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Regional Distribution of Magnetic Susceptibilities and 3D Modelling of Aeromagnetic Anomalies in the Central Eastern Alps (Western Tauern Window), Austria.

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Abstract

This study examines the magnetic properties of rocks in a north-south traverse through the area of the western Tauern Window from the Northern Calcareous Alps to the southern rim of the Tauern Window. In the course of the petrophysical investigations about 4500 in-situ susceptibility measurements and laboratory measurements from 167 specimens were taken covering the main tectonic and lithologic units along the traverse. The distributions and the median values of magnetic susceptibilities for different rock types in different tectonic units are presented. From the data it becomes clear that an unambiguous discrimination of different tectonic units based on magnetic properties of similar lithologies is not possible.

Besides these petrophysical investigations, 3D models of the magnetic susceptibilities explaining the anomalies of the earths total magnetic field in the areas of Wörgl and southern Zillertal were calculated and geologically interpreted. The source rocks of the magnetic anomalies are predominantly serpentinites, locally also metagabbros and metavolcanics. In both cases there are a number of relatively small source rock bodies, which are situated at or very near the surface. The maximum depth extent of the source rocks below the surface is 1200 m for the anomaly Wörgl, and 1600 m for the anomaly southern Zillertal respectively.

In einem Nord-Süd Querschnitt durch die Ostalpen im Bereich des westlichen Tauernfensters, von den Nördlichen Kalkalpen im Norden bis zum Südrand des Tauernfensters im Süden, wurden die magnetischen Suszeptibilitäten der wichtigsten Gesteinstypen ermittelt. Es wurden etwa 4500 in situ Messungen im Gelände und Labormessungen an 167 Handstücken durchgeführt. Die statistische Verteilung und die Medianwerte der magnetischen Suszeptibilitätswerte werden für unterschiedliche Gesteinstypen verschiedener tektonischer Einheiten in der vorliegenden Arbeit präsentiert. Aus den Daten ist ersichtlich, dass eine eindeutige Unterscheidung von geologischen Großeinheiten anhand der magnetischen Suszeptibilität nicht möglich ist.

Neben den petrophysikalischen Untersuchungen wurden 3 D Modelle der magnetischen Suszeptibilität zur Erklärung zweier lokaler magnetischer Anomalien („südliches Zillertal" und „Wörgl") berechnet. Als magnetische Störkörper konnten vor allem Serpentinite, lokal auch Metagabbros und Metavulkanite eruiert werden. In beiden Fallbeispielen setzen sich die Störkörper aus einer Anzahl kleiner Körper zusammen, die direkt an oder nahe der Oberfläche auftreten. Als Maximaltiefe wurden für die Anomalie Wörgel

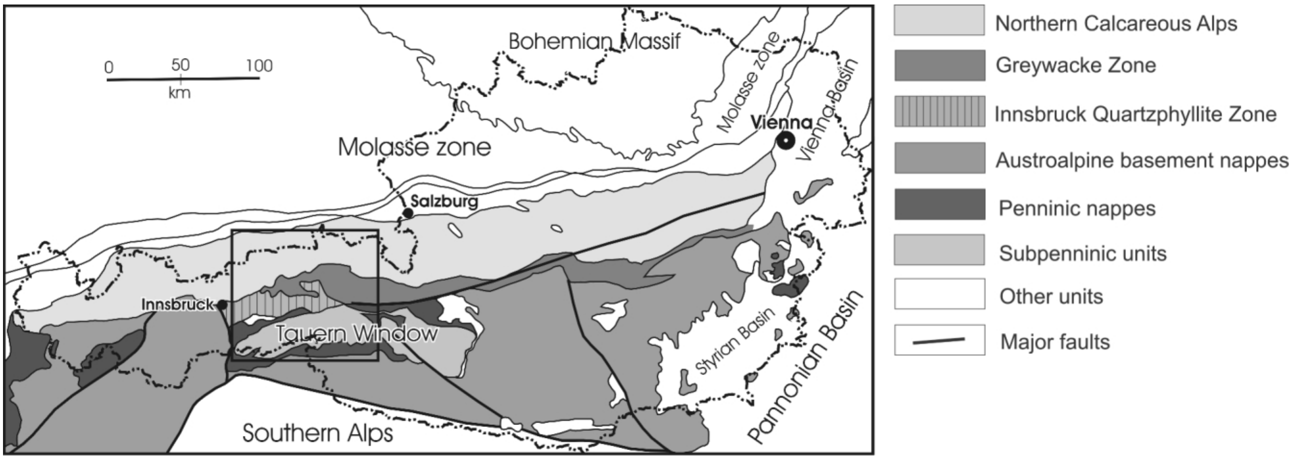

Figure 1: Simplified geological sketch map of Austria. Investigated units are shown in shades of grey, geological units beyond this study are white. The study area is marked by the rectangle, see Fig. 3 for details.

1200 m, für die Anomalie südliches Zillertal 1600 m unter der Geländeoberfläche ermittelt.

1. Introduction

In the area of the western Tauern Window the magnetic field was determined by aeromagnetic measurements by Pucher and Hahn (1979). A regional trend is attributed to the large Berchtesgaden magnetic anomaly, but there are also a number of small local anomalies. The Berchtesgaden anomaly was interpreted as a relative deep structure in the upper crust (Bleil and Pohl, 1976), but the nature of the smaller anomalies remained unclear. Preliminary interpretations of these structures were carried out by Heinz and Pestal (1988) and Heinz and Seiberl (1990), but important questions like the depth extent of the anomalies and the nature of the source rocks remained somewhat ambiguous.

In the course of investigations along the TRANSALP seismic traverse (Gebrande et al., 2006) a large quantity of petrophysical data were collected by our research group in order to support the interpretation of the structure of the upper crust, including density, velocity, conductivity, thermal conductivity, low-field magnetic susceptibility and magnetic remanence direction measurements.

The magnetic susceptibility and magnetic remanence data of these studies were used as a basis for the interpretation of the anomaly of the total magnetic field in the area of the western Tauern Window, including three-dimensional modelling of two local magnetic anomalies. The magnetic anomaly in the southern Zillertal (aeromagnetic data of Pucher and Hahn, 1979) and the anomaly near Wörgl (aeromagnetic data of Sengpiel and Keil, 1985) were chosen for further investigation.

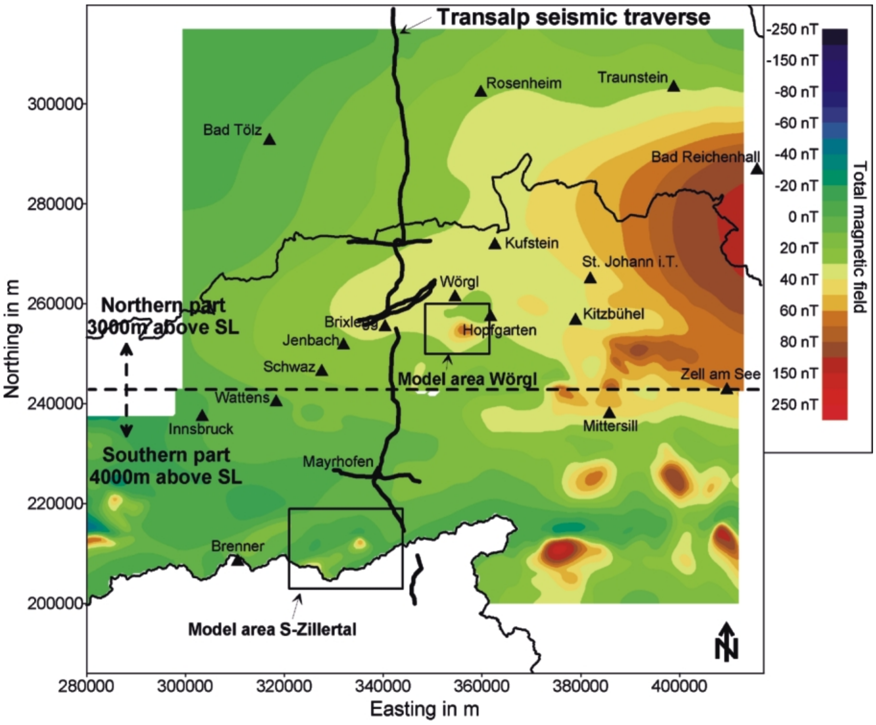

Figure 2: Anomaly of the total magnetic field measured by "Hunting Geology and Geophysics Ltd." - northern (3000 m survey altitude) and southern (4000 m survey altitude) parts. The locations of the TRANSALP seismic traverse, as well as the model areas are marked in the figure (coordinate system is Austrian Bundesmeldenetz (BMN) zones M31).

