Sunburn in the Tertiary Basalts of Silesia (SW Poland)

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ABSTRACT: The article presents an outline of issues connected to the basaltic sunburn. Results of research on this phenomenon observed in the Tertiary basaltic rocks of SW Poland are presented. Characteristics of these rocks as well as research results on the range and location of the areas they occur in are put forward. Parameters of the sunburn rocks ("spots" diameters, distance between them and content of the substance forming the "spots") change in a wide range and are interdependent. Forms of the sunburn areas are varied: irregular (pocket-like), lens-like, pseudolayer-shaped, even pipe-shaped. Sizes of the sunburn areas range between 1 m and 150 m, and the location of these areas does not correlate with the distance from the edges of the basaltic bodies. Results of the mineralogical research: microscopic (in transmitted light) and X-ray structural analysis of powder are presented. Sunburn rocks have a stable structure and the geological variety is marked only by the presence of analcite only in the sunburn "spots" and nepheline outside the "spots". These minerals are of sub-microscopic size and their presence was determined by the X-ray structural analysis. A history of research on the origin of this phenomenon as well as conclusions of the author's analysis of the sunburn issue are submitted. In the light of the author's research, the hypothesis connecting sunburn origin with the late-magmatic crystallization of analcite and nepheline from the residual melt was recognised as the most probable.

KEY WORDS: basalt, Tertiary, Silesia (Poland), sunburn, Sonnenbrand.

Introduction

Sunburn is an untypical sort of disintegration, characteristic for basaltic rocks. It has been examined for over 200 years but some of its substantial aspects (extent, formation of sunburn areas, even the origin) have remained unexplained till today.

A detailed descriptions of the sunburn have been provided by e.g. Leppla (1901), Hibsch (1920), Pukall (1939, 1940), Śliwa (1975) and Zagożdżon (1998, 2001a, b). In the first stage of sunburn development, the so-called "spots" appear – three-dimensional, isometric fair discolorations (Figs. 1, 2). Their diameter varies between tenths of a millimetre and 20 mm (Leppla 1901, Hibsch 1920, Zagożdżon 1998, 2001b). Then, a system of irregular so-called "capillary cracks" ("Haarrise" in German literature) develops, usually running between the "spots" (Fig. 2). Formation of these disjunctions consequently leads to breaking up of the sunburn basalt into debris and smaller fragments.

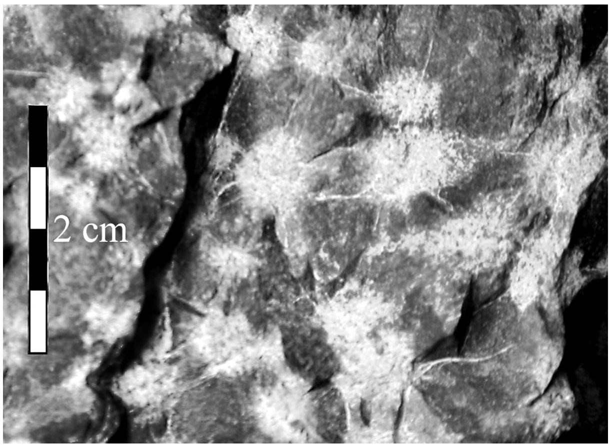

Fig. 1. Image of the sunburn rock.

The sunburn should not be confused with any of the miscellaneous symptoms of basalt weathering, mineral incrustations on the rock surface, lava breccias or tuffs.

Sunburn has been described since the end of the 18th century (Voigt 1873 and Faujas de St. Fond 1786 see Pukall 1939). Interest in this phenomenon considerably increased at the end of the 19th century, and it was particularly keen in the first four decades of the 20th century. The most important writings are those of Leppla (1901), Hibsch (1920), Pukall (1939, 1940) as well as Ernst and Drescher–Kaden (1940). In the post-war period, publications about this phenomenon became much more rare, and another increase in research took place probably only in the 1980s and 1990s (e.g., Schreiber 1991, Kühnel at al. 1994, Zagożdżon 1998, www.uni-essen.de/geologie 2000).

