs.

7. Geothermics.

Geothermal investigations are the base for a model of the thermal state at the easternmost part of the Alps and are of some importance for the solution of the geodynamic problems.

Temperature measurements are missing in this area and data only exist from the surrounding East Styrian Basin and an uplifting ridge ("Burgenländische Schwelle"). The data are from different sources, wild cat wells of the oil exploration, measurements in artesian water wells, underground temperature measurements in mine shafts (table 3).

Table 3: Temperature measurements in wells

	Depth m	Maximum Depth of Measurement m	Depth Interval of Measurement m	Vertical Temperature Gradient °C/m	Temp. Step. m/°C
Übersbach 1	2694	2694	0—1000	0,0449	28,6
Walkersdorf 1	2143	2143	0— 700	0,0442	22,6
Binderberg 1	1725	1725	0—1410	0,0529	18,9
Litzelsdorf 1	2439	2439	0—2439	0,0400	25,0
Schönau 1	269	145	65— 135	0,0229	43,6
Schönau 2	396	290	90— 205	0,0228	43,7
			245— 290	0,0253	39,5
Grafendorf	182	167	55— 167	0,0379	26,4
Penzendorf	143	143	120— 143	0,0400	25,0
Großsteinbach	120	120	60— 110	0,0534	18,7
Blumau	85	85	55— 85	0,0446	22,4
Eggendorf	89	89	55— 90	0,0420	23,8
Hatzendorf	53	53	15— 53	0,0429	23,3
Feldbach	129	129	65— 129	0,0307	32,5

The data from the deep wells are bottomhole temperature measurements. Their correction for the influence of mud circulation etc. was difficult. Only in the well Litzelsdorf 1 (ÖMV-AG) a continuous temperature log was run.

In the area of the Rechnitz unit there exist measurements from 2 holes, drilled for mineral exploration and from an antimonite mine [1]. All the values are in the same order of magnitude, a mean value for the vertical temperature gradient of 0,024°C/m is assumed.

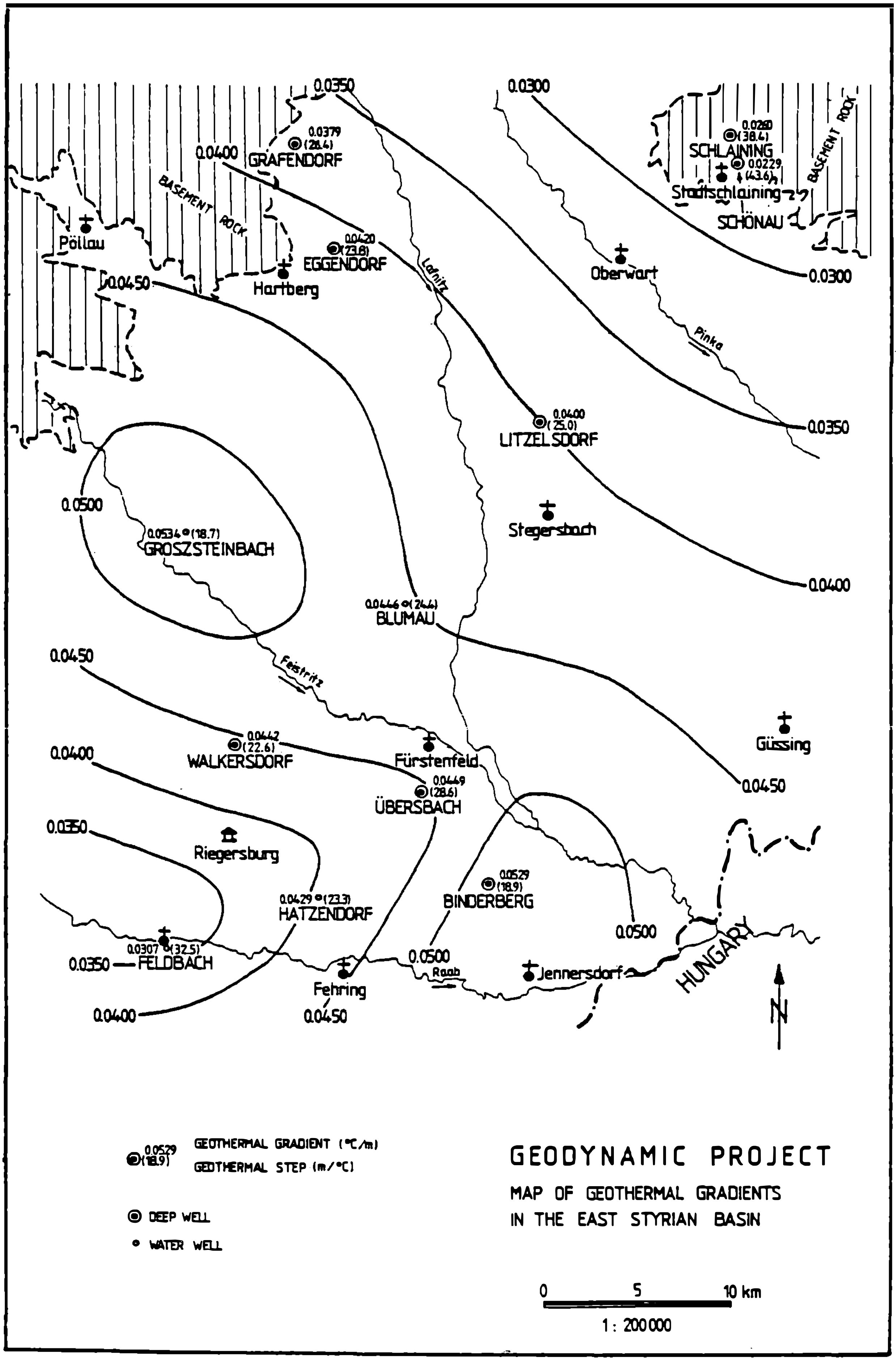


Fig. 16: Map of geothermal gradients in the East Styrian Basin

All the deep wells in the East Styrian basin have a vertical temperatur gradient which is higher than the normal value (F. WEBER 1975). The same results were got from measurements in water wells up to a depth range of 180 m. The map of vertical temperature gradients (fig. 16) is valid for the depth range of at least 500 m. A zone of maximum values is situated N of Jennersdorf, changing in a NW direction in its northern continuation. Another maximum is only represented by the high gradient in the well Großsteinbach (0,0534°C/m). A geological remarkable result is the fact, that in the uplift of the Rechnitz schists a relatively low gradient exists.

8. Palaeomagnetic Investigations on Basalts and Andesites from the Eastern Alps.

A large suite of samples from the Miocene (Gleichenberg, Schaufelmühlgraben and Birkenblösse) and the Pliocene (Klöch, Gnas, Fehring and Riegersburg) volcanic series were collected for palaeomagnetic investigations. Rockmagnetic experiments were carried out on a number of pilots and in most cases magnetite and titanomagnetite was established as carrier of the remanence (NRM).

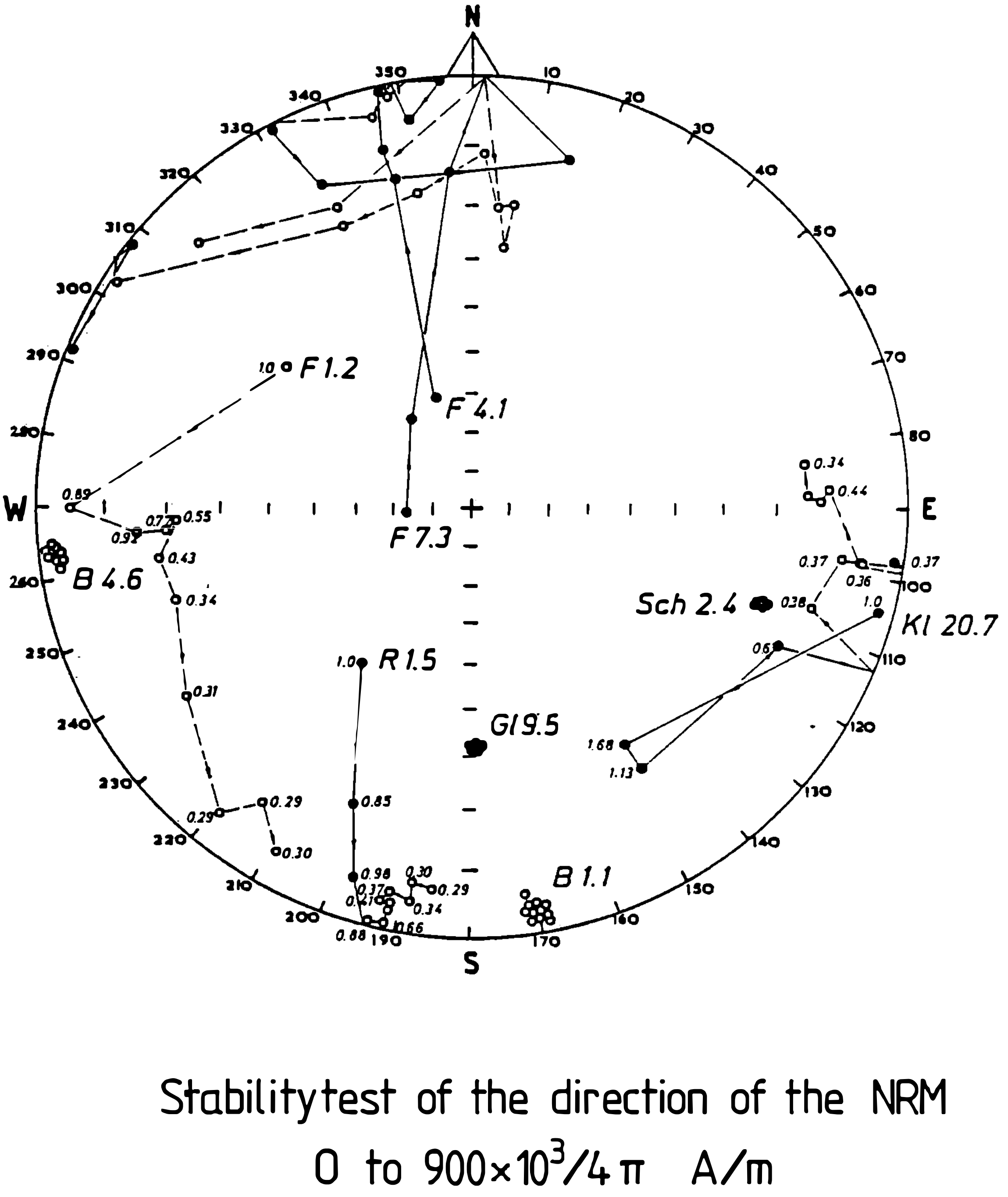


Fig. 17: Stabilitytest of the direction of the NRM

Table 4: Table of the Palaeomagnetic Results

Nr.	Locality	Rocktype	Age	CaRM		Treatm.	N	k	95	Poleposition	
				P_{Dec}	P_{Inc}					P_{Lat}	P_{Long}
1	Weitendorf	basalt (shoshonit)	miocene (14 My)	060.0	+30.0	400 Oe	10	37	5.3		
2	Mühldorf	basalt	pliocene	015.0	+30.0	400 Oe	27	26.6	5.31		
3	Hochstraden	basalt	pliocene	200.0	—60.0	400 Oe	52	88	2.0	74.0	85.1 E
4	Klöch	basalt	pliocene	260.2	—53.0	700 Oe	20	2.1	30.9	30.1	87.2 E
5	Gleichenberg	andesite	miocene	341.9	+68.5	700 Oe	9	64.3	6.5	77.2	315.2
5	Birkenblösse	trachiandesite	miocene	014.6	+77.6	700 Oe	4	317.2	5.2	69.0	32.4 E
5	Schaufelmühlgraben	quartztrachite	miocene	347.7	+69.0	700 Oe	3	686.9	4.7	66.1	104.8 E
6	Gnas	tuffite	pliocene								
7	Fehring	tuffite	pliocene								
8	Riegersburg	tuffite	pliocene	272.1	—19.9	700 Oe	1	4.9	30.3	06.1	97.0 E
	Kollnitz	basalt	miocene	339.9	+76.0	400 °C	15	21.7	8.3	69.7	348.7

In some Miocene material where the NRM is hard a strong influence of hematite was observed. The presence of hematite was proven by microscope analysis and demagnetisation experiments. Whereas the magnetisation in the basalts and andesites after the cleaning of the viscous remanence became stable, the tuffites of Gnas and Fehring were unstable. Hence these tuffites are unsuitable for palaeomagnetic purposes (fig. 17). The tuffite of Riegersburg shows a good example of multicomponent behaviour and seems to be stable above 700 x $10^3/4\pi$ A/m. Nevertheless the poleposition doesn't agree with any known Neogene poleposition. One has, therefore, to think of very deep reaching weathering effects and a bad grouping of the coarse grains during sedimentation.