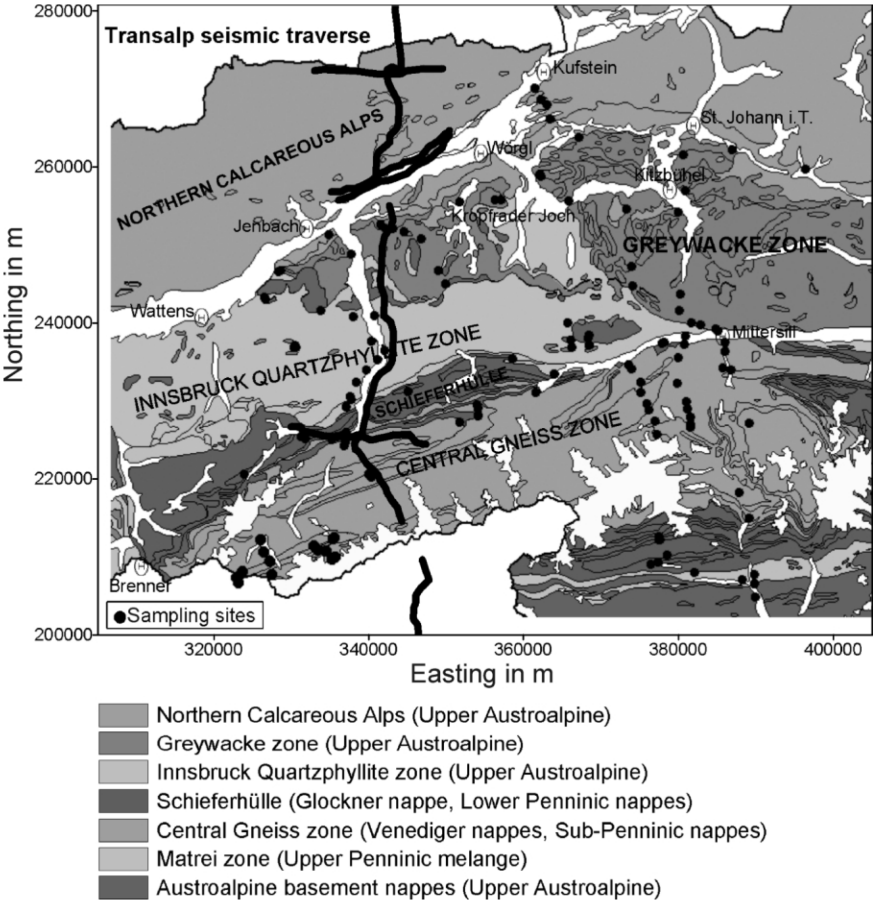

Figure 3: Geological sketch map (modified from "Metallogenetische Karte von Österreich 1 : 500000", Ebner et al., 1997) of the investigated area with the locations of sampling sites (black dots). Tectonic units according to Schmid et al. (2004) and Frisch (1979).

The primary goal was to characterize the main rock types and individual lithologic or - if possible - tectonic units by their magnetic susceptibilities. Subsequently, three-dimensional models of the magnetic properties of the rocks were established (especially concerning the shape, structure and maximal range of depth) in order to define the source of the magnetic anomalies in more detail. Finally, a geological interpretation of the geophysical results was attempted.

2. Geological setting

The study was designed to cover the major tectonic units in the area of the western Tauern Window. The deepest structural elements (Sub-Penninic and Penninic) are the Zentralgneisses with their Palaeozoic cover ("Altes Dach"), together with the Penninic metasediments of the Glockner Nappe (Frisch, 1979; Schmid et al., 2004; see Fig. 1). Concerning the tectonically higher Austroalpine units, the Innsbruck Quartzphyllite Zone (IQPZ) and the Greywacke Zone (GWZ) were investigated together with a few samples from the Northern Calcareous Alps (NCA).

3. Anomaly of the total magnetic field in the area of the western Tauern Window

Within a joint project in 1977 aeromagnetic measurements were carried out by the company "Hunting Geology and Geophysics Ltd." in southern Germany and western Austria. Because of the pronounced mountainous topography in the survey area the measurements took place at constant altitudes of 3000 m (northern part) respectively 4000 m (southern part) above mean sea level (Fig. 2). In course of the present project the results of these measurements were digitized and reprocessed for further digital processing.

4. Magnetic susceptibility investigations

4.1 Field measurements

About 4500 in-situ susceptibility measurements were undertaken covering the main lithologic units from the NCA in the north to the southern rim of the Tauern Window, near the Italian border in the south. The locations of the sampling sites are given in the geological sketch map of Fig. 3.

The in-situ measurements of the magnetic susceptibility were carried out using kappa-meters KT-5 and KT-9 of GEOFYZIKA (Brno) (sensitivity 1 x 10^{-5} SI). These instruments measure a volume susceptibility of a half space with a diameter of 5 cm, the surface layer of the rock down to the depth of 2 cm contributes about 90 % to the measured value. Taking into account

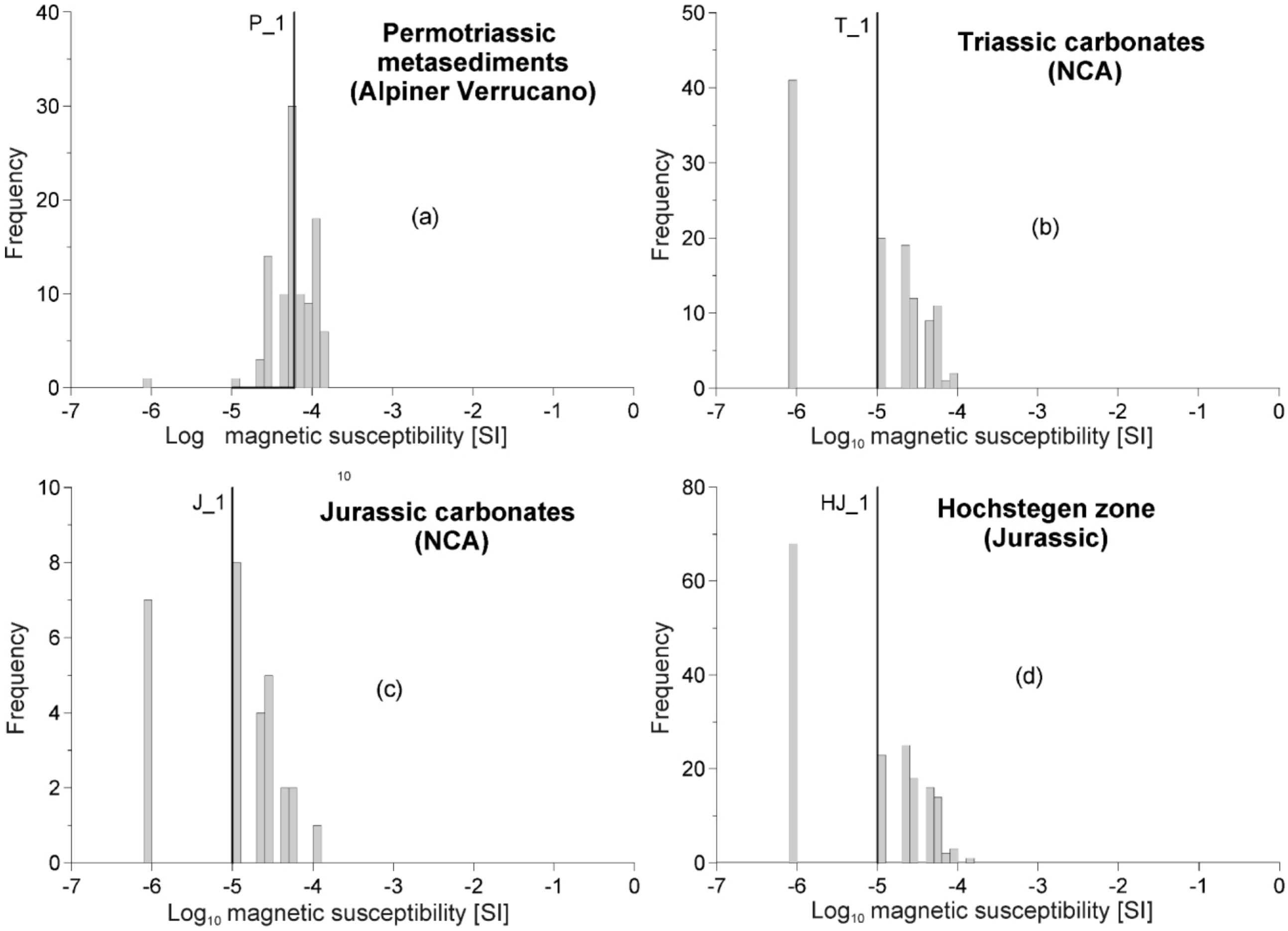

Figure 4: Distribution of the magnetic susceptibility of Permotriassic, Triassic and Jurassic rocks. (a) siliciclastic "Alpine Verrucano", NCA, (b) Triassic carbonates of the NCA, calcitic and dolomitic marbles of the Seidlwinkeltrias and dolomitic marbles of the Krimmler Triassic rocks (c) Jurassic (mainly Liassic) carbonates of the NCA, (d) Jurassic Hochstegen marble of the Venediger nappe (Mesozoic cover of the Sub-Penninic Ahorn core).

the heterogeneity in mineral content, the grain size and the fabric of the rock types investigated, each site was some square meters to some tens of square meters in size. Each site was documented by a field protocol including a sketch and a photo.

4.2 LABORATORY MEASUREMENTS.

From the 167 field specimens, cores were drilled with a diameter of 2.5 cm and cut at a length of 2.2 cm. On these samples, the low field magnetic susceptibilities were measured by using a Kappabridge of GEOFYZIKA (Brno) (sensitivity: 4 x 10^{-8} SI). The in-situ direction of the remanent magnetization of rock samples with significantly higher values of the magnetic susceptibility was measured with a three axis cryogenic magnetometer from 2G-Enterprise.

4.3 INTERPRETATION OF THE MAGNETIC SUSCEPTIBILITY DATA

The interpretation of magnetic susceptibility data had two main goals, the discrimination of lithologies and, if possible, the characterisation of different tectonic units. The distributions of magnetic susceptibility values in different tectonic units as well as in different lithologies are presented in Figures 4 to 8.

4.3.1 PERMOTRIASSIC AND JURASSIC SEDIMENTS

In Fig. 4 all carbonate rocks from the NCA, the Tauern Window, as well as the Hochstegen zone and Permotriassic siliciclastic metasediments north and south of the Tauern Window are shown. They were grouped together because of their very low susceptibilities.

