Mitt. Ges. Geol. Bergbaustud. Österr. 41, Wien 1996, 87-100

Notes on the Plio-/Pleistocene volcanism of the Styrian Basin

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ABSTRACT

Indications of phreatomagmatic eruptions and maar developments are being discussed using some examples of the Plio-/Pleistocene volcanism in the Styrian Basin (Klöch - Zaraberg, Burgfeld and Beistein south of Fehring, Altenmarkt-Riegersburg). Results of geomagnetic measurements in Altenmarkt near Riegersburg and geochemical data of Altenmarkt-Riegersburg are presented.

Keywords: Styrian Basin; Pliocene; Pleistocene; volcanism; geochemistry

Introduction

The geological methodical registration of the volcanism of Eastern Styria started in the last century (Buch, 1821) and reached a climax during the first half of this century (Winkler, 1913, Winkler-Hermaden, 1939; Winkler-Hermaden, 1957 cum lit.). In the course of mapping carried out for the preparation of a new geological map on the scale of 1:50.000 (Austrian map no. 192) a geological revaluation of the volcanic areas is this region takes place (Döhrn, 1992; Holzer et al., 1994; Pöschl, 1990; Schulz, 1994; Stattegger and Holzer, 1990; Stolar et al., 1994). Apart from some basic approaches attempted by Pöschl (1991a,b) and Fritz (1992, 1994, 1996), a comprehensive volcanogeological revaluation of the Plio-/Pleistocene volcanism, however, is still missing. A great number of mineralogical, geochemical and petrological studies (e. g. Agiorgitis et al., 1970; Heritsch, 1967, 1975; Kurat et al., 1980; Taucher et al., 1989; Vaselli et al., 1996a) have provided a lot of relevant data. The present national and international research interest in the a. m. volcanism gives reason to hope that we will soon witness a time of intensive research in all fileds of geosciences.

The area of the Styrian Basin (Fig. 1), as the most western part of the basins of the central Paratethys, is seen in the context of an extension-tectonic movement towards the east at the end of the orogenesis of the Alps. Plate tectonic discussions in regard to the Intracarpathian Basins focus on a continental lateral escape mechanism, i. e., a movement of the Eastern Central Alps along supraregional strike-slip zones (sinistral systems at the northern outskirts and within the Eastern Central Alps and along the Raab-line, a dextral system along the Periadriatic fault) towards the east into the free Pannonian area (Sachsenhofer, this vol.; Tari, this vol.). The formation of N-S directed fault systems is correlated to E-W directed extension and to extensional faults causing tilts of basement blocks towards the east (Neubauer and Genser, 1990). This is also the reason for an asymmetrical basin with prominent basement blocks in the west (Koralpen block, Sausal ridge, Ridge of Südburgenland).

The Miocene sedimentary development of the Eastern Styrian Basin probably started in the Ottnangium and is proved since the Karpatium. At the end of the Karpatium, the first volcanic activities started to produce acid to intermediate K-containing, especially latitic magmas (e. g. Ilz-Walkersdorf, Gleichenberg-Mitterlabil-Perbersdorf, Weitendorf-Wundschuh). This oldest phase of volcanism, according to radiometric data, goes back as far as to the Lower Badenium, followed by a second eruption phase, placed in the Lower Pannonium, which can only be proven in Burgenland (Pauliberg and Oberpullendorf; Balogh, 1994). After a longer phase of volcanic inactivity with predominantly marine character, the Styrian Basin saw a freshening and then, from the Pannonium C onwards, the sedimentation of limnic-fluvial sediments. These sediments that were interpreted as deposits of a branched river system including vast flood plains and large areas of still water (Kovar-Eder and Krainer, 1990). They are often found to be the sedimentary frame of the youngest volcanic rocks of the Plio-/Pleistocene.

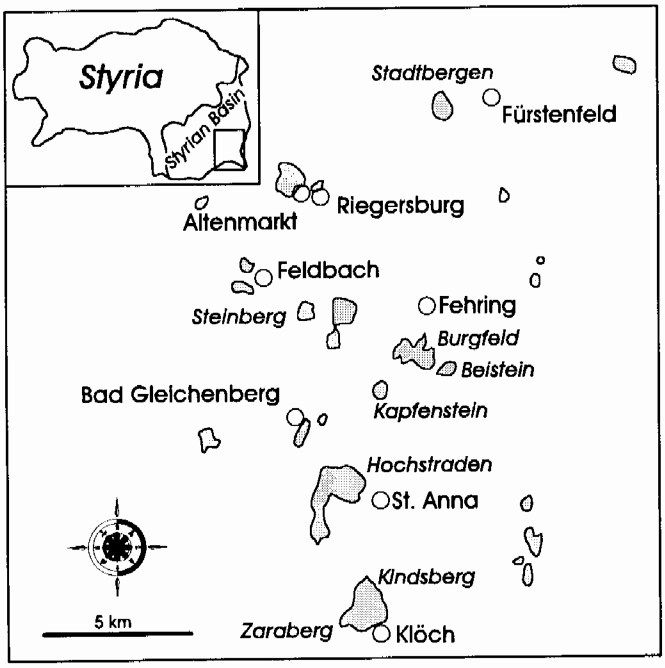


Fig. 1. Location of the Pliocene/Pleistocene volcanic and volcaniclastic deposits in the Styrian Tertiary Basin

