ACTA SOCIETATIS METHEORITICAE POLONORUM
Rocznik Polskiego Towarzystwa Meteorytowego
Vol. 11, 2020

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Remarks on a specimen of the 'Gardnos breccia', Norway

Abstract: A specimen of the 'Gardnos breccia' was explored, in which granitic gneiss clasts were found to dominate over a dark matrix. Some clasts retained their cataclastic structure. The matrix of the specimen showed various colours, such as gray, black, and beige, while exhibiting different levels of hardness. In addition, the matrix appeared as an almost isotropic and microcrystalline mass. Quartz, K-feldspar, biotite and plagioclase were identified as the main minerals of the rock. No impact-generated features were observed in the minerals; however, biotite crystals showed decorated kinky bands. In cataclastic clasts, a net of black micro-veins was found, which can be interpreted as pseudotachylite. These veins were composed of a dark non-cohesive glassy mass and carbonaceous micro-aggregates. Furthermore, such carbonaceous aggregated particles were also observed in the black matrix. The white-greenish domains containing isotropic and microcrystalline aggregates of quartz and feldspars showed partial anisotropy. Domains were surrounded by a light recrystallising polycrystalline quartz. Hard black clasts of the matrix and the white-greenish domains showed great similarity in their mineral composition. The results of the X-ray diffraction analyses revealed the minerals as quartz, K-feldspar, muscovite and chlorite (clinochlore). In the white-greenish domains, albite was found as an additional component, whereas it was absent in the black matrix. The black matrix, which was interpreted as a pseudotachylite relic, also seemed to contain allochthonic components. Fluorite, calcite, and Fe-oxides were identified as the secondary minerals that were crystallised in the free spaces of the rock, filling the voids and cracks during the postimpact stage. Oriented glassy spherules, fragments with fluidal texture, and a fragment of the semi-vesicular glassy domain were noted in the specimen, which were probably relics of the suevite breccia. Thus, the analysed breccia seemed to be an intermediate type between the 'Gardnos breccia' and the black-matrix breccia and suevite.

Keywords: breccia, Gardnos structure, impact traits, secondary minerals, XRD

Introduction

The Gardnos impact structure is located about 150 km northwest of Oslo, between Nesbyen and Gol (Fig. 1). It has a diameter of about 5 km and is partly covered by forests. The surrounding mountains reach a height of over 1000 m a.s.l. The

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Hallingdalselva River flows near it from the East. In addition, streams, including the Dokkelvi River, flow through the crater, revealing impact rocks on the surface. The age of the structure has been estimated at ca 500±10 Ma (Staffieri et al. 2019). The impact rocks of the structure were already described in 1945 and interpreted as volcanic. A study conducted by Dons and Naterstad (1992) proved the impact origin of the structure and showed the presence of minerals with impact markers in a mixture with undeformed rocks and crystal fragments in the suevite breccias.

The crystalline basement of the structure is formed by granites, granitic gneisses, quartzites and amphibolites. The latter form a central uplift and scattered outcrops, which were more resistant to impact (Fig. 2). In the structure, quartzites appear dark and their texture seems to be greatly changed, with some parts crushed. In the upper levels, the rocks of the basement are brecciated and are described as a (par)autochthonous, monomictic 'Gardnos breccia'. In general, planar deformation features were not observed in quartz in the breccia; however, some biotite textures are seen indicating the process of melting and recrystallisation. Above the 'Gardnos breccia', there are rocks with an impact melt, while in the upper parts an impact breccia, called suevite, can be found. (French et al. 1995).

The Gardnos structure has been heavily erodded during its postimpact history, especially in its eastern part, towards the Hallingdalselva River valley (Kalleson et al. 2010). Erosion destroyed the original rim of the crater and removed impactites, impactites thrown away from the crater (fallout suevite) and post-impact deposits from over 50% of its surface. This fact makes it difficult to reconstruct the structure of the original crater. The Gardnos crater is a complex impact structure with central uplift. Based on the geometry of the Gardnos bowl and distribution of impactites in it, Kalleson et al. (2008a) estimated the original diameter of the crater at ~6 km, which is greater than the cover of impactites today (5 km). The height of the surrounding crater ring was estimated to be 240 m above the original ground level. The formation of the central uplift required a pressure of 20–35 GPa. Its height was estimated at 350 m compared to the original level of the crystalline basement. Modeling showed that the central uplift was small and steep, and suevite filled the wide, flat moat around it. During the impact, the suevite was transported and deposited probably in the process of gravity flow. This resulted in the formation of elongated fragments of laminar melt in the suevite breccia. After the impact, the suevite slid down the steep walls of the crater toward the center and discovered the lithic breccia in the upper parts of the Gardnos bowl. The total volume of the suevite of the original structure was estimated at 0.3 km^3, and the volume of impact melt at about 0.05 km^3. Field observations proved that the crater deposits showed various resistance to erosion, suevite and post-impact loose deposits were more easily eroded, the lithic Gardnos breccia and its contact with the suevite breccia were more resistant. This fact is visible in the Dokkelvi River valley (Kalleson et al. 2010).