Pure limestones and marbles show clear diamagnetic behaviour, whereas the other samples show paramagnetic susceptibilities in the range between 10^{-5} and $3x10^{-4}$ SI. The variation of paramagnetic susceptibility clearly depends on the varying content of mica in the carbonates, locally 40% in some samples of the IQPZ (Jakits, 1991). Since the susceptibilities of diamagnetic rocks are negative, these field measurements are not represented in the diagrams.

In Figure 4a data of Permomesozoic schists from the substratum of the NCA, as well as from the Matreier Schuppenzone, a tectonic melange of Penninic and Austroalpine units at the boundary of the Tauern Window, are combined.

4.3.2 GREYWACKE ZONE – WILDSCHÖNAU SLATES AND METABASIC ROCKS

The Palaeozoic Greywacke zone shows the largest variability of magnetic susceptibility (Fig. 5). It includes siliciclastic rocks

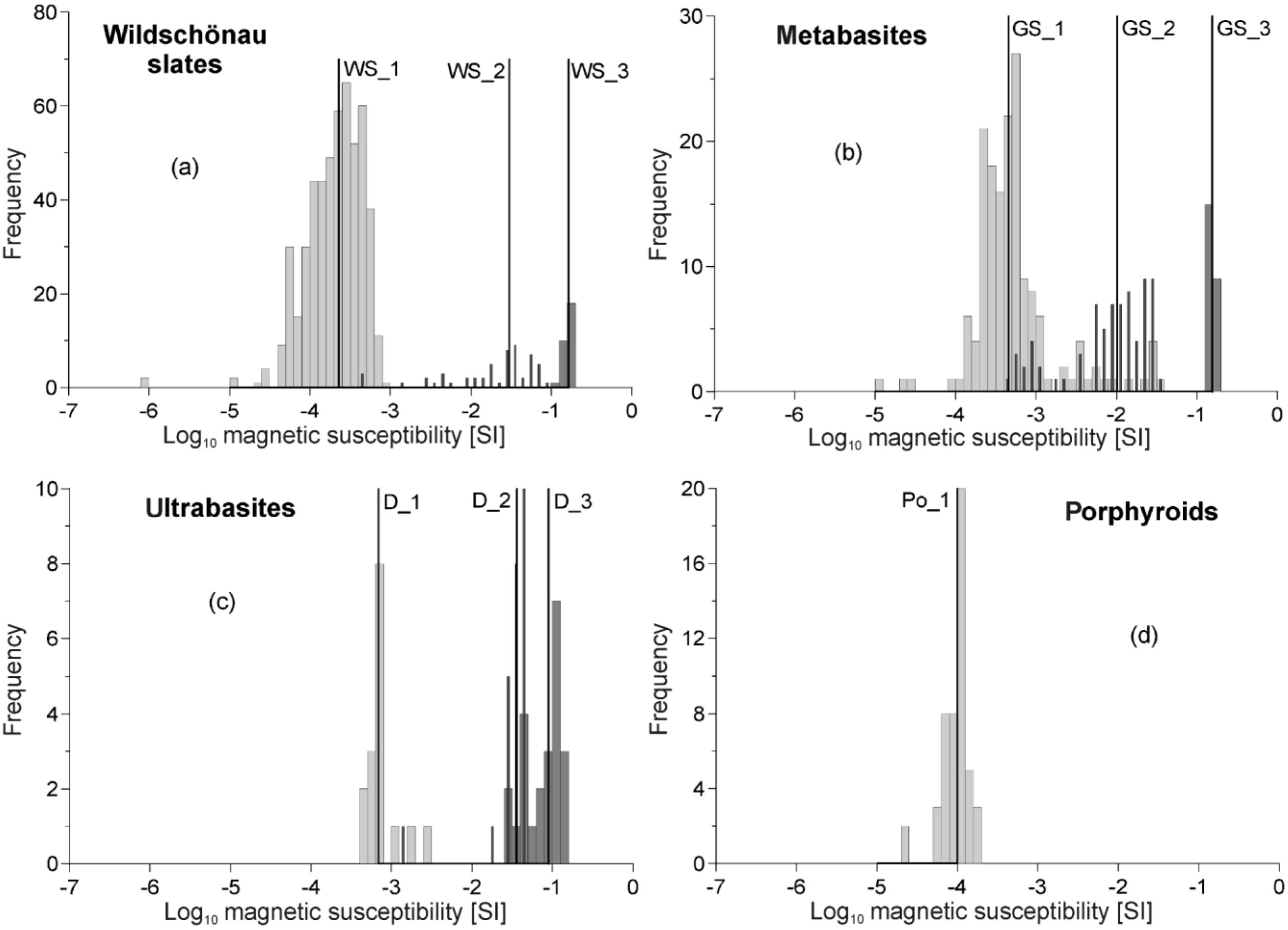

FIGURE 5: Distribution of the magnetic susceptibility of the Greywacke zone (GWZ). (a) Wildschönau Slates (WS 1…slates, WS 2…tuffitic slates, WS 3…greenschists), (b) metabasites (GS 1…greenschists, GS 2…metagabbros and diabases, GS 3…diabases), (c) ultrabasites from the Marbachjoch (D 1…diabases, D 2 and D 3…serpentinites), (d) Blasseneck Porphyroid (acidic porphyry).

(shale, sandstone, conglomerate), metabasites (amphibole schist, greenschist, metadiabase, metagabbro) and serpentinized ultramafites as well as carbonates. From a magnetic point of view the types of opaque phases (determined by reflected light microscopy and Curie temperature determination) are strongly varying. They are of major interest since they are dominated by magnetite and titanomagnetite and include minor amounts of pyrrhotite. However, pyrrhotite is of major importance in the large anomaly in the area of Pass Thurn (Uttendorfer Schuppenzone).

The majority of rock types are clearly paramagnetic. Only rock types rich in iron oxide and/or iron sulphide are strongly ferrimagnetic. The samples dominated by magnetite and/or pyrrhotite are in the range of $5x10^{-3}$ to $60x10^{-3}$ SI. The transition between ferrimagnetic to paramagnetic susceptibilities is dominated by rock forming minerals like chlorite, muscovite and amphibole.

Figure 5a shows the magnetic susceptibility values of Wildschönau Slates, with the maximum “WS 1” representing pure slates, whereas the maxima “WS 2” and “WS 3” represent layers of intercalated tuffitic slates and greenschists, respectively. Figure 5b shows generally higher values for the massive metabasites (up to several hundred meters thick), with a maximum for greenschists (“GS 1”), which is still similar to that of the pure schists, a maximum of metagabbros (“GS 2”) and one of magnetite-rich greenschists (“GS 3”). Basic and ultrabasic rocks are represented in Figure 5c (“D 1” mostly diabases, “D 2” and “D 3” serpentinites), whereas the magnetic susceptibility of the Blasseneck Porhyroid, an acidic porphyry, is rather low (Fig. 5d).

4.3.3 Innsbruck Quartzphyllite zone

The IQPZ is interpreted as part of the Upper Austroalpine basement nappes by Schmid et al. (2004). This unit comprises sericite phyllites rich in quartz and contains different amounts of chlorite, sericite, albite, rutile, clinozoisite and biotite. There are also frequent intercalations of chloritic schists, carbonates, greenschists (metabasites) and porphyries. In some smaller occurrences, parageneses of siderite, ankerite, chalcopyrite, pyrite, fahlore and cobaltine can be found. Figure 6a clearly demonstrates the predominant unimodality of the magnetic susceptibility distribution. Maximum “IQP 1” marks quartzphyllites, “IQP 2” is formed by an iron mineralization, and “IQP 3” represents metabasites (greenschists). Marbles wihin the IQPZ were treated separately, but the distribution of magnetic susceptibilities is very similar. The Kellerjoch Gneiss (Fig. 6c), an intensively mylonitizised granitc gneiss, and the Steinkogelschiefer (Fig. 6d), a coarse grained micaschist,