In the region of the Lower Silesia and Opole Silesia (SW Poland), 307 basaltic bodies have been described. About 63 of them were recognized as the eruptive foci, while more than 90

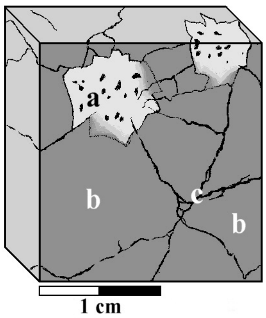

Fig. 2. A sketch of the sunburn rock, a) a "spot", b) healthy parts of rock, c) capillary cracks.

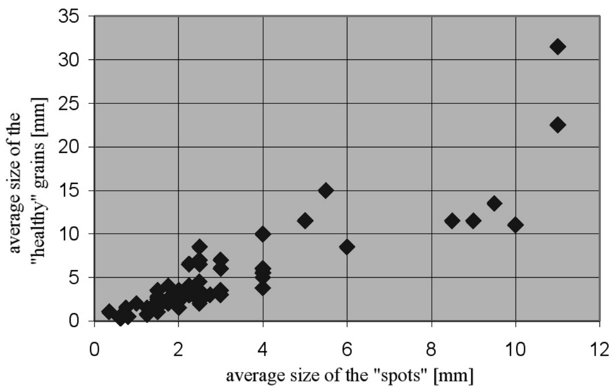

Fig. 3. Correlation between the size of “spots” and healthy grains of the sunburn rock.

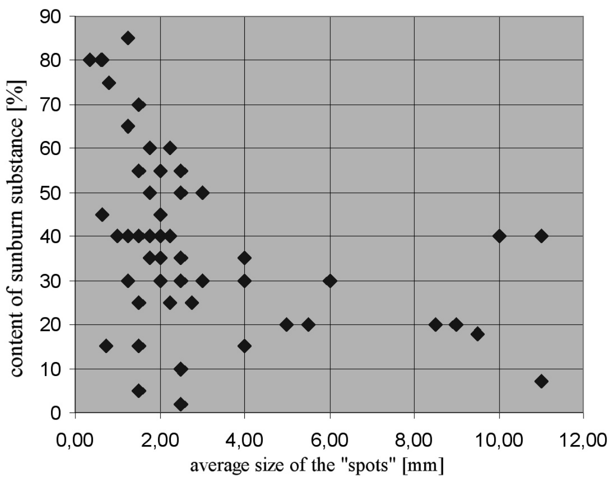

Fig. 4. Correlation between the average size of the “spots” and content of the sunburn substance.

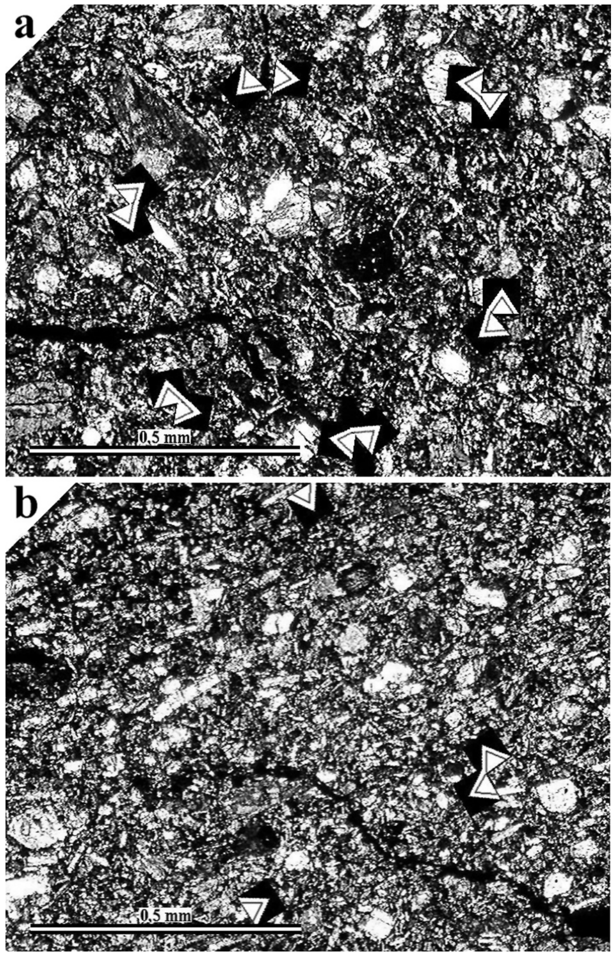

Fig. 5. Thin sections of sunburn rocks;
a) constant mineral composition and structure of a sunburn rock; a “spot” in the centre of the photo (basanite, Wilcza Góra Quarry, polarized light);
b) a penetrative fluidal structure, both in a “spot” and in a healthy part of a rock; the white arrows show a limit of the “spot”, the “spot” is on the left side of the image (tephrite, Gracze Quarry, polarized light).