This young (Plio-/Pleistocene) volcanism is of basaltic composition and shows both effusive and explosive character. The effusive deposits in Klöch and Hochstraden are interpreted as superficial lava sheets (Winkler, 1913), the lava of the Steinberg near Feldbach, however, partly as intrusion (Murban, 1939). Furthermore we know of a small basalt intrusion at Stein near Fürstenfeld (Andrae, 1855). In addition to these effusive manifestations of the volcanism in Eastern Styria there was also a great explosive activity documented by numerous tuff deposits. Such volcanic production centers (about 30 - 40 tuff volcanoes, Kollmann, 1965) can be found very often in the form of pipes. The corresponding diatremes are located on thin stumps (the diameter of these volcanic edifices bodies tapers off towards the depth) which could be proven by the Rohöl-Aufsuchungs-Aktiengesellschaft (RAG) during refraction-seismic studies of both the basaltic tuff area in Altenmarkt near Riegersburg and at the southern end of the basaltic tuff in Stadtbergen near Fürstenfeld (Kollmann, 1965). Because of their greater resistance to weathering, compared to the predominantly non-solid clastic sediments, the volcaniclastica, which were probably first deposited in a hollow area, differ, in morpholocigal terms, from their surroundings (e. g. Riegersburg, Kapfensteiner Kogel, Kindsbergkogel, Seindl).

Phreatomagmatic eruptions

Up to the sixties of our century almost nobody doubted that the fragmentation of magmas on the earth-surface during explosive volcanic eruptions is caused only by the expansion of magmatic gases. Nowadays it is assumed that external water has a great influence on, if not determines, many of the eruption mechanisms and fragmentation processes. Magma meeting external water like ground water and/or surface water (lakes, rivers, sea water, ice or snow) can be fragmented (Fisher and Schmincke, 1984; Wohletz and Heiken, 1992). The literature uses various terms for explosions in the context of this interaction between magma and water, i. e. phreatomagmatic (phreatic), surtseyan, volcanian and hydroclastic.

The term *phreatomagmatic* can be used, according to Schmincke (1977), irrespectively of the type of water involved. This is useful as the great variety of definitions refers to different types of external water although the forming mechanisms are generally the same for all types thereof. Furthermore it is often not possible to determine the type of external water (ground and/or surface water) that caused fossil phreatomagmatic volcanic deposits.

Phreatomagmatic eruptions are often the initial stadium of volcanic eruptions (Schmincke, 1988 cum lit.). This type of magma fragmentation often leads to the formation of an explosive-erupted mix of lava, fragments of wall rock and steam. In the course of phreatomagmatic eruptions the heat energy is used for heating up the external water, the result are low eruption columns and deposits near the vent.

Characteristics of pyroclastic rocks formed by phreatomagmatic activity

The characteristics of pyroclastic rocks formed by phreatomagmatic activity have been discussed by various authors (Cas and Wright, 1987; Fisher and Schmincke, 1984; Lorenz, 1985; Lorenz and Zimanowski, 1984, Schmincke, 1977; Walker, 1973; Walker and Crosdale, 1972). Some characteristics of determined processes are:

(1) Chilling of magma by means of water (steam): low vesicularity of the components; dense bombs; formation of glass.
(2) Transport in systems rich in water (steam): synsedimentary deformation fabric; accretionary lapilli; bomb sags in case of ballistically transported components (e. g. bombs); poorly graded deposits on steep slopes.
(3) High frequency and great number of eruptions: clear bedding; reduced layer thickness; great number of thin layers of few millimeters to some centimeters thickness.
(4) Expansion of water steam into the wall rock during the eruptions: strong fragmentation, wall rock split-off; deposits contain many wall rock fragments; blocks of wall rock in the crater area.
(5) Fast cooling of the whole system: thermal shock (angular-shaped particles); small size; rare indications for fritting.

Examples of hydroclastic deposits in the Styrian Volcanic Region

Some volcanic deposits in Eastern Styria show signs of phreatomagmatic eruption mechanisms. Pöschl (1991a,b), for instance, attributes a crater near Beistein (Fig. 1) to such an eruption. The following eruptions also were determined by a changing availability of ground and/or surface water and the rising magma. As indications for this type of explosion mechanism she states bomb-sag-structures and low-angle-cross-stratification, the existence of accretionary and armored lapilli.

In the volcanic area of Klöch, around Zaraberg (Fig. 1) accretionary lapilli could be found which indicate phreatomagmatic conditions (Fig. 2). Large parts of this nepheline basanite massif of Klöch are underlain by layered ash/lapilli tuffs. Here, too, we can assume that hydroclastic eruptions lead to the explosive creation of a crater. The castle rock of Riegersburg (Fig. 1) shows many signs of a phreatomagmatic eruption mechanism. The numerous sedimentary and epiclastic xenolithes at the foot of the rock, for instance, rarely show signs of fritting (Fig. 3). The low vesicularity of the juvenile components, the high frequency and great number of eruptions are just as characteristic of phreatomagmatic eruptions as the low-angle-cross-stratification which can be detected at some places.

In the volcanic area of Altenmarkt near Riegersburg (Fig. 1), the former quarry shows clear layers of (ash-) lapilli tuffs the formation of wh can be attributed largely to fall out deposits. In some areas bomb-sag-structures can be found (Fig. 4) indicating "wet" conditions. From the asymmetrical formation of the formerly plastic underground and the angle of dipping we can infer the direction of provenance and the vent area.

