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PETROGRAPHIC STUDIES ON THE NASA LUNAR SAMPLE THIN SECTION SET: I. THE TEXTURAL SEQUENCE OF THE BASALTIC SAMPLES AND THIER DESCRIPTION BY CELLULAR AUTOMATA MOSAIC MODEL AND TENTATIVE TTT-DIAGRAM

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ABSTRACT

NASA Lunar Sample Educational Set is a valuable source for planetary petrology education. Using the basaltic thin sections and clast from breccias of the Apollo expedition lunar samples we made cosmopetrographic comparisons between the lunar and a terrestrial sequence. We made a tentative parallel layered sequence of the textures from a lunar mare cross section and a terrestrial pillow lava gradient from outside to inside. On the basis of textural comparisons we compiled a tentative TTT diagram for the lunar mare cooling rates and pillow lava textures.

INTRODUCTION

During the last 10 years (see Appendix) Eötvös University received on loan the NASA Lunar Sample Thin Section Educational Set from Johnson Space Center, Houston. We made various new applications on the basis of this valuable set. One main topics was the comparison of extraterrestrial materials and selected thin sections from terrestrial rocks. We also used industrial materials for textural comparisons, where the operations in the technology manufacturing sequence give a good descritpion of the transformations of the phases (Bérczi et al., 1997, 1999, 2001). Added textures multiplied and extended the possibilities to form complex concepts: how to constitute complex material maps by starting from a sequence of textural types? (inter-connections, basic physical and textural relations of igneous rocks, and other compositions from material science, as ceramics, metallurgy).

Here we report about the study on basalts of NASA Lunar Educational Thin Section Set with comparisons to terrestrial pillow lava textures. On the basis of parameters read from lunar and terrestrial textures the tentative TTT diagram (T-TTT diagram) of basalts can be sketched. In this work we also used the basaltic clasts from breccias and soil samples. First we determined the paragenetic sequences of the samples on the basis of textural characteristics and then estimated cooling rates were determined. In the construction of T-TTT diagram some materials of corresponding technologies (cooling rates, industrial TTT diagrams of hardening steel and forming industrial textures) were also compared.

TEXTURES OF BASALTIC LAYERS REPRESENTED IN THE NASA SET

Many studies on basaltic textural types of the NASA lunar samples, from paragenetic sequence, grain size, crystal morphology, and their systematic relation with the cooling rates in the magma body were studied earlier (Meyer, 1987; Bence and Papike, 1972; Lofgren et al., 1974). In our study we first estimated these parameters from the paragenetic textural sequence from the surface edge toward the deeper layers of gradually coarser fabrics of basaltic samples in an undisturbed magma body. Both textural types, crystal morphology, were used in a cellular automata description to deduce paragenetic sequences for different lunar basalt types of the NASA Lunar Set, in a 8-10 meters thick lunar basaltic flow (Bence and Papike, 1972; Lofgren et al., 1974; Grove, 1977; Grove et al., 1973, 1977), and finally their tentative TTT diagrams (correspondence of cooling rates and textural gradual changes) were constructed.

In the second part of the course we compared basaltic samples of the lunar set, with some similar Carpathian Basin basalts and gabbros of which basalts we selected an ophiolitic textural series of the Darnó Hill, Heves C., Hungary (Józsa, 2000). where a continuous sequence of textures was found parallel with the lunar samples (Grove, 1977).

BASALTIC SAMPLES AND CLASTS IN NASA LUNAR SET IN TEXTURAL SEQUENCE

On the basis of the sequence of terrestrial textures we estimated (interpolated) the place (probable original depth) of the lunar set textures in a lunar basaltic lava flow. We also used literature data for cooling rates. The samples in a sequence starting from the greatest cooling rate are:

74220 The "highest" position (the greatest cooling rate) had the orange soil spherules in the 74220, because their ejection as a lava fountain (Meyer, 1987; Delano and Livi, 1981; McKay and Wentworth, 1992) had glass quenching cca. 1000 C/min. cooling rate (Dungan and Brown, 1977).