The samples from the Klöch locality were taken in different parts of the northern quarry where there was the best chance of getting unweathered material. The volcanic sequence consists of columns overlain by tuffites and massive basaltflows. No difference in the magnetic behaviour was found between these different flows. The grouping within a site scatters from α 95 = 4.0 to α 95 = 32.0°. A few sites lie in the opposite quadrant,

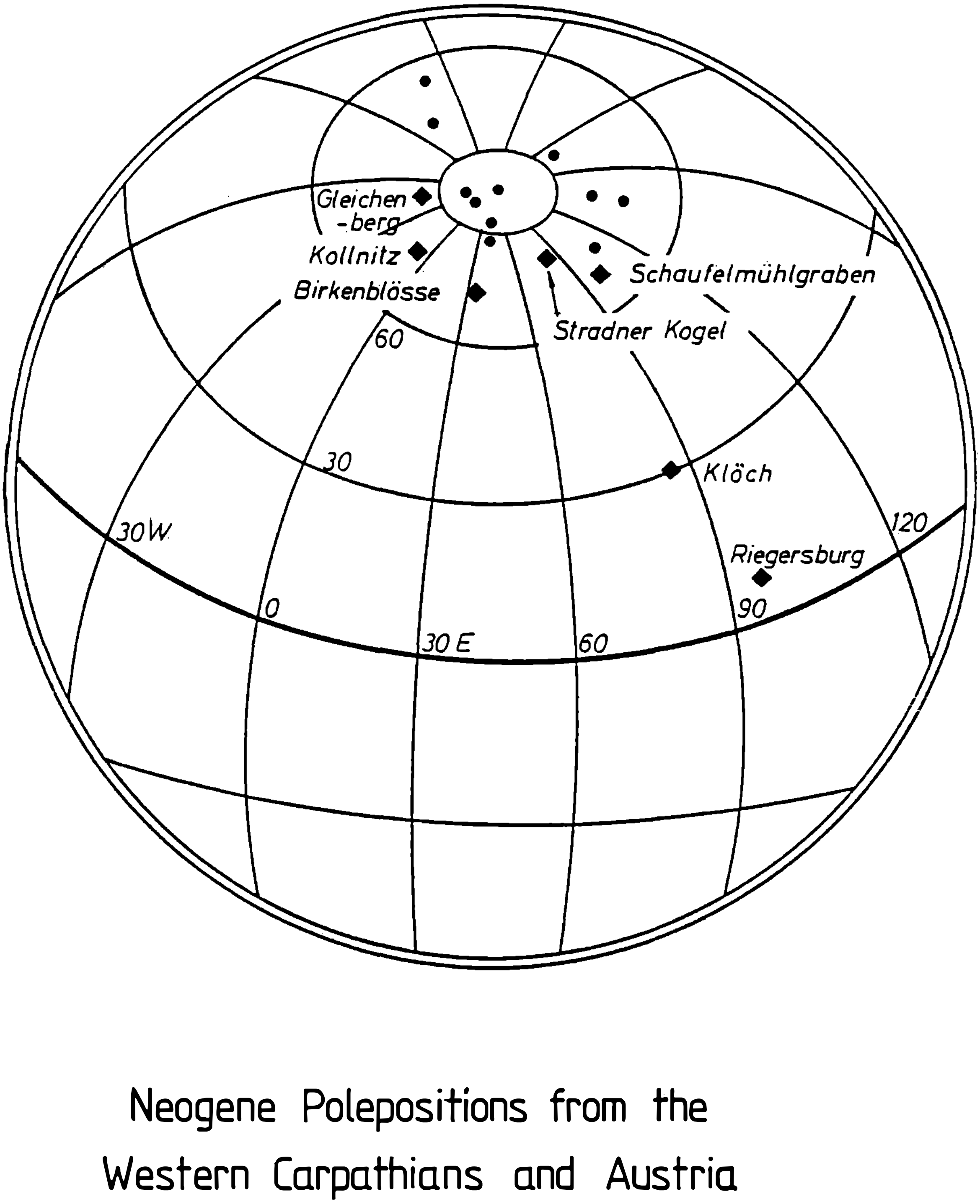


Fig. 18: Neogene polepositions from the Western Carpathians and Austria

compared to that of the majority of sites, with negativ inclinations so that one has to think of intensive movements within the lavaflow after cooling below the curie point. The overall mean-direction for Klöch shows very poor statistical parameters, therefore, the calculated poleposition was bad as expected (Table 4). The pole at this present stage is meaningless (fig. 18) and calles for more detailed fieldwork in the future. A very good grouping of the NRM was found in the trachiandesite samples taken from the Miocene sequence of Birkenblösse near Gleichenberg. The pilots showed a high stability (fig. 17) and the whole material was AC-cleaned at 700 x $10^3/4\pi$ A/m. The mean direction is well defined and allowed the calculation of a Miocene poleposition.

Quartztrachite was sampled in the Schaufelmühlgraben and again a high stability of the NRM was found (fig. 1). Of all the sampled Miocene localities, the statistical parameters are the best here (Table 4). The whole material was cleaned at 700 x $10^3/4\pi$ A/m.

To the north of Gleichenberg, fresh andesite and trachiandesite outcrops in the new part of a quarry were sampled and pilots confirmed a high stability of the NRM (fig. 17). For all Miocene localities the paleopoleposition was calculated as mentioned before and compared with polepositions from Austria and Czechoslovakia. One can see, that the agreement is quite good. Only the position of the Birkenblösse indicates a steeper inclination than the others. The reason seems to be a local tectonic complication. The same reason could be the cause for the slight clockwise deviation of the Schaufelmühlgraben.

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RESEARCH
at the INSTITUTE OF GEOPHYSICS of theTECHNICAL UNIVERSITY OF VIENNA in the INTERNATIONAL GEODYNAMICS PROJECT

by

Adrian E. Scheidegger

With 4 Figures

1. Introduction

The Institute of Geophysics at the Technical University of Vienna was founded in the Spring of 1971. Since its inception, the Institute took part in the International Geodynamics Project. The main research effort was spent on the elucidation of the geophysical stress field and the concomitant mass motions in Austrian Alpine regions. During the summer months, regular field work was undertaken which was supplemented in the winter by in-situ stress measurements below ground. The whole research program was divided into several sub-programs which will be discussed below in detail.

2. Observations of valley closures and tectonic slope movements

Geodetic measurements of mass movements were made near Hallstatt, on the Lesach Ledge, at a slope near Wörschach and on a mountain side near Irschen. At the three locations mentioned last, markers were established and zero measurements were made.

In later years, follow-up measurements were made which were supplemented with other geophysical investigations, such as seismic studies of the ground, in order to ascertain the structure of the sliding masses. In every case, mass movements of the order of centimeters were found; the pattern of the motion fits in every case into the scheme envisaged by Terzaghi ("rotational slump"). Thus, Fig. 1 shows the results from the Lesach Ridge. The displacement vectors evidently correspond to those of a slump and are of the order of mm/year. A comparison with investigations of the neotectonic stress field shows that the mass movements are predestined by the latter and triggered by the erosion at the valley floor. The mean displacement direction coincides closely with one of the principal stress directions of the neotectonic stress field. The change in the orientation of the schistosity surfaces in the displaced masses indicates a tilting of the strata. The thickness of the layers loosened up by the mass-movements was determined by seismic experiments as of the order of 100 m.

With regard to Hallstatt, our measurements constituted a follow-up to geodetic measurements that were made in 1954 by the Bundesamt für Eich- und Vermessungswesen. It was possible to establish that large displacements (up to meters) took place in the interval. The observed displacements were also compared with measurements of the orientation of recent joint-surfaces. It could be shown that the mechanics of the motion as well as of the formation of the joints can be explained by picturing the slope as creeping plastically with the surrounding rock boundaries acting as abutments. Thus, the material of the slope is partially in an active, partially in a passive Rankine state. The joints found in a mine beneath the slope can be explained by the overburden pressure and the active flowing pressure.

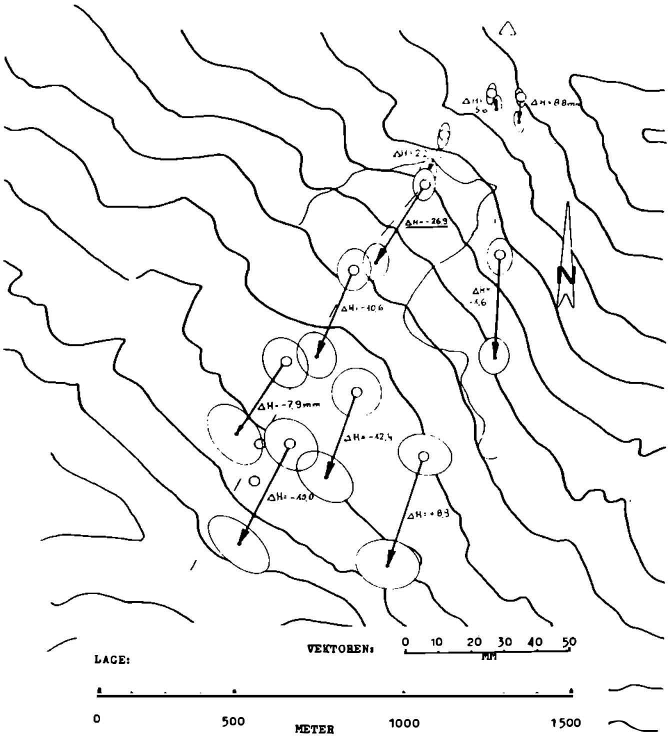

Fig. 1: Displacement vectors on the Lesach Ridge between 1973 (o) and 1976 (.) ΔH = significant change in altitude.

3. Investigation of the dynamics of unstable areas

Originally, this project concerned the investigation of the dynamics of scree slopes. Later, it was extended generally to creeping slopes.

Thus, topographic, morphologic and geophysical investigations of scree slopes in the Hochkönig area of Austria were made. It was found that a scree slope consists of various independent scree streams; the average inclination decreases from top (34.9°) to bottom (27.4°) over 300 m of elevation. The debris size distribution does not change over the slope (there is no increase in sizes from top to bottom). The individual sizes are distributed in stripes and tongues; this points to the fact that the buildup of the slope occurs in the form of miniature overlapping landslips. The grain size decreases with depth points to a sieving effect (small pieces fall through the holes between large ones). Seismic measurements yielded the result that there are 3 layers: a layer on top, some 15 m thick, a consolidated layer to a depth of 30 m and rock below. There is no significant variation of the depth to rock over the entire scree slope.

Exact geodetic measurements of the scree slopes in subsequent years yielded the result that the motion of such slopes takes place entirely by surficial mini-slides; there is no internal creep. This is quite contrary to what had been expected in the literature by other authors.

Investigations of grass slide phenomena at the Lesach Ledge yielded the result that the latter can be explained by a dry-frictional model. The origin of terracettes is to be sought in the slowing down of the internal creep in the slope by consolidation-phenomena.

A geomechanical investigation has been made of a slide area in the Felber Valley (Salzburg Province) in Austria. For this purpose, tachymetric, seismic, geomorphological and geological studies were carried out. It was found that slow mass movements occur from the ledge atop the valley down to the very bottom. Atop the ledge, the movements present the aspect of a "mountain fracture", in the middle of the slope, the aspect of soil-creep and at the bottom, the aspect of an actual slide. It was found that the orientation of the "mountain fractures", of the joints in the rocks bounding the slide area and of the features on the creeping slope all fit into one single geophysical stress-pattern, viz. into one with a maximum horizontal compression in the N-S and a minimum compression in the E-W direction. This fits together well with the general views on the tectonics ofthe Alps commonly found in the literature.

Similar results were obtained from an investigation of an unstable area near Bad Gastein. Many houses of this resort-town show traces of movement (cracks in walls and foundations). Data from the Bundesamt für Eich- und Vermessungswesen in Vienna were used for a determination of the displacement patterns. Support was again obtained for the conjecture that all movements are basically designed by the tectonic stress field, although the individual triggering effect must be sought in exogenetic agents.

4. Investigations of the visible effects of the geophysical stress field

Geomorphological features, joint orientations and the layout of valleys in a mountain region can often be interpreted as visible effects of the stress system that produced these phenomena. Thus, a large program was undertaken to analyse the geotectonic significante of such features.

First of all, on-the-spot geomorphological investigations were undertaken in the Hochkönig region and in the Pinzgau. Thus, it was shown that the characteristic features in mountain massifs can be classified into those that have been primarily caused by the tectonic stress field and those in which selfgravitational effects are of major importance. In this fashion, the morphology of mountain peaks can be shown to be primarily stress-induced.

Second, a thorough study of the orientations of joints not only in Austria, but in many parts of the world was undertaken. It has been known for some time that large-scale faults are caused by forces in the Earth's crust. However, it has now also been recognized that the innumerable small joints seen everywhere in outcrops are the direct outcome of neotectonic stresses. The phenomenological evidence has recently been summarized by Scheidegger [43] as follows:

a) At a single outcrop, one finds ordinarily three joint systems which are usually very definite: One system is near-horizontal (dips 0° to 40°) and corresponds to some lithological factor; the other two systems are near-vertical and almost orthogonal to each other (angle of intersection 80°—90°).

b) The non-lithological joints in fresh outcrops appear to cut clear across joint systems of obviously older age. These joints are therefore to be interpreted as "tectonic" joints.

c) Several outcrops near to each other (within a few kilometers) usually show preferential joint orientations that are consistent with each other.

d) Outcrops within a region (10—20 km radius) commonly show, if treated together, definite preferential "tectonic" joint orientations. When the outcrops are considered singly, however, one often finds that about 1/5 of them show "anomalous" tectonic joint orientations which are rotated up to about 30° with regard to the "regionally" preferential orientations. The "anomalous" outcrops are not randomized, but show a consistency amongst each other.

e) The well-developed regional joint system can commonly be explained in terms of the neotectonic stress system if the bisectrices of the regional joint strikes are taken as principal horizontal tectonic stress directions. It has generally been assumed that the tectonic joints (as defined above) are Mohr type fracture surfaces, but the commonly observed large angles between conjugate joint sets may, in fact, indicate that the fracture is not of the Mohr- type at all. The joint sets align themselves very closely with the planes of maximum shear in the tectonic stress field which may indicate that they are the result of some ductile or plastic slippage process. Thus, an obvious phenomenological explanation of joints would be that they are the response to an instantaneous creep process induced in the horizontal plane by the momentarily acting tectonic stresses.

