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THE STUDY OF SELECTED MAGMATIC ROCKS THERMIC REWORKING FOR THE PURPOSE OF THERMIC SINKING

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ABSTRACT
To verify possibilities of the thermic sinking technology the experiments with magmatic rocks (muscovite-biotite granite, amphibole-pyroxene andesite, pyroxene basalt) were made in the preliminary research phase. The contribution presents the microscopic study results of petrographic and structural observations of the rocks after their thermic reworking. Mainly distribution of melted rocks in the form of glass, forming of brittle deformations (fractures) on the level of mineral and rock, and penetration of melt into fissures were observed.

KEYWORDS: thermic sinking, granite, andesite, thermic reworking

INTRODUCTION

Nowadays energy consumption determines wide use of the Earth energy resources. Effective search and acquisition of new resources requires proposing and testing new technologies. It is one of the aims of the project "New detection methods for inquiring unconventional energy sources of the Earth". The developing technology uses the prototype equipment which produces high temperatures and pressures for thermic sinking (deepening) of narrow vertical openings (Lazar et al., 1998; Sekula et al., 2001). Experiments that focused mainly on development of the above mentioned technology examined also some physical and chemical qualities of formed melts (Rybár et al., 1998, 1999, 2000, 2002, 2004). The selected types of magmatic and sedimentary rocks were studied for further verification of the possibilities of the thermic sinking technology. So far only the experiments with magmatic rocks have been evaluated.

INFLUENCE OF HIGH TEMPERATURES ON THE SELECTED ROCK TYPES

Within the frame of the above mentioned project some experiments have been made on several kinds of magmatic rocks. The aim of experiments was thermic sinking of vertical openings of cylindrical shape into prepared rock samples in the laboratory. The rocks were exposed to the temperatures between 1700 – 1800 °C for the period of two minutes. Technical parameters of the high temperature generator, the mode of its operation and the course of the rock melting process will not be published before all the experiments will have definitely been completed.

Part of the research was petrographic study of the rocks before and after the exposure to the high temperatures, observations of the thermic deepened openings, characteristics and analysis of the rock structure near the deepened openings, furthermore characteristics of the cracks and melt penetration into the cracks, characteristics of the melts. The paper presents results of the microscopic analyses. Influence of the high temperatures was examined on the samples (Table 1) of common types of magmatic rocks in the opening phase. The rocks were selected to represent the main types of magmatic rocks (ultrabasic rocks excluding) according to SiO_2 content. Overall selection was conditioned by geomechanical criteria. The number of rocks was limited by the project budget.

Table 1 Basic data about rock samples (measurements of the samples: width, length, thickness).

Sample number	Type of rock	Classification of the rock	Sample size [mm]
1	pyroxene basalt	magmatic, volcanic, basic	55x60x30
2	muscovite-biotite granite	magmatic, plutonic, acid	50x50x75
3	amphibole-pyroxene andesite	magmatic, volcanic, intermediate	50x50x75

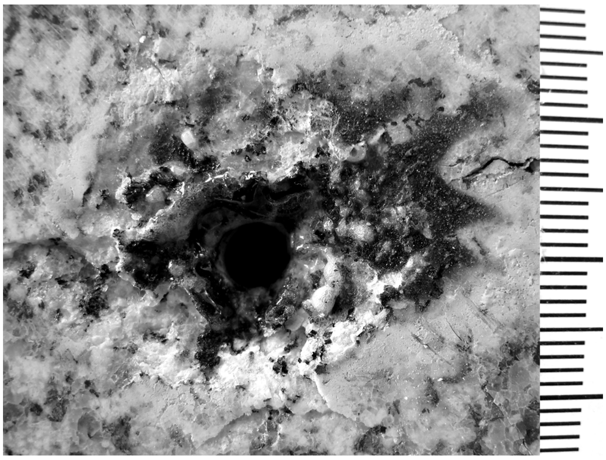

Fig. 1 Surface of the granite sample after thermic sinking of the opening. Mouth of the opening is rimmed by the thermal aureola. Scale division = 1 mm.

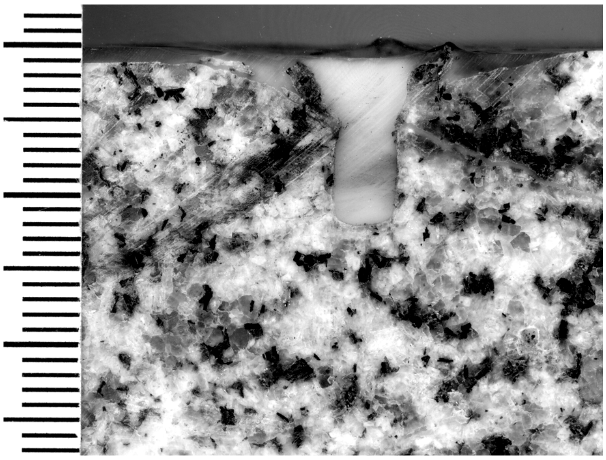

Fig. 2 Thermic deepened cylindrical opening in the cross section of the granite with the mouth of the conic shape. By the reason of thermic destruction the sample was fixated by epoxide before the thin section making. Scale division = 1 mm.