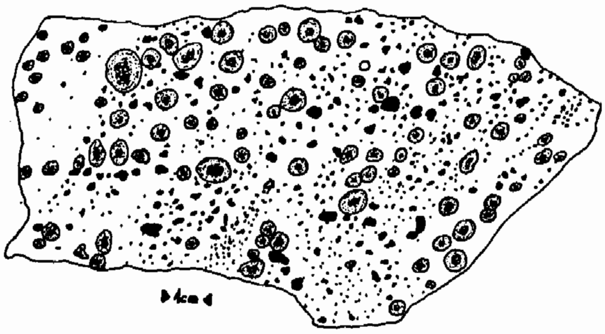


Fig. 2. Accretionary lapilli from Zaraberg near Klöch.

Fig. 3. Layered ash-/lapillituff with xenolithes in front of the second gate on the way to Riegersburg Castle.

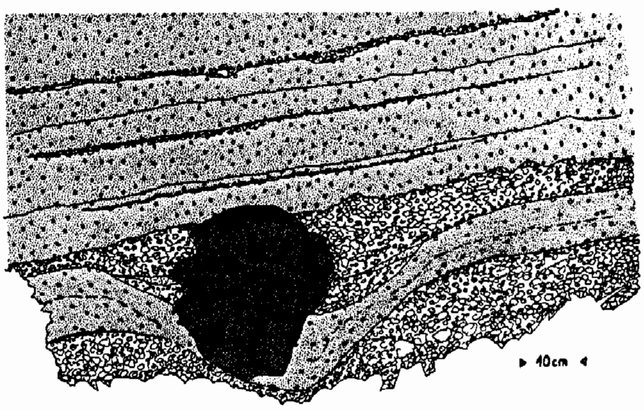


Fig. 4. Bomb-sag-structure (old quarry in Altenmarkt near Riegersburg).

Maar volcanoes

Many tuff cones in Eastern Styria can be well classified as volcanoes with primarily negative relief (Maars). Maar volcanoes are, after the scoria cones, the most frequent subaerial volcano types and consist largely of layered tephra layers, extremely rich in country rocks, transported horizontally and cold-deposited. The following criteria for the classification of a Maar (Noll, 1967) are presented on the basis of the example of Altenmarkt - Riegersburg:

(1) Existence of a funnel-shaped hollow mould negative volcanic form: encircling, discordant, steep contact of the volcaniclastica to the surrounding prevolcanic sediment.

(2) Independent volcanic formation, i. e., independently shaped routes of production (diatreme; volcanic breccia vent or veins have to be included): in Altenmarkt a center of volcanic production could be ascertained; in Riegersburg such a center can be assumed.

(3) Maars are not caused by abrupt "shots" but by a continuous progress determined by magma gas output under fluidisation: the continuous, partly cyclic development of volcanic structures could be ascertained in both areas.

Lorenz (1973, 1982, 1985, 1986) has profoundly discussed the subject of Maars and defines the term of maar as follows (Lorenz, 1986): „ Maars are volcanic craters that have been cut into pre-eruption surfaces and pre-eruption rocks. Older rocks are thus exposed in the crater walls. Maars are surrounded by low rims of ejecta beds which accumulate on the surface and decrease in thickness very rapidly outward".

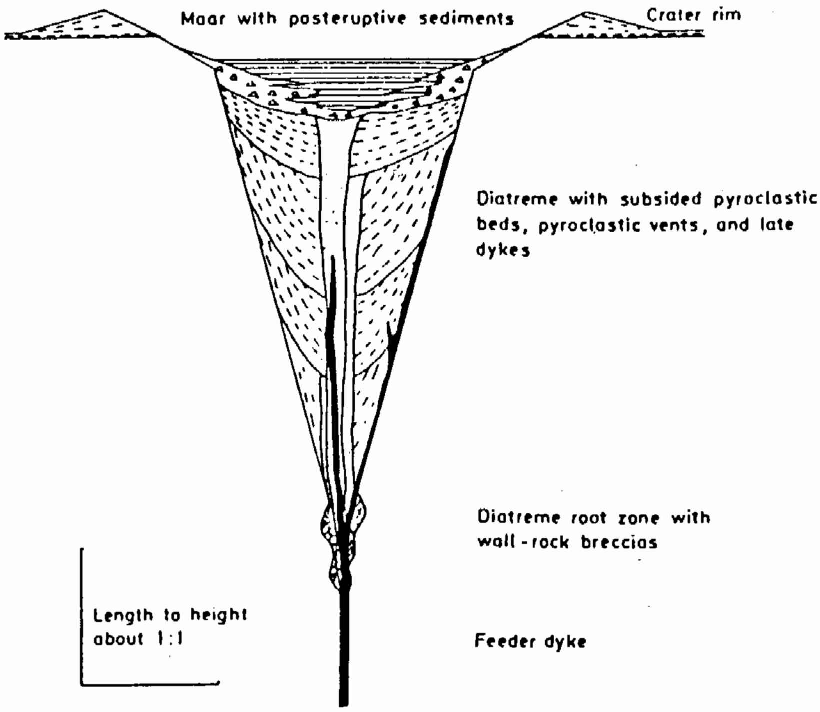


Fig. 5. Schematic drawing of a model maar-diatrem volcano with post-eruptive crater sediments and feeder dyke (from Lorenz, 1986).