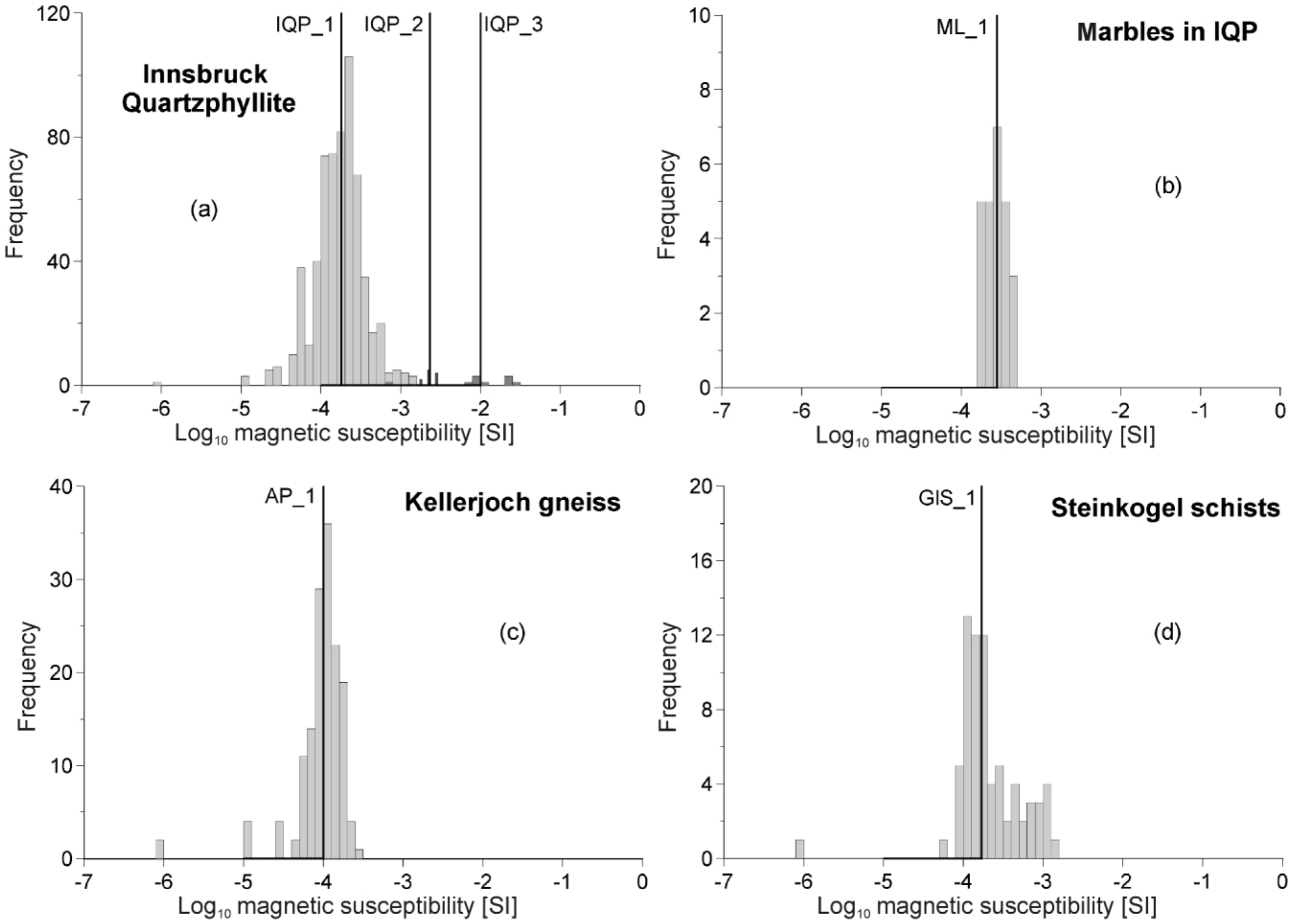

FIGURE 6: Distribution of the magnetic susceptibility of the IQPZ. (a) (IQP 1…phyllites and a few greenschists, IQP 2…Fe-mineralization, IQP 3…metabasites), (b) marbles in quartzphyllites, (c) Kellerjoch gneiss (mylonitic granitic gneisses), (d) Steinkogel schists (micaschists).

have been recently interpreted as belonging to the stratigraphic sequence of the IQPZ (Heinisch and Zadow, 1990).

4.3.4 SCHIEFERHÜLLE (GLOCKNER NAPPE)

Penninic rocks were intensively sampled in the northern and southern part of the Tauern Window. The sedimentary succession contains mainly Bündnerschiefer (calcareous schists and calcareous slates, black slates) and intercalated metabasites of different metamorphic grade (greenschist to amphibolite to eclogit facies).

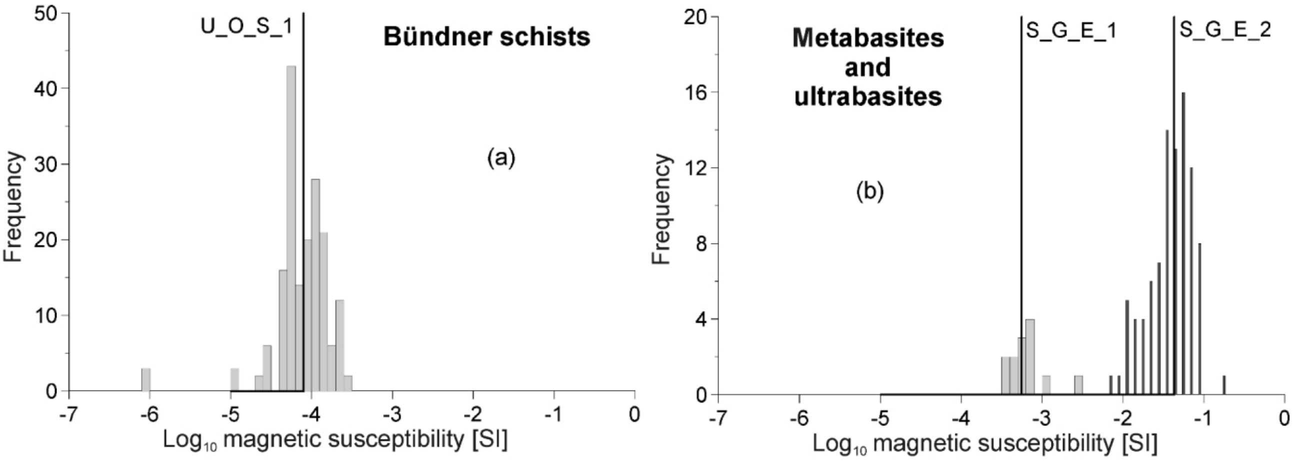

FIGURE 7: Distribution of the magnetic susceptibility of Penninic nappes (Glockner nappe). (a) Bündnerschiefer (calcareous schists and micaschists), (b) metabasites and ultrabasites (SGE 1…eclogites, SGE 2…metagabbros and serpentinites).

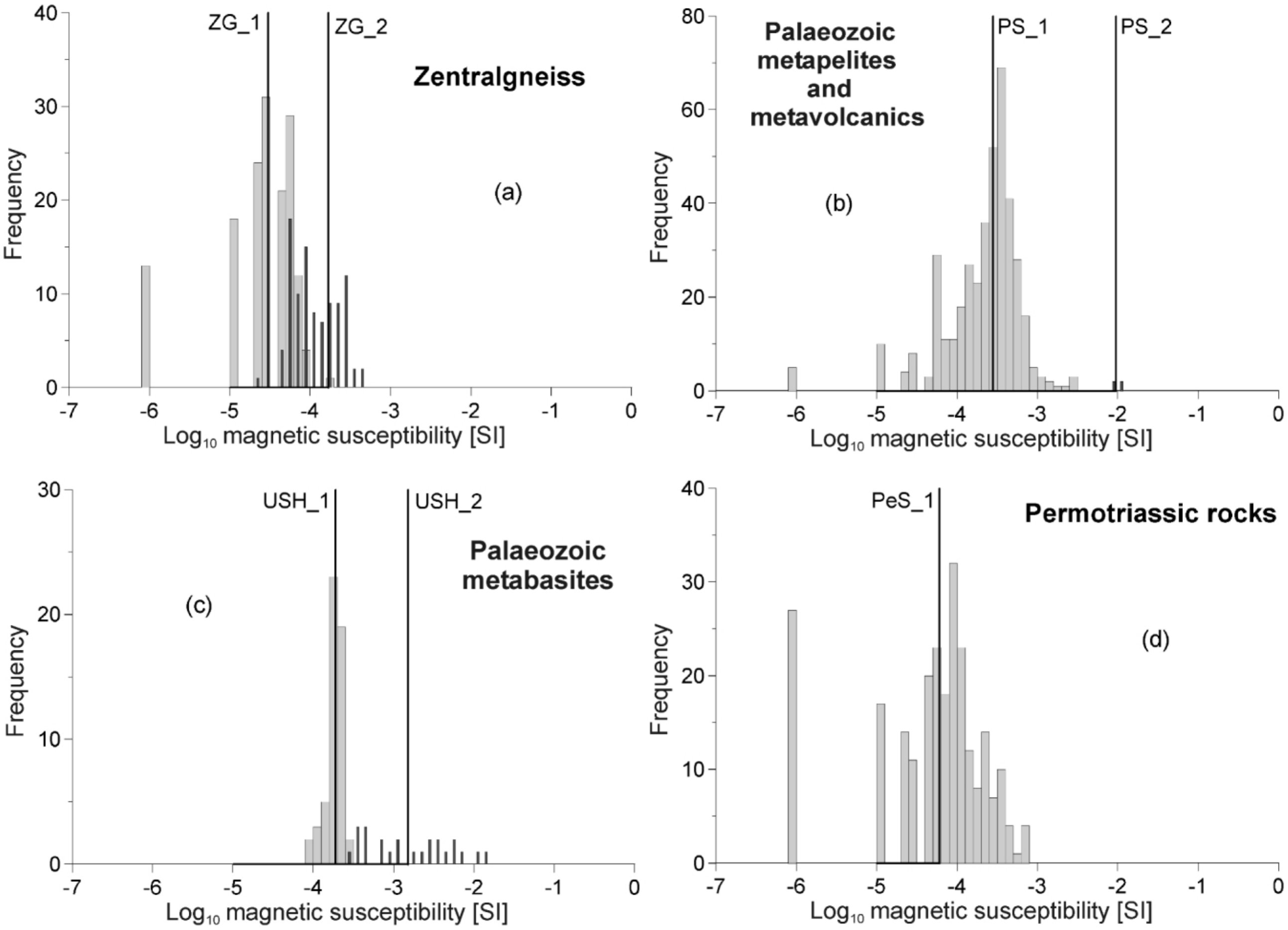

FIGURE 8: Distribution of the magnetic susceptibility of Subpenninic nappes (Zentralgneisses, Venediger nappe). (a) Zentralgneiss, (b) Paleozoic metapelites and metavolcanics of the Central Tauern Window (PS 1…different lithologies like amphibolitic and porphyric schists, amphibolites and paragneisses, PS 2…Fe-mineralization), (c) Paleozoic metabasites from the Western Tauern Window (USH 1…amphibolitic shists, USH 2…porphyric shists), (d) Permotriassic rocks.