are rests of lava sheets (Śliwa 1974). Basaltic rocks in this area belong, according to the TAS classification, among foidites, tephrites, basanites, trachybasalts, picrobasalts and trachytes (Kozłowska–Koch 1987). Author’s own research covered 83 sites located both within vents or veins and within lava sheets and lava flows. The presence of sunburn was recorded at 63 % of these sites (including 93 % of operated quarries).

Characteristics of the sunburn rocks in the SW Poland

Sizes of the “spots” in the analysed sunburn rocks ranged from 0.2 mm to 15 mm, however, in most cases (at 76 % of the sites analysed) it was about 1–5 mm. “Spots” usually had an irregular, though isometric, shape, only in few cases they were almost perfectly round. The discolorations were usually light grey, rarely red. The content of sunburn substance (forming the “spots”) in the total rock weight was considerably variable: 3–85 % of the rock volume, and at the same time, its proportion was stated at about 25–50 % in about 50 % of cases. In few cases did the sunburn substance predominate in the rock volume, while the healthy basalt formed small isolated bodies. Healthy parts of the basalt have various sizes: from extremely tiny (invisible to an unaided eye) to about 35 mm (Zagożdżon 1998, 2001b).

It has been stated that there exists a correlation between the “spots” diameter and the size of the healthy parts of sunburn rock (Fig. 3) as well as a dependence between the spots diameter and the content of sunburn substance (Fig. 4).

Sunburn “spots”, in most cases, completely lose their distinctness in the microscopic view (transmitted light). There is no structural difference between them and the healthy fragments of the sunburn rock (Fig. 5a). While applying a mag-