68501 Variolitic clast. In an earlier loan of the NASA Lunar set No. 6. the 72275,509 breccia contained a larger vitrophyric-variolitic clast. 72275 is the thin section with the largest surface in the lunar set. The No. 4. set contains a clast with spherulitic-variolitic texture among the soil grains of 68501 This clast had second highest cooling rate in our sequence (tentatively: some hundred degrees Celsius per day).

12002 This Apollo 12 porphyritic sample 12002 represents slower initial cooling rate for the large olivine grains and higher cooling rate (wide range) for the surrounding (variolitic) laths of clinopyroxenes and plagioclase feldspars (Dungan and Brown, 1977). In a revised model cooling rates may vary from some degrees Celsius to 2000 C/hour (Walker et al., 1975).

14305 The breccia 14305 contains intergranular type clasts, such representing the third texture in the cooling rate sequence (tentatively: hundred degrees Celsius per week)

72275 The subophitic clast of 72275,128 breccia represents an even slower cooling. Over breccias all three basaltic samples represent well crystallized beautiful specimens.

70017 This poikilitic sample of 70017 has paragenetic sequence similar to A-11 High Ti- basalts (Grove, 1977), rich occurrence of sector zoned clinopyroxenes. The rich population of ilmenites make dark the thin section: this ilmenite rich specimen has a counterpart near to Darnó Hill (at Szarvaskő), in a gabbro with high ilmenite cont. bw. 8-10 % wt.)

12005 The Apollo 12 poikilitic 12005 sample had the slowest cooling, so this specimen closes our cooling rate series. It contains large, zoned pyroxene oikocrystals with embedded idiomorphic (euhedral) olivine grains of chadacrysts (Dungan and Brown, 1977).

TERRESTRIAL COUNTERPART TEXTURES: AN OPHIOLITIC SEQUENCE OF DARNO HILL

In the Darnó Hill (basalts and microgabbros) textural sequence of ophiolitic gabbros and basalts can be found. From the outer edge high cooling rate textures to the inner part of the magmatic body (as to the center of a pillow lava "sphere") the following textures represent this series: spherulitic, variolitic, intersertal, intergranular, subophitic, ophitic, poikilitic (Józsa, 2000). Although important details are different in a terrestrial flow and in a lunar flow (chemical compositions, - e.g. 74220 and 12002 are picritic basalts (Nord et al, 1975; Grove et al., 1973; Walker et al., 1974) - water content can change paragenetic sequence of crystallization for plagioclase feldspar and pyroxene), the main textural characteristics determined by cooling rates remains important basis for comparisons and TTT diagrams.

COOLING RATES FOR LUNAR AND TERRESTRIAL BASALTS AND TENTATIVE TTT DIAGRAM FOR THE LUNAR BASALTS

On the basis of experimental determination of the cooling rates and also from TEM measurements of clinopyroxenes both cooling rate sequences and TTT-diagrams were studied and determined (Bence and Papike, 1972; Grove, 1977, 1982; McConell, 1975; Nord et al, 1975). The lunar basalt layer was 8-10 meter thick (Grove, 1982; Nord et al, 1975). This thickness is larger, but comparable to pillow lava units as terrestrial pairs.

Table 1. Texture vs. cooling rate relations in a cooling pillow lava body.

textural type	cooling rate	depth in a pillow lava	length of cooling time
glassy	45000 - 1800 C / min.	1 centimeter	1 min.
spherolitic	22000 - 1000 C / min.	some centimeters	some minutes
variolitic	1000 - 200 C / min.	decimeter	10 minutes - 0,5 hour
intersertal	200 - 30 C / min.	some decimeters	0,5 - 2 hours
inter-granular	0,5C / min.	central region of pill.l.	1 - 2 days

A pillow lava cools during 2 days, but 8-10 meters thick lunar layers cooled for months or years in their inner regions. In a pillow lava textural sequence only the intergranular texture could be reached because of the quick cooling and smaller lava body size. In the lunar basalt case all textural types in our sequence could be reached. The corresponding cooling rates were given by Grove (1977) as 3 C/min. for a vitrophyric, 30 C/hr for a coarser vitrophyric and 3 C/day for a porphyritic Apollo 15 sample. Data of a pillow lava are in Table 1. as follows: (Józsa, 2000; Szakmány, 1995).