Maars are often underlain by large diatrems (Fig. 5) which are filled with frequently well-layered, bowl-shaped pyroclastic deposits rich in wall rock, and go down as far as 2000 m (Lorenz, 1986). They develop most probably because the energetically favorable phreatomagmatic eruption level can be lowered in the course of an eruption because of high intrusion of water. The repeated collapse of the crater and the falling back of erupted material can cause the vent to widen and to be filled continuously (Schmincke, 1988).

A model

The definition of Lorenz (1986) serves as the basis of the following model of the maar development of Altenmarkt near Riegersburg. It is essential for the elaboration of the intended model to prove the existence of sufficient water reservoirs. In this context we note that the material of the sloping parts of the Eastern Styrian Basin consists of fine-sandy, silty-clayish and sandy-gravelly sediments which were formed primarily during the Sarmatium and the Pannonium. In the sand-gravel layers between the fine clastic sediments are indications for ground water (Winkler-Hermaden and Ritter, 1949; Zetinigg, 1982). This gives reason to assume that during the Plio-Pleistocene volcanic activity, ground waters, in addition to surface waters, could be found on various levels. This, at least in some layers, high content of water, together with former surface water of rivers and lakes, is essential to the following model (Fig. 6).

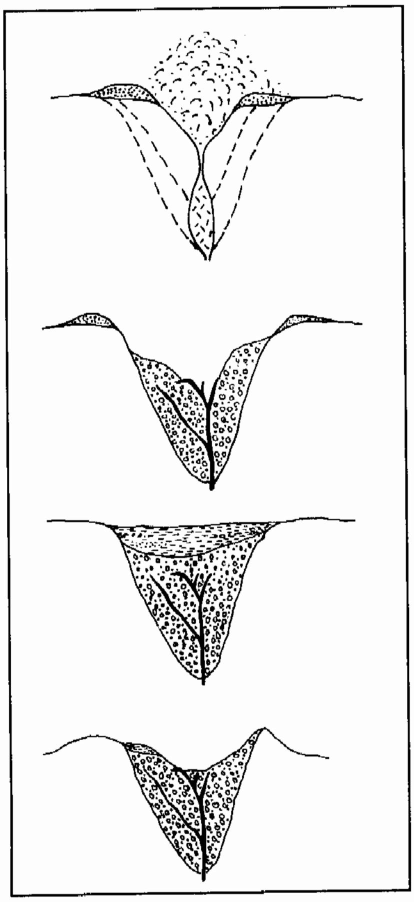


Fig. 6. Stages of development of maars (from top: *initial stage, development stage, stage of sedimentation, erosion stage*).

Lorenz (1985, 1986) differentiates primarily between three stages of development of maars (*initial stage, development stage, erosion stage*). For the model under discussion it is useful to introduce a fourth stage (*stage of sedimentation*) as a large part of the exposed material belongs to this class. The *stage of sedimentation* represents a continuous transition from the *development stage* to the *erosion stage* during which the sedimentation of interbedded clayish silts and fine sands (Fig. 7) and the odd tuff layer or tuffaceous rock takes place. The *stage of sedimentation* (*maar lake stadium* in the wider sense) will be discussed shortly using the examples of Burgfeld and Altenmarkt.

Stage of sedimentation

During this stage the ridge of the crater develops. It shows redeposition from pyroclastic rocks from an assumed tuff cone and the resedimentation of prevolcanic sediments which derived from the wall of the vent. Often this stadium is characterized by one or more phases of maar lake developments which can be separated by volcaniclastic deposits. Remains of this fine clastic, well-layered deposits at various volcanic formations of Eastern Styria could be registered on maps (Ebner and Gräf, 1979; Winkler-Hermaden, 1939) and are exploited in Burgfeld (Vinzenz, 1988).

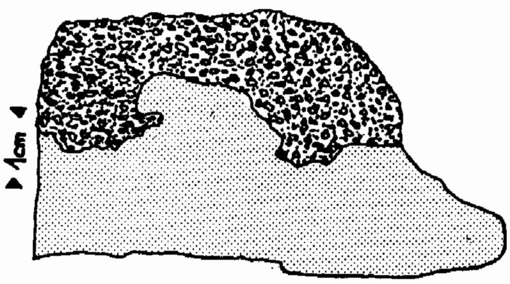


Fig. 7. Clayish silt overlain by tuffaceous sandstone from Altenmarkt near Riegersburg (*stage of sedimentation*).

(1) South of Fehring: This deposit of clay owes its development to extensive volcanic activities in the area. Pöschl (1991a, b) shows a genetical relationship between the volcanic region of Burgfeld and that of Beistein (Fig. 8). Massive tuffites with numerous mantle xenolithes are the basis for the silty clayish sedimentation unit. In 1989, a channel section was exposed in the central part of the area where, apart from the clay layers, samples of wood and other fossil remains of a former forest (cones, needles of conifers) could be found. In addition to this, the channel section with a maximum width of 8 m, also showed coarse clastic components, like gravel and tuff spheroides. The longitudinal axis of the channel, which has meanwhile been exploited, had a flat incline from south to north. Its presumably southern part was exposed at the southern exploitation slope in 1995 where similar fossil relicts were found. This formation is interpreted as a type of lahar, parts of wood, soil and some ground being shifted to the lake. The still shapable lake deposits were ploughed, which has been well-documented by the outer boundary of the channel structure.