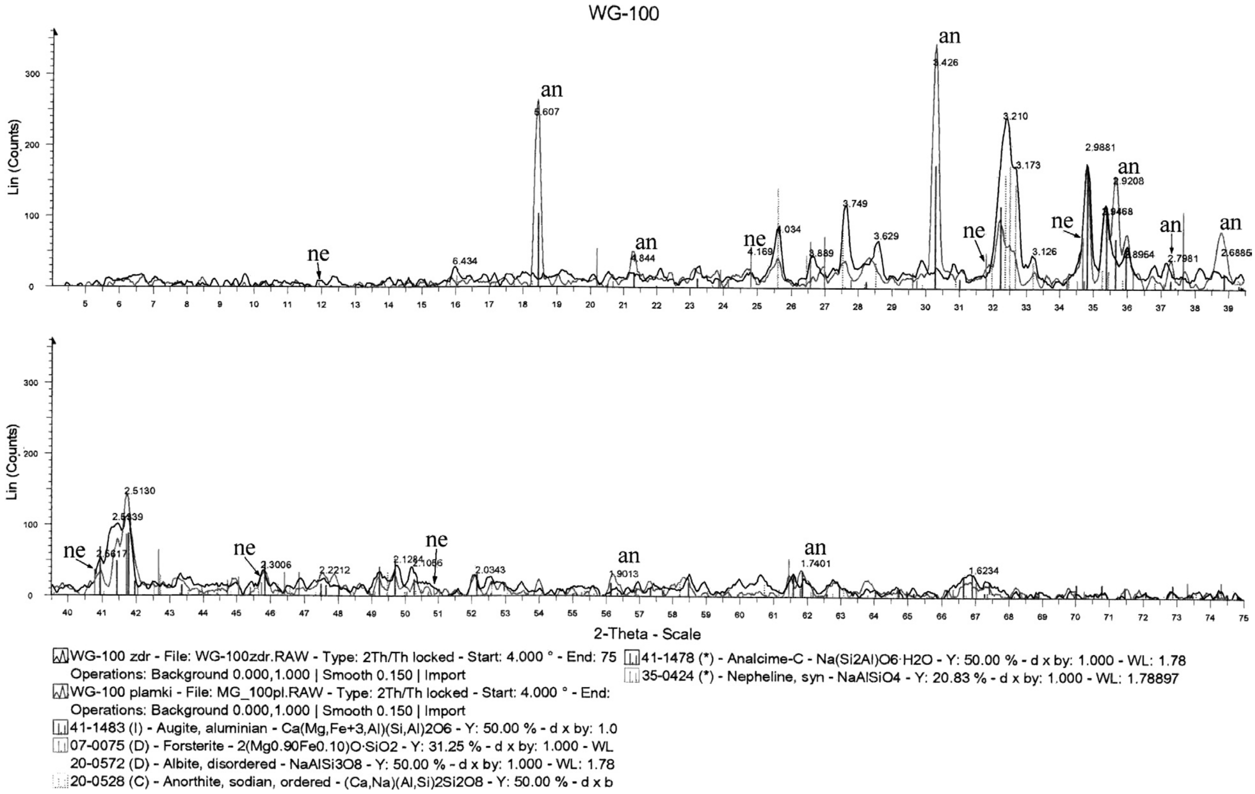

Fig. 6. Powder diffractogram of the sunburn material (grey) and healthy parts of rock (black); the peaks of analcite (an) and nepheline (ne) are marked.

nification (up to 150 times) one cannot see a difference in the mineral composition, either (Fig. 5b). Presence of the mineral difference has been proven by a powder diffraction analysis of rock using the DSH method (Zagożdżon 2001b, Zagożdżon and Wojciechowska 2001). Sunburn "spots" proved to be rich in analcite, while the healthy fragments of sunburn rock are enriched in nepheline (Fig. 6). These minerals are probably of submicroscopic size and cannot be observed by the magnification applied.

Sunburn "spots" are usually distributed in a homogenous manner (distances between them are constant within the range of one outcrop). In few cases one comes across relatively narrow areas of the "spots" concentration described in literature by Lord (1894 see Pukall 1939), Leppla (1901) or Ernst (1960). At the studied sites, such "mesostructures" had the form of concentrations of "spots" lying only inside the basaltic columns (Fig. 7a) or only near to their walls (Fig. 7b; Zagożdżon 2001a). Less frequently did the "spots" form irregular and much varied areas not related to basaltic jointing. Sometimes, streaks-like areas of the rock with fine "spots" are present within the sunburn basalt with particularly large "spots" (Fig. 8; Zagożdżon 1998).

Attempts to establish the petrography of sunburn rocks were made since the beginning of the 20th century (e.g., Leppla 1901, Hibsch 1920, Hoppe 1936 – see Zagożdżon 2001b). It has been considered that alkaline types and those containing nepheline were more prone to the formation of sunburn. Analysis of all the literature data available let the author claim that the sunburn most often appears in basalts and basanites (according to the TAS classification), and according to older classification in: nepheline basalts, olivine basalts, nephelinites, trachyandesites, ankaratrites (Zagożdżon 2001b).

Form of the sunburn areas

In the literature one can find few references to the shape and size of the sunburn areas. Hoppe (1936) reported that they have lens-like and pocket-like forms of various sizes or they constitute "vast portions" within the basaltic substance, while Hibsch

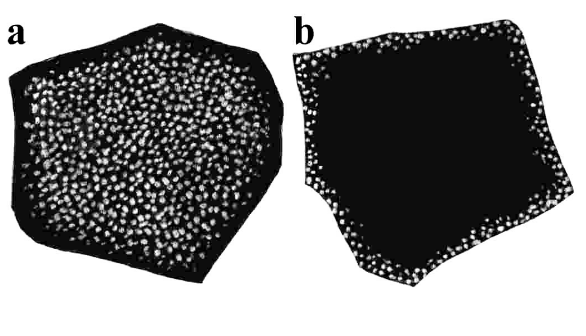

Fig. 7. Schematic sketch of "mesostructures" related to basaltic jointing.

