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PETROGRAPHY AND CHEMISTRY OF VITROOPHITIC AND DENDRITIC FRAGMENTS FROM THE MARE FECUNDITATIS (LUNA 16) REGOLITH

(Tab. 1 — 2, Figs.1 — 8)

Abstract: Two vitroophitic fragments (Nos. 1058, 3040) and a dendritic cryptocrystalline one with sheaf-like texture (No. 3042) from Mare Fecunditatis regolith exhibit closely related textures as well as mineral and chemical compositions. They correspond to the ANT group of lunar rocks, i. e. to anorthositic-noritic gabbros and norites. The fragments display the same high Al_2O_3 content, the same CaO/Al_2O_3 ratio (0,55) and low contents of TiO_2 and alkalies.

The first two fragments consist of „porphyritic" („ophitic") plagioclases and vitreous dendritic matrix, the third one of skeletal dendritic laths of inhomogeneous, mostly plagioclasic composition and homogeneous vitreous interstitial matrix. The vitreous matrix of all the fragments corresponds to the mixture of plagioclase and mafic minerals in chemical composition (with mafic components prevailing).

The textural development of fragments and their origin are discussed. The fragments are suggested to have crystallized from a supercooled melt. They are considered to be fragments of lunar chondrules of the ANT group. They can be held for further argument supporting the view that the presence of highland material is not exceptional in mare regions. The fragments indicate that hemicrystalline to cryptocrystalline vitreous particles here are of non-mare composition and that chondrule type material is widespread on Lunar surface.

Резюме: Два витроофитовых (1058, 3040) и один дендритовый радиально-стебильный (3042) фрагмент из реголита Луны 16 имеют взаимоподобные структуры и аналогический состав. Составом они отвечают породам АНТ — группы, анортозитовым норитовым габбро и норитам. Что касается химизма — там очень заметное тоже самое высокое содержание Al_2O_3 и тоже самое соотношение CaO/Al_2O_3 (0,55); содержание TiO_2 и щелочей низкое. Первые два фрагмента состоят из „порфирового" („офитового") плагиоклаза и дендритовой основной массы, третий из скелето-образных дендритовых плагиоклазовых лейст и гомогенной стекловатой основной массы. Основная масса во всех случаях отвечает смеси плагиоклазов и мафитов с преобладанием мафитов по химическом составе.

Дискутируются микроструктуры и возникновение фрагментов. Фрагменты кристализовали из переохлажденного расплава и можно считать их фрагментами лунных шариков, классифицированных как лунные хондры (или хондроиды) группы АНТ. Они лишным доказательсвом, что присуствие материкового материала в морской области Луны 16 не редкое, что лунный стекловатый материал с подобными микроструктурами отвечает породам не морского состава и что он распространен по всей поверхности Луны.

Introduction

Lunar particles similar to those studied in the paper (1058, 3040) have been described for the first time by V. Smith et al. (1970) from Apollo 11 regolith as plagioclase vitrophyres. Similar textural types from Mare Fe-

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cunditatis (Luna 16) regolith have been shown and their composition determined as spherical particles by K. Keil et al. (1972, 252), G. Kurat et al. (1972, 708, 709) and from Luna 16 and 20 regolith by A. V. Ivanov et al. (1976, 746). The fragment 3042 is texturally identical with the material from Apollo 11 regolith described by J. L. Carter, L. Padovani (1973, 327) also in the form of a spherule, and it is texturally close to the spherule according to A. V. Ivanov et al. (1976, 748). By all these authors spherical particles are interpreted as lunar chondrules (chondroids). By A. Cimbálníková et al. (1973) the fragments studied were preliminarily called as feldspar basalts or non-mare basalts and they were classed into the anorthositic group of rocks (A. Cimbálníková, M. Palivcová, 1975).

Methods

The polished thin microsection were made from the fragments selected under the stereomicroscope. Analyses of bulk composition as well as of minerals were performed with a JEOL-JXA-50A electron microanalyzer (EMA). Attention was paid to the photomicrographical documentation of the textures. Several analyses covering most of the surface of the fragments were averaged for bulk composition. The determination of the distribution of elements by EMA was an additional method in the illustration of textures. Analyses were performed by K. Jurek, M. Kozumplíková and A. Langrová, microphotographs by V. Matějková.

Comments to the terminology of the textures

The fragments 1058 and 3040 exhibit hemicrystalline textures. They contain well, lath- to needle-shaped plagioclases, arranged in a similar way as in an ophitic texture, or interpenetrating one another. The texture similar to that of the fragment 1058 was described as intersertal by A. V. Ivanov et al., 1976, as porphyritic by G. Kurat et al., 1972 and vitrophyric by V. Smith et al., 1970; A. Cimbálníková, M. Palivcová, 1975 used the term „vitroophitic". All the terms do not lack a certain degree of justification. By the term „intersertal" the hemicrystalline character and similarity with ophitic texture are emphasized; the original definition of the term, however, implies only a small quantity of interstitial matrix, partly vitreous, partly crystalline. The term „porphyritic" has been used to point out the phenocrystic development of plagioclases in the microcrystalline matrix. The term „vitrophyric" gives the idea of individual fenocrysts in glass — it does not express „the ophitic" arrangement of plagioclases. There is still another term at disposal — „hyaloophitic" — but in such texture a large volume of hyaline matrix should be present (in the A. Johannsen's definition). The present authors used an analogous term „vitroophitic" which enables to point out the analogies with an ophitic texture on one hand and with a vitrophyric one on the other hand.

The cryptocrystalline texture of the fragment 3042 is known from various chondrules. J. L. Carter, L. Padovani (1973, 327) denoted it as sheaf-like skeletal texture, A. V. Ivanov et al. (1976) as sheaf-like texture. The authors called it divergently dendritic sheaf-like texture to emphasize the dendritic to skeletal substructure of the sheaves. In the literature diverse terms were used for it, e. g. recently fascicular, intrafascicular (see the following chapters).

The reason why special attention was paid to the textural terminology is the fact that often the description of textures is subjective and different. Consequently, without microphotographical documentation, the correlation of analogous materials — a useful and notworthy approach to the study of lunar samples — cannot be followed precisely.