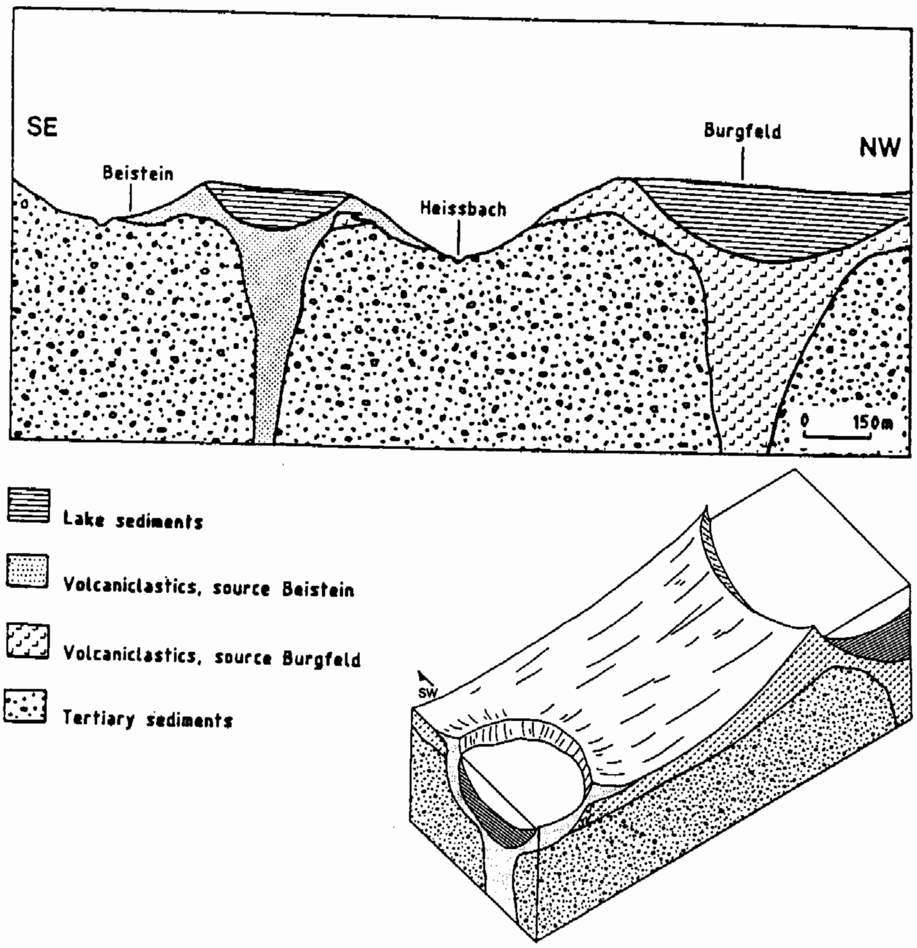


Fig. 8. Schematic model for the volaniclastic succes-sion near Beistein (from Pöschl, 1991a).

(2) Altenmarkt near Riegersburg: In this volcanic area the deposits of a maar development show a series including both individual maar lake development phases and phases of volcanic activity. Some natural outcrops with sedimentary character show reworked tuffs (Fig. 9). The petrological and geotechnological properties of the clayish silts (typical maar lake sediments) of Altenmarkt can be compared to those of Burgfeld. Size and distribution of these sediments, however, is much smaller in Altenmarkt which is probably a result of erosion.

Geomagnetic mapping of a vent in the volcanic area of Altenmarkt near Riegersburg

The first measurings in the terrain were carried out with a protone magnetometer (Company GEOMETRICS model G 816) belonging to the Institute of Geophysics of the University of Leoben in autumn 1991. The geomagnetic measurements primarily aimed at testing the usefulness of geomagnetics in the volcanic area of Altenmarkt, supporting mapping in this area and locating the basanitic feeding vent as a magnetic disturbing body in the area under discussion. The first stage of measuring included the positioning of a radial gridline system over the mapped vent area (Fig. 10, profile A in Fig. 11) which allowed the detection of a subdivided disturbing body (Fritz, 1992). Based on the results of the first stage of measuring the area of the *Talknoten* (Fig. 10) was covered with a narrow gridline system of the size of 200 m x 250 m, the gridlines positioned at about 10 m of each other, in order to measure the subdivisions of the vent area. This took place in December 1993. In order to attain the exact measure points, the measuring lines were poled. The measurements were carried out by two people using a 10 m distance rope and the corresponding direction indications. In this way a regular gridline system could be established well reflected by the measuring results (Fig. 12).

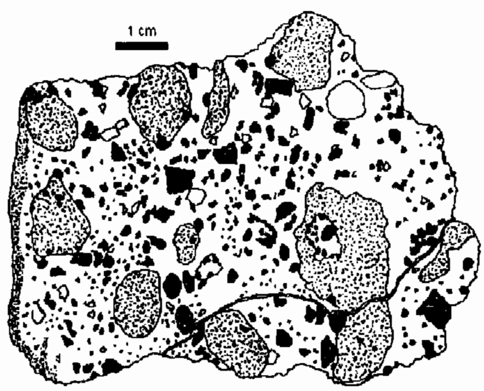


Fig. 9. Reworked ashtuffs in tuffaceous sandstone from Altenmarkt near Riegersburg (*stage of sedimentation*).