The Gardnos breccias were characterised by the variability of clasts, as both their quantity in the matrix and their sizes and shapes differ (Kalleson 2009). The

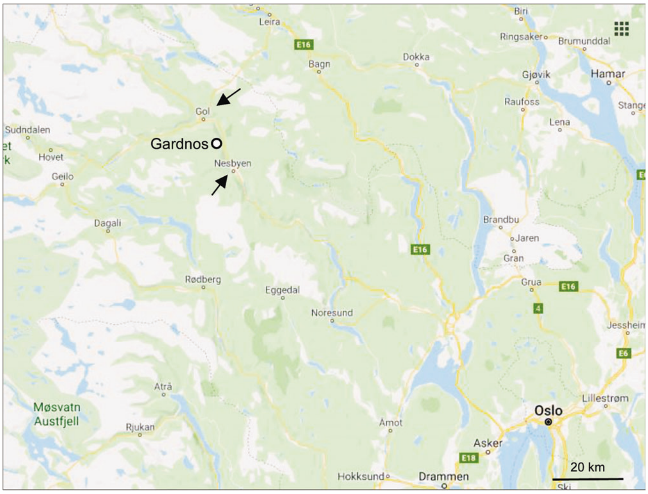

Fig. 1. Location of the Gardnos crater in the northwest of Oslo, between Nesbyen and Gol (arrows). Source: GoogleMaps (completed).

most important phenomenon observed in the crater is that the occurrence of impact melt not only varies in the suevite but also in the fragments of breccia that are in contact with the suevite, despite the fact that field studies have noted a sharp boundary between both types of breccia (Kalleson et al. 2010). Such variation of impact rocks and the diversity of the crystalline basement make the Gardnos impact structure an interesting research object.

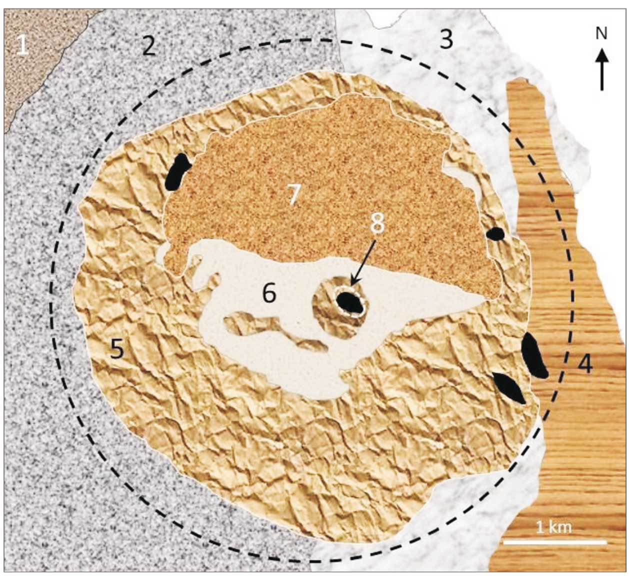

Fig. 2. A simplified geological map of the Gardnos structure (encircled by a dashed black line). 1 – granite and granitic gneiss, 2 – granitic gneiss, 3 – quartzite and quartzitic gneiss, 4 – quartzite and gneiss, 5 – 'Gardnos breccia', 6 – melt-bearing impact breccia, 7 – post-impact sediments, 8 – central uplift, black spots- amphibolite. Source: From Lindgren et al. (2019), modified.

Easy access to the Gardnos structure, together with numerous natural outcrops of impact rocks, for instance in the stream beds, made the Norwegian researchers recognised this region as worthy of protection, and above all as a valuable educational object. An appropriate path has now been created for visitors who are interested in exploring this structure (Kalleson et al. 2008b).

Materials and methods

The object of the study was a flat fragment of a monomictic breccia having a diameter of approximately 15 cm, which was initially described as a 'Gardnos breccia'. The specimen had a polished surface, while the opposite surface was a fracture. The specimen was analysed macroscopically using a stereomicroscope, and its microfragments were studied with an Amplival polarisation microscope (Carl Zeiss Jena). Images were taken using Konica Minolta Dimage-Z6 and Nikon Coolpix A10 cameras. X-ray diffraction (XRD) analysis was performed on two rock samples, which were obtained from the hard black matrix and white-greenish domains, using a Bruker D8 Advance X-ray diffractometer operating at 40 mA and 40 kV. Samples were recorded in the 2θ range of 4–75°, in steps of 0.300°. CuKα radiation having a wavelength of 1.54060 Å was used for the analysis, and detection was carried out using a LynxEye XE-T detector. The obtained results were qualitatively analysed using the Diffrac.suite Eva software.

Results

Macro- and microscopic description

The breccia specimen analysed in the study contained visible angular granite or granitic gneiss clasts differing in their sizes and shapes. These clasts were clearly delimited from the surrounding dark matrix (Fig. 3A). A rock cavity characterised by free crystallisation of minerals (Fig. 3B), as well as a gray or black matrix sticking the rocky clasts (Fig. 3C) was observed in the analysed specimen. In addition, a beige matrix was noted in a fragment of the specimen (Fig. 3D), within which veins with a fluidal texture were detected. When preparing the rock fragments for the microscopic study, it was observed that the black and beige matrices exhibited greater hardness than the gray matrix. Oval- or round-shaped clasts were rarely seen, while elliptic and matrix-oriented ones were even lesser (Fig. 3E). In the black matrix, the clasts were not identified macroscopically on the polished surface. Some of the clasts showed cracks in the form of thin veins formed during the cataclasis process (Fig. 3A, a clast marked in its upper part with a white dashed line). Moreover, the morphology and distribution of the black veins in the clast fragment (Fig. 3F) indicated the possible formation of pseudotachylite. These black veins were sharply delimited from the adjacent minerals and contained the rounded and elongated microclasts of quartz. The larger veins formed a series of injection branches having microdimensions. These veins were definitely capillary