MACROSCOPIC DESCRIPTION AND CHARACTERISTICS OF STUDIED ROCKS

To illustrate the impact of how the high temperatures influence rocks, we present brief data of macroscopic study. Study of the rocks was made both on their surfaces (Figs. 1, 3) and internal parts of the samples. Internal parts were studied on set of sections vertically oriented on the surface of thermic sinking (Figs. 2, 4). In course of experiments, openings were formed at places exposed to the burner flame on samples No. 2 and 3 (Table 1). The openings have cylindrical shapes with conic mouth near the surface (Figs. 2, 4). Near the mouth, they are surrounded by a ring of solidified melt (Figs. 1, 3). The ring made of glassy material is a part of thermal aureola surrounding the sinking opening. It is the area where the influence of high temperatures is demonstrated on rock melting and rock colour changing. No opening was formed on sample No. 1. The rock was melted in the place exposed to the flame and only a wide shallow opening was formed. As the aim was not reached (technological reason) the above mentioned specimen will not be analyzed until the next series of experiments.

Studied rocks were not macroscopically deformed by cracks (fissures) before the experiments were started. In order to obtain intact trial samples, the most compact blocks of rocks were intentionally selected. After the exposure to high temperatures, cracks were formed on samples (Figs. 1 - 4). Most of the cracks are fixed on thermic aureolas. They are non-penetrative cracks destructing shallow subsurface parts of rocks. Most of them were formed on the periphery of mouth opening. Other cracks are penetrative. They destruct the sample integrity up to its the edges. The cracks, mainly the penetrative ones, are important structures for application of verified technology. In theory, technology expects crack formation and its further opening by pressure of burning gases. Opening formed in this way should be used for intrusion and accumulation of melts in rock environment. The intrusion of melt into penetrative cracks was not macroscopically recognised.

PETROGRAPHIC ANALYSIS OF THE ROCKS

The rock samples (Table 1) were studied in detail macroscopically and microscopically. They were petrographically defined and classified (Zacharov et al., 2010). In this contribution, summarised microscopic features of the original rocks are presented. Microscopic analyses were made using polarising microscope OLYMPUS BX-53. Microphotographs were obtained by Lumenera Infinity 1-5 camera and processed by software for capturing images, for editing digital images and measurements QuickPHOTO MICRO 2.3.

PETROGRAPHY OF THE MUSCOVITE – BIOTITE GRANITE

Muscovite–biotite granite has massive structure, without preferred orientation of minerals. Mineral grains are macroscopically visible and their size sometimes reaches 6 – 7 mm. It has light colour, which is caused mostly by its major felsic rock-forming minerals, quartz and feldspars.

The rock has phaneritic-holocrystalline-hypidio-morphic-granular texture. The average size of minerals exceeds 0.5 mm. It consist of euhedral but mainly subhedral grains of plagioklase and biotite and anhedral grains of quartz and K-feldspar. In terms of mineral composition, the granite consist of major felsic minerals: quartz (33 %), plagioclase (29 %) and