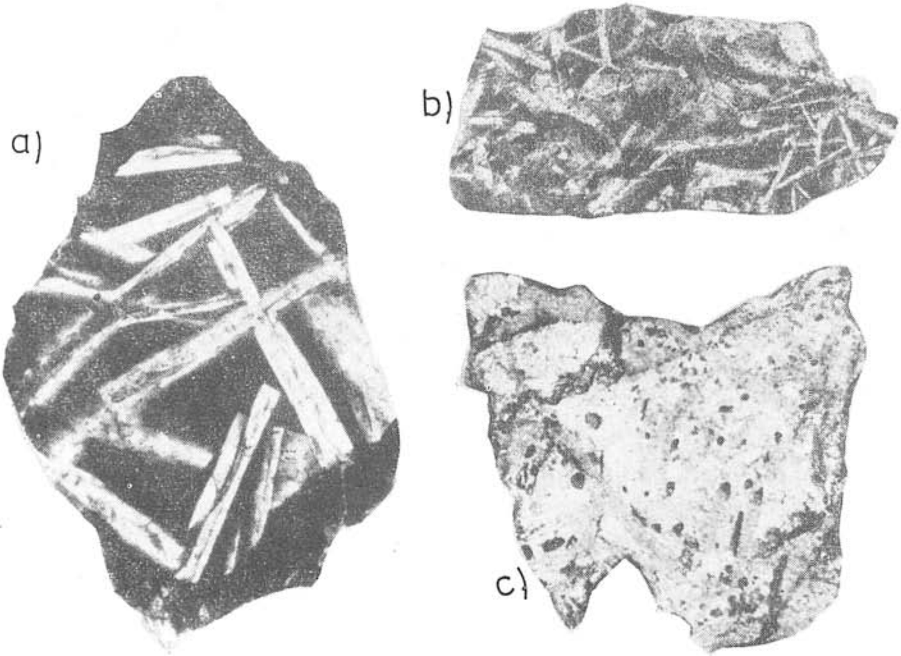

Fig. 1a, b, c — fragments studied under 75× magnification. a) 1058 — olivine anorthositic gabbro; b) 3040 — olivine anorthositic norite; c) 3042 — quartz normative anorthositic norite.

Petrography

The fragments display irregular forms, under stereomicroscope they are dark grey to white grey in colour and they have a glassy appearence. By the arrangement and shapes of feldspars, the textures of the fragments 1058 and 3040 resemble the microophitic textures of basaltic rocks. In the fragment 3042 the sheaf-like texture of skeletal laths can be seen indistinctly and the light greyish-white colour indicates already macroscopically the affinity to anorthositic rocks.

The fragment 1058 (0,5 mm in diameter — fig. 1a, 2; chemical anal. No. 1 in tab. 1) is distinguished by long perfectly euhedral laths of plagioclases (0,2 mm), arranged in an ophitic textural manner of basaltic rocks. Some of

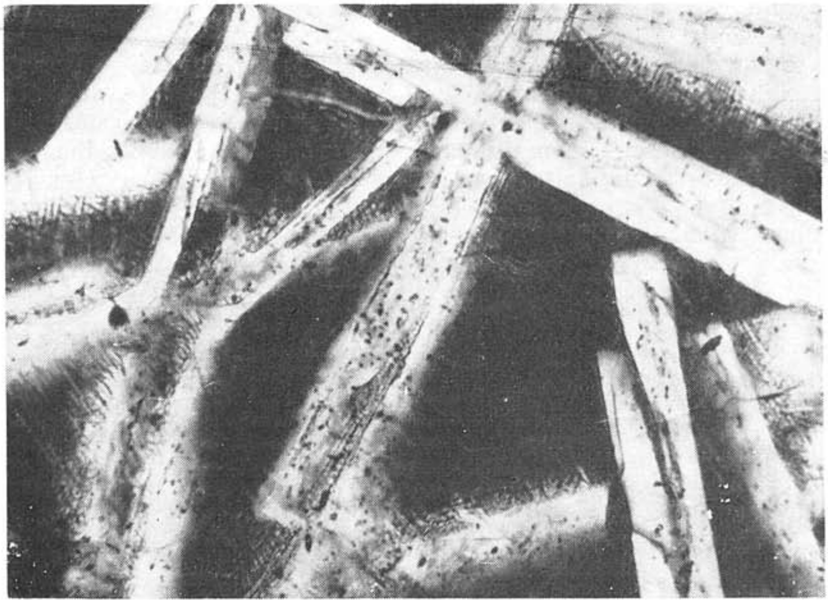

Fig. 2. Vitroophitic fragment 1058 showing euhedral plagioclases and dendritic vitreous matrix (matrix of olivine gabbro composition). Without polarizer, 490×. V. Matějková.

them are contiguous with each other. The interstitial matrix among plagioclases consists of greyish brown vitreous material. The texture is called vitroophitic, it also could be termed vitrophyric. The plagioclases are unzoned, in some of them simple albite twins are developed. Often twins of two mutually shifted individuals occur, with filling following their central axis. Thus the so called „cored", „hollow" or „tubular" plagioclases originate (Fig. 2). The filling is formed by vitreous material of the matrix or by glassy or opaque pigmentation. The An content of plagioclases determined by EMA corresponds to anorthite An_{93}, normative plagioclase is An_{94}. The matrix is vitreous and exhibits slight anisotropy in some places. The anisotropy is due to some amount of patches of skeletal framework. Similar framework was described as dendritic by some authors (see M. Palivcová, A. Cimbálníková, in print). This texture is often well developed at the plagioclase boundaries (comp. fig. 6 in the following sample). The margins resemble reaction zones, however, if element distribution by EMA is examined, sharp boundary lines appear, (fig. 7a, b). By this method the texture of the fragments becomes distinct.