SYNOPTIC VIEW BY COMPLEX MATERIAL MAPS

Textural structure contains a versatile characterization possibility for rocks. Microscopic studies give comparative possibilities with other materials. In material science and technology we frequently summarize the behaviour of a metal (or ceramics) by a path of state changes in the field of different physical parameters: we call them material maps. (This synoptic-synthetic view is also used in biology, by the niches. Niches are parameter-cells, where living beings occupy distinct, or partly overlaping regions.) We developed synoptic view in interplanetary comparative petrography by materail maps.

The basaltic samples of the NASA lunar set form a sequence from quick to slow cooling. They represent stages (phases from different depth) from a cross section of a cooling lava flow. (The samples are: 74220 - Orange Soil - volcanic spherules, 12002, porphyric-variolitic texture, 70017, and 12005, ophitic-poikilitic texture (Józsa, 2000). These stages of a sequence represent gradually slower cooling rates. They also represent different SiO_2 ranges: while ranges of picritic (74220 and 70017) and basaltic (12002 and 12005) rocks involve the SiO_2 classification, the cooling rates involves TTT diagrams to be attached (and other C-rurves from metallurgy). While compositional evolution brings the Bowen type ternary and quaternary system diagrams, the TTT diagrams brings the volcanic, subvolcanic and plutonic distinction for igneous rocks. The extended fields bring other lunar samples to "appear" on material maps, as representatives of plutonic type rocks (60025, anorthosite, 78235, norite). Step by step the material maps can be extended by new parameters, and both terrestrial and Martian (meteorite) rocks may be involved into such material maps.

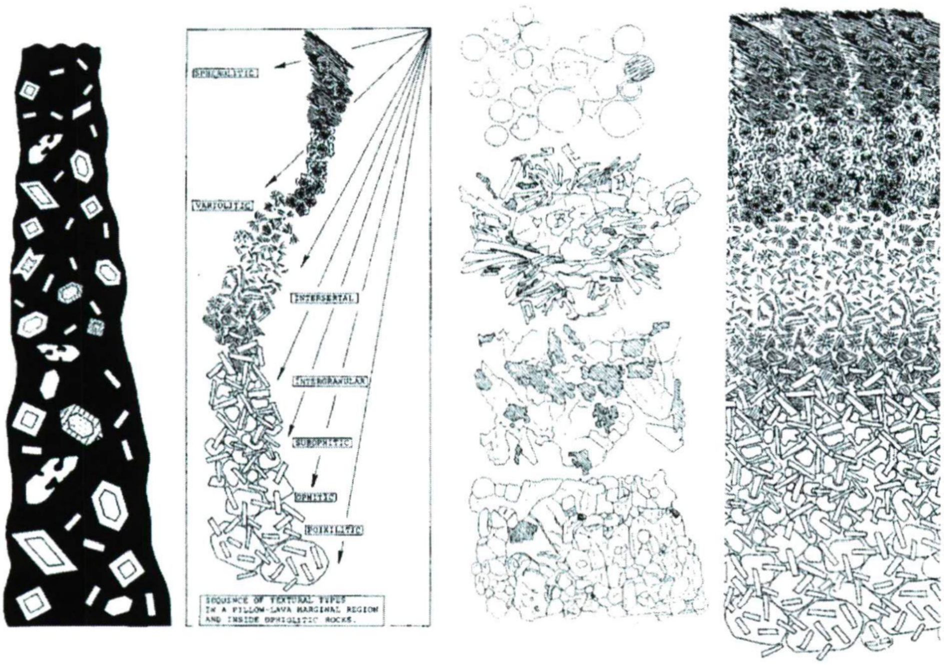

Fig. 1. Sequence of textures and the corresponding T-TTT diagram for the cross section of a lunar lava layer.