On the basis of the above remarks, it is possible to deduce the orientation of the principal tectonic stress directions from a measurement of joint orientations. In the case of Mohr-type fracture, the bisectrix of the smaller angle should be the greatest compression. However, inasmuch as, as noted, the angle between steeply dipping conjugate joint sets is usually close to 90°, it is often not possible to distinguish reliably between the largest and smallest principal stress direction.

The determination of the preferred joint orientations in an area has to be carried out by a statistical procedure. For this purpose, a computational method was developed by Kohlbeck and Scheidegger [26]. In that method, two statistical probability distributions of the type exp (k $\cos^2$ d) about a mean direction are fitted to the data; the two best-fitting mean directions are determined by computer using a function-minimization procedure. The computational procedure is nothing but a development of the older method of drawing density-diagrams for the joint-directions in some suitable projection of a unit sphere and picking two density maxima. From the position of the two density maxima, the principal stress directions can then be calculated. If the angle between conjugate sets is substantially different from 90°, it is even possible to identify which is the largest (P) and which is the smallest (T) compression direction. For visualization, it is often convenient to also give the corresponding joint-density diagrams. As noted, the above idea has been applied world-wide to the determination of the orientation of the principal stress directions of the stress field causing the joints. It was found, world-wide, that the principal stress directions determined in this fashion agree with those that one would expect from present-day plate tectonics. As an example, Fig. 2 shows the principal stress directions found for the northern rim of the Mediterranean. This implies the perhaps somewhat startling inference that the vast majority of visible surface joints are of very recent origin. However, when one considers the fact that in most tectonically active areas of the world vertical motion rates of mm/year (= km/million years) are prevalent, the idea that surface joints are very new indeed, is perhaps no longer so surprising.

The above idea was further extended to the hypothesis that even valley trends might be pre-designed by the geotectonic stress field. The assumption that valley trends are predetermined by geotectonic phenomena stands in contrast to the assumption of valleys being solely caused by exogenic agents (i. e. wind, water and ice). In fact, there is a certain controversy about this matter to this day, but the evidence in favor of some geotectonic control of the valley orientations is building up steadily. Thus, it has been shown that the main characteristic of exogenic agents is their randomness [15]. Valleys caused by erosion alone should, therefore, be randomly oriented. Evidence from statistical analysis of valley directions shows that the latter are not random (see below). Furthermore, the often large vertical displacement rates in mountain areas suggest that the surface features are of very recent origin. This makes it difficult to believe that modern river-nets should have been determined by some ancient drainage pattern which is retained to this day.

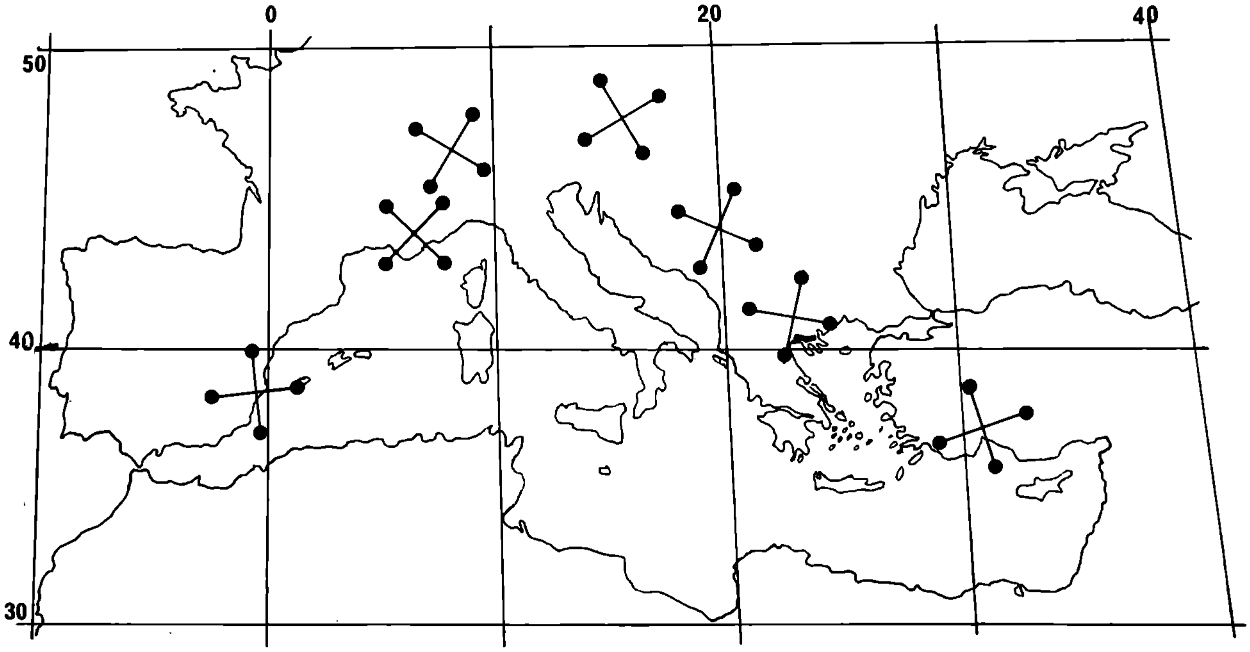

Fig. 2: Principal stress directions on the northern rim of the Mediterranean.

In order to study their orientations, the valley directions have to be "rectified" (i. e. straightened) by considering them as edges in a graph. This may be a somewhat "brutal" procedure, but it is at least independent of the bias of the researcher. Otherwise, the fitting of straight (and therefore measurable) segments to the "wiggly line" representing the river course on a map, would be extremely arbitrary. However, in the described fashion, the distribution of valley orientations can be represented numerically. By considering valley trends so to speak, as "vertical joints", and by calculating the preferred orientations of the latter in an area, it was found in the Alps (Switzerland and Austria) that the preferred valley trends do indeed correspond to the preferred orientations of the surface joints, and thus, that they are primarily induced by the neotectonic stress field.

5. In situ stress measurements

Measurements of stress in situ were made by the so-called doorstopper method below ground in the copper mine at Mitterberg, in a drive of a tungsten mine in the Felber valley, in a highway-tunnel through the Gleinalm, in a lead-mine near Bleiberg, in a coal-mine near Fohnsdorf, as well as at the surface in the Ebriach gorge. In all cases, the so-called "doorstopper" (stress relief) method has been applied.

The copper mine at Mitterberg underlies the Hochkönig Massif which is formed by a Triassic calcareous block lying above softer Paleozoic layers. Three holes were drilled from a drive 750 m below the surface so that, in principle, the complete stress tensor could be determined. It was found that the absolute stress values obtained were not significant. However, it could be established that the direction of the maximum pressure is downwards from NNW (upward from SSE) with a plunge of 70° towards the horizontal. The stresses normal to that direction have a value of about three quarters of the maximum pressure. It appears that the presently acting stresses are caused entirely by the overburden inasmuch as the maximum pressure direction points exactly towards the summit of the Hochkönig. In the directions normal thereto, a stress relief occurs in the relatively soft Paleozoic layers.

For the stress measurements in the tungsten mine of the Felber valley the point of the measurements was located in the lower slate-cover of the Tauern Window of the Austrian Alps. Three holes were drilled in different directions for the complete determination of the stress tensor. The elastic properties of the rock were investigated by various methods. The most important result was the determination of the orientation and value of the maximum principal compression. It turned out that there is no indication of a tectonic modification of self-gravitational stresses.

The location in the Ebriach gorge was in the vicinity of the Periadriatic Lineament in a small diabase dyke which is bounded on both sides by slates of much smaller rigidity. For the principal stresses, values of $\sigma_1 = 2$, $\sigma_2 = 6$ and $\sigma_3 = 9$ MPa were found. σ_3 has an inclination of 30° towards the vertical and corresponds to the action of the superjacent rock masses. σ_2 and σ_3 are approximately horizontal. The direction of σ_3 is NNW. However, in view of the closeness of the values of σ_2 and σ_3, one can hardly speak of a preferred orientation.

The average values of the horizontal and vertical stresses are in the ratio of 2:1. This ratio is in conformity with those found on a world-wide basis near the surface of the Earth.

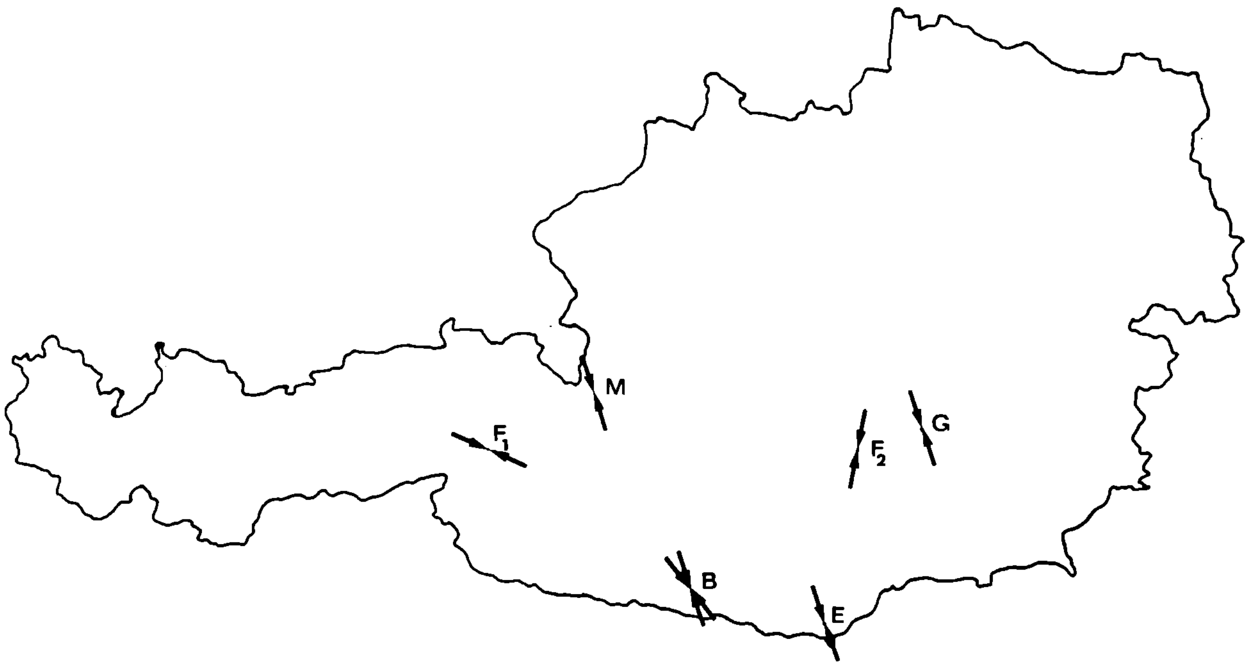

Fig. 3: Horizontal projection of the maximum compression directions obtained by in-situ stress measurements in Austria. B: Bleiberg, E: Ebriachklamm, F_1: Felber Valley, F_2: Fohnsdorf, G: Gleinalm-Tunnel, M: Mitterberg.

In situ stress measurements have been carried out in the Alpine basin of Fohnsdorf not only with CSIR doorstoppers but also with triaxial cell equipment. The site was situated within sandstone at 414 m below sea level at a depth of 1100 m. The modulus of elasticity, Poisson's ratio, the density and the strength of the sandstone have been evaluated. The measurements yielded a stress tensor with greatest stress of about 40 MPa **in NS** direction and lowest stress of 10 MPa in E-W-direction. The intermediate principal stress is vertical and corresponds to the weight of the overburden.

Thus, an indication of the neotectonic stresses was obtained at some keypoints in Austria. The procedures are very expensive and also scatter somewhat; they generally show that the directions of the principal stresses agree with those expected from plate tectonic theory as modified by the gravitational effects of the surrounding topography. Fig. 3 summarizes the results obtained.

The measured stress-values were compared with finite-element calculations of models of the surrounding areas. For the Hochkönig massif, a two-dimensional calculation was made by using the real elastic properties and the real rock densities. It turned out that the calculated stresses agreed with the observed ones, which confirms the hypothesis that the measured stresses are essentially self-gravitationally induced.

In the case of the Felber Valley, theoretical calculations of the stresses by means of a finite-element model show that the experimentally found values can be explained by the weight of the material alone as a consequence of the local topographic conditions. An essential assumption herein is that the mountain range rests on a plastic substratum so that approximately the same pressure is acting everywhere along the horizontal basis. If the mountain mass rests on a (vertically) rigid material, then the experimental stress values cannot be reproduced by the calculations. Thus, one has an indication that the rheological state of the material in the earth's crust is plastic (over geological time-ranges) already at comparatively shallow depths.

6. The Diendorf Fault

In the vicinity of Vienna, at the Eastern boundary of the Bohemian massif, there is a very pronounced fault (the Diendorf Fault) which presents itself, on account of its easy accessibility and nearness to the Institute, for study as a convenient example of a geodynamic type-feature. The fault is directly visible morphologically and is evidently also responsible for damage to buildings in various villages (Fig. 4). For its study, gravimetric, seismic and geotectonic investigations have been made.

Data on seismic intensities indicate a zone of decreased density along the fault. The shape, size and depth of the anomalous low-density mass has been calculated upon the basis of an extensive gravimetric survey of the region. By making a fit of the gravity anomalies on the two sides of the fault it is shown that the shift of the two sides has been 40 km. Magnetic investigations corroborate the gravity-results and indicate a further strong anomaly in the area around the town of Theras.

Furthermore, measurements of the orientations of joints were made. The preferred strike directions of 10 groups of outcrops in the vicinity of the Diendorf-Fault were determined; they show a basic parallelity, except for a deviation by about 30° at the entrance of the Wachau in the direction of the break-through of the Danube. The principal stress directions calculated from the joints form an essentially E-W and N-S system for the whole region.

A documentation of damage to buildings in built-up areas and of consolidationphenomena in the free field indicates a zone of tectonic activity along a line in the vicinity of the Diendorf Fault which can be related to the latter.