The fragment 3040 (0,8 mm in diameter, fig. 1b; chem an. No. 2 in tab. 1) illustrates demonstrably analogous texture when compared with the preceeding fragment. The texture is finer-grained, some decrease of the grain size at one margin of the fragment is visible. Plagioclases are lath-shaped to acicular. They often interpenetrate one into the other so that continuous framework is developed. (Fig. 3). Two generations of plagioclases seem to be present, the acicular crystals penetrate into the older larger plates; ho-

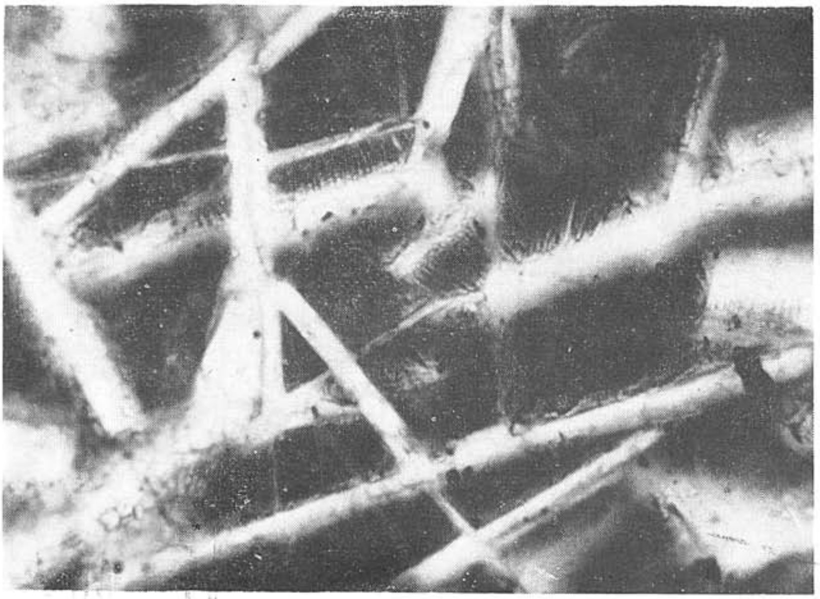

Fig. 3. Vitroophitic fragment 3040 showing platy and acicular plagioclases in vitreous dendritic matrix (matrix of olivine melagabbro to troctolite). Without polarizer, 490×, V. Matějková.

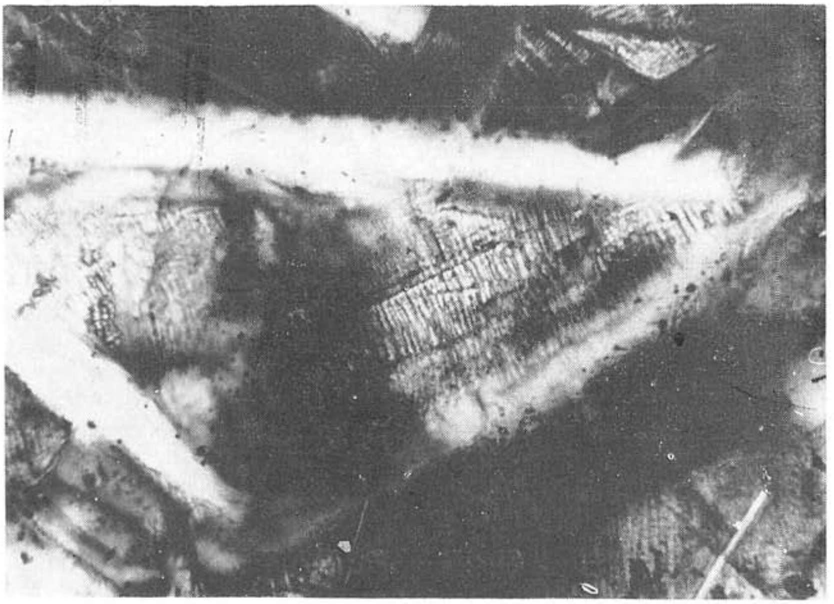

Fig. 4. Dendritic (skeletal) morphology in the vitreous matrix of the fragment 3040; without polarizer, 550×, V. Matějková.

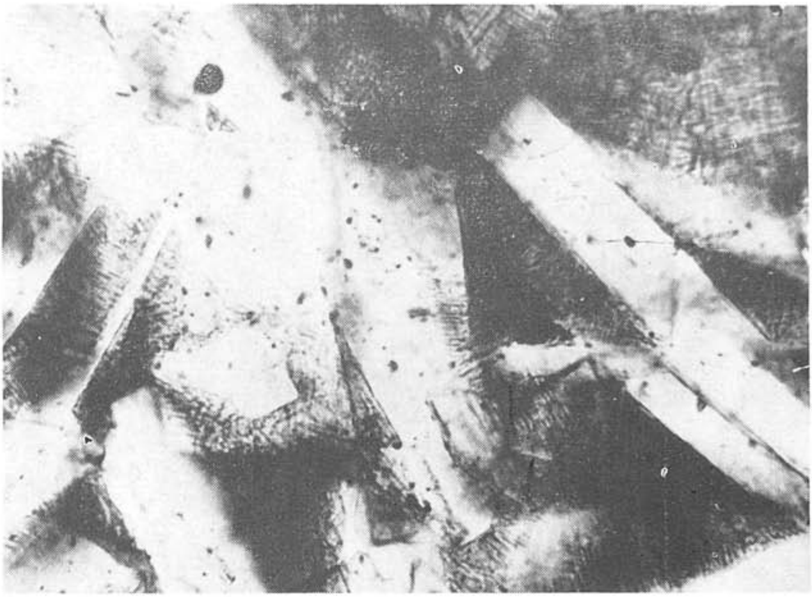

Fig. 5. Dendritic texture at the plagioclase boundaries in the fragment 3040. Without polarizer, 550×. V. Matějková.

wever, no difference in composition was established — the composition of both is anorthite An_{97}, normative plagioclase An_{95}. The residual glass is greyish white, slightly yellowish under the microscope. Dendritic patches similar to those in the preceeding sample are abundant. (Fig. 4). The development of dendritic texture at the contact of plagioclases is seen in fig. 5.

The fragment 3042 (0,8 mm in diameter, fig. 1c, 6a, b; chem. an. No. 3 in tab. 1) is macroscopically white, slightly yellowish. Sheaf-like to lath-like texture with skeletal, dendritic substructure of the sheaves is particularly well developed as seen in fig. 6b (in reflected light by EMA — fig. 6b — the light component in dark, the mafic one in light). The sheaf-like laths — 0,2—0,3 mm long — are made up of submicroscopic intergrowths of imperfectly developed lamellae (indistinctly birefringent or vitreous) of plagioclase composition and of mafic vitreous material among them. The internal structure of the sheaves is subparallel, dendritic to skeletal, and, sometimes, it is close to that described as vermicular in some papers (J. C. B a i l e y et al., 1970). The mafic vitreous material also fills the interstices among the sheaves in the form of residual glass. This glass is markedly homogeneous. Minute dark to opaque spherical particles are always present in this type of lunar fragments (fig. 1c).