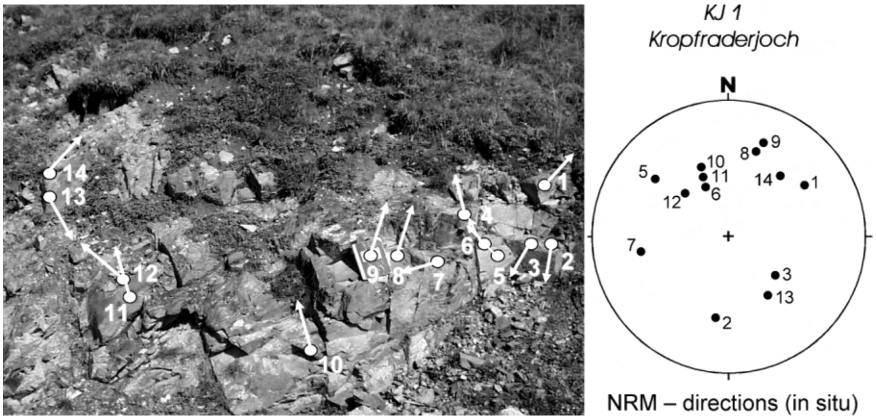

Figure 9: Directions of the natural remanent magnetization (NRM) at the Kropfrader Joch.

The metasediments show a unimodal distribution of susceptibilities in the higher paramagnetic range (Fig.7a). In some pure quartzites, a diamagnetic behaviour can be seen. High susceptibility rocks (Figure 7b) comprise metavolcanites, greenschists, eclogites, amphibolites, serpentinites and metadiabases. The very high ferrimagnetic susceptibilities (5 – 5x10^{-3} SI) are related to magnetite content. The maximum “SGE 1” shows susceptibility values of eclogites, while “SGE 2” contains data from serpentinites and metagabbros.

4.3.5 Central Gneiss Zone

Samples of this Sub-Penninic units were taken from Zentralgneisses (Granatspitz core, Habach unit, Tuxer core and Ahorn core), from Palaeozoic metamorphic rocks and from Permomesozoic metasediments. Granites and gneisses of the Central Gneiss Zone show a distribution of susceptibilities in the higher paramagnetic field (Fig.8a). Local zones extremely rich in quartz are diamagnetic. Figure 8b comprises rocks of the Venediger nappe system (Habach Group, Riffl nappes). The distribution of susceptibilities is unimodal, maximum “PS 1” is made up from a variety of rock types (porphyric schists, amphibolites, paragneisses, amphibole schists etc.). The small maximum “PS 2” is a result of a Fe-mineralization. Figure 8c shows data of Palaeozoic rocks from the Schönach syncline (“USH 1” amphibolitic schist, “USH 2” porphyric schist). Data from the siliciclastic Permoskythian rocks of the Wustkogelserie and from the Krimmler Triassic are combined in Figure 8d.

4.4 Determination of the natural remanent magnetization NRM

Besides the induced magnetization, the remanent magnetization can be of great importance. Since rocks with very high susceptibilities were identified, oriented samples were taken to measure the in situ direction of the remanence.

Samples from one site (Fig. 9) were taken as oriented drillcores. Thermomagnetic experiments established magnetite as the main source of the magnetization, as already seen in the microscopic analysis. The direction of the NRM is more or less random (see stereogram in Fig. 9). Since local tectonism can be excluded as a reason for this distribution, weathering and/or lightning strikes are the most probable causes. A similar example for scatter of the direction of NRM by lightninginduced IRM (isothermal remanent magnetization) is given by Butler (1992). The assumption of a remanent magnetization through lightning strikes is supported by numerous burn marks on trees in the surrounding area. The very limited extent of these highly magnetized areas can also be seen in the aeromagnetic anomaly of Wörgl. Besides a dominating bipolar anomaly in the orientation of the present earth field, caused by the induced magnetization, smaller remanence anomalies are present (Fig. 15).

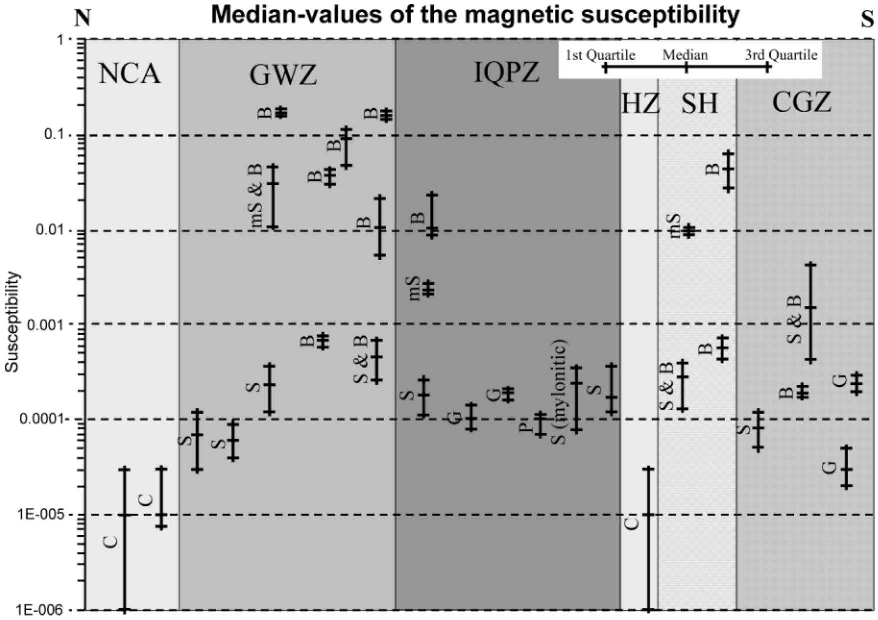

Figure 10: Comparison of the magnetic susceptibility: NCA – Northern Calcareous Alps, GWZ – Greywacke zone, IQPZ – Innsbruck Quartzphyllite zone, HZ – Hochstegen zone, SH – Schieferhülle, CGZ – Central Gneiss zone. Further abbreviations are: C – carbonate rock, S – metasiliciclastic rock, mS – mineralized metasiliciclastic rock, B – metabasic and ultrabasic rocks, G – gneiss, P – quartzporphyry.

4.5 Conclusion of the rock magnetic investigations.

The results suggest that within the study area an unambiguous discrimination of different lithologic and tectonic units based on their magnetic properties alone is not possible. However, these data provide a good base for 3D modelling, because they constrain the theoretically possible scatter of magnetic susceptibility values (e.g. data from literature) to the actually occurring range of values.

5. MODELLING OF THE TOTAL MAGNETIC FIELD

Since the petrophysical investigations in the survey area has shown no relevant remanent magnetisation, respectively no remanent magnetisation with representative magnetisation directions, remanent magnetisation was not included in the 3D modelling.

For the 3D modelling, the mapped geological situation was considered as detailed as possible. Some preparatory work was necessary before the actual model computation could be carried out. These includes: (1) determination of petrophysical parameters, (2) compilation of a simplified geological map, with regard to the magnetic susceptibilities.

In the first step of the 3D modelling the geometry of the model (position, extension) was defined. The model geometry was in accordance with the size and shape of the measured magnetic anomaly and the geological model assumptions.

Next the model body was divided into a number of cubes of equal size. Based on the simplified geological map and the determined petrophysical properties of the present rocks, an individual susceptibility value (the most feasible value according to known or assumed lithology) and a remanent magnetization (amount and direction) was assigned to each one of these cubes. Due to the results of the petrophysical investigations the amount of the remanent magnetization was set zero for all cubes. In addition the amount and direction of the corresponding geomagnetic reference field for the time period of the magnetic survey was calculated (according to the International Geomagnetic Reference Field - IGRF) for the position of each cube.

In the last step of the preparation of a start model the topography of the survey area was considered (for all cubes with centres above ground the susceptibility values were put on zero). According to Militzer and Weber (1984) the anomaly of the total magnetic field $\delta T(x,y,z)$ for each of the cubes of this model body can be calculated. Based on this initial model the susceptibility values of the cubes were changed manually in such a way that the calculated anomaly of the total magnetic field and the measured anomaly agree as well as possible (for details see unpublished report Ahl et al., 2002).

5.1 MODEL AREA SOUTHERN ZILLERTAL (S-ZILLERTAL)

One area of detailed investigation of magnetic anomalies was located is in the southern Zillertal, NE of the Pfitscher Joch, around Ochsner and Rotkopf (Fig. 11 A). The area is part of the 1977 aeromagnetic survey of western Austria and southern Germany. The flight level in this sector was 4000 m above sea level. The geological maps of Christa (1931), Lammerer (1975, 1986) and Oehlke et al. (1993) were taken as basis for the geological model and interpretation.