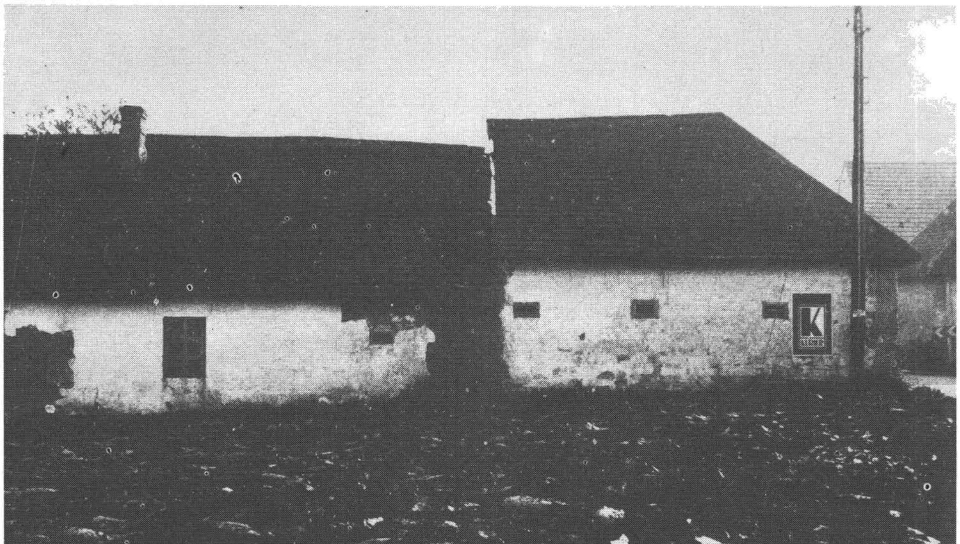

Fig. 4: Damaged building on the Diendorf Fault (in the village of Platt)

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Geologische Bundesanstalt

Geological Survey of Austria

SUMMARY REPORT ON THE IGP-ACTIVITIES OF THE GEOLOGICAL SURVEY OF AUSTRIA

By T. E. Gattinger

With 3 Figures

The main topies of the IGP-activities of the Geological Survey were investigations and measurements of regional mass movements connected with actual tectonic movements.

Investigation and measurements of the geothermal flux in connection with orogenesis and metamorphism in the Eastern Alps were carried out additionally.

Investigations of regional mass movements in Eastern Alps.

These investigations aimed at clearing up the tectonical mechanism which lead to regional, sometimes disastrous slope movements. It must be emphasized, that these solpe movements differ from landslides in so far as gravitation, pore pressure, frictional resistance etc. are not the only factors to be taken into account.

Present tectonic agents such as thrust movements, effects of residual tensions in different tectonic units and/or uplift movements in the Eastern Alps are of major importance for the occurence of this kind of regional mass movements.

Therefore, investigation areas were selected according to their special tectonic situations and conditions in order to cover spheres of main structural importance (Fig. 1).

1. The area of Felbertauern south of the Salzach Valley near the village of Mittersill, Salzburg, tectonically belongs to the northern frame of the Tauern Window. In this position considerable residual tensions in the gneisses and schistous rocks, originating from the compression of this zones during the Alpine orogenesis, could be expected (Fig. 1, point 1).

Although the average inclinations of the valleys slopes looking northwestwards do not exceed 35 degrees, the whole slope area is in disaggregation. Rock masses of altogether some million tons are in slow movement. The top ridge of the mountain area separating the Felbertal from the next valley to the east, is disconnecting so that two to three top ridges are formed out of originally one.

Gravitational landslides in the northern and southern part of the slope occure consequently to the failfure of stability of the whole area.

First point of the programme was detailed geological and structural mapping of the region. This was followed by special investigations concerning the fault system, the vectors of movements and the types of disaggregation of the rock.

The fault system showes three predominating directions. The main disjoint of the northward dipping rock series is marked by steep or vertical faults which strike from westsouthwest to eastnortheast, and by perpenticular faults striking in direktions from southeast to northwest.

According to the configuration of the terrain and the fault system, joint blocks carry out rotation movements. The rotation angels open towards the south. The average rotation angle is four degrees.

Measurements of the rates of the movements showed that generally a continous opening of the clefts running parallel to the top ridges takes place which lies in the order of centimeters per year.

2. Investigations in a second area (Fig. 2) near Hallstatt in the Salzkammergut, Upper Austria, were started already in 1966, and were continued within the IGP-programme of the Geol. Survey of Austria (Fig. 1, point 2).

After geological surface-mapping in the scale of 1:5000, investigations were carried on underground in the Hallstatt salt mine.

The mass movement of Hallstatt originates from a fault zone of 1200 m length on the eastern flank of Plassen mountain. This fault zone runs across solid and loose rock, reaching a vertical displacement up to 20 m. The horizontal movements come up to a displacement in the range of tens of meters (Fig. 2, area F).

It was possible to divide the slope movement into several areas, each of which has its own vector.

The largest area of the slope movement is located above the Hallstatt salt mines, which is situated at an elevation of about 1200 m above sea level.

It was found out that the cavities created by the mining do not cause the movement of the slopes but intensify the movements due to settlement.

In the mine itself the following observations of movements were made:

1. With a superposition of approximately 700 m, open clefts were found in the clay series, which take the direction of the open-pit-mine fault.
2. In some galleries it was noted that the floor runs ahead of the roof in the direction E throught NE. Deformations of rails refer to a movement from W to E.
3. In a tunnel with only little superposition (up to 150 m) a deformation of the tunnel lining (part of it goes back to the year 1952) was noted, which was brought about by a movement going from SW to SE.

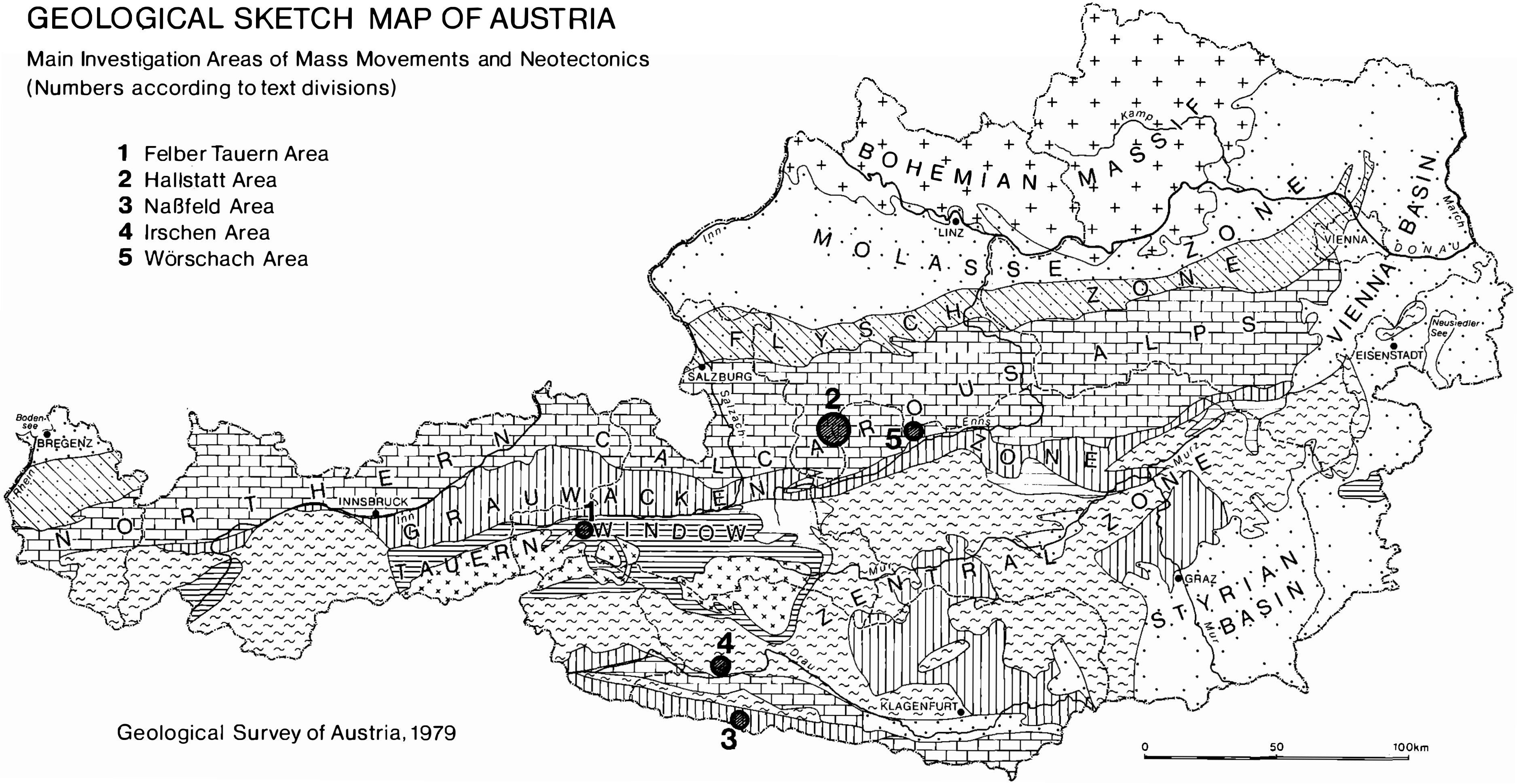
   In 1969 a movement (horizontal, 120 cm) was noted in the lower region of the slope. In the same year water appeared in the mine not far from this place, with a superposition of more than 100 m of salt bearing clay series.

These facts may be explained by the following:
ref. to 1: The clefts in this depth may most likely be caused by recent tectonical movement going from NE to SW.

Fig.1

GEOLOGICAL SKETCH MAP OF AUSTRIA

Main Investigation Areas of Mass Movements and Neotectonics
(Numbers according to text divisions)



1 Felber Tauern Area
2 Hallstatt Area
3 Naßfeld Area
4 Irschen Area
5 Wörschach Area

Geological Survey of Austria, 1979

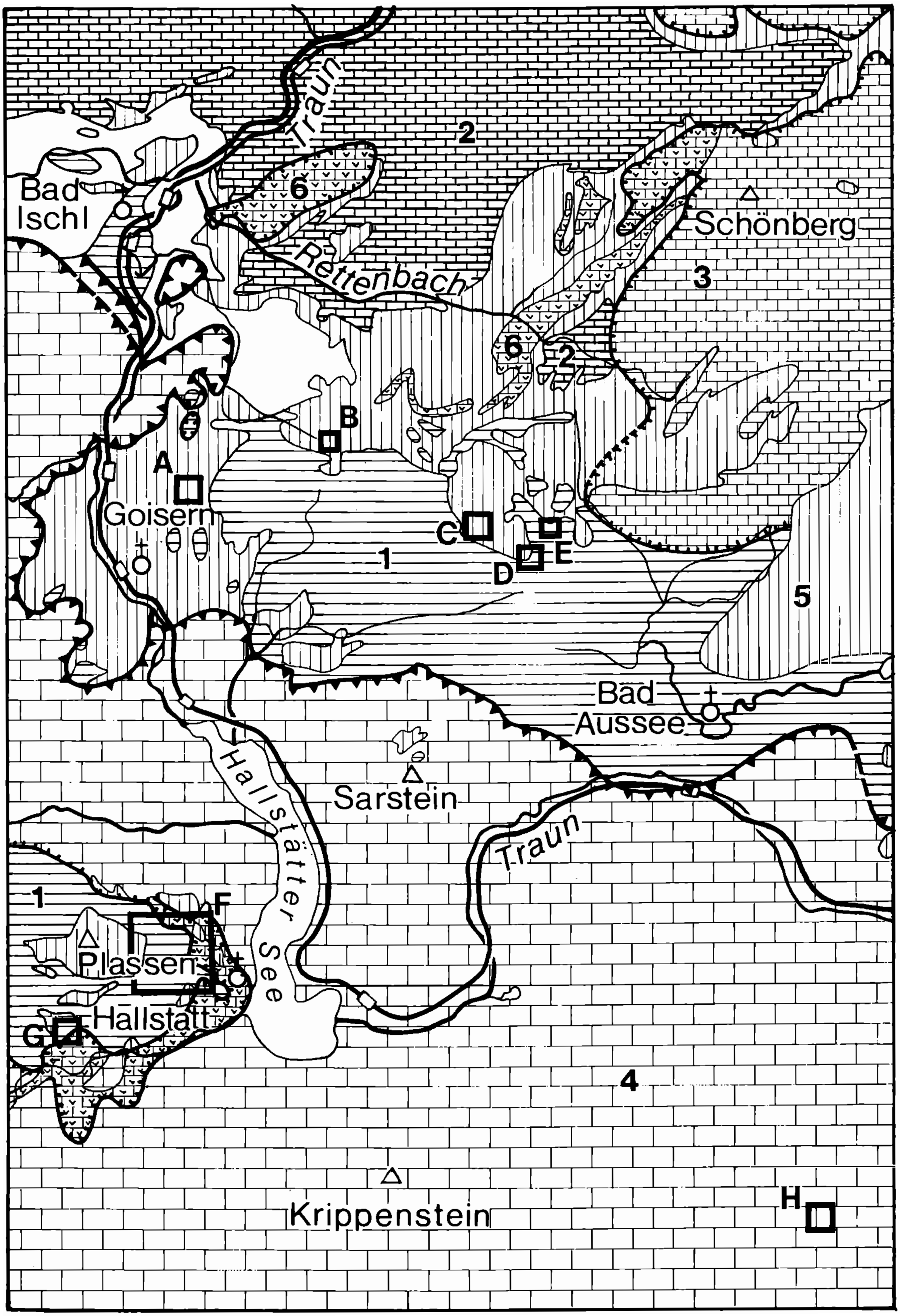


Fig. 2

G. SCHÄFFER, 1979

Fig.2

TECTONIC SKETCH MAP OF THE HALLSTATT AREA AND MASS MOVEMENTS UNDER INVESTIGATION

EXPLANATIONS OF SIGNS AND NUMBERS

▼▼▼ Overthrusts

▾▾▾▾▾ Bordering lines of jurassic slide masses

□ AREAS OF NEOTECTONIC MASS MOVEMENTS:

A: Predigstuhl mass movement

B: Zwerchwand rock fall (Oct.15, 1978)

C: Sandling rock fall (1921)

D: Mass movement of Altaussee salt mine

E: Brochener Kogel mass movement

F: Plassen mass movement

G: Große Abrutschung land slide

H: Prechtelsboden neotectonic fault

TECTONIC UNITS:

1: Hallstatt zone

2: Höllengebirgs nappe

3: Totengebirgs nappe

4: Dachstein nappe

5: Jurassic zone

6: Jurassic slide masses

ref. to 2: This phenomenon is caused by the salt buoyancy. In the western part limestone with a thickness up to 700 m superposes the salt bearing clay series. It is completely missing in the E. The salt bearing clay series moves aside to the E in the direction of the area which is not superposed by limestone.

ref. to 3: These facts can be explained by a relatively shallow movement of the slope.