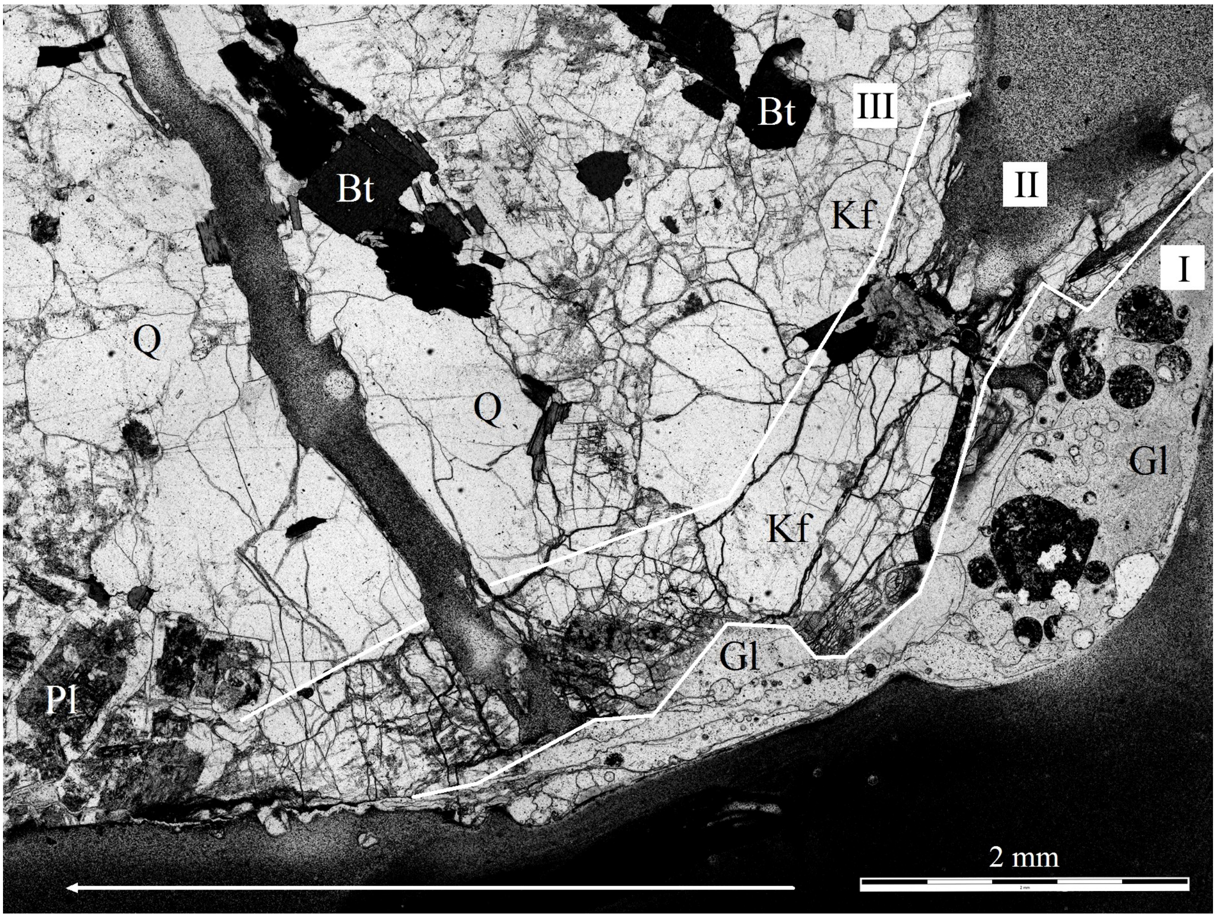

Fig. 3 Cross section of the granite near the deepened opening. The direction of sinking is marked by horizontal arrow, the boundaries of the structurally different zones are marked by broken line. Gl – glass, Q – quartz, Kf – K-feldspar, Pl – plagioclase. Uncrossed polarizers.

alkali feldspar (27 %). The minor mineral is mafic biotite (7 %). Small modal proportions of accessory minerals are represented by muscovite (2 %) and zircon. The remaining part of accessory minerals is formed by secondary aggregates of sericite and chlorite.

Anhedral quartz forms big grains or aggregates of grains with typical undulatory extinction. The size of single grains reaches 5 - 6 mm. Quartz represents the final stage of rock crystallisation. Subhedral grains of biotite, plagioclase and euhedral grains of zircon are enclosed in bigger quartz grains. Subhedral grains of plagioclase (oligoclase) often show zoning caused by slight chemical variations. Crystals of plagioclases reach 3 mm. Internal parts of crystals are strongly altered. They are sericitised under hydrothermal conditions. Alkali feldspars are represented by orthoclase and microcline. Anhedral perthitised orthoclase forms grains up to 5 - 7 mm in diameter. In the grains are enclosed smaller subhedral biotites, muscovites and plagioclases. Orthoclase crystallises towards the end of crystallization sequence in magmatic rocks. Anhedral microclines form grains with size up to 0.5 – 1 mm. Alkali feldspars, unlike plagioclases, are not markedly altered. Euhedral but mainly subhedral crystals of biotite usually have tabular shape. On average, they reach the size of 0.5 – 1 mm. Some of biotite grains alter to chlorite around its edges or along its cleavage traces. The grains of the subhedral muscovite form crystals of tabular shapes with maximal size not exceeding 1.5 mm. Euhedral crystals of zircons are enclosed in bigger quartz grains.

GRANITE AFTER THE APPLICATION OF HIGH TEMPERATURES

The planes of studied thin sections in the granite pass approximately through the axis of thermally deepened narrow opening, which is 12 mm deep. The diameter of the opening in its bottom is 4.5 mm and 6 mm in its upper part near the collar. The rock close to the deepened opening could be dissected into three structurally different zones I – III (Fig. 3).

The first zone (I) is composed predominantly of glass. The solidified glass forms thin cover on the walls of deepened opening especially in its upper part into the depth of 4.5 mm (Fig. 3). The thickness of glass varies in the interval from 0.3 to 0.7 mm. From the depth of about 3 mm, the glass forms only fine film with thickness of 0.040 mm. The biggest