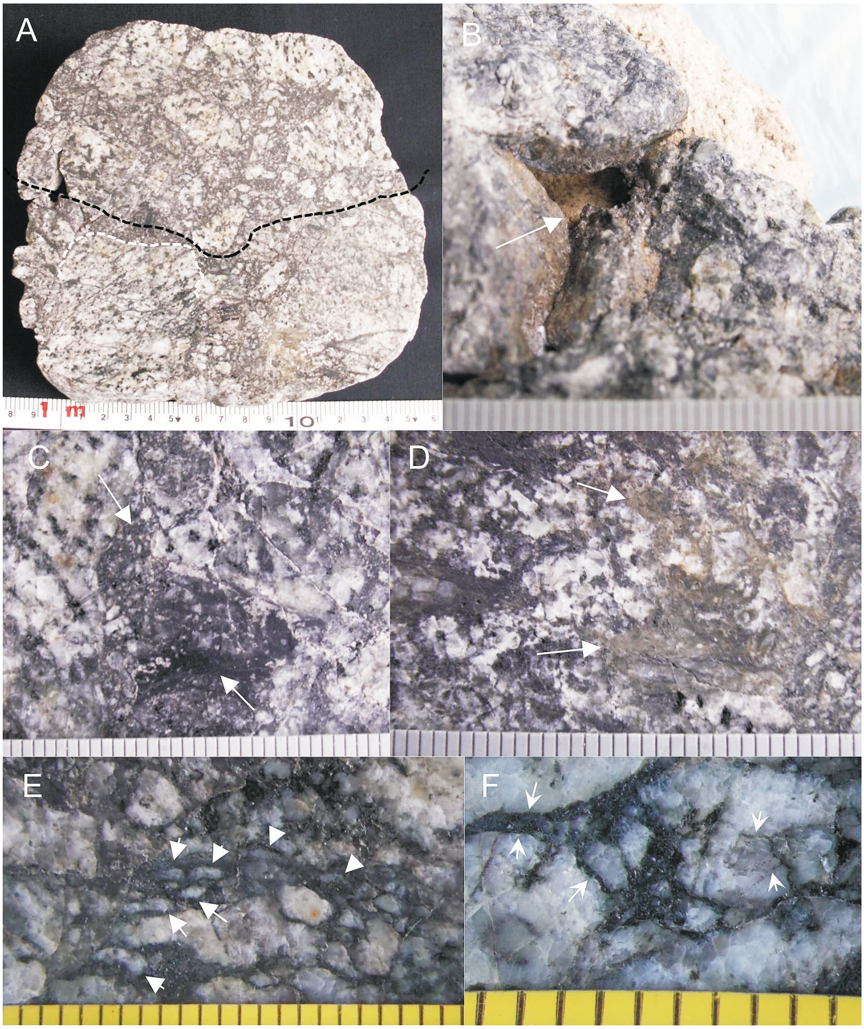

Fig. 3. Macroscopic characteristics of the breccia. A – the studied specimen seen from the polished side; the black dashed line delimits the upper part showing more numerous white-greenish domains, while the white dashed line delimits the cataclased clast in its upper part; B – a rock void showing free secondary crystallisations, C – the gray matrix showing tiny light clasts (upper arrow), within which a fragment of the black matrix is seen without any visible clasts (bottom arrow); D – the area of the beige matrix (arrows), E – oval, elongated and directed clasts (arrows), F – black microveins sharply delimited from the surrounding rock (left arrows), vein anastomosis (middle arrow), and capillary veins (right arrows). A – scale in cm and mm, B-F – scale in mm.

and disappeared in the surrounding rock. In the microscopic image, the matrix of these veins was found to be structurally homogeneous and appeared glassy, dark, and isotropic, showing signs of anisotropy.

In the clasts embedded within the gray matrix, the fragments of the hard black matrix were observed in the form of melt (Fig. 4A). This type of matrix also appeared as a separated domain and was observed on a fractured side, which proved that the clasts in the black matrix were chronologically older than those the gray