CELL-MOSAIC AUTOMATA MODEL DESCRIPTION OF PETROLOGIC TEXTURAL TRANSFORMATIONS

Cell-mosaic automata model helps to formulate all those descriptions we do in practice during textural analyses. The sequence of discrete changes in a cell-mosaic system is formulated on two hierarchy levels: on cellular one (minerals), and on global one (texture itself). (Bérczi, 1990, 1993) The cell-automata mosaic's flow-chart has a framework of description: it is composed from two parts. The first one gives the structure and initial conditions of the cellular background, the second one gives the transitional functions (Bérczi, 1993). Both parts form a pair of approach: a local and a global one, as follows (Fig. 1.)

The advantages of the cell-automata mosaic model come from this separability of local and global picture: both for conditions and operations, and from the expressed connections (feedback possibility) between the local and global characteristics. We made such style of descriptions of sequence of crystallization of 70017 high Ti basalt texture, a metamorphic sequence of terrestrial textures (Vollmar, 1978), Grossman type CAI condensational sequence (this last one was almost in this form (Grossman, 1974), and carbonaceous chondritic aqeous alteration sequence (Krot et al., 1998; Sztrókay et al, 1961).

DESCRIPTION OF PETROLOGIC TEXTURAL TRANSITIONS BY CELLULAR AUTOMATA

We can formulate descriptions of textural analyses by cell-mosaic automata model. It helps to reconstruct the sequence of discrete changes in a cell-mosaic system. The model is formulated on two hierarchy levels: One level is that of minerals (that of cellular one) and that of the texture (global one). The "flow-chart" of the cell-automata mosaic's is composed from two parts: A) that of the structure and initial conditions of the cellular background, and B) that of the transitional functions (Bérczi, 1993). Both parts form a pair of approach on a local and a global one.

The cell-automata mosaic model has advantages coming from the separability of local and global picture. One is the feedback possibility between the of sequence of crystallization of 70017 high Ti basalt texture was made in the paragenetic sequence. From this we reconstructed a

Table 2. Local vs global level of descriptions in a cellular-automata mosaic model.

	a. LOCAL (CELL-LEVEL)	b. GLOBAL (TEXTURAL)
A.. *CELLULAR BACKGROUND*	Aa. Local characteristics of the cell-mosaic system give the cells, as actors in events, the form of the cells, their connections (i.e. faces) and neighbourhood relations.	Ab. Global characteristics of the cell-mosaic system give the texture and the sum up of the local relations. (i.e. the texture is a piokilitic type, because of enclosing relations)
B. *TRANSITIONAL FUNCTIONS*	Ba. Local transitional function for cell mosaic elements which are individual automata (discrete function in space and time, step by step transforming cell-states, i.e. how distinct minerals change)	Bb. Global transitional function for the whole surface populated by the cell-mosaic system (sequence of stages of the texture taken step by step, as a consequence of summed up (for all cells) of the local transitional functions.)

tentative TTT diagram. This texture solidifies between 1250 and 950 C, contains the textural fabrics of a sequence, with the cooling rates from glassy quenching 1000 C/min. rate till 0.5-0.05 C/hr.

Conclusions

We studied the basaltic samples of the NASA Lunar Set and the comparing pillow lava sequence of the Darno-hill ophiolitic thin section set from the Bükk Mts. Hungay. We constructed from lunar basaltic textural characteristics via cellular automata modeling paragenetic and cooling rate sequences, and a tentative TTT-diagram of lunar basalts (lava flows). In this program we compared lunar textural layers to that of a terrestrial pillow lava textural layers and we also compared basaltic TTT diagrams to steel industrial TTT diagrams. In this work role of textural studies of unusual materials for studies of industrial ones were also emphasized. This way studies of planetary materials has a spin-of direction in space science education, too. Another space science educational outreach of this program was the application of the cellular automata type description to textural transformations.

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