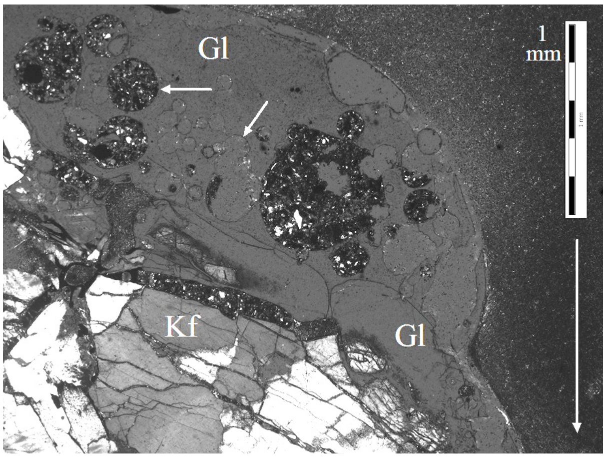

Fig. 4 Glass accumulation (Gl) near the deepened opening. The unfilled spherical pores, vesicles (oblique arrow) and filled spherical pores (horizontal arrow) of immiscible material occur in the glass. Under the glass zone (I) is K-feldspar (Kf) deformed by micro-cracks along its cleavage planes (II zone). The direction of sinking is marked by vertical arrow. Crossed polarizers.

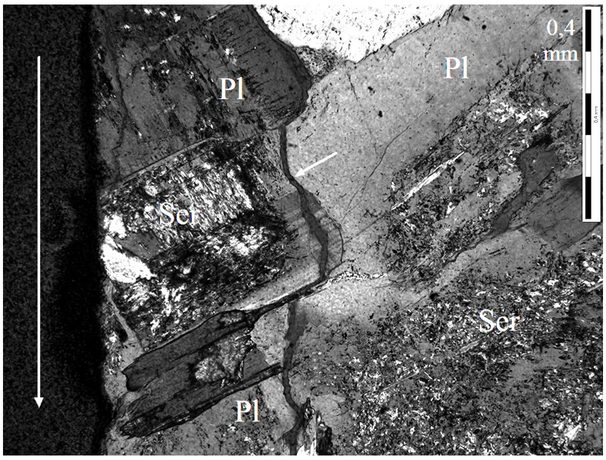

Fig. 5 Micro-crack near the edge of deepened cylindrical opening (oblique arrow) based on borders of the mineral grains or cleavage planes. The direction of sinking is marked by vertical arrow. Pl-plagioclase, Ser-sericite. Crossed polarizers.

accumulation of glass is on the surface of sample near the collar. Its proportions are 1.5 x 4.0 mm (Figs. 3, 4). The reason of the accumulation of melt and its cooling in the form of glass near the collar is the technology of sinking, where molten rock is rejected from relatively shallow opening towards surface. The originated glass is a metastable product of rapidly cooled and solidified melt. It is amorphous, colourless or pale brown. The unfilled vesicles of spherical shape with diameter up to 0.5 mm occur in the glass. In the zone (I) near the collar of the opening, sub-spherical accumulations of fine grained angular clasts of minerals from destructed rock occurs. They do not mix with surrounding melt and considering to glass they are sharply delimited (Figs. 3, 4). The accumulations have dark colour caused by presence of the opaque mineral aggregates. Under the glass material is the zone (II) of the minerals, which are strongly damaged by microscopic cracks. The cracks originated as the effect of thermal sinking (Fig. 3). The destructed zone is noticeable especially near the upper part of the opening into the depth of approximately 3 – 4 mm. Its thickness varies from 0.7 near the surface of the specimen to 0.9 mm in the depth of 3 mm. The geometry of micro-cracks depends mainly on cleavage of minerals, which form the margin of deepened opening. Minerals with very good or perfect cleavage (feldspars, micas) are damaged by system of the straight micro-cracks (Fig. 3), which corresponds with original system of cleavage traces in minerals. Minerals without regular system of cleavage planes (quartz) are destructed only by irregular rough fractures and cracks (Fig. 3).

Brittle destruction of the rock near the upper part of the deepened opening was caused by intensive fast warming and volume increasing of minerals which was followed by fast cooling with subsequent contraction of minerals. Under the zone of intensive brittle destruction of minerals, single discontinuous crack traces the edge of deepened opening (Fig. 5), and eventually changes into a set of cracks. Irregular cracks are separated in about 0.3 – 0.4 mm from the wall of opening, they are up to 0.015 mm thick and sometimes digitated. The cracks trace mineral grain borders or their cleavage planes. In three dimensions, cracks are structures which destroy nearest surroundings of the deepened opening and copy its cylindrical shape. In the depth of 3 mm under the collar of the opening, rough thick transverse crack develops. It contains angle 61° with axis of the deepened opening. Thickness of the crack varies from 0.3 mm to 0.5 mm. The melt does not intrude into the mentioned disjunctive cracks. The other zone (III) is not affected by thermal sinking (Fig. 3).