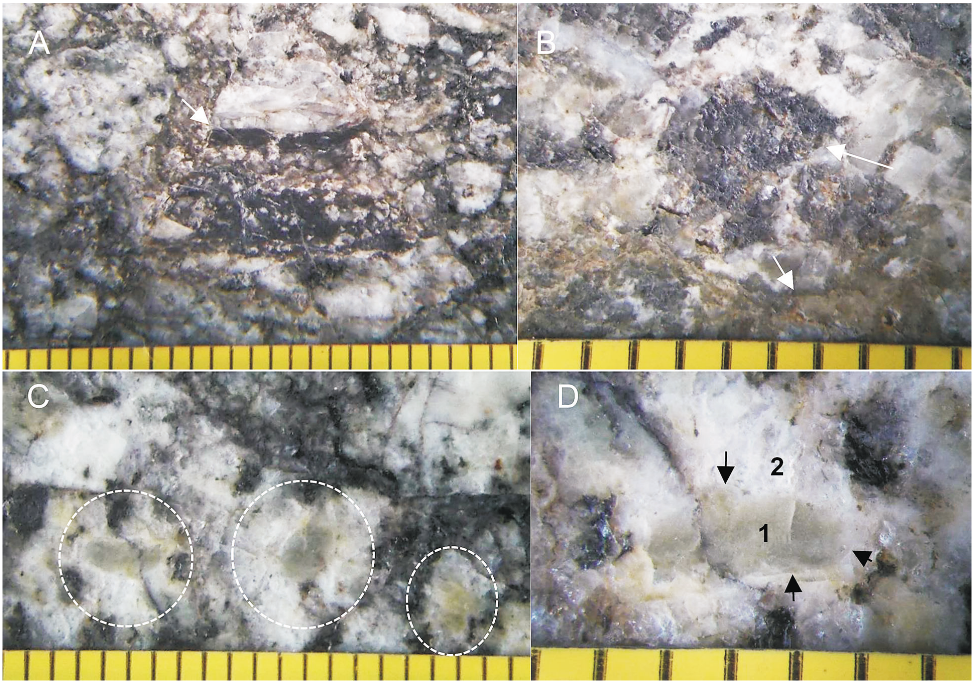

Fig. 4. Clasts and postimpact domains of breccia. A – a clast containing fragments of the black matrix (arrow), B – the black domain (upper arrow) and beige matrix (bottom arrow) showing microcavities resembling a vesicular texture, C – white-greenish domains in the granitic gneiss clasts (outlined by dashed white lines), D – a greenish center of the domain (1) sharply delimited (arrows) from the surrounding, recrystallising light quartz (2). Scale in mm.

matrix. In the breccia region, where hard beige and black matrices were present (Fig. 4B), microcavities forming a semi-vesicular texture were noted. A characteristic feature of the breccia specimen was the presence of white-greenish domains in the large granite clasts, which revealed a partly mat center on the polished surface.

The white, outer part of the domain was observed to be consisted of a bright, transparent, recrystallising quartz crystals that were clearly recognisable under the magnifying glass (Fig. 4C). The greenish center of the domain (1), which had a typical automorphic outline of feldspar, was sharply delimited from the surrounding quartz (2). This boundary was wavy, and was created by matching the greenish center with the uneven surface of the recrystallising polycrystalline quartz (Fig. 4D). The quartz grains present in the domain showed mutual wavy contacts, which were rarely straight, indicating the grain boundary area reduction. The white-greenish domains were identified to be quantitatively dominating the breccia by zone, while fewer domains were found in other regions, including the upper part of the large cataclased clast (Fig. 3A).

Furthermore, microscopic observations with partially crossed nicols revealed the presence of 'kinky' bands in biotite (Fig. 5A). These bands were noted in about 10% of the analysed samples. Cracks in a single crystal appeared parallel, decorated, and twisted in relation to the twin plates at an angle of approximately 70° and

130°. Oriented isotropic spherules were very rarely observed in the analysed slides (Fig. 5B). In addition, the white-greenish domains contained an isotropic and microcrystalline material (Fig. 5C), while the gray matrix that was dominating in the breccia contained clasts of distinct crystals (Fig. 5D). The black and beige matrices displayed a different structure, which was harder compared to the gray matrix. These matrices appeared microcrystalline and isotropic in parts (Fig. 5E). The breccia fragment revealing a semi-vesicular texture contained isotropic melt, which was partially recrystallising (Fig. 5F).