Chemistry and norms of the fragments

Bulk chemical composition was determined by several analyses (about 6—7 in each sample) sufficient to cover the greater part of the fragment

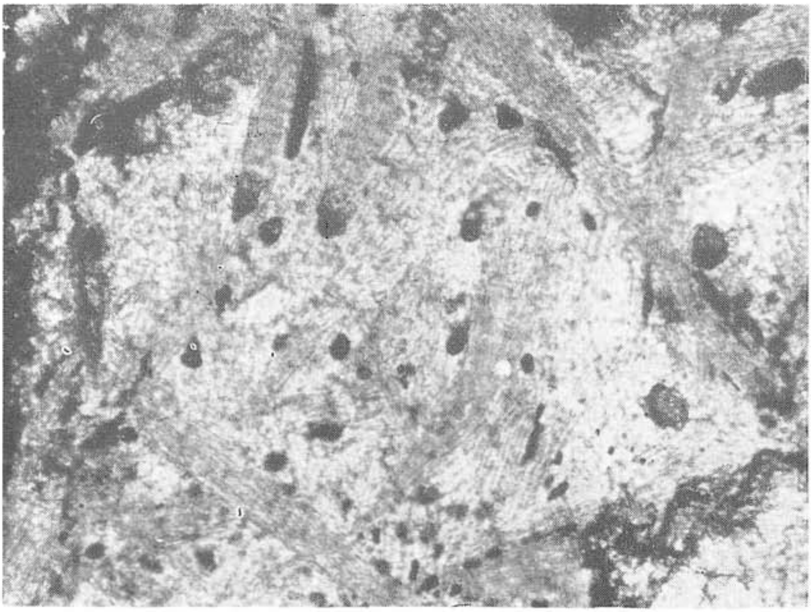

Fig. 6 a. The texture of the fragment 3042 enlarged 200×. Microphoto without polarizer. V. Matějková.

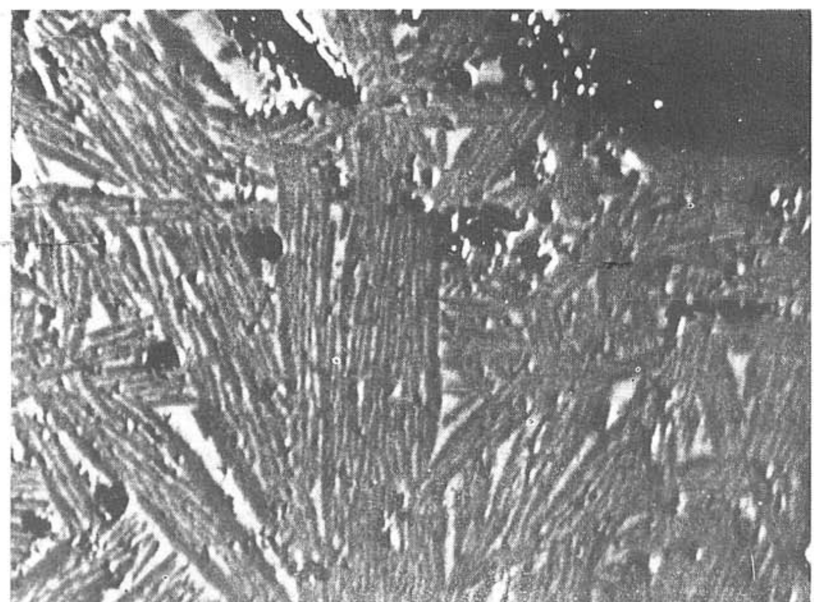

Fig. 6 b. Divergently sheaf-like dendritic texture of the fragment 3042 in reflected electrons (dark-plagioclasic constituent, light — mafic glass). The composition of interstitial glass corresponds to the olivine gabbro in composition. 300×. Photo K. Jurek.

Table 1

Chemistry and CIPW molecular norms of fragments (an. 1—3, total rocks) and their vitreous matrix (an. 1′ — 3′)

	1	2	3	1′	2′	3′
SiO_2	44,20	43,46	46,95	46,07	44,04	43,91
TiO_2	0,29	0,16	0,33	0,48	0,28	0,43
Al_2O_3	25,24	25,09	26,78	18,56	10,51	17,61
FeO	5,66	5,79	4,22	9,63	11,55	9,92
MnO	0,07	0,06	0,07	0,14	0,14	0,13
MgO	8,39	10,41	6,74	14,77	24,87	14,29
CaO	14,17	13,80	14,69	10,66	8,30	10,39
Na_2O	0,38	0,38	0,20	0,31	0,24	0,36
K_2O	0,12	0,05	0,02	0,16	0,07	0,05
	98,52	99,20	100,00*	100,78	100,00*	97,10
+ calculated to 100 %						
CaO/Al_2O_3	0,56	0,55	0,55	0,57	0,79	0,59
FeO/MgO+FeO	0,40	0,35	0,38	0,39	0,32	0,40
MgO/MgO+FeO	0,59	0,64	0,61	0,60	0,68	0,59
CIPW norm.:						
or	0,72	0,28	0,11	0,95	0,39	0,28
ab	3,20	3,20	1,68	2,62	2,04	3,04
an	66,75	66,55	72,03	48,73	27,36	46,23
qu	—	—	1,10	—	—	—
ne	—	—	—	—	—	—
di	2,83	1,50	0,63	3,32	11,04	4,27
hy	11,09	5,82	23,76	23,12	10,11	19,25
ol	13,33	21,46	—	21,02	48,30	23,09
ilm	0,55	0,30	0,62	0,91	0,53	0,82
	98,46	99,11	99,92	100,67	99,77	96,98
SAL/FEM	70,67/ 27,79	70,03/ 29,08	74,92/ 25,01	52,30/ 48,37	29,79/ 69,98	49,55/ 47,43
norm. plg.	$An_{94,5}$	An_{95}	$An_{97,6}$	$An_{93,2}$	$An_{91,8}$	$An_{93,3}$

1 — bulk composition of the fragment 1058 (1_8) by the electron beam with a diameter of 10 to 15 microns by EMA; average from 6 analyses)
 — *olivine anorthositic noritic gabbro*

2 — bulk composition of the fragment 3040 (3_8); average from 7 analyses
 — *olivine anorthositic norite*