Measurement-results

The N-S-oriented measuring lines are mostly situated in the grounds of the valley (Fig. 10). Frequent test measurements at the calibration points showed a constant measured value with maximum deviations of 8 nT. The whole gridline system showed 500 measuring points with a total intensity of ΔT. There were anomalies in measured values of up to 3000 nT within the area of 50,000 m^2. Measuring brought about areas with clear minimum values presented in Fig. 12. Three main areas of minimum values, two of them being proven by basanites in the field, were determined. The third minimum area covered by valley fills, is indirectly confirmed by the results of refraction seismic drilling (F 1189, F 1192, F 1102) carried out by the RAG.

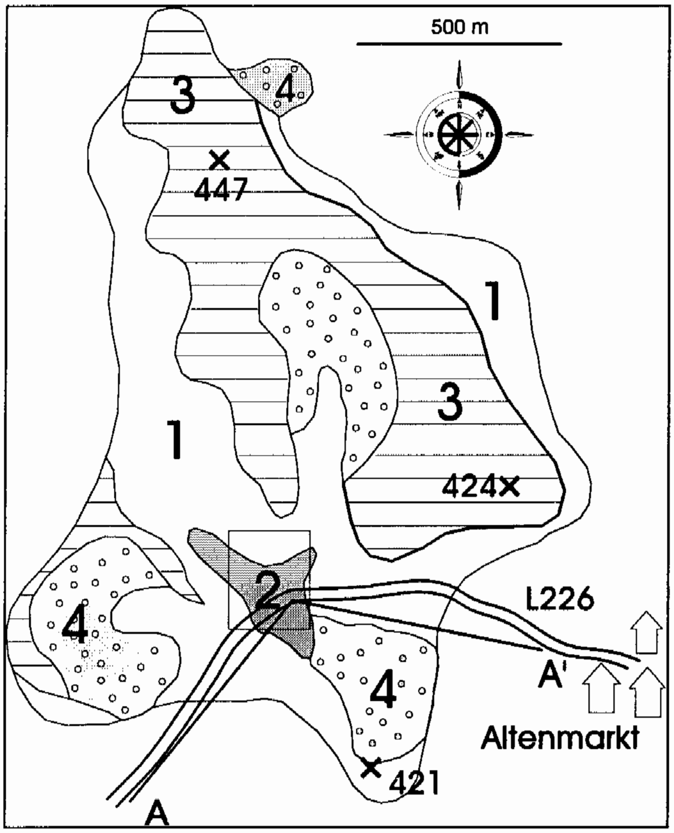


Fig. 10. Simplified uncovered geological map from Altenmarkt near Riegersburg. Legend: 1 undifferentiated ash-/lapillituffs (*development stage*), 2 basanitic intrusion (*development stage*), 3 tuffaceous sandstone and clayish silt (*stage of sedimentation*), 4 undifferentiated volcaniclastics (*erosion stage*)

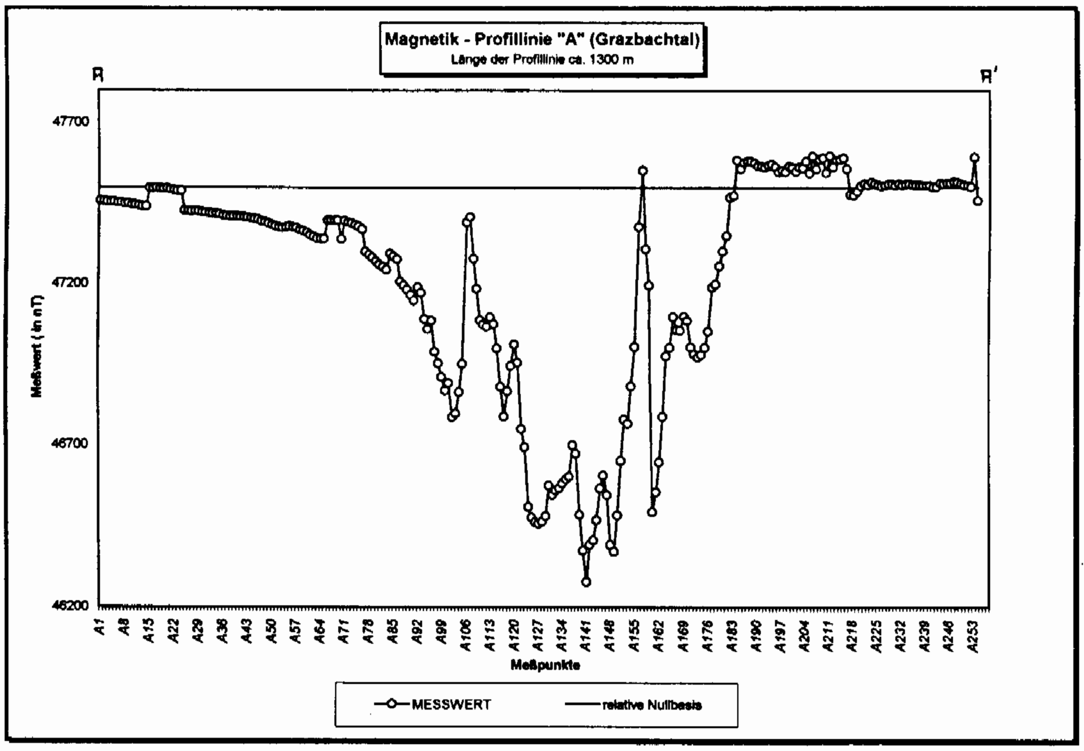


Fig. 11. Profile A: geomagnetic measurements in Altenmarkt (see Fig. 10).