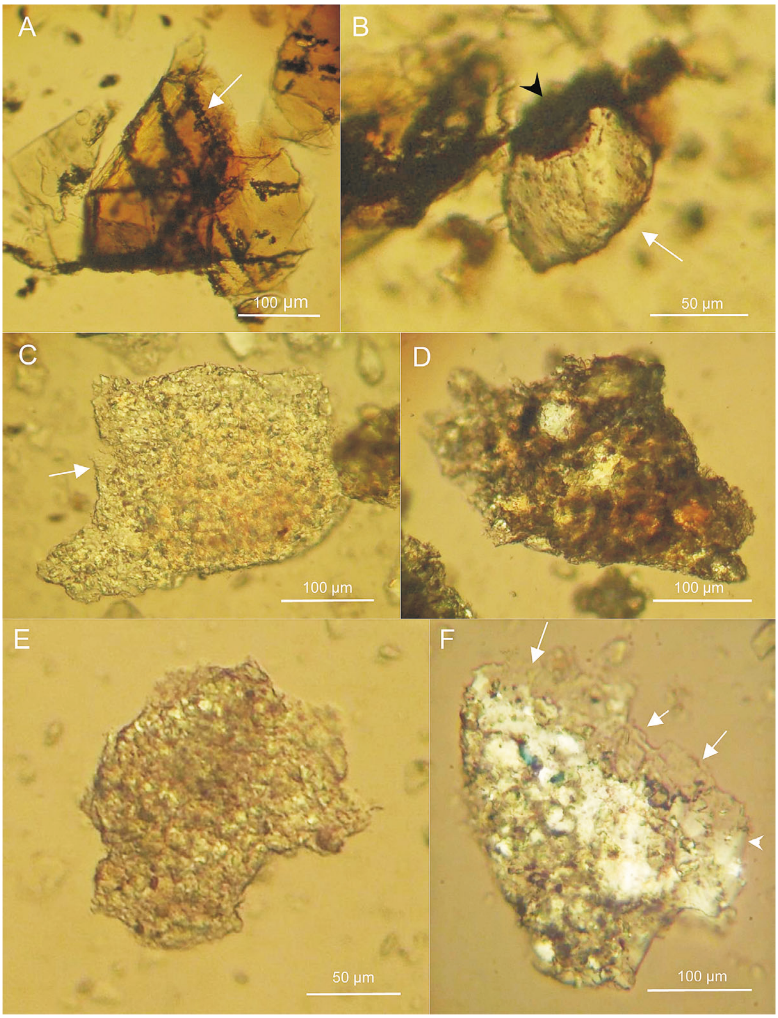

Fig. 5. The impact structures of the 'Gardnos breccia', A – decorated 'kinky' bands (arrow) in biotite plates, B – an isotropic oriented spherule (white arrow) in contact with amorphous carbon(?) aggregate (black arrowhead), C – a piece of microcrystalline quartz-feldspar melt (detected by XRD) with an isotropic fragment (arrow) isolated from the white-greenish domain, D – a fragment of the gray matrix showing light crystalline clasts and black carbonaceous(?) particles, E – a fragment of the microcrystalline black matrix, F – a fragment taken from the beige semi-vesicular matrix showing an isotropic melt (arrows) and partial recrystallisation (white arrowhead). Nicols partially crossed.

X-ray diffraction analyses

XRD analyses were performed for the two samples of the 'Gardnos breccia' taken from (1) – the black hard matrix (see Figs 3C and 5E) and (2) the white-greenish domains (see Figs 4C, D and 5C), and the results are presented in the diffractograms (Figs 6 and 7). Both the analysed samples showed great similarity in their mineral composition, with quartz and potassium feldspar found to be dominating. In the sample taken from the white-greenish domains, Na-feldspar (albite) was also detected (Fig. 7). In addition to the mineral composition, the microscopic image of the samples also appeared similar (compare Fig. 5E and 5C). However, the minerals in both samples were found to form different structures in the breccia (matrix *versus* rocky clasts). In addition, muscovite detected ion both samples was not macroscopically confirmed in the examined specimen of the breccia. Probably it occurred as sericite/illite.

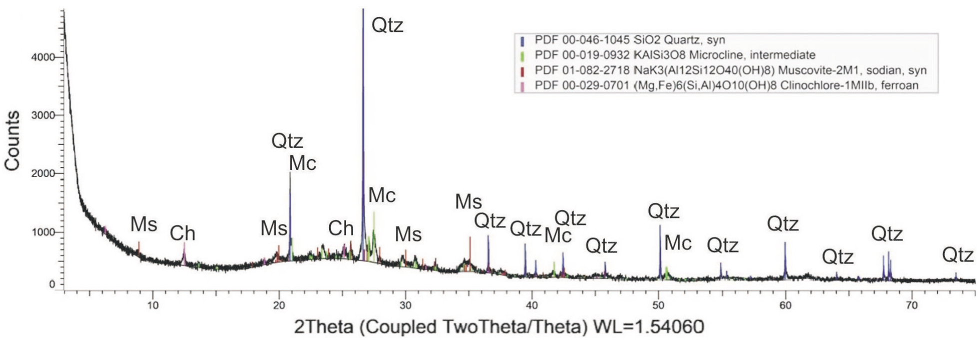

Fig. 6. X-ray diffractogram of minerals taken from the hard black matrix of the 'Gardnos breccia'. Abbreviations used: quartz – Qtz, microcline – Mc, muscovite – Ms, chlorite (clinochlore) – Chl. On-line in colours: Qtz – blue, Mc – green, Ms – brown, and Chl – violet.

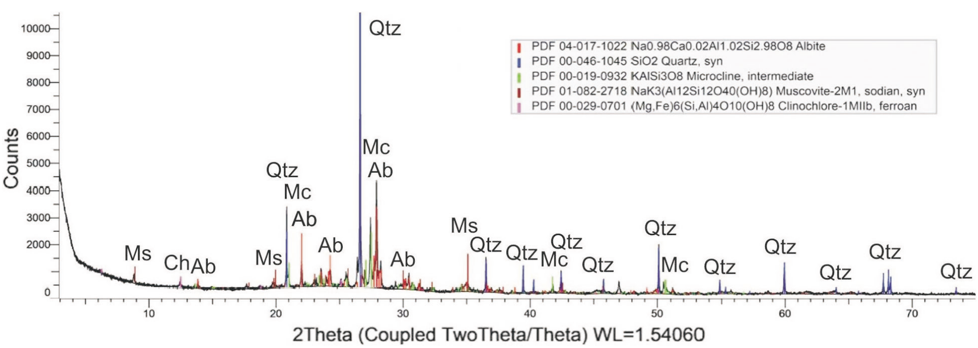

Fig. 7. X-ray diffractogram of minerals taken from the white-greenish domains of the 'Gardnos breccia'. Abbreviations used: quartz – Qtz, microcline – Mc, albite – Ab, muscovite – Ms, chlorite (clinochlore) – Chl. on-line in colours: Qtz – blue, Mc – green, Ab – red, Ms – brown, and Chl – violet.

Secondary mineralisation

A free formation of fluorite crystals [d (I): 3.155 (100), 1.932 (65), 1.647 (20), 1.366 (7); XRD analysis] was noted in the rock voids (Fig. 8A). This mineral also filled small cavities, branching out of them into fine veins (Fig. 8B). With crossed nicols, it appeared isotropic and was stained slightly purple (Fig. 8C). Larger free spaces in the breccia were covered by calcite as compacted lamellar crystals, which in turn filled smaller voids (Fig. 8D). Some iron oxide deposits were also noted in the rock. The presence of sericite/illite (muscovite) and a trace amount of albite (XRD analysis) indicated hydrothermal alterations in the recrystallising melt of alkaline feldspars (K, Na-feldspars).