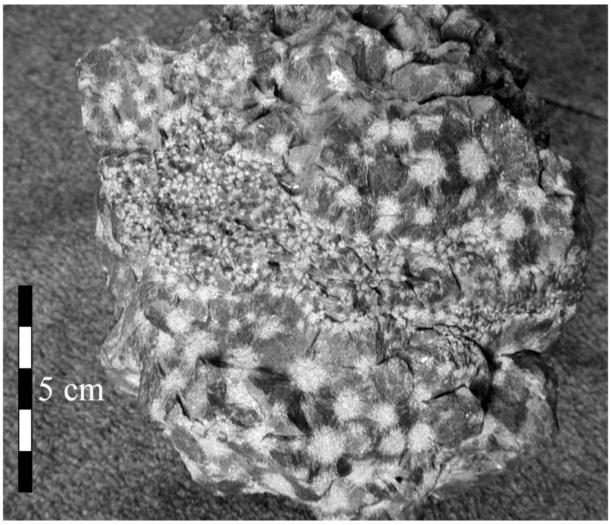

Fig. 8. Streak-like area of basalt with fine "spots" in basalt with large "spots".

(1920) estimated that the sunburn area examined by him measured 100 square metres. Author's own research allowed to observe that the sunburn areas take much varied forms: irregular (pocket-like), lens-like, pseudolayer-shaped, even pipe-shaped (Zagożdżon 1998, 2001b). Sizes of the sunburn areas range between 1 m and 150 m.

According to the pre-war German literature, the occurrences of sunburn were rather connected to vent areas (Hibsch 1920, Hoppe 1930, 1936, Henglein 1939). In Polish literature opinions on this subject are much more divergent. Geological records of the basaltic deposits provide information about the presence of phenomena of this kind only in the volcanic vents or only in the lava sheets and lava flows, or in all these forms of basaltic rocks (see Zagożdżon 2001b). Śliwa (1975) supported the last possibility, additionally observing that in the lava flows, the amount of the sunburn rock declines proportionally to the distance form the volcanic vent, and in the very place of eruption "location of the sunburn is a much more complicated issue". Author's own research revealed that sunburn occurs with a similar frequency both in effusive forms of basalts (sheets and flows) and in eruptive foci (Zagożdżon 2001b).

Location of the sunburn areas does not correlate with the distance from the edges of the basaltic bodies. The development of the phenomenon does not depend on the proximity to the land surface, either. The presence of sunburn rocks has been noted even in areas 70 metres deep while the upper parts of the quarries examined were free of such changes (Zagożdżon 2001b).

Various opinions appeared when the proportion of sunburn areas in the general volume of basaltic substance was considered. Some authors (e.g., Hibsch 1920) recorded small quantity of sunburn. Other publications (e.g., Klemm 1902 see Pukall 1939, Zagożdżon 1998) and numerous geological records of basaltic deposits in SW Poland provide information about large amounts of sunburn rocks. Author's own research proved a considerable variability of this parameter. At some sites was the sunburn sporadically observed (few blocks of rock containing sunburn in the range of a whole quarry), at others it was probably present in about 30 % of the rock available for observation (Zagożdżon 2001b).

Origins of the basaltic sunburn

Attempts to establish the origins of sunburn have been made since it was recognized in literature, however, much varied and often contradictory opinions on this subject have appeared in individual publications. Faujas de St. Fond (1786 vide Pukall 1939) initially recognized the sunburn rock he described as a new type of basalt. Finally he inclined to a speculation that sunburn is rather a type of disintegration caused by contractional diminution and by the influence of water in the later stage. In the following years, sunburn formation was believed to be connected with separation of some magma ingredients, weathering or turning the basalt glass into zeolites (see Pukall 1939). Several hypotheses formulated at the beginning of the 20th century were divided into three groups by Pukall (1939). The first group of Pukall (*die physikalischen Theorien*) included a contraction hypothesis developed by Tannauser (1910 see Pukall 1939) and another hypothesis that assumed a completely opposite direction of stress acting – rock bursting as a result of forming the sunburn "spots". The physical-chemical hypotheses (*physikalisch-chemische Theorien*) were exemplified by the opinion of Hibsch (1920) who perceived the rock streaky structure (*schlierigen Aufbau des Gesteins*) that had formed right before the melt congealed as a cause of the sunburn. According to Hibsch, a joint operation of physical factors (humidity, temperature and insolation fluctuations) and chemical factors (chemical influence of oxygen, steam and carbon dioxide) causing rock disintegration was also supposed to occur in the weathering stage. The utmost interest was awaken by the chemical hypotheses (*die chemischen Theorien*). Some of their advocates thought this phenomenon to be a result of **losing** the natural moisture by the rock and of the basalt glass disintegration (e.g., Chelius 1905 see Pukall 1939). Others believed that it is connected with turning of nepheline glass into zeolites, caused by water **absorption** by the rock (Leppla 1901). Sometimes, it was assumed that the discussed phenomenon is just a specific type of chemical weathering of the rocks (see Pukall 1939).