3 — bulk composition of the fragment 3042 (MS—10); average from 6 analyses
 quartz normative anorthositic norite

1′ — residual vitreous dendritic matrix from the fragment 1058, average of 3 analyses; the composition corresponds to:
 — *olivine gabbro*

2′ — residual vitreous dendritic matrix from the fragment 3040, average of 2 analyses; the composition corresponds to:
 — *olivine melagabbro to troctolite*

3′ — residual homogeneous glassy matrix from the fragment 3042; average of 3 analyses; it corresponds to:
 — *olivine gabbro*

Table 2

Chemistry of plagioclases (an. 1p, 2p) and the calculation of the vitreous matrix (1′ — 3′) to the mineral composition

	1p	2p	1′	2′	3′
SiO_2	45,87	45,29	46,07	44,04	43,91
TiO_2	0,02	0,02	0,48	0,28	0,43
Al_2O_3	33,39	31,83	18,56	10,51	17,61
FeO	0,76	0,32	9,63	11,55	9,92
MnO	0,00	0,00	0,14	0,14	0,13
MgO	1,14	0,33	14,77	24,87	14,29
CaO	18,17	19,43	10,66	8,30	10,39
Na_2O	0,76	0,34	0,31	0,24	0,36
K_2O	0,03	0,03	0,16	0,07	0,05
	100,00*	97,62	100,78	100,0*	97,09
* calculated to 100 %					
calculated to 8(0)			calculated to 6(0)		
Si	2,115	2,147	1,648	1,618	1,638
Al	1,817	1,776	Al^{IV} 0,352	0,382	0,362
Ti	0,001	0,001	Z = 2,00	2,00	2,00
Z =	3,93	3,92			
			Al^{VI} 0,429	0,073	0,410
			Ti 0,013	0,007	0,012
Fe	0,029	0,012	0,287	0,354	0,308
Mn	—	—	0,004	0,004	0,004
Mg	0,079	0,000	0,792	1,371	0,799
Ca	0,900	0,987	0,409	0,327	0,415
Na	0,068	0,017	0,021	0,017	0,026
K	0,001	0,001	0,007	0,003	0,002
X =	1,08	1,04	1,96	2,15	1,98
plagioclase normat.:			pyroxene		
	An_{93}	An_{97}	Fe 19,28	17,24	20,25
	Ab_{07}	Ab_{03}	Mg 53,26	66,82	52,49
			Ca 27,46	15,93	27,25

1p *felsic constituent* of the dendritic fragment 3042 calculated to plagioclase (average of 3 analyses)
2p *plagioclase* from the vitroophitic fragment 1058
1′ *vitreous matrix* of vitroophitic fragment 1058, if recalculated to pyroxene
2′ *vitreous matrix* of the fragment 3040
3′ *vitreous matrix* of the fragment 3042

surface, and chemistry of main constituents by point analyses by EMA. The results of averaged analyses (1, 2, 3) and their norms are in table 1; the analyses 1', 2', 3' correspond to the composition and norm of the matrix (averaged analyses). In table 2 chemical composition of plagioclases is given (1P, 2P).

The bulk composition of all three fragments indicates their mutual affinity, which is particularly well demonstrated by high Al_2O_3, higher CaO, low TiO_2 and higher MgO versus FeO, if compared with mare basaltic rocks. The chemistry of the three fragments — in spite of the basaltic macroscopic appearance of the first (1058) — corresponds to that of the ANT group in the sense of K. Keil et al., 1972. Especially the fragment 3040 is enriched in MgO in its matrix. The affinity to the anorthositic group is also proved by normative composition according to the amount of salic constituents (69—75 % — see J. M. Rhodes, 1973) as well as according to the nature of normative femic minerals (hypersthene and olivine both rich in Mg component, both prevailing, low amount of the normative diopside and ilmenite). Normative plagioclases of vitroophitic fragments are anorthites An_{94-98}, which is in accordance with the chemistry of plagioclases examined by EMA (1P, 2P). Increased FeO and MgO contents in plagioclases are probably due to pigmentation (mechanical admixture). The Na and K contents in the fragments are negligible. Mafic constituents are concentrated in the matrix, in fragment 3042 also as interstitial filling among plagioclase lamellae in the sheaves. This is evidenced by element distribution under EMA (fig. 7a—d). The distribution of MgO and FeO is very distinct, both elements are concentrated in the matrix, while Ca is almost equally distributed in both the plagioclases and the matrix.

Thus according to the bulk chemistry the fragments can be classified as noritic gabbros and anorthositic norites (Glossary, 1974). The 1058 fragment is close to olivine troctolite (high olivine content), the 3042 fragment is slightly quartz normative. According to the composition and petrochemical indices (e. g. CaO/Al_2O_3 = 0,55, MgO/MgO+FeO = 0,61, about 70 % An_{94-98}) the fragments approach to the group classified as non-mare highland basalts by P. Jakeš et al., 1972; they differ only in the low TiO_2.

The matrix of the three fragments has the composition of olivine noritic gabbro, in 3040 fragment it is melanocratic, close to troctolite. The attempt to recalculate the matrix to mineral composition has shown that the composition of the matrix cannot be expressed by the composition of one mineral (high Al content in comparison with pyroxenes and olivine, high Mg, Fe contents in comparison with plagioclases). Thus the vitreous dendritic matrix represents a mixture of mafic and felsic constituents enriched in mafic ones.

The chemistry of the fragments was compared with that of lunar chondrules examined by K. Keil et al., 1972 and A. V Ivanov et al., 1976 from Luna 16 and 20; in all diagrams (fig. 8) the analogy in chemistry is manifested, which is especially perfect with K. Keil's et al. samples. In agreement with A. V. Ivanov et al. (c. 1.), low alkali content in the rocks and high An content of plagioclases (almost pure anorthite) can be seen in the fragments studied. The SiO_2 content varies. The interstitial vitreous matrix of the fragments studied is always close to mafic glass, not plagioclase glass.