PETROGRAPHY OF THE AMPHIBOLE-PYROXENE ANDESITE

Amphibole-pyroxene andesite has pale-grey colour with macroscopically visible phenocrysts of mafic and felsic minerals (Figs. 6, 7). The average size of phenocrysts visible by naked eye is 1 – 3 mm. The size of phenocryst rarely exceeds the value of 4 mm. The rock has massive structure, without pores and without preferred orientation of mineral grains. The texture of the rock is porphyritic aphanitic with phenocrysts surrounded by microcrystalline matrix

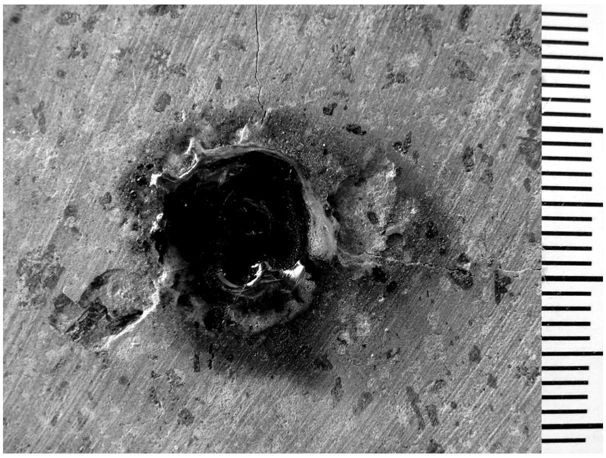

Fig. 6 Surface of the andesite sample after thermic sinking of the opening. Mouth of the opening is rimmed by the thermal aureola. Scale division = 1 mm.

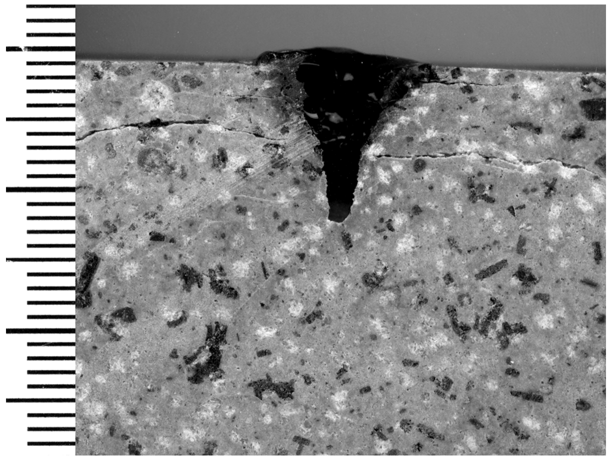

Fig. 7 Thermic deepened cylindrical opening in the cross section of the granite with the mouth of the conic shape. Scale division = 1 mm.

made of microlites of euhedral plagioclase grains. By optical methods, only bigger microlites could be identified in the matrix. Andesite does not contain microscopic dislocations.

The rock consists of 25 % phenocrysts and 75 % matrix. Phenocrysts are represented by plagioclases (18 %), pyroxenes (4 %) and amphiboles (3 %). Euhedral to subhedral plagioclase (andesine) phenocrysts are often markedly zoned and show polysynthetic twining according to albite or pericline laws. They are moderately affected by alterations. Most often, they are sericitised. In some grains, calcite aggregates forms. Phenocrysts of orthopyroxenes are represented by hypersthene. They form euhedral to subhedral colourless crystals of columnar shape, which are partly grouped in small clusters together with plagioclases. Orthopyroxenes contain tiny inclusions of irregularly shaped opaque minerals. Euhedral to subhedral strongly pleochroic phenocrysts of amphiboles form columnar shapes or hexagonal shapes typical for basal sections perpendicular to the c-axis. Amphibole phenocrysts are strongly decomposed. Reaction rims formed mainly by opaque Fe – Ti oxides are visible most frequently along the edges of mineral grains. In many phenocrysts, secondary mineral associations of Fe - Ti oxides, clinopyroxenes and plagioclases form completely decomposed (pseudomorphed) grains with shape of original minerals. Microcrystalline matrix is formed predominantly by plagioclase (andesine) microlites. Pyroxene and opaque mineral microlites are present in matrix in small amount.

ANDESITE AFTER THE APPLICATION OF HIGH TEMPERATURES

The thin sections does not pass through the thermally deepened opening in the andesite. They cut the specimen close to the opening in the planes parallel to its axis. In the thin section profiles successive transitions from the solidified glass material, formed by effect of the thermal sinking, to thermally untouched rock could be observed. The thermally deepened opening is 13 mm deep. The diameter of the opening in its bottom is 4 mm and 7 mm in its upper part near the collar. In term of its composition and structure could be studied profile divided into the several zones (Figs. 8, I – V).

First zone (I) is formed by glass material without rock fragments, which solidified near the mouth of the sunk opening (Figs. 8, 9). Glass is colourless, sporadically brownish. The thickness of the zone is from 0.4 to 1.5 mm. Marked fluidal structures could be observed in the glass material. In the glass unfilled pores of spherical shape are present with diameter from 0.05 to 0.6 mm. The pores form 20 – 30 % of the glass zone volume. In the glass of the first zone the formations of spherical or sub-spherical shape concentrate, which are formed by angular mineral fragments, aggregates of opaque minerals, oxides and hydroxides of iron. They represent the solid immiscible phase with sharp boundaries to glass, which did not mix with surrounding melt.