Pukall (1940) thought that the sunburn is a result of irregular accumulation of gases (e.g., steam) in magma. Volatile substances were supposed to concentrate within spheroidal areas that later, when the rock lost natural moisture, turned into the "spots". In the course of cooling, the presence of gases resulted, according to Pukall, in stresses destroying the coherence of the rock.

Ernst and Drescher-Kaden (1940) submitted another hypothesis (presenting, among others, results of diffraction analyses). Clear mineral diversity, widespread among sunburn rocks, caused these scientists to recognize the sunburn as a process of a late-magmatic origin. Analcite (present only within the "spots") and nepheline (only outside the spots) were supposed to have crystallized synchronously from residual melts rich in water at a temperature of about 550 °C. Relatively small PT differences caused by an unequal distribution of gases were decisive for the formation of a particular mineral at a given place. Such not uniform crystallisation occurring under conditions of variable temperature and pressure was supposed to induce internal stresses and micro-crack formation within the rock, thus resulting in its final disintegration. This hypothesis, with small modifications, was presented again by Ernst (1960).

Other mechanisms of sunburn formation have been set forth in the latest publications. According to Kühnel et al. (1994) this process is caused by diminution of rapidly cooling rock. The micro-cracks that appear then, enable the penetration of water solutions. Such fluids induce transformations of less stable mineral constituents (olivine, glass, foids) into clay minerals. This results in an increase in volume and destruction of the rock coherence. The most important was supposed to be the influence of the minerals of smectite group.

A different opinion was set forth by Schreiber (1991) who recognized the sunburn in the rocks examined as a result of assimilation of quartz grains of the covering rock by the basaltic melt. Reaction of these substances at the presence of water is supposed to lead to the formation of areas enriched in pyroxene, analcite and basalt glass. These areas become sunburn "spots" in the course of the subsequent weathering. During the melt solidification process, quartz grains additionally become centres of the tensional stresses that cause rock disintegration.

Another hypothesis points out to a co-relation between the sunburn formation and the characteristic manner of magma mixing observed in the Tertiary volcanic rocks of Westerwald (Schreiber et al. 1999). It has been stated that the latitic melt was subject to dispersion in the form of spherical bodies (globules) several millimetres big within the dominating trachytic melt. Ionic diffusion caused additional diversity of the composition of these substances and their crystallisation temperature. Consequently, their solidification began at different moments (while the surrounding melt had already become crystallised, the latitic globulas were still in the liquid state). Globules congealing was supposed to result in a considerable decrease in their volume and stresses emerging in the cooling rock. Additional forces disintegrating the rock are supposed to be generated by the crystallisation of analcite and re-crystallisation of basalt glass (www.uni-essen.de/geologie 2000).

Results of the author's own research on basalts of SW Poland (field research, macroscopic analyses, microscopic analyses and diffraction analyses of structure – see Fig. 6) prompted the author to recognize the hypothesis of Ernst and Drescher-Kaden as the most probable one. However, apart from magmatic phenomena, atmospheric factors, such as temperature and humidity fluctuations, are very important in manifesting the sunburn symptoms (Zagożdżon 2001a, b).

Conclusions

1. Sunburn is a type of disintegration of basaltic rocks, the diagnostic feature of which are three-dimensional, isometric, fair "spots".
2. In the sunburn rocks examined, a considerable fluctuation of parameters (dimension of "spots" and healthy rock parts, content of the sunburn substance) was noted. These parameters are in correlation.
3. Sunburn areas range between a few metres and 150 m in size. They appear with a similar frequency in the eruptive foci as well as in the lava sheets. Location of the sunburn areas does correlate with neither the distance from the edges of basaltic bodies nor the depth.
4. Results of the current research support connection of sunburn origin with late magmatic processes and non-uniform crystallization of analcite and nepheline from the residual melt. Manifestation of the sunburn symptoms ("spots" and capillary cracks) is caused by physical weathering.

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