Textural development of the fragments

The fragments investigated exhibit similar textures, petrography and chemistry as in lunar spherical particles which have been interpreted as lunar

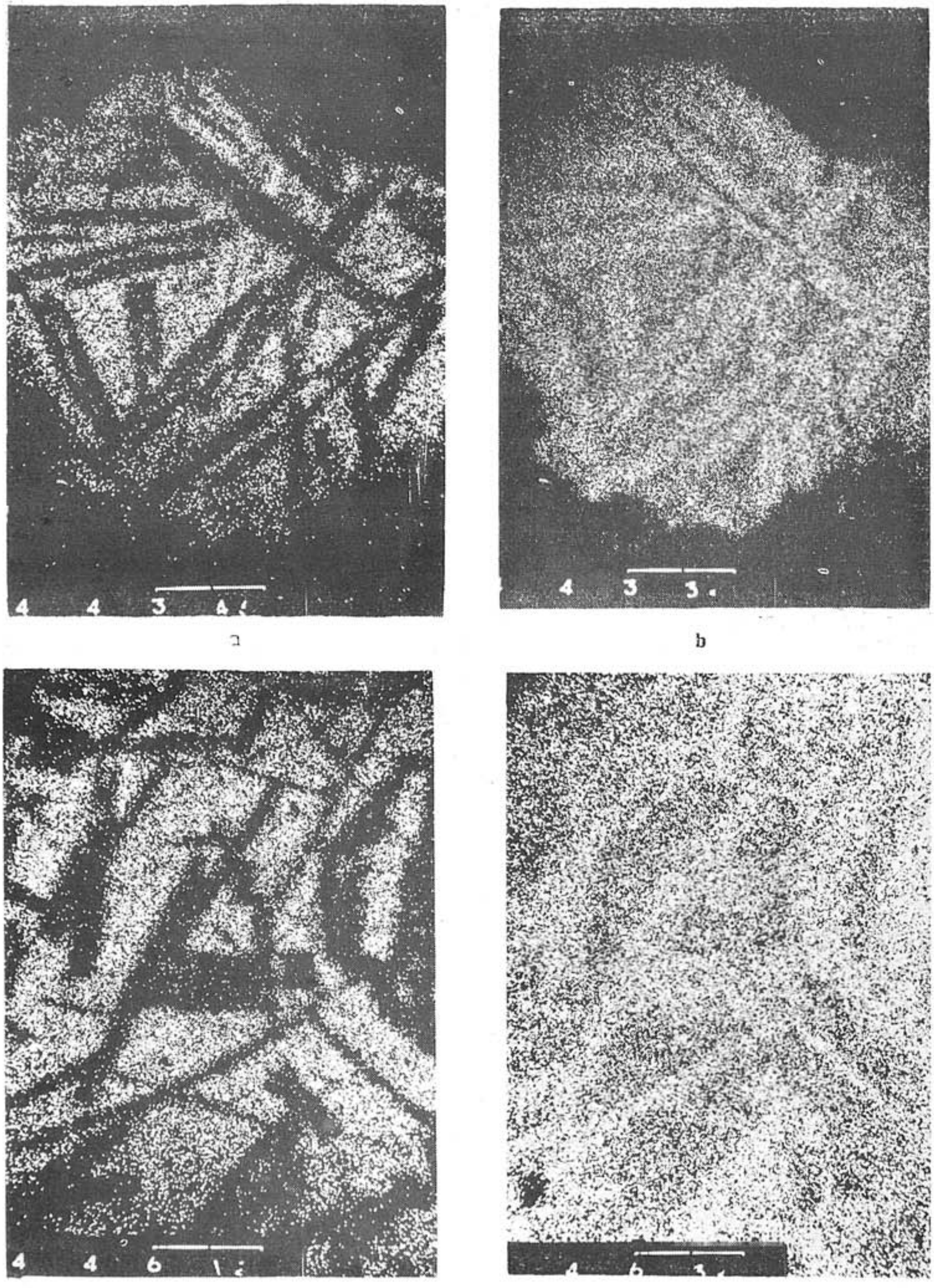

Fig. 7 a—d. Element distribution by EMA in fragments 1058 (a, b) and 3040 (c, d), a, c — distribution of Mg, b d distribution of Ca. Compare figures 2 and 3.

chondrules or chondroids (K. Keil et al., 1972; A. V. Ivanov et al., 1976) from Luna 16 and 20 and from other localities of lunar samples, too. (G. Kurat et al., 1972 and others). It, seems, therefore, reasonable to consider them as clasts of crystalline and cryptocrystalline lunar chondrules.

From the beginning of investigation the textures of lunar chondrules were interpreted as textures of rapidly solidified, supercooled melts. K. Fredriksson (1970, 419) has explained the chondrules as „quenched silicate drops", K. Keil et al. (1972, 252) as products of spontaneous crystallization from supercooled, rapidly solidified melt. Already in the first papers some different explanations of their crystallization were expressed (e.g. devitrification — E. Roedder, P. W. Weiblen, 1970; G. Lofgren, 1971) and there exists a number of different views in details depending on or leading to various theories of their origin (newly discussed for ordinary chondrules by Makoto Kimura and Kenzo Yagi, 1980). Almost all authors favour their crystallization from supercooled melt. Following features in the fragments studied can be quoted to support their rapid crystallization: „tubular" („cored", „hollow") euhedral plagioclases (1058), interpenetrating of plagioclases (interface texture, cross intergrowth), lath-shaped and acicular plagioclases, skeletal textures of plagioclase sheaves, their dendritic substructure; the presence of interstitial (residual) glass, probably also regular „dendritic" framework in the glass.

All three fragments are of similar composition as the rocks of ANT group. In spite of some differences in the crystallinity of the individual fragments on the one hand, they have some textural similarities on the other hand. The conclusion can be deduced that *all three fragments represent one genetical series, in which the differences are due to unevenly progressed crystallization,* similarly as documented by A. V. Ivanov et al., 1976. Thus the vitrophitic fragment 1058 — containing well shaped „porphyritic" euhedral plagioclases arranged in the same manner as in an ophitic texture — represents the best developed crystallization stage. The fragment 3040 of similar texture characterized by interpenetrating plagioclases is a less perfectly developed and the sheaf-textured fragment 3042 marked by an ophitic sheaves arrangement — the least perfect developed crystallization stage. All fragments have vitreous residual matrix. They represent almost continuous crystallization series of hemicrystalline to incompletely crystalline textures.

According to the examples from the literature *the said series can be extended in two directions:* to the hemi- to holocrystalline (intersertal, ophitic) textures on the one end and to the typical cryptocrystalline (fibreous, fascicular, spherulitic etc.) ones on the other end.