In the second zone (II) the volume of minerals in the glass material increases. These minerals are probably partly preserved microlites, especially plagioclases of the rock matrix. The volume of the minerals in the glass is 12 – 15 %. It was determined by the image analysis.

In the third zone (III) the volume of the minerals in the glass increases to 18 – 22 %. Size of the mineral fragments in the glass varies from 0.010 to 0.050 mm, which matches the size of the microlites (0.010 – 0.100 mm) in the matrix of the andesite. In both second and third zones the unfilled pores and spherical or sub-spherical formations of angular mineral fragments and opaque minerals are present. Glass material is generally colourless, sporadically brownish. On the boundary of third and fourth zones,

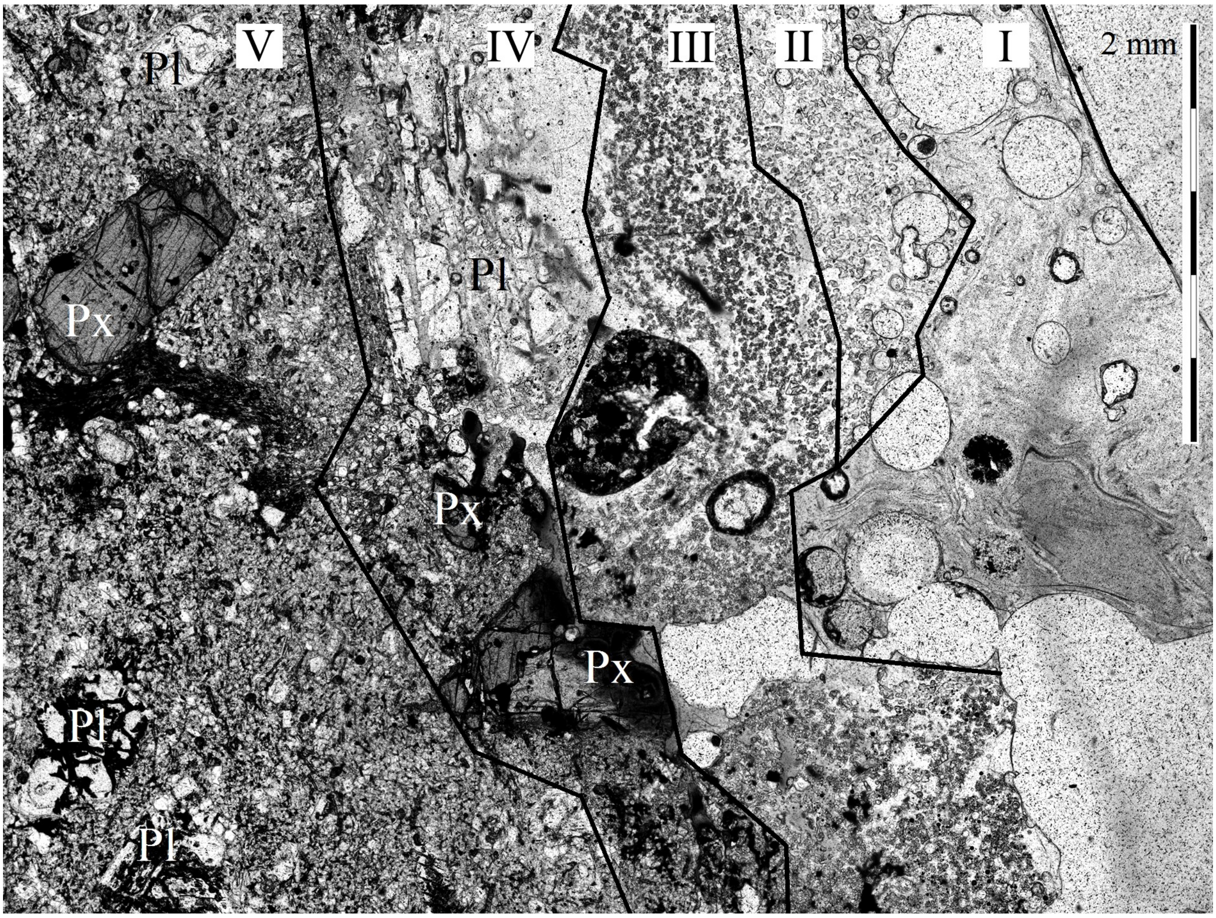

Fig. 8 Different structural zones in the profile of the amphibole-pyroxene andesite (I – V). Longer edge of the figure is parallel with the axis of the thermally deepened opening. The cross-section was made near the deepened opening. Uncrossed polarizers.

bigger accumulations of glass without mineral fragments occur (Figs. 8, 11).