In 1954 the Federal Topographic Survey of Austria carried out a reference-measurement of a net of movements on behalf of the mining authorities.

In 1973 the measurement was repeated and extended by the Geological Survey of Austria in cooperation with the Geophysical Institut of the Technical University Vienna.

In order to demonstrate the order of magnitude of the movements during the past 19 years the migration of two points can be mentioned:

Next to the main joint the movement adds up to 79 cm horizontal and 172 cm vertical (Fig. 3).

In the lower region the movement was 440 cm horizontally and 156 cm vertically (Fig. 3).

In 1974 further measurements were carried out. A new movement of approximately 25 cm in horizontal direction was observed by distance measurements in the lower part of the area.

The result of geodetic measurements relating to the order of magnitude and direction of the movements are in accordance with the geological observations.

Finally it should be pointed out that in this case three factors play a distinct role:

— neotectonic movements

— salt buoyancy

— as a consequence of both: slope creeping and landslides.

The measurements of the displacements were continued during the following years. Today it can be stated that the neotectonic movements of the adjoining limestone massiv is one of the main factors of the mass movements of Hallstatt.

Further investigations of regional mass movements were carred out in Karinthia.

3. On the southern slope of the Gailtal near Weißbriach, Karinthia, the area of Naßfeld was investigated (Fig. 1, point 3).

Geological mapping in this area especially of "Reppwandgleitung" — a recent slope-movement, was carried out from 1974 on.

The main rockslide affects "Naßfeldschichten" (shales, sandstones, conglomerates and subordinate massive layers of limestone — Upper Karbon/Perm). The moving masses cover an area of about 12 square kilometers.

The mapping of the slope-movement region below the "Reppwand" was done in the scale 1:10.000 and partly 1:5000.

The investigations showed a very complex situation concerning the surfaces of translation, the hydrogeological conditions (recharge, discharge, reinfiltration etc.) and the effects of constructions for slide and flood protection.

The toe of the slope moves intensely against the left bank f "Oselithengraben", a brook forming the backbone of the areas drainage system.

Numerous springs with a discharge of 2—20 l/sec occur in the area. Most of their water again disappears after a short superficial course, as the slope surface is cut by series of open clefts caused by tension.

Secondary slides accompanied by longtudinal and transverse joints add up to a complicated system of vectors which was studied during further investigations and measurements.

4. On the northern slope of the Drau valley, Karinthia, investigations were carried out in the area of Irschen since 1972. After working out a geological detail map (scale 1:10.000 and partly 1:5.000) and a photogeologic map, measurements of the movement rates were initiated (Fig. 1, point 4).

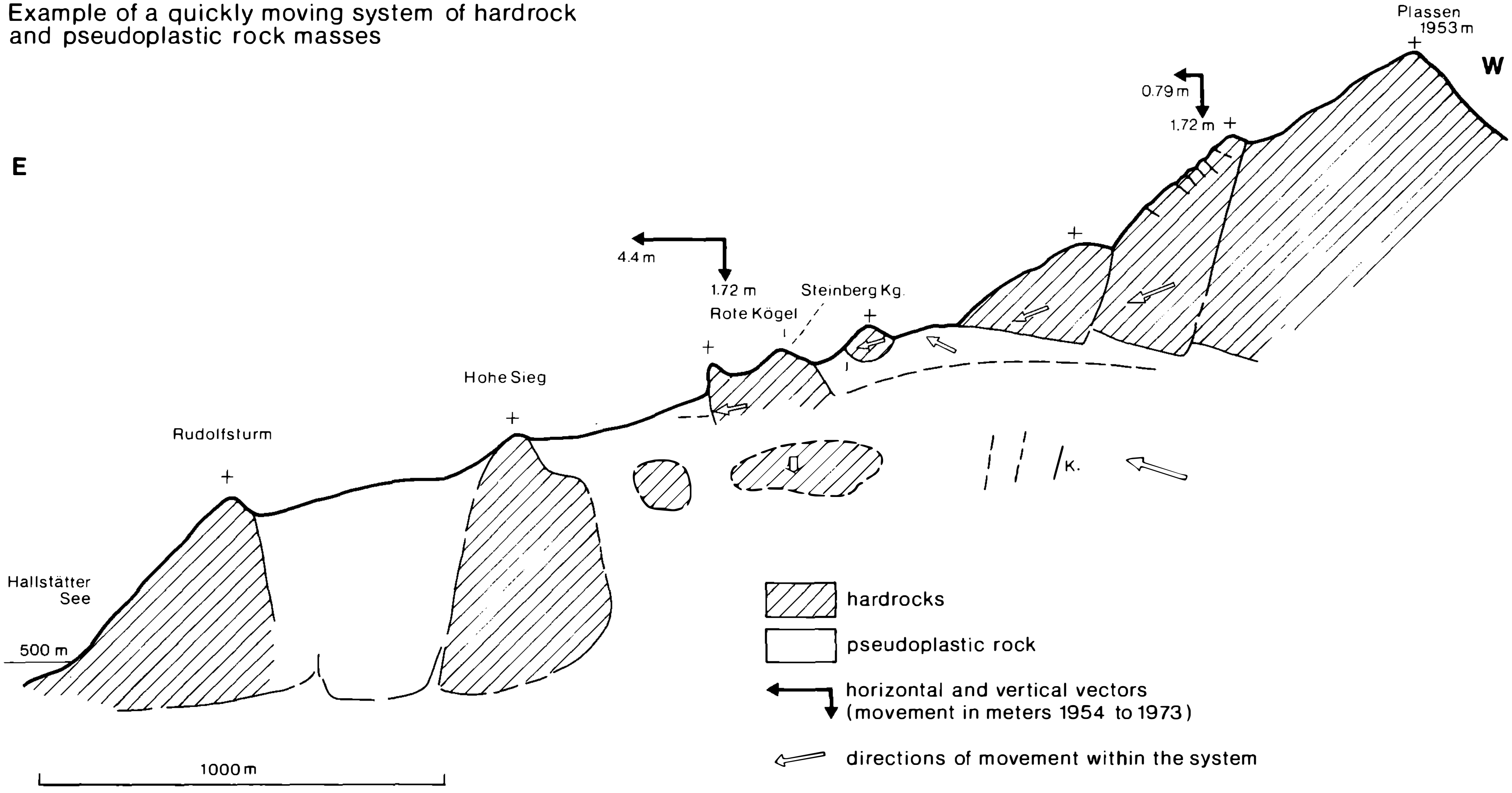
In this area it has shown that the slope movement, affecting some 10 square kilometers, causes considerable compaction ofthe moving material (mainly schists) in the lower parts of the slope by lateral compression. This mass movement also feeds mudflows during flood periods of the adjacent brook, the Mödritschbach. Further investigations included the continuation of measurements of the movements in relation to the tectonic feature of the region. In the case, the assumed connection of the mass movement with neotectonic movements could not yet be prooved, as so far the reference measurements cover only a period of three years.

The two areas, at the southern slope of the Gail valley and at the northern slope of the Drau valley, have been selected for investigation as they flank important tectonical fault-zones of the Alpine system, the Gail valley lineament which forms the boundary between the Alps and the Dinarids (Northern Alps and Southern Alps), and the Drau lineament bordering the Tauern window to the South.

Fig.3

MASS MOVEMENT PLASSEN/HALLSTATT

Example of a quickly moving system of hardrock and pseudoplastic rock masses



5. Another important tectonical lineament is marked by the valley of the Enns river. It separates the belt of the Northern Calcareous Alps from the Eastern Alpine Central Zone. At the northern side of the valley near Wörschach, rockmasses of some million cubic meters are in motion. The area was geologically mapped in detail and reference measurements were executed in cooperation with the Institut of Geophysics of the Technical University Vienna. Repeated measurements were undertaken to find out the magnitudes and directions of movements within the instable rock mass in order to get informations about recent tectonic events in connection with the lineament mentioned above (Fig. 1, point 5).

Investigations on the thermal flux in the Eastern Alps.

Investigations on the termal flux in the Eastern Alps were carried out in cooperation with the Geological Institute of the Universiy of Oxford, England, in three areas: the Katschberg-Tauernpass district, the Polinik group in the southeastern Tauern, and the Kals-Hochtor district. In the Katschberg-Tauernpass district temperature measurements were made in test-borings and tunnels of the Tauern-Autobahn, a federal highway then under construction.

The principal object of this work was the erection of a thermal model of the Eastern Alps during the past 100million years which is consistence with the geological history of the region, the chemistry and physical properties of the rocks, and the thermal state of the region at the presentday and giving a picture of its geotectonical development.

The emplacement of the Eastern Alpine thrust sheets provided sufficient burial of its central part, the Tauern region, that metamorphism ensued.

The heat required for the metamorphism must arise in large part from two sources, the decay of instable isotopes within the thrust sheets and their basement, and what may be termed additional deep sources. Numerical modelling of the Alpine events shows that the metamorphic temperatures may be attained 30 million years after overthrusting, which is rather high to represent a conduction flux from the mantle, although such an explanation is not impossible. Alternatively, a part of this heat may be conveyed by igneous rocks or aqueous fluids rising within the root-zone of the Eastern Alps.

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OLD AND YOUNG STRUCTURES ALONG SOME FAULT ZONES OF THE CENTRAL EASTERN ALPS

By Christof Exner

With 1 Figure

Prominent fault zones reaching deeply into the outer part of the earth's crust separate different geological units of the Eastern Alps. By geological investigation of some special areas (Fig. 1), age relationships of the structures observable in the field were analyzed. The observations include relic structures of Paleozoic deformation, diversified structures of Cretaceous to Paleogene age, features of Neogene tectonics as well as Quaternary and Recent movements. Field investigation has been completed by thorough petrographic research of the metamorphic rocks.

In the period from 1972 to 1979, teamwork has been carried out together with geophysical working groups along the Periadriatic lineament and at the eastern margin of the Tauern Window. In the eastern Hohe Tauern, Recent movements of the earth's crust have been investigated in co-operation with geodetic surveyors. Along the Periadriatic lineament, a fault zone of 700 km length between Maribor and Torino, comparative studies were carried out in co-operation with Slovenian, German (F. R.), Italian and Swiss geologists.

1. The Periadriatic lineament in the eastern Karawanken range ("KAR" in Fig. 1; publications: 2, 6)

Paleozoic structures are preserved in the contact aureole of the Karawanken granite which intruded in Hercynian times: there are hornfelsized fold structures in Paleozoic phyllite and greenschist ("diabase belt of Eisenkappel-Ebriach") as well as in Lower Paleozoic paragneiss, amphibolite and orthogneiss ("Altkristallin of Eisenkappel"). The time of intrusion of the Karawanken tonalite is still uncertain. Biotite of the tonalite yielded Oligocene radiometric age. In Alpidic time, both granite and tonalite have strongly been deformed along Periadriatic lineament into lamellae of up to 40—45 km length and only 2 km width. Numerous petrographic details confirm the close relationship to other intrusive bodies along the lineament (e. g., the granodiorite of Brixen or the Adamello tonalite).

Young tectonic structures are reflected by north-vergent slices, slickensides with N-S oriented strias, and mylonite zones up to 30 m thick.

2. The Periadriatic lineament in the Gail valley near Nötsch and in the western Karawanken range near Finkenstein ("NO" in Fig. 1; publications: 4, 6, 9)

Paleozoic (Lower Devonian) strata, i. e. thin lenses of carbonate rocks in the Gailtal phyllite, could be verified paleontologically by SCHÖNLAUB (Geological Survey, Vienna). The granite of Nötsch forms a 7 km long and a few tens of metres wide tectonic lamella. Granite pebbles revealing retrograde metamorphism of Paleozoic age, are found in the transgressive Permo-Scythian sandstone. Alpidic compression and late mylonites are also characteristic of this section of the Periadriatic lineament. The deformation of boudinaged, strongly thinned rock bodies persisting over a length of 100 km along the strike of the lineament, is remarkable.