The gradual transition *to holocrystalline textures* is evidenced e. g. by those examples that but little differ from the fragment 1058, by the microcrystalline or holocrystalline nature of the matrix only (G. Kurat et al., 1972, 709; K. Keil et al., 1972, 252).

Hemicrystalline to holocrystalline textures of such a type can be followed also in the material in which typical ophitic to intersertal textures of basaltic rocks enriched in plagioclases are developed (e. g. P. W. Weiblen et al., 1974, 752, fig. 1g; E. Dowty et al., 1974, 473, filg. 2c; J. I. Goldstein, 1974, 655, fig. 1c; G. J. Taylor et al., 1973, 561, fig. 6F; I. M. Steele et al., 1974, 923, fig. 3b. and other). The frequent presence of small amount or traces of dendritic glass in these rocks can be mentioned as the best evidence of their affinity to the samples under study. The intersertal and ophitic textures of these rocks are commonly thought to be magmatic, crystallized from a primary melt, less frequently from a secondary (impact) melt (especially the dendritic glass is used in support of the latter.)

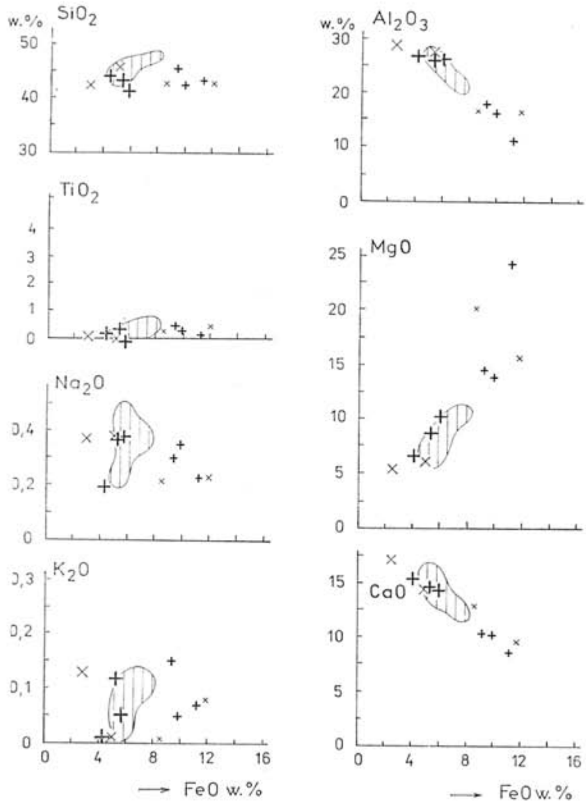

Fig. 8. Chemistry of main oxides related to the FeO content in the fragments studied (the vertical large crosses = bulk composition, the small ones = their matrices) compared with the chemistry of Luna 16 chondrules by K. Keil et al., 1972 (dashed field) and by A. V. Ivanov et al., 1976, (diagonal large crosse = bulk composition, diagonal small crosses = residual glass).

Towards the less perfect cryptocrystalline textures, the variability of the textures and consequently the diversification and discrepancy in terminology increase enormously. A series of textures can be traced that are close to the fragment 3042 by some features and different by another ones. Various textures are involved which are common in spherical particles, such as radiate, excentrically radiate, fasciculate, intrafasciculate etc., characterized by divergently or radially arranged sheaf-like, lamellar, fibreous, plumose etc.

formations, gradually passing to fine fibreous and spherulitic, (terminology see in G. Lofgren et al., 1974 on the basis of plagioclase growth). Many of these textures have been experimentally imitated (G. Lofgren et al., c. l., M. Blander et al., 1976 by means of laser-action and many others). A. V. Ivanov et al., 1976, 748, fig. 7 show the gradiation of some textures from the well-crystallized centre to the less crystallized margin in the individual chondroids. Some of these textures (e. g. an analogon of the fragment 3042) are thought to be primary (J. L. Carter, L. Padovani, 1973), magmatic (A. V. Ivanov et al., 1976) textures, in other cases — very often — they are considered to be the devitrification products (e. g. S. E. Haggerty, 1974, 197, fig. 2 d; R. F. Dymek et al., 1974, 243, fig. 6F) and still in another case the shock induced isotropization and devitrification products (M. R. Dence et al., 1970; A. C. Waters et al., 1971; E. Roedder, P. W. Weiblen, 1970).

The dendritic framework in interstitial (residual) glass — as typically developed in fragments 1058, 3040 — is commonly held for an evident result of devitrification in the primary (e. g. in vitrophyres according to P. W. Weigand, L. S. Hollister, 1973) as well as in secondary rocks (e. g. C. B. Sclar, 1970, 866).

A similar series from crystalline textures to cryptocrystalline ones was established during the crystallization of melted basalts (L. Kopecký, J. Voldán, 1959 — compare M. Palivcová, A. Cimbálníková, 1981) partly due to cooling of the melt (porphyritic textures, skeletal textures), partly due to heating of quenched material (dendritic, spherulitic textures). Newly, typical „lunar textures" in the entire series from cryptocrystalline to holocrystalline have experimentally been modelled on the experimental or natural lunar materials and the conditions of the textural types formation have been determined (G. Lofgren, 1971; G. Lofgren et al., 1978; P. I. Nabelek et al., 1978; D. Walker et al., 1978). From the analogies in melted basalts and experiments it can be deduced — provided the melt being of the same composition — that the formation of various textural types depends not only on the different cooling history (L. Kopecký, J. Voldán, 1959), the degree of supercooling and the rate of the cooling (e. g. G. E. Lofgren et al., 1974, 1977; T. M. Usselman, G. W. Pearce, 1974 etc.), but especially on the precooling history of the melt (P. I. Nabelek et al., 1978; G. F. Lofgren et al., 1978). For instance the different time of heating or melting of the material before cooling evokes different degree of nucleation (i. e. number of submicroscopic nuclei in the melt), and different textures can thus originate even if the cooling rate is the same. Typical „lunar" textures have been gained in this way, from cryptocrystalline (radiate, fasciculate) to intersertal and subophitic ones. When comparing the study of lunar fragments with the results of these experiments and basalt melting, the present authors are inclined to the view that *vitro-ophitic textures of the fragments (1058, 3040) derive from crystallization of supercooled melt,* not from devitrification process. From the analogies with the textures gained by P. I. Nabelek et al. (c. 1., p. 733, fig. A, B) it can be judged that these textures were influenced by the degree of nucleation. Analogous experimentally reproduced textures were gained by cooling of partially crystallized melts at 1292 °C; the texture similar to the vitroophitic fragment 1059 (tending to porphyritic) was gained if the duration of the precooling melting was 4 hours, the texture similar to finer-grained vitro-ophitic fragment 3040 (interface texture) needed 12 hours. Similar textures were reproduced by G. L o f g r e n, 1977 (in P. I. N a b e l e k et al., 737, figs C. D) by cooling rate 2 °C/hour, initial temperature 1280 °C, but precooling heating 24 and 88 hours. G. E. L o f g r e n et al., 1978, 969, fig. B, CD succeeded to reproduce even holocrystalline textures in similar way. The pattern of plagioclases in the textures of fragments 1058 and 3040 represents two most common patterns in lunar „primary" textures — hemicrystalline as well as holocrystalline. *The same mode of origin,* i. e. crystallization from the melt, not devitrification, *is assumed for the cryptocrystalline fragment 3042.* The present authors suggest that the divitrification process can be excluded, the interstitial (residual) homogeneous glass bearing no signs of devitrification.