The fourth zone (IV) is characterised by phenocrysts of plagioclase and pyroxene, which are markedly altered by the effect of thermic sinking. The plagioclase phenocrysts disintegrate on the cleavage planes to smaller fragments (Figs. 8, 11). The fragments are softly melted-down, rounded and the space between the fragments is filled by the glass of brownish colour. The plagioclase grains in the contact zones with glass are sporadically recrystallised (Fig. 12). The pyroxene phenocrysts are melted-down and corroded with the rim of opaque minerals at the contact with the glass (Fig. 8). At points of intensive thermal effect they get rich brown colour. The glass penetrates into the matrix structure in the fourth zone. The fifth zone (V) is formed by the rock without thermal effect (Fig. 8).

DISCUSSION

Microscopic study of thermic reworking of rocks is an integral component of research for verifying of technology possibilities in question. Results of this study enable more detailed evaluation of thermic deepening process, especially its character, distribution of matter and structures, which arise during the process.

Petrographic and particularly structural characteristics of the nearest thermally deepened ambient was the main goal of microscopic study. Mainly distribution of melted rocks in the form of glass, forming of brittle deformations (fractures) on the level of mineral and rock, and penetration of melt into fissures were observed from the point of view of thermic rocks reworking.

In the case of sample No. 1 (Table 1 - basalt) despite of equivalent technology and identical physical conditions of thermic deepening, slim cylindrical space was not deepened. Only a broader dish-shaped cavity followed by system of fissures sub-parallel with heated surface arose. Structural characteristic of thermically deepened space in basalt will be therefore described and published after another series of laboratory experiments. Structurally different fabric of nearest deepening space surrounding was observed in the case of samples No. 2 (granite) and No. 3 (andesite). Granite (sample No. 2) is relatively more coarse-grained rock with grain size up to 6 mm and with homogeneous structure. A sharply defined slim cylindrical space was a result of thermic sinking

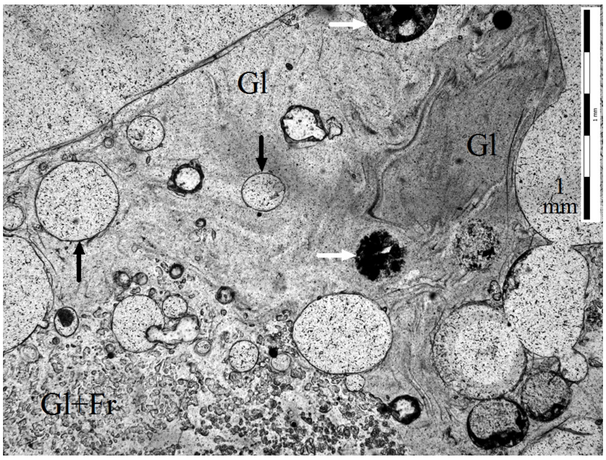

Fig. 9 Glass material (Gl) with fluidal structures (zone I) is replaced by zone of glass with mineral fragments (zones II and III, Gl+Fr). In all zones containing glass the unfilled pores occurs (vertical arrows) and spherical formations of mineral fragments with opaque minerals (horizontal arrows). Uncrossed polarizers.

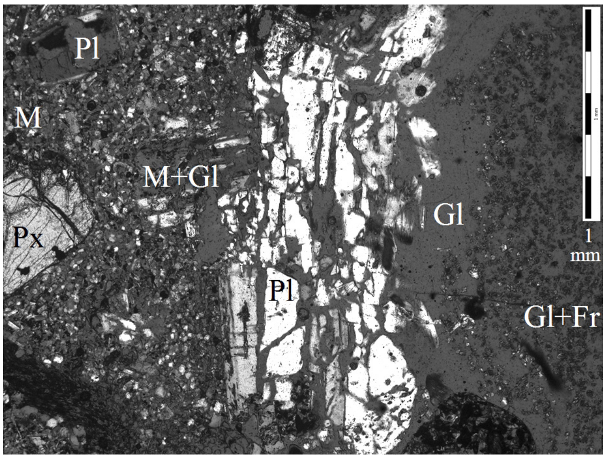

Fig. 11 On the boundary zone of glass with mineral fragments (zone III, Gl+Fr) bigger accumulations of pure glass occur sporadically (Gl). Phenocrysts of plagioclases (Pl) disintegrate by thermal effect on predisposed planes (zone IV) and space among the fragments is filled by glass. Glass material in this zone penetrates into the matrix (M+Gl). The zone V is formed by thermally untouched phenocrysts of pyroxene (Px), plagioclase (Pl) and matrix (M). Crossed polarizers.

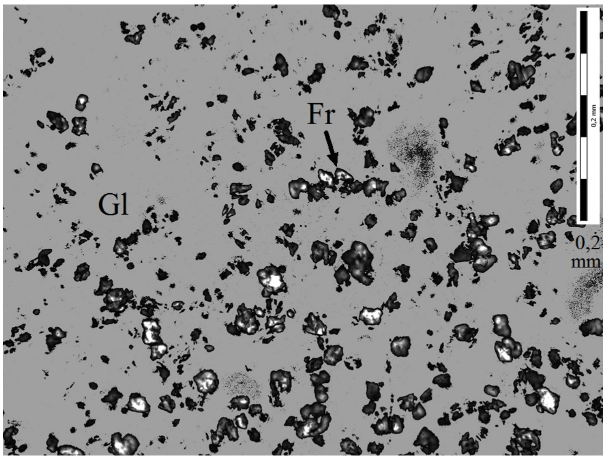

Fig. 10 The volume of the glass (Gl) and mineral fragments (Fr) determined by image analysis using Quick PHOTO Micro 2.3 in the zone III.