Chemical analyses of the volcanic area of Altenmarkt - Riegersburg

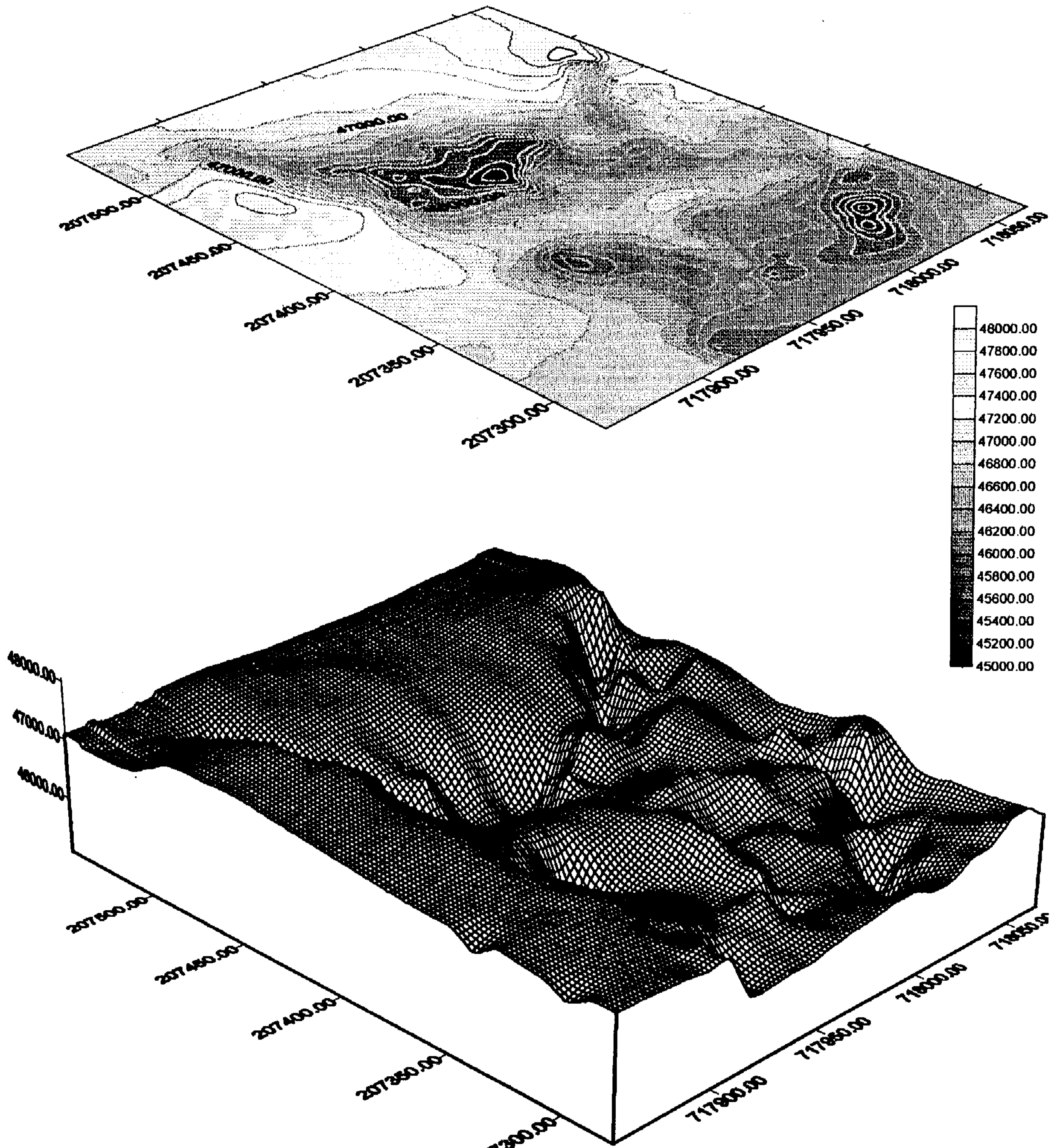
A comparatively great number of chemical tests were made for the volcanic area of Eastern Styria (e. g. Heritsch, 1967; Heritsch and Rohani, 1973; Schoklitsch, 1932, 1933; Zirkl, 1986) which allow a rough comparison of the various volcanic deposits. They, however, so not always seem suitable for more profound research as the localisation of the sampling is not always documented. Petrological and geochemical analyses, being already the standard in similar areas, like the Eifel, Auvergne or in Italy, Hungary and the Slovakia Republic, would therefore be an additional scientific necessity besides the geological and volcanological research. The following analytical values (Table 1) refer to studies of the last few decades. Apart from the analyses carried out by T. Ntaflos (University of Vienna) in 1994, the studies do not allow a clear identification of the places of sampling. The sample is an unweathered piece from the natural outcrop of basanite in Altenmarkt (Fritz, 1996). The results of another recent analysis provided by G. Serri (Instituto di Volcanologia e Geochemia, Urbino, Italy) are also included in the following table. A medium value of the basaltic rocks of Eastern Styria serves as the basis of the comparison of various analyses of Altenmarkt (Table 1).