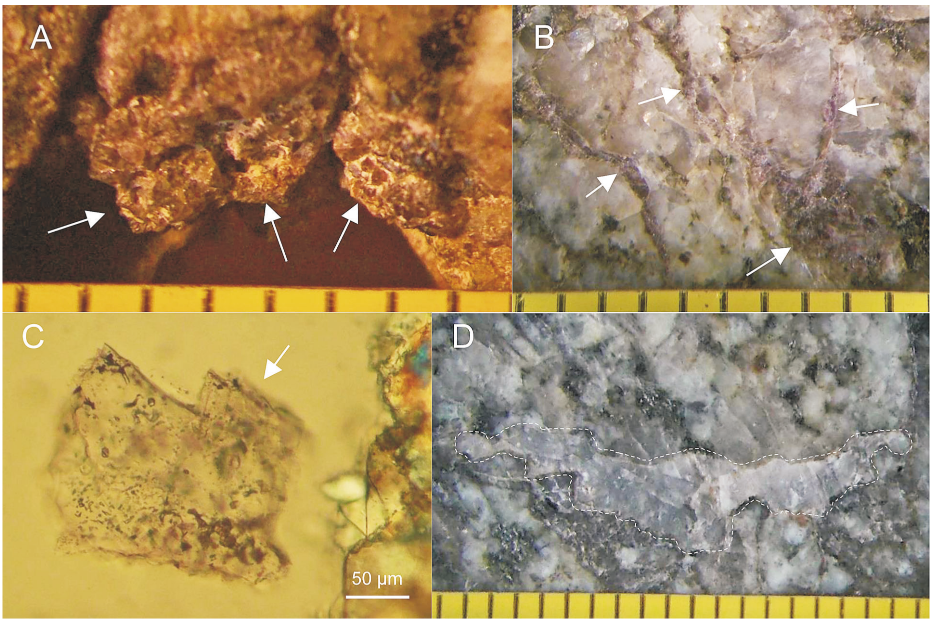

Fig. 8. Secondary minerals of the breccia – crystallisation of fluorite and calcite. A – idiomorphic fluorite crystals seen in the rock cavity (arrows), B – fluorite seen in the veins (upper arrows) and filling a cavity (bottom arrow), C – an isotropic fragment of fluorite crystal, D – a void filled with calcite (outlined by a dashed line). C – nicols partially crossed. A, B, D –scale in mm.

Discussion

A macroscopic view of the examined rock allowed classifying it initially as a 'Gardnos breccia' known in the literature (French et al. 1995; Kalleson 2009). The breccia contained clasts varying in dimensions from sub-millimeter to several--centimeters, embedded in a dark matrix. Directional textures were very rarely seen on the specimen. In the crater rock outcrops, they were also few (Kalleson et al. 2010). Some of the clasts were cataclased, co-creating the breccia in this form. This means coexistence during the impact of the two processes, brecciation and cataclasis. Clasts arising as a result of both these processes were also described by French et al. (1997). This postimpact state, seen on the surface of the Gardnos structure would correspond to the much greater depths at which the two processes coexist tectonically (Sibson 1977). In the Rochechouart-Champagnac structure, the cataclasis zone was dependent on lithology and was observed in gneisses, while granites were brecciated (Bischoff and Oskierski 1987). The directed oval microclasts seen in the breccia (Fig. 3E) indicated their formation during sliding movements that occurred together with fluidisation of the rock material, possibly in the form of pseudotachylite. This was also confirmed by the structure of fine veins in the cataclased clast (Fig. 3F) and fragments of the black, hard matrix (Fig. 4A), which are probably a relic of the larger pseudotachylite vein. This vein containing elongated quartz clasts, parallel to its course, which made it similar to the vein of pseudotachylite from the Ries crater, as well as microveins chaotically arranged in the specimen (Fig. 3F), point to the pseudotachylite formed by the impact (Kosina 2015). The creation of these veins in the melt injection process cannot be ruled out. The variability of pseudotachylite has also been indicated by studies of its melt in the Rochechouart structure, in which its composition was different. It contained a vitreous matrix, which was partly chloritised and recrystallised, recrystallising clasts and interstitial glass between quartz crystals (Bischoff and Oskierski 1987).

The 'Gardnos breccia' has been described as a (par)autochthonous, monomictic rock (Dons and Naterstad 1992; Kalleson et al. 2010). The XRD-analysis showed a similar mineral composition of the black hard matrix and the white-greenish domains from the granitic-gneiss clasts. Quartz and K-feldspar were identified as the dominant minerals, while albite was also found in the white-greenish domains. These data basically confirm that the breccia is monomictic.