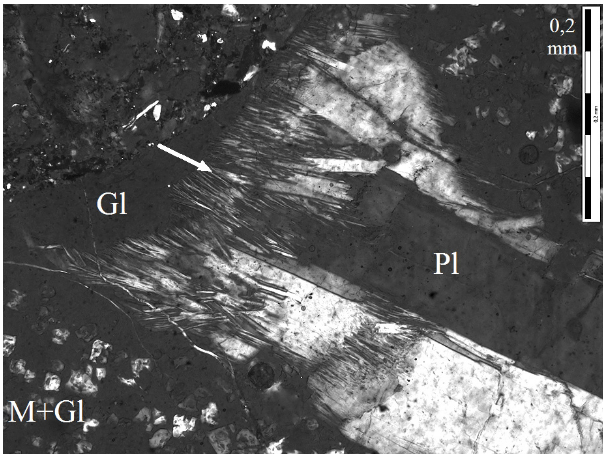

Fig. 12 Partially recrystalised plagioclase phenocryst (Pl, arrow) on the contact with melt (glass, Gl). M+Gl – matrix and glass. Crossed polarizers.

of the rock. In its surrounding, no signs of gradual or selective melting of minerals were observed. Thermal impacts are expressed particularly by brittle ruptures on mineral grain levels. There are evident crack openings along cleavage plains of feldspars, and irregular microscopic cracks in quartz. Fissures following mineral grains boundaries arise, too. Brittle destruction is an effect of thermal expansion and following contraction of deepened space surroundings. Melting creates only cover on deepened opening walls and does not penetrate into arisen fissures. Andesite (sample No. 3) is a relatively fine-grained rock with irregularly grained structure. It is composed of phenocrysts up to 3 mm big and also of matrix with grains reaching up to 0.1 mm dimensions. During thermic space deepening, there is evident preferential gradual melting-down of matrix, which forms 75 % of the rock. Wider surrounding of deepened space is molten down. It is possible to observe gradual increase of microlite relics portion in matrix in direction from deepened opening borders into intact part of rock sample. Glass locally creates digit-shaped offsets into rock matrix. Plagioclase phenocrysts crumble along cleavage planes, glass fills space among fragments. In macroscale, it is possible to observe in andesite distinct fissures which are subparallel with surface of disintegrated sample. Because the molten rock matrix behaves like plastic matter, cracks in proximate surrounding of deepened space were microscopically not observed. Forming of these brittle structures could be joined with less heated parts of the rock sample, or it is possible, that they were fused during thermic sinking process.

So called "pure melt", ergo amorphous glassy matter composed of fully molten mineral components of rock, does not arise during the process of rock melting by thermic space sinking. The matter of solidified melts is heterogeneous. It is a mixture containing glass, mineral fragments, accumulations of fragments and mineral components of spherical or irregular shapes, and also pores primarily filled by gasses. The above mentioned components are distributed irregularly. Presumably, analogical composition will be proven also in melts arising by an operation of high temperatures and pressures generator during future operational experiments. Penetration of mentioned heterogeneous character melt into generated fissures will be a complicated process, mainly due to presence of solid phase. For this reason, it will be necessary to pay increased attention to the study of presence of individual phases in melts.

CONCLUSION

Deepening of hollow in samples No. 2 and 3 was achieved in course of experiments. In case of sample No. 1, deepening was unsuccessful due to technological reasons. It is necessary to widen the group of tested rocks considerably for more complex testing of the thermal disintegration technology. It would be necessary to complete igneous rocks by other types. Sedimentary rocks, which constitute the uppermost part of earth's crust and metamorphic rocks should not be missed out from group of tested rocks. It would be appropriate to test rocks with structurally anisotropic fabrice.

As far as the fissure creation in surrounding of thermally deepened opening and penetration of melt into these structures is concerned, it would be necessary to adjust the technology also in laboratory conditions so as to avoid leaking of melted matter through mouth of deepened hole on the surface of tested sample. Melt would then more efficiently create pressure in lower part of deepened opening and the simulation of practical conditions of sinking would be more realistic.

Study of thermal reworking of rocks in laboratory conditions brought some interesting knowledge, which should be taken into account when examining possibilities of the thermic sinking technology. It is necessary to research zonality of thermal reworking of rock in a greater extent; devote a greater respect to phase determination in melt and also to characteristics of these phases. Furthermore, it is necessary to examine micro-fissures, which are the prime phase for generation of macro-fissures and their systems.

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