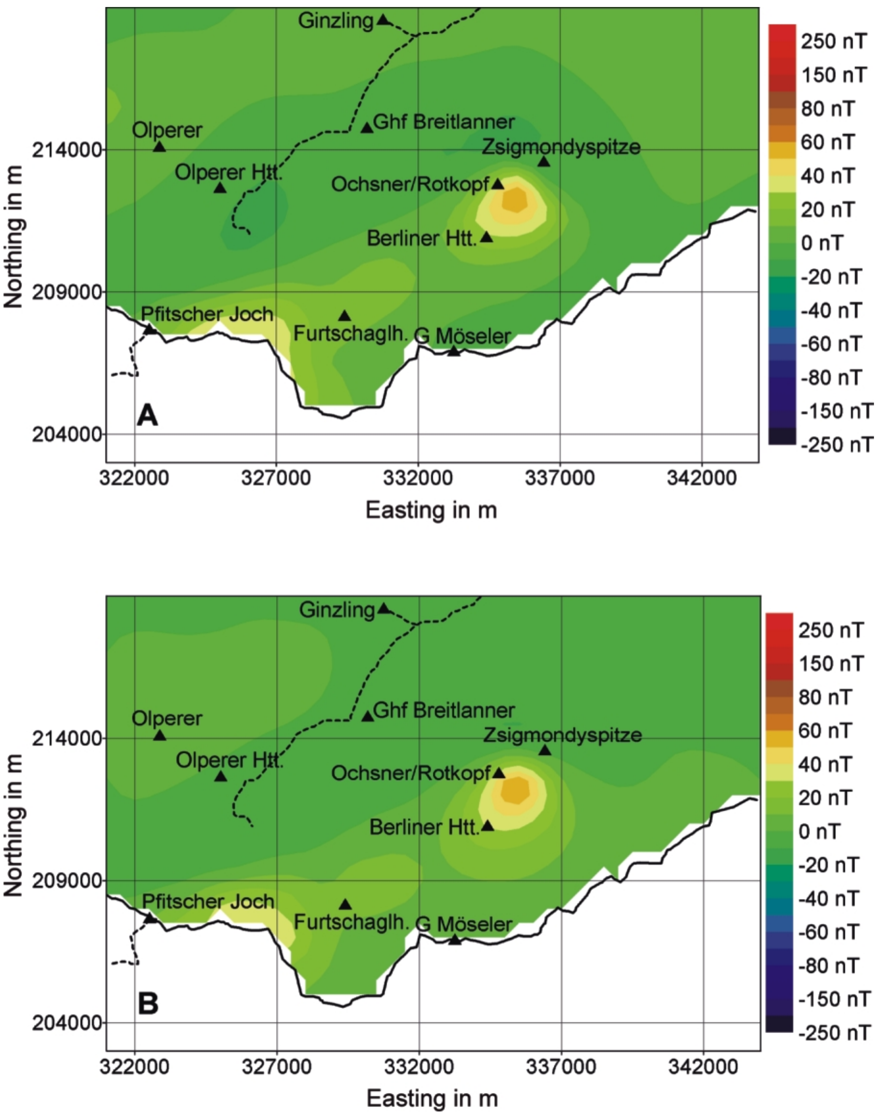

FIGURE 11: Magnetic anomaly S-Zillertal: (A) Measured anomaly of the total magnetic field, (B) Calculated anomaly of the total magnetic field. (Roads, some geographic points as well as the border between Austria and Italy are shown, coordinate system is Austrian BMN zones M31).

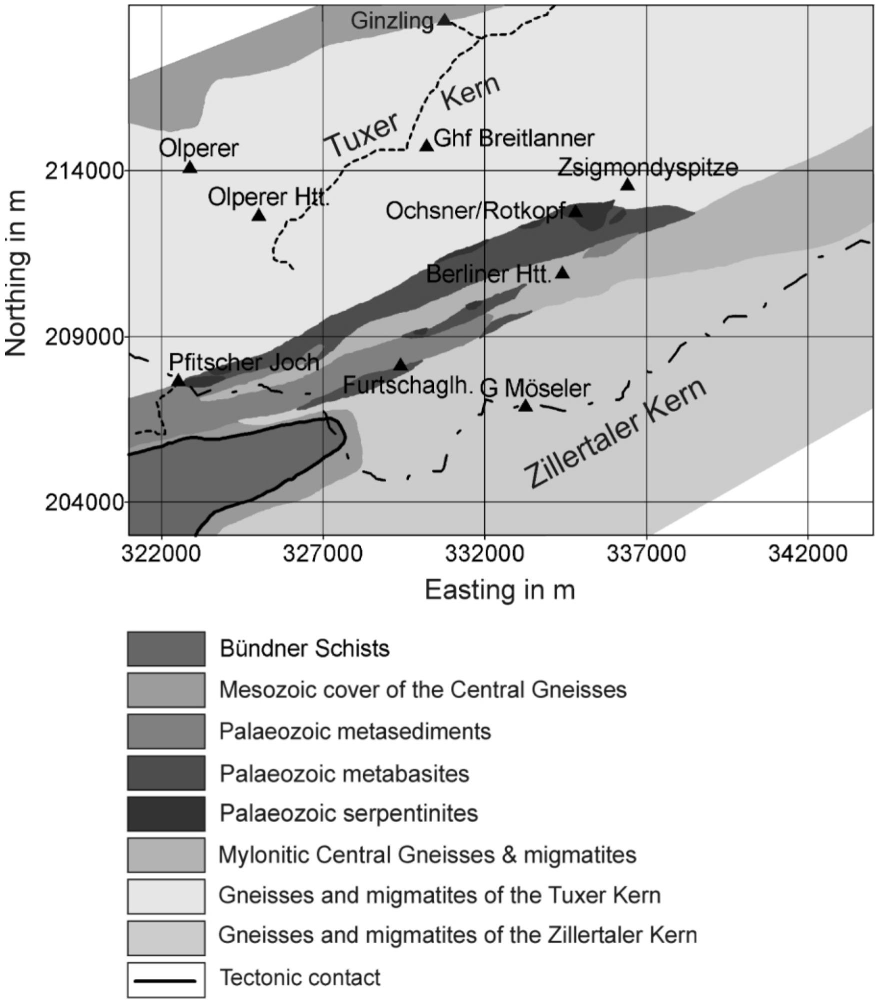

FIGURE 12: Geological sketch map of the model area S-Zillertal.

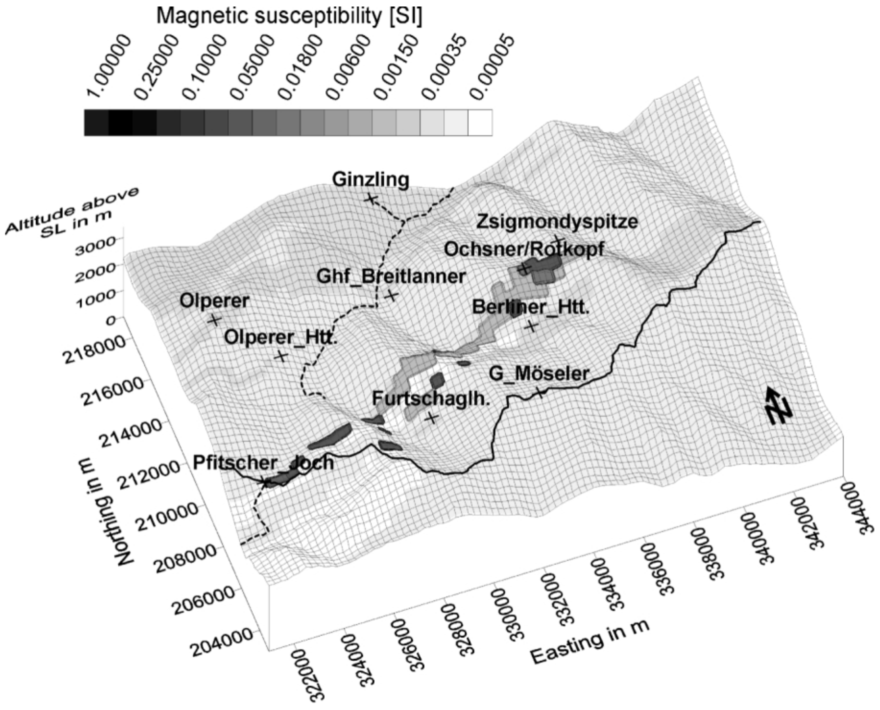

FIGURE 13: Model area S-Zillertal: modelled magnetic susceptibility at the surface. (Roads, some geographic points as well as the border between Austria and Italy are shown, coordinate system is Austrian BMN zones M31).

5.1.1 GEOLOGICAL SETTING

The survey area is situated in the Penninic of the SW Tauern Window. The main lithologies are late- to post-Hercynian granitic, granodioritic and tonalitic gneisses (Zentralgneiss) as well as Palaeozoic and Mesozoic metasediments and metavolcanics. Multiphase Alpidic deformation led to the formation of large gneiss-domes overlain by several km thick, steeply dipping zones of Palaeozoic metamorphic rocks.

The northern part of the survey area is formed by the Tuxer core (gneiss-dome). South of it, there is the Greiner Synform, a WSW trending vertically dipping zone of Palaeozoic schists and metavolcanics. The main rock types are hornblende gneiss, hornblende-biotite gneiss, two-mica gneiss, graphitic biotite schist, migmatite, amphibolites and serpentinite (Lammerer, 1986). The complex internal structure shows two recumbent synclines (Greiner and Schönbichler Synform) which are separated by a strongly tectonised migmatitic antiform (Talggenkopf Antiform) (Lammerer, 1988). To the south, the broad anticline of the Zillertaler core (gneiss dome) follows. In the SW of the survey area autochthonous Mesozoic (Hochstegen Formation), a complex zone of imbricated rocks (Eisbrugg-Lamellen) and the overthrust Bündner schists of the Glockner nappe are found above the Zillertaler core (Oehlke et al., 1993). A reconstruction of the tectonic evolution of the complex structure can be found in Lammerer and Weger (1998).

5.1.2 GEOPHYSICAL MODELLING

The 3D model used for this model area has an east-west extension of 22.8 km (easting of 321000 to 343800 m), a south-north extension of 16 km (northing of 203000 to 219000 m) and a depth extension of 14 km (-10000 to 4000 m above mean sea level. The modelled volume was divided into 79,800 cubes with a side length of 400 metres.

Being based on this starting model the susceptibility distribution in the subsurface was modelled. With this model, the standard deviation of the mean value of the differences between measured and calculated anomaly of the total magnetic field should be minimized. The result of this modelling is represented in Fig. 13. A 3D model of the magnetic anomalies S-Zillertal is shown in Figure 14. Applying the geophysical model shown in Fig. 13, the shape of the anomaly of the total magnetic field can be calculated (Fig. 11 B).