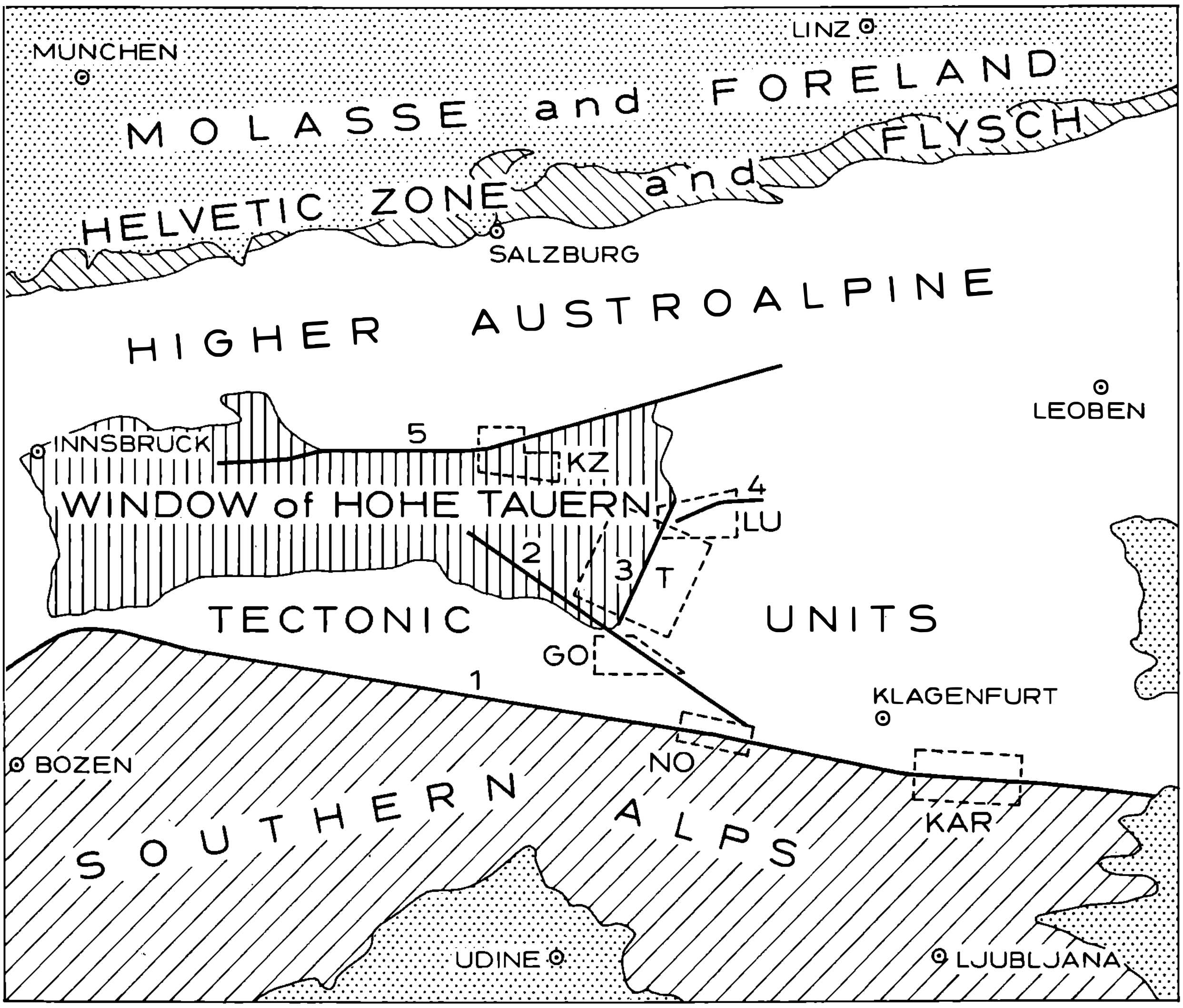

Fig. 1: Fault zones investigated in the central part of the Eastern Alps. 1 = Periadriatic lineament. 2 = Möll-Drau fault. 3 = Katschberg zone. 4 = Fault zone of Lessach. 5 = Salzach-Enns fault.
Special areas investigated: GO = Goldeck mountain group. KAR = Eastern Karawanken range. KZ = Klammkalk zone. LU = Lungau. NO = Surroundings of Nötsch and Finkenstein in Carinthia. T = Eastern margin of Hohe Tauern.

3. The Möll-Drau fault, the Goldeck mountain group, and the repeated levelling across the eastern part of the Hohe Tauern ("GO" in Fig. 1; publications: 1, 11, 17)

The Paleozoic structures south of the Möll-Drau fault have been studied in the eastern Goldeck mountain group: There is an unconformity between folded phyllite and transgressively overlying Permo-Scythian sandstone. From Lower Paleozoic dolomite within phyllite, conodonts are reported (SCHÖNLAUB). There is also an unconformity of the fold axes between the Paleozoic phyllite and the Permo-Triassic members. The intense Alpidic deformation along the Möll-Drau fault can be traced from the tectonically deep level of the Tauern Window into the high level of the Higher Austroalpine Units (mylonites in the Altkristallin of the Goldeck mountain group).

The repetition of the precision levelling across the strike of the Hohe Tauern (Gastein, Mallnitz and Möll valleys) carried out by SENFTL (Bundesamt für Eich- und Vermessungswesen, Vienna) revealed vertical uplift of the Hohe Tauern of about 1mm per year. The highest values have been measured immediately north of the Möll-Drau fault.

4. The Katschberg zone ("T" in Fig. 1; publications: 3, 4, 8, 12, 13, 16)

SCHÖNLAUB determined Silurian conodonts in lenses of dolomite and limestone embedded within Katschberg phyllite. The gneisses and micaschists of the Altkristallin of the Higher Austroalpine Units east of the Katschberg zone contain Paleozoic and possibly Precambrian relic minerals and structures. Pebbles of these Altkristallin rocks metamorphic in amphibolite facies, are found as components in the Upper Caboniferous conglomerates of Turrach-Innerkrems.

The rocks of the Hohe Tauern west of the Katschberg zone are recrystallized in Alpidic time, mainly in greenschistfacies. The structures are rather flat-lying with an axial plunge of 30—35° to the east. The E-W trending fold axes formed by the main Alpidic deformation act, are locally overprinted by N-S trending axes. In the Zentralgneiss area, it was possible to trail over a great distance a tonalite gneiss nappe lying upon micaschists.

West of the Katschberg zone, the sequence of formations already known from the Lungau could be traced to the south as far as the Drau valley.

The Alpidic movements along the Katschberg zone are responsible for retrograde metamorphism and the formation of mylonites. The distinction between progressively metamorphic Lower Paleozoic phyllite and phyllite retrograde after micaschists ("phyllonite") was principally made with the aid of the hiatus in the grain size of the white micas. There are relics of gneiss within the phyllonite in some places.

An interesting new result is the existence of a zone made up of phyllitic micaschists containing phenoblasts of garnet and albite; this zone is restricted to the base of the Higher Austroalpine Units between Lungau and Gmünd in Carinthia.

It is suggested by the geomorphology, observable faults, seismic activity (earthquake of Gmünd), and mineral springs that faults are active along the Katschberg zone. To evaluate this suggestion, a new levelling profile was installed across the Katschberg zone in E-W direction. The western end of the profile is based on the Schieferhülle of the Hohe Tauern, the eastern end on phyllitic micaschists at the base of the Higher Austroalpine Units.

It is provided to repeat the measurements after periods of several years. The levelling profile was specifically built up for this scientific porpose across the Katschberg pass in 1973/74 by the Bundesamt für Eich- und Vermessungswesen, Vienna (SENFTL). Direction measurements and electronic distance measurements were carried out a the Torscharte in 1976/79 by the Institut für Landesvermessung of the Technical University of Vienna (SCHMID, PETERS) with the aid of geodetic pillars on both sides of the fault zone.

5. The fault zone of Lessach and the Lungau basin ("LU" in Fig. 1; publications: 10, 15, 16, 18)

At the northern end of the Katschberg zone, the fault zone of Lessach branches off in an easterly direction. Lenses of dolomite contained in the phyllite yielded Silurian conodonts which were determined by SCHÖNLAUB.

The basement of the Paleozoic syncline are gneisses and micaschists of the Higher Austroalpine Units which were intensely sliced in Alpidic time. Phyllonites are originated from micaschists by retrograde metamorphism.

The clastic sediments of the Miocene fresh-water sediments of the Lungau basin contain the material derived from gneisses and micaschists of the adjacent Altkristallin of the Higher Austroalpine Units. Rocks typical of the Tauern Window are missing. Therefore it is suggested that, in the Miocene, the rocks of the Tauern Window were still buried beneath the erosion level.

Post-Miocene movements could be established in several places of the Lungau basin. Steeply inclined bedding planes, formation of graben structures, strike slip displacements and slickensides bear witness of the deformation of the fossiliferous Miocene strata.

6. The Salzach-Enns fault ("KZ" in Fig. 1; publications: 4, 7, 14, 19)

In continuation of the investigations of HEISSEL, HORNINGER and MOSTLER (University of Innsbruck, Technical University of Vienna), the E-W striking fault on the northern margin of the Hohe Tauern was analyzed in a special area (Salzach valley, Klammkalk zone).

In the section investigated, the Graywacke zone of the Higher Austroalpine Units north of the Tauern Window consists of Lower Paleozoic phyllites, diabases and carbonate rocks; the metamorphic influence increases from north to south (anchimetamorphism to greenschist facies). South of the Salzach fault, the bordering Bündner Schiefer (Schistes lustrés) of the Tauern Window in part closely resemble the phyllites of the Graywacke zone in their lithology, composition and fabric. Graywacke zone and Bündner Schiefer jointly suffered deformation and recrystallization during a late phase of Alpidic orogeny.

Breccias, flysch-like sandstones, diabases and ultramafic rocks are characteristic of the tectonically mobile, marin domain of the Bündner Schiefer during older periods of the Alpidic orogeny (Sandstein-Breccien zone).

Postdating the deposition of the Neogene fresh-water sediments, intense compression accompanied by vertical and lateral slip motions affected the rocks along the Salzach-Enns fault. Mylonites formed during this phase attain a thickness of 100 m. HORNINGER reports faulting in Quaternary sand and gravel.

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A GEODETIC CONTRIBUTION TO THE IGP

by K. Rinner

With 1 Figure

1. Introduction

It is the task of geodesy to determine the geometric, astronomic and gravimetric parameters describing the geometric shape, the orientation and the gravity field of the earth. The geodetic contribution to geodynamic projects consits in determining these quantities and their variations as a function of time.

The geodetic work being carried out in Graz in the scope of the IGP is in conjunction with the GEO-station at Graz-Lustbühel (GL) and the test net (TN) "Steiermark" (Styria) connected thereto (see Fig. 1 a, b). The work concerns the extension of this equipment and the realization of projects for the determination of space positions (position and height), direction of the plumb lines and gravity values, earth-tides, parts of an astrogeodetic geoid, polar motions and the geodetic connection to neighbouring GEO-stations in the German Federal Republic, Poland and Hungary.

2. Description of the GEO-station at Graz-Lustbühel

The GEO-station at Graz-Lustbühel (GL) is part of the geodetic department of the Institute of Space Research in the Austrian Academy of Sciences. It comprises some equipments of the observatory at Graz-Lustbühel, three earth-tides stations and the TN Steiermark (Styria) (see Fig. 1 b).

The observatory disposes of a ballistic camera (BMK 75,Zeiss Oberkochen) for the photographic determination of directions to satellites and the earth's axis, Doppler receivers and computers for determining space positions with the aid of TRANSIST and GEOS-satellites. The time required therefore is derived from a cesium atomic clock available at the observatory. A pulse laser for satellite-ranging will be available in 1980. Four horizontal pendulums (Verbaandert Melchior) and two gravimeters (Geodynamics and Askania GS 11) are used for recording the horizontal and vertical components of the earth-tides vector at the stations of Graz-Schlossberg, Peggau and Gleinalpe. Connection and parallel measurements with Hungarian stations (Sopron and Tihany) have been carried out.

The TN Steiermark (Styria) was originally established for investigations of the propagation of electromagnetic waves [2, 3]. Now it is being extended to a threedimensional net for the hypothesisfree determination of the space positions of net points and their variations. Astronomic measurements are to be used to determine a precise astrogeodetic geoid in the area of the TN.

Within the frame of IGP an absolute gravity value was determined for the Graz-Schlossberg station; the earth-tides measurement was intensified by erection of two new stations (Peggau and Gleinalpe) and the use of new equipment. The determination of the polar motion with the BMK 75 as zenith camera and permanent Doppler measurements as well as the astronomical-geodetic determination of a geoid part in the area of the TN Steiermark (Styria) and in the 47th parallel were initiated. The connection to the Hungarian Geo-station at Sopron has been performed by means of a space traverse and initiated to the GEO-station at Wettzell (German Federal Republic) by stellar triangulation. The connection to the Hungarian station at Penc (Budapest) and the Polish station at Borowiec was made by means of Doppler multilocation. Within the frame of a German-Austrian Doppler Campaign (DÖDOC) the space positions of seven points of the Austrian national triangulation and the terrestrial positioning in the European RETRIG system were checked and a basis created for structural investigations in the Austrian national triangulation.

3. Earth-Tide measurements

Austria's first tidal station was established in 1963 in the Schlossberg of Graz by the author of this report. After test recordings and an interruption due to a rock slip continuous recordings of the horizontal components have been made since 1969 with the aid of Verbaandert-Melchior (VM) pendulums [5, 6]. Within the frame of IGP it was intended to intensify the observation of earth-tides with the following aims:

- Erection of further stations in the surroundings of Graz (earth-tides nest) in order to eliminate local effects and obtain representative parameters for the area of the Lower Alps.
- Recording of horizontal and vertical components to cover the whole tide vector.
- Parallel recordings with various types of instruments in Graz and at the GEO-station of Sopron (Hungary) to réalize instrumental influences.
- Installation of programmes for the preparation and analysis of recordings in the computer centre of Graz.