The degree of brecciation was found to vary within the Gardnos structure and decreases toward its outer parts. Moreover, the variability of the 'Gardnos breccia' is dependent on lithology. The 'Gardnos breccia' was clearly delimited from the suevite breccia located above it, but there were sites with mutual displacements of both the breccias and their mixing was observed. Thus, the fragments of the brecciated rocks of the basement were observed in some parts of suevite. Finally, a transition zone thick up to several-meter characterised by a mixture of the 'Gardnos breccia' and suevite has been considered (Kalleson et al. 2010). A similar transition state was also found in the Rochechouart crater, between the clastic rock melt and the suevite breccia (Sapers et al. 2014). Furthermore, K-feldspar was found to dominate in the matrix of 'Gardnos breccia' (French et al. 1997), while the melts of suevite breccia mainly contained quartz, chlorites, and a small amount of feldspar (Kalleson et al. (2010).

The results of the XRD analysis of the black matrix showed the dominance of quartz, with a smaller amount of K-feldspar and chlorite (clinochlore). These findings suggest that the analysed specimen is an intermediate type between the lytic breccia and the suevite breccia.

Another type of breccia called 'black-matrix breccia' was found in the contact between the 'Gardnos breccia' and the suevite breccia. This was characterised by a predominance of the black matrix over light rock and mineral clasts, and displayed rare but distinct shock features (French et al. 1997). Kalleson (2009) described it as a variant of the 'Gardnos breccia'. In addition, planar deformation features in quartz grains were identified in a Gardnos breccia sample from the Branden drill, located approximately 1 km northwest of the central uplift (Kalleson 2010). This structural characteristic classifies the Gardnos breccia as closer the impactites covering it. The above mentioned variation of the breccias and the structures documented in the examined specimen justify its placement in the following series of breccia variants:

Gardnos lytic breccia ↔ tested specimen ↔ black-matrix breccia ↔ suevite breccia.

In the suevite breccia from Gardnos, there were detected numerous fragments of melt showing fluidal and laminar texture (Kalleson 2010). The relics with fluidal texture, the isotropic spherules, the fragments of the black, isotropic, microcrystalline matrix, and the glassy, recrystallising domain identified in the examined specimen (Fig. 5A, E, F) all together indicate the possibility of interaction between the tested breccia and suevite. It has been reported that glassy spherules are usually associated with the formation of suevite and are also observed in the suevite of the following structures: Ries, Rochechouart-La Valette, Rochechouart-Chassenon, Jänisjärvi, Ilyinets, Ternovka, and Puchezh-Katunki (Kosina 2017a, b; 2018, 2019). Apart from the glassy spherules, several other types of spherules, including lithic ones, were found in the suevite of the Ries structure (Sears et al. 1996).

'Kinky' bands are another structure found in the minerals that were changed by the impact. These were identified in biotite and muscovite in the breccias of the Rochechouart-Chassenon structure (Ferrière and Koeberl 2007). Such a change is quite common and has also been indicated in several other craters, including Ilyinets (Kosina 2017a) and Puchezh-Katunki (Kosina 2019). 'Kinky' bands were also found in the Gardnos suevite (Kalleson 2010). However, the decorated 'kinky' bands found in the 'Gardnos breccia' are an unusual phenomenon.

Another rare characteristic noted in the Gardnos impactites was the presence of amorphous carbon, mainly in the black matrix that filled even the smallest cracks in the breccia (Dons and Naterstad 1992). The carbon content in the 'Gardnos breccia' was estimated to be as low as 0.07–0.70 wt.% (Gilmour et al. 2003), and the composition of the carbon isotope proved its organic origin (French et al. 1997). In the Gardnos suevite, carbon particles were found to be associated with the melt (Kalleson et al. 2010). In addition, amorphous carbonaceous particles were found along with the glassy spherule and in the black matrix of the examined specimen. In fact, they were present in varying amounts in all the analysed microscopic slides. It should be mentioned that according to French et al. (1997) carbon found in the Gardnos crater could origin from two sources, as follows: the Proterozoic Biri Shales located about 100 km E from Gardnos, and the organic marine sediments deposited *in situ* before the impact. In addition, Gilmour et al. (2003) also considered the Cambrian Alum Shales located about 50 km east-north-east from the crater as the C source. Both types of shales could be a cover of the crystalline basement during the impact. The discovery of diamonds in the Gardnos suevites proved that graphite carbon was transformed by impact *in situ*. The Biri shales are believed to contain too little C, compared to the Alum shales, to be its donor to the Gardnos impactites. Two stages of carbon introduction into the Gardnos impactites were proposed, during the impact from the crystalline basement and the organic sediment deposited on it, and after the impact, in the hydrothermal processes during cooling of the crater or later in the processes of the regional metamorphism. The Biri and Alum shales could be included in the latter processes. The later stages of the crater metamorphism were characterized by the structural variability of carbon in impactites, from the poorly ordered form to the crystalline form of graphite (Gilmour et al. 2003).

In the Gardnos structure, the post-impact transformations of minerals were manifested by the formation of chlorite, stilpnomelane, amphiboles, and Na- and K-feldspars, and by recrystallisation, which, however, did not lead to the removal of minor impact textures. Chlorite and stilpnomelane were detected in the fine veins (French et al. 1997). The mixed melt of quartz and feldspar had numerous vesicles containing chlorite and other phyllosilicates (Kalleson et al. 2010). Thus, the recrystallising isotropic quartz-feldspar melt of the black matrix and the white--greenish domains as well as the presence of chlorite (clinochlore) proves that similar processes had occurred in the analysed specimen. It is known that a decrease in the impact temperature and pressure leads to the transformation of minerals. This supports that at a temperature below 300°C, biotite is changed to chlorites (Borkowska and Smulikowski 1973) and such a reaction might have also occurred in Gardnos (French et al. 1997). Moreover, Lira and Ripley (1992) demonstrated the transformation of biotite in biotite monzogranite to clinochlore during the hydrothermal processes. The XRD analyses of both the Gardnos samples changed by the impact examined in the present study showed the presence of chlorite (clinochlore), not biotite. However, biotite was present in the less changed parts of the rocky clasts. French et al. (1995) believed that the main transformations that can be detected in the Gardnos impactites following the impact are the rock melt recrystallisation and probable crystallisation of chlorites in the matrices. Both these types of mineral transformation were observed in the samples analysed in the present study. Around the greenish center of the domain of the microcrystalline quartz-feldspar melt, recrystallisation of polycrystalline quartz had taken place, according to Passchier and Trouw (2005), during the process of grain boundary area reduction.