On the contrary, the dendritic texture of interstitial glass in the matrix of vitroophitic fragments 1058, 3040 cannot be explained unambiguously. In all cases described in the literature this texture is considered as devitrification one. The present authors suppose that not the primary skeletal growth during cooling of the melt cannol be excluded even in this case but no proof for such an assumption is available.

Provenance of the material, primary or secondary origin of the melt

In the previous chapter it was shown that the fragments studied conformed to the material of lunar chondrule type. They correspond to the ANT group of rocks. Thus the results are in accordance with the conclusions of K. K e i l et al., 1972 stating that the chondrules of Luna 16 are of the same chemical composition as the highland rocks.

The highland material is a strange, exotic element in lunar mare regions. It had to be transported into the present place of occurrence from lunar highlands. Considering the distance of Luna 16 station from highland regions, it is necessary to presume the transport most likely by an explosive action of a strong violence. There are two main possibilities of explanation according to the investigations achieved until now: either exogeneous impact process or endogeneous volcanic process. In the first case the melt is of secondary origin, in the second case it is of primary origin (although some local secondary melting of surrounding rocks or solidified volcanic material during volcanic explosion should also be admitted).

Most of the lunar scientists prefer the impact origin of lunar chondrules. The main reasons for such interpretation — in addition to the geological ones — are particularly: the spherical form of the particles (a phenomenon unknown in the terrestrial volcanic products), textures speaking for a rapid crystallization of the melt, a frequent occurrence of glass or dendritic material interpreted as devitrified glass. A. V. I v a n o v et al., 1976 for instance newly consider hemicrystalline and cryptocrystalline textures of lunar chondroids to be the result of impact process, and even from various stage of crystallinity of chondroids they judge the position in the „impact nebula" during their formation.

The textures of the fragments studied represent — as shown above — transitional intermediate members of a textural series. At one end of the series holocrystalline rocks developed analogous to those of primary rocks, at the other end cryptocrystalline material which is common in lunar spherical particles or glass is formed.

The occurrence of hemicrystalline to holocrystalline textures in chondrules of ANT group (K. Keil et al., 1972; G. Kurat et al., 1972) permits a tentative conclusion that the series is a genetic one. The experimentally reproduced series of the textures — as mentioned above — supports such a view. All series from cryptocrystalline to holocrystalline textures originated during one experimental process — under minimal (atmospheric) pressure, by changing the cooling rate, nucleation rate etc..

Textural analogy with melted rocks is usually used as an argument supporting the secondary, impact origin of the melt. On the other hand B. M. French's view (1972) should be taken into consideration that — particularly in partially vitreous material it is difficult to distinguish wheather the textures are products of rapid solidification of primary magmatic melt or of crystallization from quenched melt. Consequently textural criteria should not be used — as usually do (e. g. V. Smith et al., 1970, 901; C. B. Sclar, 1970, 866 etc.) — in support of crystallization from secondary (i. e. impact) melt. Neither the common presence of glass and its dendritic morphology on lunar surface, nor the textures of rapid crystallization or dynamic influence, isotropization of minerals etc. can justify such a view. The entire textural series of similar textures was produced from experimental melts under normal atmospherical, not abnormal pressure conditions. The dryness of lunar endogeneous melts and their crystallization under the vacuum conditions must have evoked crystallization analogous to the experimental dry melts. Due to the pressure change during the explosion into vacuum such phenomena that are unusual or unknown in terrestrial volcanism, could originate. The tendency to form spherical particles not only from glassy material but also from some minerals could be one of such special features caused by these conditions. Therefore, neither the textures nor the composition of lunar spherical particles of chondrule type can be used in support of one of the origin of chondrules from the two possibilities mentioned above. According to most authors they could be transported into their present region — allochtoneous to their origin — either as products of exogeneous impact events or of endogeneous explosive volcanic events. However, it is most probable that — in respect of their textural as well as compositional analogies — they originated only by one of these ways.

Conclusions

1. Three fragments from Luna 16, two of hemicrystalline (vitroophitic) and one of cryptocrystalline (divergently sheaf-like, dendritic) texture represent fragments of lunar spherical particles of chondrule type.

2. The composition of the fragments agrees with the ANT group of lunar rocks; it is analogous of the Luna 16 chondrules according to K. Keil et. al., 1972 and to Luna 16 and 20 chondroids according to A. V. Ivanov et al., 1976.

3. The textures of fragments represent a series from hemicrystalline (vitrophitic) to cryptocrystalline members. The series can be considered to be a genetic one, originated from supercooled melts under different ways and degrees of cooling. The textures are similar to those of melted basalts as well as to experimentally produced (experimental and natural) lunar melts.

4. The ANT fragments represent an exotic, allochtoneous material in the mare region, analogous to highland regions. The possibilities of transport from their parent region to the present place of occurrence are discussed.

5. Neither textural nor compositional character of the chondrules can determine the endogeneous or impact origin of the melt. The interpretation is distinctly influenced by the working hypothesis about the geological development of Luna surface. Therefore, textural and compositional criteria should be used cautiously. On the other hand the new applied method of experimental modelling of the textures could throw light on approximative conditions of crystallization of Lunar material.

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