The analytical data of the samples of Altenmarkt and Riegersburg correlate as expected. The non-significantly higher SiO_2 and Al_2O_3 values of Zirkl's more global analysis (4) are peculiar as they prove that the sedimentary quartz proportion in the total rock (tuffite, Zirkl, 1986) is only very small. We have to note, however, that the place of sampling has a great influence on the result. According to the model under discussion, the exposed rocks of the quarry are classified as being part of a volcanic stage when the vent was almost free of country rock and the magma had almost reached the earth surface. The result of this was that especially juvenile components were cast out in the form of fallout. The table also shows that the rocks of Altenmarkt are, on average, very poor in Na_2O and Fe_2O_3 but rich in MgO. The type of magma is classified as theralite-gabbroid to gabbro-theralitic. The nephelinite or nepheline-basanite rocks fit well, according to the classic classification, into the Atlantic character of the Eastern-Styrian Volcanism (Heritsch and Rohani, 1973).

	Riegers-burg	Altenmarkt A 178	Altenmarkt ejecta	Altenmarkt ejecta R 3	quarry Altenmarkt Bulk analysis	Steinberg Feldbach	*medium* Eastern Styrian basaltic rocks
SiO_2	46,35	46,4	44,2	44,92	46,47	44,18	44,33
TiO_2	1,82	1,9	1,99	1,98	1,39	2,76	2,05
Al_2O_3	14,04	15,89	14,13	14,38	12,07	15,93	15,01
Fe_2O_3	4,28	9,87*)	4,78	4,53	6,3	7,21	5,31
FeO	6,1	-	4,75	4,77	3,76	5,18	5,6
MnO	0,17	0,17	0,16	0,19	0,1	-	0,16
MgO	8,3	8,78	8,11	8,34	8,27	7,38	7,23
ZnO	-	-	-	-	0,62	-	-
CaO	9,67	10,92	9,8	9,34	9,63	8,37	10,07
Na_2O	3,2	2,32	3,83	5,11	1,97	5,25	4,53
K_2O	2,27	2,31	2,4	2,58	1,29	2,09	2,12
P_2O_5	0,67	1,09	0,98	0,57	0,39	-	0,49
CO_2		-	0,46	0,92	-	-	0,39
FeS		-	-	0,49	-	-	-
Glv.	2,94	-	2,81	1,15	7,76	-	-
H_2O		-	1,73	0,92	5,25	0,88	2,54
Total	100,1	99,65	100,13	100,19	100,02	99,23	
	1)	2)	3)	3)	4)	5)	5)

Table 1: Chemical analyses of basanitic samples from Altenmarktand Riegersburg compared to a sample of Steinberg (Feldbach) and the medium value of the basaltic rocks of Eastern Styria. (1) XRF major analyses (wt%) by Serri, this vol.; (2) Analyses by Ntaflos, 1994, in Fritz (1996); (3) Heritsch and Rohani (1973) (4) Zirkl (1986); (5) Heritsch (1967); *) Fe total as Fe_2O_3

Geomagnetik - Detailmessungen "Talknoten" (Dez 1993 - Jän 1994)



x - Koordinate: Rechtswert nach BMN - System
y - Koordinate: Hochwert nach BMN - System
z - Koordinate: Meßwert in [nT]

Fig. 12. 3-d model of the geomagnetic measurements in the vent area in Altenmarkt near Riegersburg.

Conclusions

Geomagnetics is a useful instrument for the mapping of volcanoclastics in Eastern Styria. The results of the localisation and demarcation of the suspected vent area in Altenmarkt are especially important. Studies of a similiar character were carried out by Novak at the Pliocene tuff vent of Stadtbergen (from Walach, 1986). The measurements in the tuff areas of Altenmarkt which are locally rich in tertiary sediments (clays, silts, sands and gravels) show minor differences in their magnetic behaviour compared to the prevolcanic background, which, however, are certainly not significant. The reason for this can probably be found in both, the high content of primarily epiclastic material in individual layers and the comparatively low forming temperature of many pyroclastic layers within the system. Significant results, however, were obtained with well-hardened lapillituffs rich in juvenile components. These lapilli show a high content of magnetic minerals (titanomagnetit) and were hot enough during their sedimentation to preserve the direction of magnetization of that time.

Without extensive geochemical studies, a new research into the volcanites regarding a plate tectonic model is not possible. Some important national and international projects can be considered decisive in this respect (Belocki et al., 1996; Serri et al., 1996; Vaselli et al., 1996; this vol.).

The wide field of geosciences could play an important role in this region in the context of a comprehensive registration. On the basis of detailed scientific studies and research it should be possible to present the results to the interested visitor of the Volcanic Region of Eastern Styria in a well-prepared form. The presentation could include e. g. signboards indicating volcanological peculiarities, the construction of geo-routes and their integration into existing hiking and biking routes, excursions and subject-relevant events. This kind of public oriented work based on scientific, geological results could raise the public´s interest in the fascinating world of volcanism and, at the same time, establish a common understanding for the work and the aims of the geoscientist.

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