3.1 Erection of new stations

Station Peggau: In a tunnel of the Peggauer Wand (rock wall at Peggau), about 20 km north of Graz, a station was erected for the recording of earth-tides and set in operation in August 1974. It is situated in the geological structure called "Schöckelkalk" at 420 m altitude; 47°12'33" north latitude, 15°21'02" east longitude and termed "Peggau No. 0696" within the frame of international programmes. The motion of the plumb line were recorded on 576 and 502 days with VM pendulums at this station (see Table 1). A comparison with D factors obtained at the station in Graz shows no significant differences in spite of different geological structures at the two stations (dolomite in Graz, Schöckel limestone at Peggau).

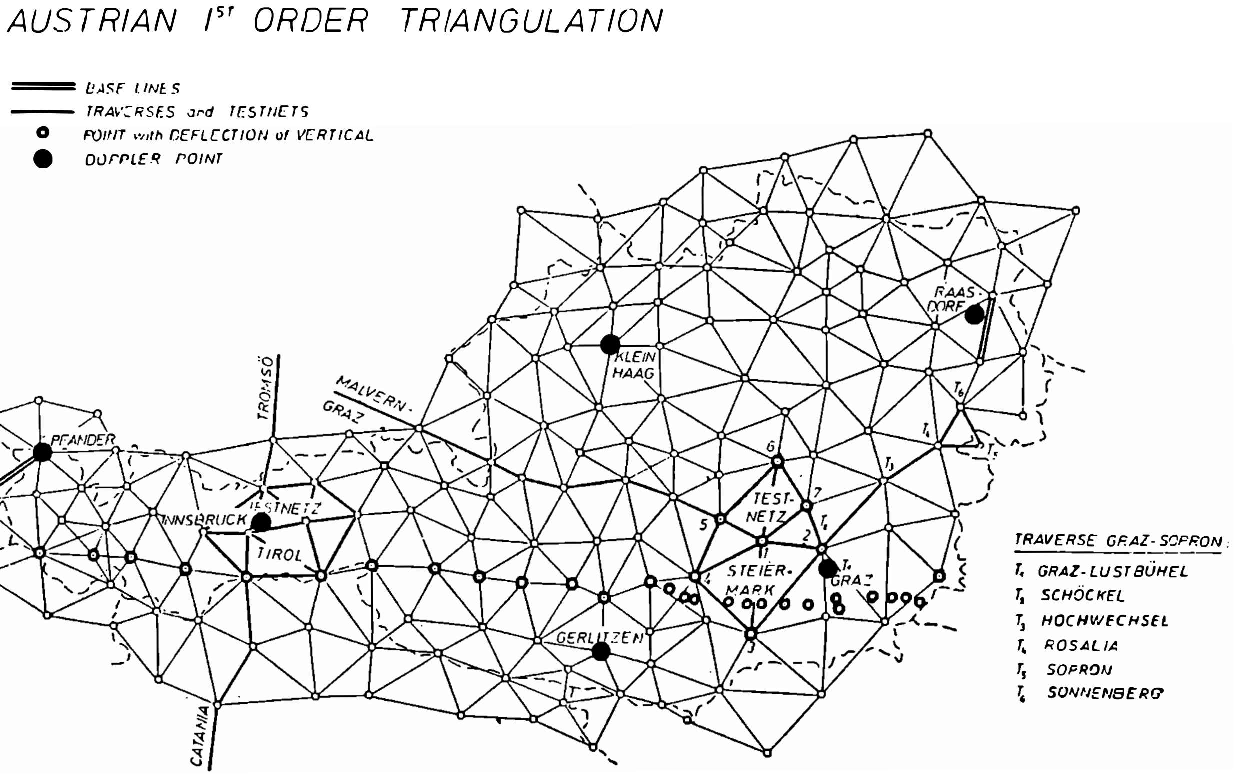

Fig. 1a: Austrian first order Triangulation

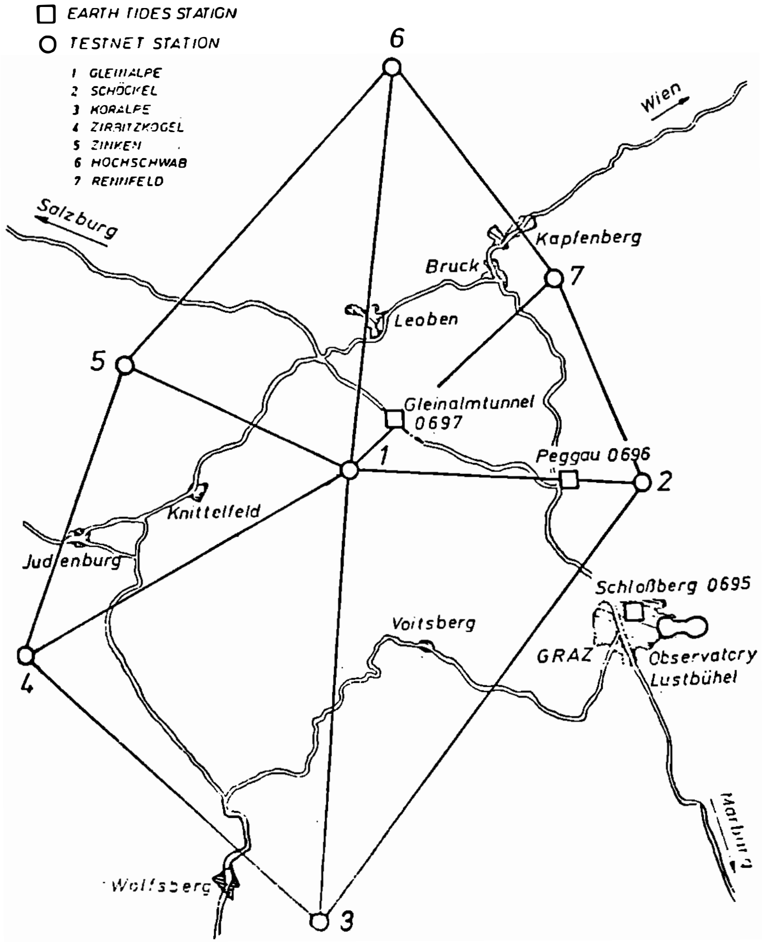

Fig. 1b: Geo-Station Graz-Lustbühel

4. Astronomic-geodetic work in the test net Steiermark (Styria)

In the test net (TN) Steiermark (Styria) (Fig. 1 b, Table 2), a central figure of the Austrian national triangulation of 1st order consisting of seven mountain points, very accurate light and micro wave distances, zenith distances, horizontal angles and heights are available from a preceding research project [2, 3, 4]. If, in addition, the latitudes, longitudes and azimuths are determined for each point by astronomic measurements it is possible to make a hypothesis-free three-dimensional adjustment of the net and an astronomic levelling to determine an astrogeodetic geoid portion in the area of the test net. By repeating these operations it is possible to recognize dynamic processes and describe them by displacement vectors and changes of shape of the geoid.

Tab. 2.: TN Steiermark, Astronomical data.

Nr.	Station	Center	Latitude		n	Longitude		n	R	Azimuth		n	Height
1	Gleinalpe	KT	47°13'39"97	±0"20	7	15°03'00"21	±0"39	3	2	275°41'30"93	±0"32	6	1988 m
2	Schöckl	KT	47 11 50.58	0.14	6	15 28 00.81	0.44	5	7	160 48 39.96	0.32	3	1445 m
3	Koralpe	PF	46 47 09.73	0.28	5	14 58 10.49	0.12	5	1	186 46 43.06	0.50	5	2140 m
4	Zirbitzkogel	KT	47 03 47.18	0.18	6	14 34 03.14	0.75	4	1	243 20 11.74	0.35	4	2395 m
5	Zinken	KT	47 20 23.83	0.13	3	14 44 17.75	0.42	4	1	297 39 08.19	0.17	2	2397 m
6	Hochschwab	KT	47 37 09.72	0.24	3	15 08 33.08	0.48	4	7	325 20 52.03	0.43	3	2277 m
7	Rennfeld	KT	47 24 18.34	0.20	3	15 21 34.01	0.51	4	2	340 43 53.87	0.39	4	1628 m

KT	monumented by cadastral triangulation stone
PF	monumented by pillar
n	number of observation nights
R	number of Reference Object

4.1 Astronomic observations

The observations were made with a KERN DKM 3A universal theodolite. It was set up in three points (Gleinalm, Schöckel, Koralpe) on existing pillars, in the other points on tripods.

The latitudes were determined from meridian zenith distances according to Sterneck, the azimuths were derived from hour angles of Polaris, the longitudes were determined by measuring the times for meridian transits by H. Lichtenegger. The observers personal equation was determined at the beginning and end of the observation campain from parallel measurements and at the Austrian reference station (Observatory of University, Vienna). A weighted mean value of $+0^s028$ was found for the reduction of the time measurement.

The mean values of several measurements are compiled in Table 3 a with reference to the mean pole of the epoch and the centre of the national triangulation. Likewise the azimuths reduced on account of the heights of target points.

The mean errors of latitude and azimuth are small and inferior to the limits mentioned in the literature. For the longitudes the errors are larger by the factor 1.5 which can be explained by the observations having been made on tripods.

4.2 Astrogeodetic levelling

The astronomic data were compared with the values following from the ED 77 system (European datum 1977). The resulting deflections of the vertical are listed in Table 3 a. A statement on the quality of the astronomic data and the orientation of the Austrian national triangulation follows from the Laplace contradictions shown.

Only on the Schöckel point they reach an amount beyond normal, probably due to anomalous refraction phenomena.

The differences ΔN_{ik} of the undulations N of the net points (not considering any reduction factor) are compiled in Table 3b. Since there are redundant observations for the TN, adjustments were made for weight assumptions p = const., p = 1/s (s distances). With the value N = 3.25 m taken for the Gleinalpe point [7] the undulations N listed in Table 3 a follow for both adjustments.

4.3 Final remarks, outlook

The undulation values determined show the rough structure of the geoid. To determine detail shapes it is necessary to condense deflection of vertical points to abt. 10 km point distance. This should be carried out within the frame of another project. Test calculations were made for the three-dimensional adjustment in the TN. Since few rendundant observations are available for the existing net configuration it is intended to expand the net within another research project.

Tab. 3 a.: TN Steiermark, Deflections of the vertical

Station	ξ"	ηλ"	ηα"	w"	N (m)
1	—1.06	+0.92	+0.76	—0.17	3.25±0.3
2	—5.77	+0.81	+2.35	+1.67	3.5 0.3
3	—6.35	—8.02	—7.61	+0.43	2.1 0.3
4	—4.53	—1.53	—1.67	—0.16	2.7 0.3
5	—0.43	+2.99	+2.04	—1.03	3.3 0.3
6	+1.26	—2.18	—2.53	—0.38	3.3 0.3
7	—0.88	—3.18	—3.32	—0.15	3.6 0.3

$$\left.\begin{array}{ll}\xi & = (\varphi - B)\\ \eta\lambda & = (\lambda - L)\cos B\\ \eta\alpha & = (\alpha - A)\cot B\end{array}\right\}\text{ Deflections of vertical (ED 77)}$$

w = $(\eta\alpha - \eta\lambda)\tan B$ Laplace Contradictions

N = Undulation

Tab. 3 b. TN Steiermark, Undulations

Line	s (km)	α°	ΔN_{ik} (m)
(1.2)	32	275.7	—0.19
(1.3)	49	6.8	—0.98
(1.4)	41	63.7	—0.30
(1.5)	27	117.9	+0.27
(1.6)	44	189.2	+0.00
(1.7)	31	229.9	+0.22
(2.3)	59	39.6	—2.00
(3.4)	44	135.1	+0.10
(4.5)	33	202.6	+0.32
(5.6)	44	224.5	—0.12
(6.7)	29	325.3	+0.23
(7.2)	24	340.7	—0.32

$\Delta N_{ik} = 1/2\,(\varepsilon_i + \varepsilon_k)\,s_{ik}$

$\varepsilon_i = \xi_i \cos\alpha_{ik} + \eta_i \sin\alpha_{ik}$

α south azimuth

Tab. 4 a. Traverse Graz-Sopron, Astronomical Data, Heights

	Station	Center	Latitude		Longitude		ED 77		Height
							ξ"	η"	
T1	LUSTBÜHEL	PF	47°03'56"6	± 0"2	15°29'39"3	± 0"2	—6.5	—0.7	481 m
T2	SCHÖCKL	KT	47 11 50.6	0.1	15 28 00.8	0.4	—5.8	+0.8	1445 m
T3	HOCHWECHSEL	KT	47 31 49.2	0.2	15 54 59.6	0.2	—3.3	+4.4	1743 m
T4	ROSALIEN KAPELLE	KT	47 41 57.9	0.1	16 18 33.8	0.4	+3.8	+4.4	747 m
T6	SONNENBERG	TP							484 m
T5	SOPRON	PF	47 40 53.1	0.2	16 33 38.6	0.3			340 m

Tab. 4 b. Traverse Graz-Sopron, Laser Distances

Line	s (m)		m_s	n_s
T1—T2	14 778.938	±	0.004	2
T2—T3	50 121.943		0.007	6
T3—T4	34 911.408		0.004	4
T5—T4	18 948.116		0.029	9
T5—T6	22 631.954		0.019	8

n_s = number of observations

s = space distance

5. Connection of neighbouring GEO-stations

By means of geodetic connection of neighbouring GEO-stations it is possible to detect local system errors and refer all data to a unified system. The repetition of these measurements leads to a detection of dynamic variations of the stations. For the geodetic connection of neighbouring GEO-stations various techniques are available such as the space traverse, the space net, the stellar triangulation and the positioning with the aid of satellites.