Thus far, the post-impact hydrothermal mineralisations of the 'Gardnos breccia' have not been widely reported in the literature. In rock voids, calcite coexists with fluorite, and iron oxides are less commonly observed on the fractured surface. In a review of hydrothermal activity occurring in the impact structures formed on the crystalline basements, Naumov (2005) reported that secondary mineralisation processes were most often noted in the case concerned chlorites, calcite, and zeolites. Fluorite was detected only in the crater Ilińce. Furthermore, Bischoff and Oskierski (1987) identified fine fluorite veins in the monomictic granite breccia in the Rochechouart-Champagnac structure.

Concluding remarks

The macro- and microstructural features suggested that the analysed specimen of the 'Gardnos breccia' is an intermediate between the lytic breccia and the breccia with a large amount of melt. Some characteristics observed in the samples indicated that an interaction had occurred between the specimen and the suevite breccia. The literature data reveal sites with a blurred border between different impact deposits and the possibility of their mutual penetration. This proves, that during the first stages of the crater formation, the displacement of impactites inside and outside the crater disturbed the process of the continuous deposition of material in the form of distinct layers, and it is corroborated by the structure of the specimen under study. Partial recrystallisation of minerals was noted in the specimen, and in part they were isotropic melts and also glassy. The mineral composition of melts was similar to the rocky clasts, which confirms the local origin of the breccia.

However, the question about the presence of sericite/illite in both melts, in the black matrix outside the clasts and in the white-greenish domains in the granite gneiss clasts, and the origin of this mineral, autochthonic from local rocks and/or allochthonic from the pre-impact deposit, is worth considering. The finding of suevite allochthonic elements in the breccia may also justify this question.

The possibility of pyrometamorphism in the structure of Gardnos in the presence of organic carbon (Spray and Thompson 2008) may explain some parageneses of minerals, including muscovite (Brearley 1986), besides its hydrothermal origin from transformed alkaline feldspars. The recognition of the black hard matrix as a relic of pseudotachylite supports the conclusion that the process of its creation with the participation of allochthonic components was different from the formation of the rocky clasts and the gray matrix. The originality of the tested breccia is strengthened by the new secondary mineralisation processes not confirmed in the current references on Gardnos.

Acknowledgement

The authors would like to thank Dr. Marta Prell for performing XRD analyses and for cooperation in the study.

Streszczenie

Uwagi o okazie 'brekcji Gardnos', Norwegia

W egzemplarzu skały znanej jako 'brekcja Gardnos' klasty granito-gnejsu dominują nad ciemną matriks. Niektóre klasty zachowały strukturę kataklastyczną. Matriks wykazywała różne kolory, szary, czarny i beżowy, a także różną twardość. Matriks była głównie masą izotropową i mikrokrystaliczną. Kwarc, K-skaleń, biotyt i plagioklaz są głównymi minerałami skały. W minerałach nie zaobserwowano struktur charakterystycznych dla impaktu, jednak w kryształach biotytu odnotowano dekorowane spękania 'kinky'. W klastach kataklastycznych sieć czarnych mikrożyłek można

interpretować jako pseudotachylit. Te żyły składają się z ciemnej, niespoistej szklistej masy, w tym z węglistych mikroagregatów. Zagregowane takie cząstki zaobserwowano również w macierzy czarnej. Biało-zielonawe domeny mikrokrystalicznych agregatów kwarcu i skaleni wykazały częściową anizotropię w partiach izotropowych. W domenach, zielonawe centra stopu skaleniowego otoczone są jasnym, rekrystalizującym polikrystalicznym kwarcem. Twarde czarne klasty macierzy i biało-zielonawe domeny charakteryzują się dużym podobieństwem w składzie minerałów. Analizy dyfrakcji rentgenowskiej wykazały, że były to kwarc, K-skalenie, muskowit i chloryt (klinochlor). W biało--zielonawych domenach dodatkowo występuje albit, nieobecny w czarnej macierzy. Macierz ta interpretowana jako relikt pseudotachylitu zawiera prawdopodobnie również składniki allochtoniczne. Fluoryt, kalcyt i tlenki żelaza były minerałami wtórnymi krystalizowanymi w wolnych przestrzeniach skały i wypełniały puste przestrzenie i pęknięcia w procesach poimpaktowych. Zorientowane szkliste sferule, fragmenty o fluidalnej teksturze i fragment szklistej domeny semi-pęcherzykowej są prawdopodobnie reliktami brekcji suevitu. Analizowana brekcja wydaje się być typem pośrednim między 'brekcją Gardnos' a brekcją z czarną matriks i suevitem.

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