5.1.3 Structural interpretation

The rocks with the strongest magnetization in the survey area are the serpentinites. The metabasites (amphibolites, hornblende schists) of the Greiner syncline mostly show only slightly enhanced magnetisation. However, in the area WNW of the Pfitscher Joch, they do cause a remarkable anomaly. The metabasites of the Bündner schist show no magnetic significance in this area.

The biggest source body is the serpentinite on the summits of Ochsner and Rotkopf, with a size and thickness of about 1 km. The magnetic model shows that this serpentinite body is oblong, steeply dipping and slightly thinning to the SE. It can be traced for another 1.5 km below the migmatites, until it eventually terminates below the Mörchnerkar, about 1 km below the surface. The maximum depth of the magnetic source rocks below the surface is 1600 m.

Another large source body is proven to the SW of the last one, below the Schwarzensteinalm, N of the Berliner Hütte. The magnetic modelling shows, that the top of this source body, which is probably also a serpentinite, cannot be deeper than 400 m below the surface. Its extension is at least 800 x 400 x 800 m, and it seems to be an irregularly shaped oblong body, and also dipping to the SE.

Because of their size and their dip oblique to the regional trend of the Greiner and Schönbichl synclines, the tectonic position of this two source bodies (serpentinites) within the internal structure of the synclines is not evident from modelling. For geological reasons it seems most probable, that they are connected with metabasites at the edges of the synclines.

Along the northern border of the Greiner syncline a chain of small serpentinite lenses has been mapped. However, because of their small size, their influence on the magnetic pattern is insignificant. Only one source body, which is situated at a maximum depth of 400 m below the surface, in the area of the NE edge of the Große Greiner, causes a significant anomaly.

A long magnetic anomaly can be traced from ESE of the Pfitscher Joch (the southern end of the aeromagnetic survey area) to ENE for about 10 km. This anomaly may be caused by rocks of varying lithology. Serpentinite bodies at the Pfitscher Joch are associated by amphibolites and hornblende gneisses to the NE. From the magnetic model it is evident, that the source rocks of the magnetic anomaly are not far below the surface, i.e., less than the size of a cube in the model, which is 400 m.

Several small bodies of serpentinite in a zone of amphibolites at the northern edge of the Schönbichl syncline cause small local anomalies near the surface. One distinct major body E of the Grießscharte (WSW Furtschagelhaus) is located at or very near the surface, but is completely covered by glacial detritus. This source rock (serpentinite ?) seems to be part of an amphibolite-rich zone at the southern edge of the Schönbichl syncline.

5.2 Model area Wörgl

For the model area around Wörgl, additional aeromagnetic (helicopter in this case) results were available. These measurements of the survey area Wörgl (see Fig. 15) were carried out by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, Hannover) in August and September 1980. Due to the topographical measured survey (small and almost constant distance of the sensor to the ground) and to the small line spacing these data show a high spatial resolution. For this reasons these data were used for the 3D modelling of this model area.

The target of this local study was the distinct magnetic anomaly S of Wörgl, in the area of the Kropfrader Joch/Marbachjoch. Fig. 15a shows the distribution of the anomaly of the total magnetic field in this area. As a basis for the simplified geological map of the magnetic model the unpublished geological map „Geologische Karte des Gebietes zwischen Zillertal und Brixental 1 : 25.000“ (Alber et al., 1984) was used.

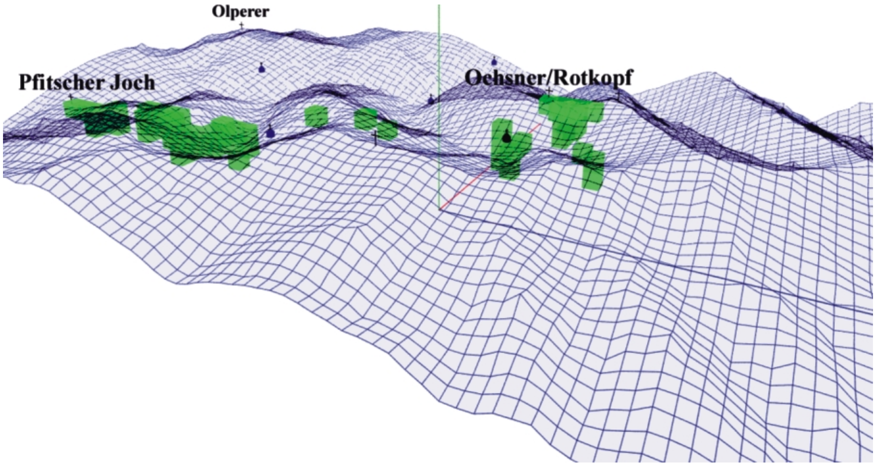

Figure 14: 3D model of the magnetic anomalies S-Zillertal. The cubes of the model (400 x 400 x 400 m) are represented in green. The thin red bar in the center of the figure points to the north, the blue bar to the east.

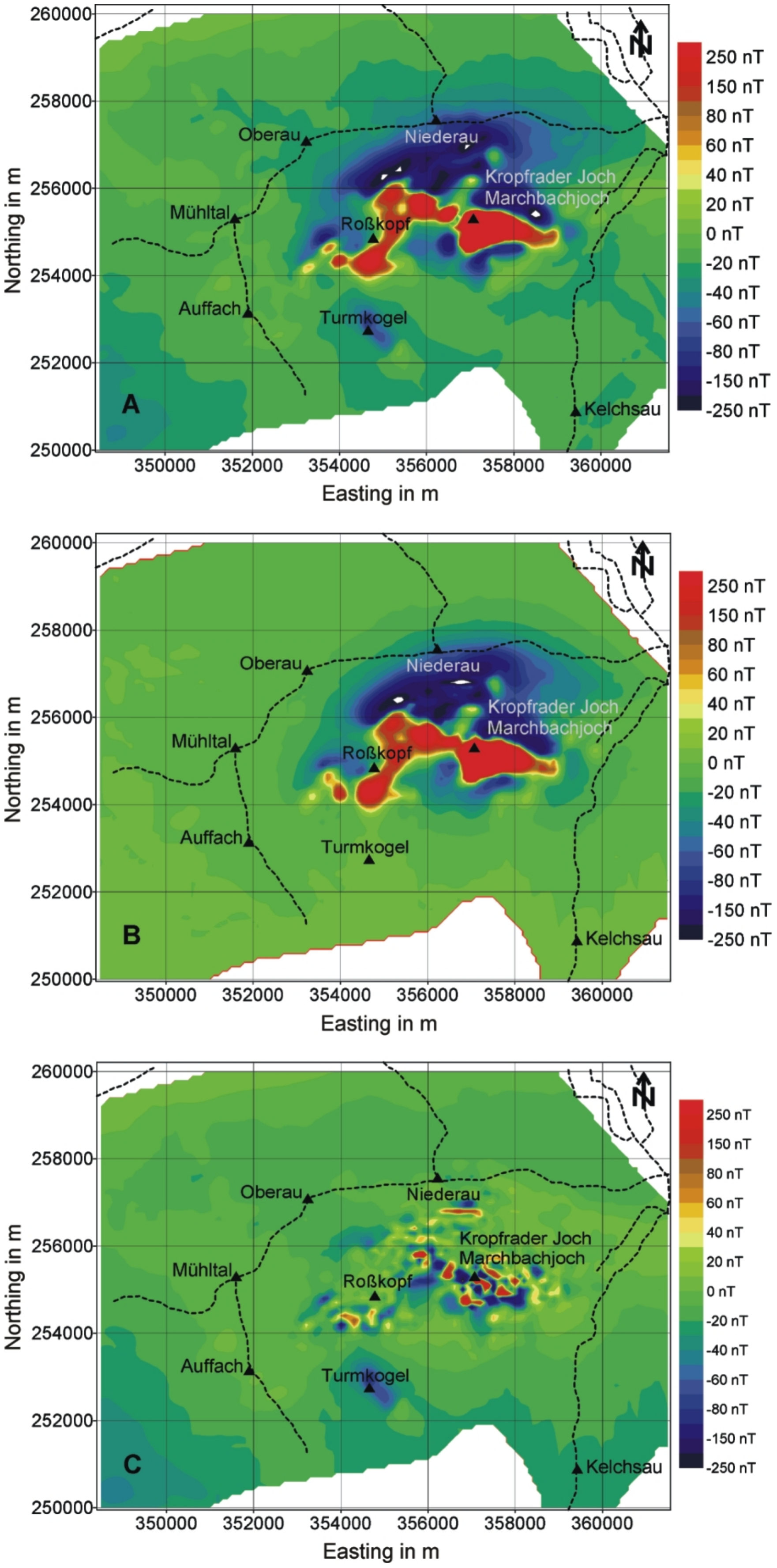

Figure 15: Magnetic anomaly Wörgl: (A) Measured anomaly of the total magnetic field, (B) Calculated anomaly of the total magnetic field, (C) Difference between measured and calculated anomalies. (Roads and some geographic points are shown, coordinate system is Austrian BMN zones M31).

5.2.1 GEOLOGICAL SETTING

The model area comprises parts of several tectonic units that were imbricated during Alpine orogeny, the NCA, the GWZ and the IQPZ. The lowest unit, the IQPZ, crops out in a tectonic half window (half window of Kelchsau) beneath the GWZ. In this area it is composed predominantly of siliciclastic metasediments and intercalated mafic metavolcanics of Early Ordovician age (Haditsch and Mostler, 1982; Reitz and Höll, 1990).