The GEO-stations at Graz and Sopron were connected by a space traverse. It runs from the starting point at Graz-Lustbühel over the points Schöckel, Hochwechsel, Rosalienkapelle and Sonnenberg in the Austrian national triangulation of 1st order to the end point in the observation tower of Alomhegy at the Sopron station. The angles and heights between the Austrian points are known from the national triangulation, the angles towards the Hungarian station will have to be determined.

Within the frame of IGP the distances between all points were determined with light waves, and the astronomic longitudes and latitudes were determined for all points. The results are given in Table 4 a, b. The calculations of the space traverse could not be made as it was not yet possible to determine the directions to the Hungarian station. The connection vector between the GEO-station at Graz-Lustbühel and Wettzell (Germany) is determined by the method of stellar triangulation (within another research project). Oriented directions from the two stations to an auxiliary point on the Schafberg are derived from photographs of balloons against the stellar sky and time measurements. The distances of the two-side traverse are determined by Doppler measurements. The measurements for Wettzell-Schafberg side are completed, for the Austrian portion (Schafberg-Graz) they are to follow this year.

Doppler measurements were carried out to connect the Graz-Lustbühel GEO-station with further stations in the surrounding area. By the participation in the European and German-Austrian Doppler campaigns (EDOC II and DÖDOC) connections exist to nearly all West-European observatories. The connection to the Hungarian station at Penc (Budapest) and the Polish station at Borowiec was realized within the frame of special projects in cooperation with the competent academies and surveying authorities. Doppler coordinates were determined for the first time for East-European stations. A repetition of these measurements and an extension of the connection is intended.

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REPORT ON THE IGP-ACTIVITIES OF THE INSTITUTE FOR PETROLOGY

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During the periode of the I. G. P. 1971—1979 petrological problems involved in geodynamics have been tackled by working groups of the Institute of Petrology (former Mineralogisch-Petrograpisches Institut).

The most important item in this respect is the ophiolite problem in the Eastern Alps. The basic problem to be solved by the presented study is to what extend the serpentinites and periodtites of the metamorphic zones can be considered to be ramnents of a former oceanic curst. A paper about this item will be presented in full length during the Int. Geol. Congress, 1980, Paris. The relations of the igneous and metamorphic basement of the Northern Alps in Eastern Austria to the "Zentral Gneiss Zone" of the Hohen Tauern have also been studied [13].

As a result of this work "Zentral Gneiss Zone" is considered to be the ultimate fringe of the Northern plate of the alpine geosyncline in Austria.

A geotraverse between the SW-part of the Wechsel fenster and the "Grazer Paläozoikum" (Geotraverse East) has been studied to evaluate the available tectonic-geodynamic models in the light of petrological datas.

A complete geologic mapping was carried out (Blatt Birkfeld 1 : 50.000). The plate tectonic model of TOLLMANN [11] seems to fit the best to the results of petrological work in this area.

1. Contributions to the occurence and genesis of ultramafitites and related rocks of the Eastern Alps.

On the boundary of the Western and the Eastern Alps the Penninic zone is dipping below the East-Alpine nappes and reappears in several tectonic windows. These are from the west to the east the Gargellen — the Unterengadin — and the Tauern window and the window group of Rechnitz-Bernstein. The detailed correlation of the Penninic formation of the Eastern Alps with the troughs of the Penninic zone of the Western Alps is difficult and contradictionary. TOLLMANN [12] compares the Hochstegen welt facies of the Hohen Tauern with the Brianconnais of the Western Alps. The "Schieferhüllen" nappes were correlated with the Piemontese. The lower of these nappes is characterized by the prevalence of calcareous phyllites and micaschists which correspond to the "Bündner Schiefer" of Switzerland. Serpentinites, metagabbros, greenschists, metavolcanites, prasinites and rodingites are associated with the calcareous metapelites. Metaradiolarites and manganese rich rocks are also characteristic for these association of Jurassic-Cretaceous age. The ultramafititic-mafititic rock association is considered to be "ophiolites" following the definition of the Penrose field conference of the A. G. S. 1972. But this term must be used careful and critically taking into account the complicated stratigraphy and structures of the metamorphic zones of the Alps. Peridotites and serpentinites of the Praetriassic metamorphic basement of the Eastern Alps do not belong to the alpine ophiolite association. Even those peridotites ocurring within the Tauern window but belonging to the "Untere Schieferhülle" cannot be considered as members of the alpine ophiolite family. If we agree to plate tectonic models developed by DEWEY et al. [1], DIETRICH [2], TOLLMANN [11], only those ultramatitic and mafititic rocks can be considered to be alpine ophiolites for which a generation by ocean floor spreading during Jurassic or Cretaceous time is probable.

The "Mittelostalpin" sensu TOLLMANN [12] is divided into two tectonic units of preaealpidic origin and metamorphoses: the Muriden and the Koriden. Both these units contain ultramafitites. The deeper Muriden nappe consists of lower grade metomorphic rocks like garnet micaschists, staurolite schists, gneisses and marbles, eclogites do not occur in this unit. The large ultramafitite complex of Kraubath belongs to this unit. The lense shaped NW-SE striking body has a length of 14,5 km and is associated with amphibolites. It consists predominantly of dunites and orthopyroxenites, which are partly serpentinized. The Kraubath peridotite is the largest of the ultramafitite lenses which are embedded in amphibolites. These amphibolites surround the Gleinalpe consisting of banded gneisses.

The dunite of Hochgrößen is situated farther to the west in a different tectonic position. It is fringed by eclogites which are partly transformed to amphibolites by a regressive metamorphism. As a result of detailed studies it is supposed that the dunite of Hochgrößen is derived by tectonic movements from the Penninic zone below. The Koriden nappe consists of kyanite schists, gneisses, micaschists, amphibolites and eclogites. Peridotites are bound to the Plankogel formation consisting of micaschists and characteristic manganese quartzites.

It is a remarkable fact that ultramafitites associated with metasediments of Upper Mesozoic age are completely serpentinized whereas those of Praetriassic age contain many relicts of primary minerals specially olivines, pyroxenes and spinels. We suppose that this striking fact is caused by the implacement of the Penninic ultramafitites in water rich sediments. The emplacement of the Prealpidic ultramafitites took place obviously in a more dry perhaps metamorphic environment.

Within the Tauern Window the ultramafitites are represented by antigoritites in the Unterengadin and in the Rechnitz window group chrysotile lizardite serpentinites with completely preserved primary textures occur. Higher temperatures during alpine metamorphose within the Tauern window seem to be responsible for this characteristic feature. A metamorphism by constant volume explains the complete preserved primary structures in spite of the total replacement of the primary minerals by serpentine and other minerals. Secondary Ni-minerals have been found in most serpentinites. The primary olivine-pyroxene spinel associations points to an upper mantle origin of the Praetriassic peridotites. The same origin is supposed for the serpentinites of the Penninic zone. In spite of some difficulties the rhythmic layering of clinopyroxenites, dunites and wehrlites of the Stubachtalkomplex PETRAKAKIS [7, 8] may be caused by a cumulus process within the upper mantle. Metamorphic olivines characterized by low Ni- und Fe-content are proved for the Stubachitcomplex and are supposed for the dunite of Hochgrößen.

The Unterostalpine serpentinites are included into the group of alpine ophiolites. The lack of ultramafititic rocks in the Unterostalpine of the Semmering-Wechsel window is explained by the absence of Jurassic-Cretaceous strata and the existence of continental crust in this region. Pumpellyite-prehnite alpidic metamorphism has been confirmed in the Unterengadin window. The ophiolites of Rechnitz-Bernstein window group are recrystallized in higher pressure greenschist facies.

This is confirmed by the evidence of new generated magnesio-riebeckites in metagabbros [5]. Chrysotile and lizardite have been proved in the accompaning serpentinites. In these rocks primary textures are completely preserved by chrysotile and lizardite. A detailed study was devoted to serpentinite lenses of the flysch zone near Kilb and Gstadt [9]. According to X-ray tests of the Gstadt serpentinite lizardite is the unique detectable serpentinite mineral in this rock. From relictic textures we conclude, that mostly rocks of harzburgitic petrography have been the source rocks of the serpentinites. The regional distribution primary textures seem to indicate an isovulmetric metamorphism in an open system. Chlorite embedded in some serpentinites may be derived from pyroxenites, supposed metamorphism is approximately isochemical. Summing up our observations serpentinisation after the implacement of peridotites and related rocks into the Jurassic-Cretaceous Penninic sediments seem probable.

The ultramafitites of the Tauern belonging to the alpidic ophiolite suite are transformed to antigoritites. The antigorites form plates up to 2 mm in diameter. The average Al_2O_3 content is distinctly higher compared with typical chrysotile serpentinite. In spite of the lack of primary textural relicts the derivation from dunites, harzburgites and other ultramafititic rocks is evident. The evolution of Tauern antigorites is comparable to that of the other Penninic zones (Unterengadin, Rechnitz). Formation of chrysotile is caused by a higher grade metamorphism. Comparing alpine and praealpine ultramafititic-mafititic rock suites, it is a characteristic feature that metavolcanites characteristic for the former are lacking completely in the latter.

The question to what extend praealpidic ultramafitites could be considered as remnants of Paleozoic ocean floor is up till now an open one. Plankogel formation, Habach- and Greiner formation and the lower part of the Gleinalpen "Schieferhülle" and their ultramafitites are probably elements of a Caledonian or Variscian geosyncline. The basic problem of praealpidic ultramafitites is the question of direct mantle origin versus gravitative differentiation from a basic melt. The Paleozoic ultramafitites are genetically associated with metabasites (mostly amphibolites). The volume of peridotites surpasses that of the basic rocks many times over. In our opinion this is explained easier by consideringy the basic zones as a product of partial melting and the peridotite as a residual product. Spinelpyroxenites within the peridotites confirm this supposition.

Chemistry of 94 minerals was done by microprobe analyzer ARL-SEMQ.

2. Petrology and geology between the SW-part of the Wechsel Fenster and the "Grazer Paläozoikum"

The most characteristic rocks of the Lower East alpine part of the studied area coarse grained granite gneisses (abbreviated grobgneiss). The petrology of these rocks has been described in earlier reports. Radiometric dating (S. SCHARBERT personal comunication) gives the expected Carboniferous age (340 ± m. j.). Mineral ages (K, Ar, S. SCHARBERT), approximately 80 m. j. point to an old alpidic metamorphism.

Leucophyllites are chlorite-muscovite quartz schists which contain occassionally kyanite. According to the field studies leucophyllites are nearly exclusively associated with grobgneiss und bound to stress zones. The details of their formation are already published [6]. The country rocks of the grobgneisses are phyllitic micaschists. Small lenses of metagabbros containing sometimes spinel and corundum, small bands of amphibolites and lenses up to 1 m³ of turmaline rock. On some places feldspatisation of the phyllitic mica schist is to be observed on the boundary to the grobgneiss. A Devonian age of the phyllitic-micaschists seems to be the most probable. Grobgneiss and phyllitic micaschists and the associated rocks are forming the grobgneiss formation sensu stricto.

In the last years a characteristic rock association could be separated from the grobgneiss formation. This association consists originally of staurolite-, sillimanite- and andalusite-bearing schists. Now these minerals occur only in rare relics because of a retrograde alpine metamorphism. In place of staurolite chloritoide is now widely distributed. Migmatites, arkose gneisses, medium grained metagranites (Stubenberg), migmatites and graphite-quarzites and graphite schist belong also to this rock association. Using and redefining a term introduced by SCHWINNER [10] we gave this ~~rock~~ association the name Strahlegg — gneiss and schist formation. The formation is distributed in the middle part of Blatt Birkfeld, E of the Feistritz Valley.

Tectonically the Strahlegg unit is overlying the grobgneiss formation. Within this formation a lithostratigraphic sequence is proposed, beginning with biotite schists with or without staurolite. The next event is a migmatisation followed by weathering and formation of metaquartzites. The metasedimentary cover of the grobgneiss formation are the Permotriassic Semmering quartzites, metadolomites and marbles, including phyllites, arkoses, porphyroides and conglomerates of the base (alpine Verrucano). The latter formation has been indentified widely distributed in the southern part of the Fischbach window.

The north-south stricking Koglhof marble complex is situated at the boundary between the Unterostalpin and the Mittelostalpin formation.

White quartzites associated with the marbles are petrographic comparable to quartzites of the Central Alps generally attributed to the Lower Trias. Rauhwackes within the marbles may also be considered as an indication for Mesozoic age. But other indications are less favorable to this opinion. Near Wieden, a village not far from Koglhof, pegmatites are crossing the marbles. After a statistical experience pegmatites in the Eastern Alps should be of Praetriassic age and probbably comparable to marbles of the Bretstein formation. Graphitic schists accompanying the marbles are an additional evidence for a higher age. We agree to SCHWINNER [10] and H. FLÜGEL [3] that presumably Paleozoic and Mesozoic strata together form the Koglhof marble complex. But in spite of detailed mapping it was not possible up till now to distinguish stratigraphic different carbonate rocks. The Mittelostalpin between the Koglhof marble and the Grazer Paläozoikum has a thickness of only 2 km. This poor thickness corresponds to the thinning out of this unit toward the frame of the

Penninic windows and toward the east end of the Alps [12]. Garnet mica- and quartzitic mica schists are the predominant rocks of this zone. Small lenses of garbenschiefer are characteristic lense shaped inclusions in the micaschists. In the Unterostalpin they are totally lacking.

Diaphthoresis is widely distributed in the upper zone of the Mittelostalpin. Therefore it is difficult to draw a sharp border line between the Mittelostalpin and the Grazer Paläozoikum. A good mean to distinguish phyllites of progressive metamorphism (Grazer Paläozoikum) from diaphthorites (Mittelostalpin) is the widespread occurence of transversal foliation in the former.

The Raasberg formation is situated between Mittelostalpin and the Grazer Paläozoikum. Some indications seem to confirm a Mesozic age for this formation [4].

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