Local tectonic complications at the thrust plane and local slices of Kellerjoch Gneiss between the IQPZ and the GWZ are irrelevant for the magnetic investigations because of the low magnetic susceptibilitiy contrasts between those rocks. The ovelying GWZ is represented by the Alpbach unit, the lowest of the subunits of the GWZ (Mostler, 1974). It shows similar to the area of the IQPZ, lithologies comprising mostly siliciclastic metasediments (Wildschönau schists) and intercalated basic metavolcanics, likewise of Early to Middle Ordovician age (Reitz and Höll, 1991; Loth et al., 2001; Schauder, 2002). Prominent features are serpentinized ultrabasites and metagabbros at the Kropfrader Joch/Marbachjoch, which are interpreted as ultramafic cumulates (Davogg, 1981; Pogoriutschnigg, 1997). In the N and NE of the survey area, the basal series (mostly siliciclastic Alpine Verrucano and Buntsandstein Formation, Permian and Lower Triassic) of the NCA are in sedimentary contact with the GWZ, but this contact is complicated by faults.

5.2.2 GEOPHYSICAL MODEL

The 3D model used for this area has an east-west extension of 13 km (easting of 348500 to 361500 m), a south-north extension of 10 km (northing of 250000 to 260000 m) and a depth extension of 5 km (-3000 to 2000 m above mean sea level). The modelled volume was divided into 81,250 cubes with a side length of 200 metres.

Being based on this starting model, the susceptibility distribution in the subsurface was modelled. With this modelling the standard deviation of the mean value of the differences between measured and calculated anomalies of the total magnetic field should be minimized. The result of this modelling is represented in Fig. 17 and Fig. 18.

Assuming the determined geophysical model the anomaly of the total magnetic field represented in Fig. 17 can be calculated (Fig. 15 B). In addition the difference between the measured and the calculated anomaly of the total magnetic field is shown in Fig. 15 C.

The determined 3D model is not able to explain strong short-wave anomalies which result from near-surface and partly strong remanent magnetization, because they are much too small to be considered adequately in a model with cube size of 200 m. These remaining anomalies can especially be observed for the area west of the locality “Roßkopf” (Fig 17) and the area of the Kropfrader Joch. Such remanent magnetisations were also observed by petrophysical investigations (Fig. 9). An evaluation of these anomalies might be achieved only by a reduction of the cube size in the model. However, the number of cubes and the connected expenditure would ascend tremendous.

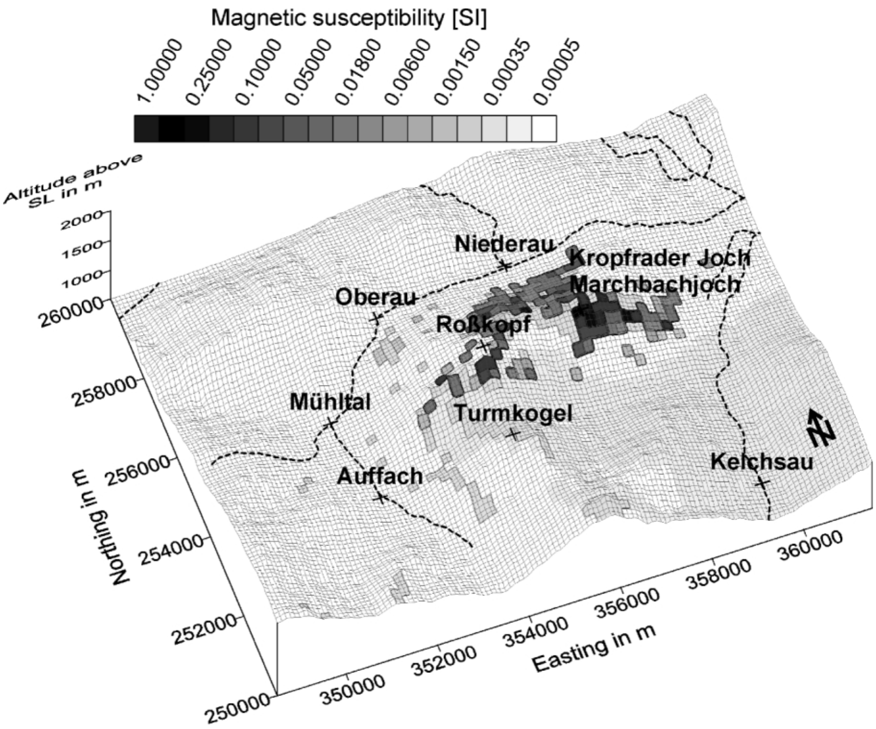

FIGURE 17: Model area Wörgl: modelled magnetic susceptibility at the surface. (Roads and some geographic points are shown, coordinate system is Austrian BMN zones M31).

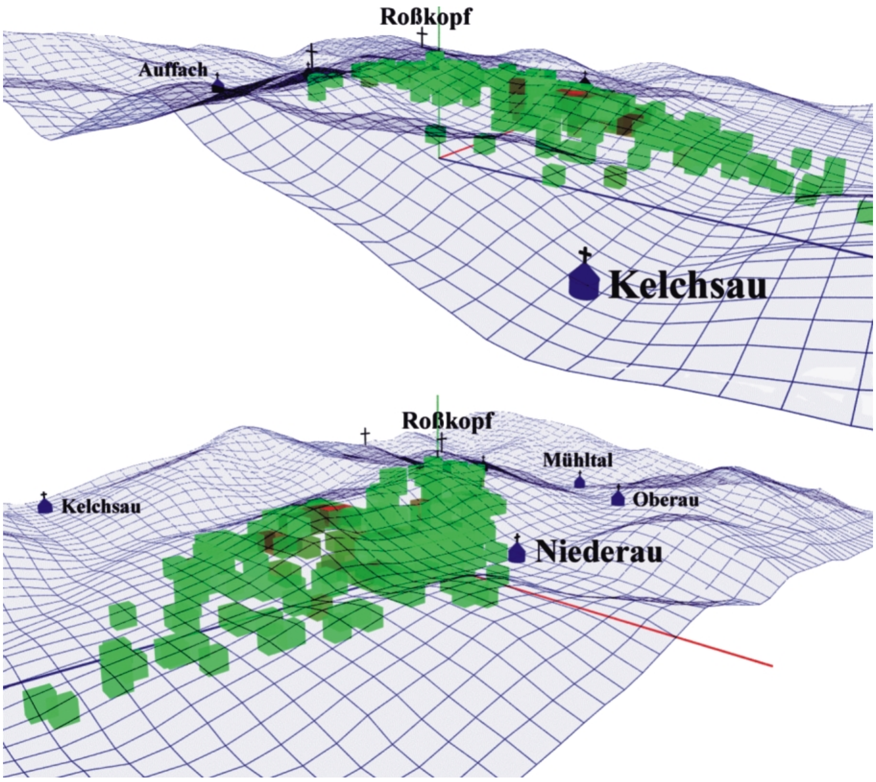

FIGURE 18: 3D model of the magnetic anomalies in Wörgl area. The cubes of the model (200 x 200 x 200 m) are shown as green cubes. The thin red bar in the center of the figure points to the north, the blue bar to the east.

5.2.3 STRUCTURAL INTERPRETATION

The area of high and very high magnetic susceptibilities is confined more or less to the ultrabasites and serpentinites of the Kropfrader Joch (= Marbachjoch). The 3D model shows, that the confinement of the calculated source bodies can be traced to a depth of maximally 1200 m below the surface and is dipping steeply to the NW and relatively flat to N and NE. The largest thickness of the source rocks is below Roßkopf and Niederau with about 800 m. Towards the E, they are thinning considerably to no more than 100 to 200 m. The whole magnetic source body seems to form a cupola- or tunnel-like structure with an axis dipping about 20° to ENE. By the magnetic model this rocks can be traced below the overlying Buntsandstein about 4 km to the NE, below the Brixental.

The model clearly demonstrates that the magnetic anomaly is not caused by a single source rock body, but by a number of separated ones. This corresponds well with the interpretation as a wildflysch (Schauder, 2002). The model also corresponds very well with the results of recent geological mapping by Heinisch (2005) describing the structure of the ultrabasites as a steep dipping U-shaped fold that is open to the south. The southernmost part of the anomaly is caused by magnetite-rich greenschists (albite-chlorite-carbonate schist), which clearly belongs to the IQPZ.

6. CONCLUSIONS

The in situ susceptibility measurements and the lab measurements of 167 specimens characterise the magnetic properties of the whole range of important rock types of the TRANSALP area. Most of the lithologies fall into the paramagnetic field. Clearly ferrimagnetic rock types contain noticeable amounts of magnetite, sometimes also pyrrhotite.

An unambiguous discrimination of the different tectonic and lithologic units along the TRANSALP profile based on their magnetic properties is not possible. The magnetic properties of different lithologies are mainly controlled by their composition. Different degrees of metamorphism or varying tectonism show no significant influence on the values of magnetic susceptibility. For pyrrhotite-rich rocks of the Uttendorfer Schuppenzone the contact with Alpidic metamorphic fluids may have come in contact, but this has still to be proofed.

The remanent magnetization in the survey area is mostly negligibly small. In areas with more prominent remanent magnetization of the rocks no unambiguous direction of magnetization can be found. In some areas there is an extreme change of the directions of the remanent magnetization within very short distance (Fig. 9).

The regional trend of the magnetic field strength in the research area has to be seen in connection with the large Berchtesgaden magnetic anomaly. Superposed onto this trend there are a number of smaller anomalies, which can be explained from local geology, related to basic or ultrabasic rock bodies, in most cases serpentinites.

3D modelling of the local magnetic anomalies of S Zillertal and south of Wörgl show source rocks positioned at or very near the surface. In both locations they can be identified as serpentinites, and in some cases also as metagabbros and metavolcanics, all of Early Palaeozoic age. These anomalies are caused by a number of relatively small source bodies.

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