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Makroskopický a mikroskopický výzkum chondritů z Příbramska

Macroscopic and microscopic Investigations of the Chondrites from the vicinity of Příbram (ČSSR)

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Po třech hromadných pádech meteorických kamenů, které se udály na území dnešního Československa v první polovině minulého století (Stonařov j. od Jihlavy 22. května 1808, Lysá nad Labem 3. září 1808 a Blansko na Moravě 25. listopadu 1833), nastal čtvrtý hromadný pád 7. dubna 1959, v 19,30 hod. světového času. Z deště 17 úlomků meteorických kamenů byly až dosud nalezeny jen čtyři kusy o celkové váze 5.695 g. Podrobným morfologickým výzkumem na nich provedeným bylo zjištěno, že jde vesměs o orientované individuální exempláře polyedrického tvaru, zhruba klínovitého, s výraznou až charakteristickou čelní i týlní částí. Všechny nalezené kameny mají černou natavenou kůru, místy s patrným hnědým odstínem o tloušťce kolísající v rozmezích 0.25—0,35 mm. Její zajímavá povrchová struktura je převážně hrbolkovitá, vzácněji také proužkovitá. Kůra je tvořena mikroskopicky zrnitou směsí převládajícího magnomagnetitu a natavených silikátů.

Vlastní světle šedá, jemně nazelenalá a místy narezavěle zbarvená holokrystalická hmota kamenů je tvořena převážně jemnozrnnou směsí olivínu s enstatitem se shluky nikelnatého železa, troilitu a chromitu s akcesorickým maskelynitem, příp. i klinoenstatitem. V základní hmotě vynikají především rezavé skvrny vzniklé počáteční limonitizací nikelnatého železa a místy velmi hojné chondry a jejich úlomky. Nejvýrazněji se ve struktuře kamenů uplatňují polysomatické, excentricky paprsčitě vláknité chondry enstatitové. Olivínové chondry jsou většinou mikroporfyrické, vzácněji se vyskytují také chondry trámcové. Celá řada mikroporfyrických chonder se rozplynula v základní hmotě vlivem metamorfních procesů, jimiž byl vedle silného tlaku, meteorit postižen. Vedle chonder nacházíme v základní hmotě kamenů poměrně hojné porfyroblasty olivínu a enstatitu, které na průřezech prozrazují tvar jen nízkých sloupců zploštělých podle (100), řidčeji také podle (010).

Vzhledem k výsledkům mikroskopického výzkumu mineralogického složení a struktury lze kameny příbramského hromadného pádu zařadit mezi *krystalické chondrity*.

Macroscopic and microscopic Investigations of the Chondrites from the vicinity of Příbram (ČSSR)

A brightly shining bolide appeared on the 7th of April 1959 at 19 h 30 m Universal Time (20 h 30 m Central European Time) at a height of 98 km above Jihlava in eastern Bohemia and illuminated almost the whole territory of Bohemia and part of Moravia. It moved with a velocity of 20.9 km/sec in the direction WNW towards Příbram, SSW of Prague.

On its orbit through the atmosphere it fell gradually and disintegrated at a height between 44 km and 22 km above the surface of the Earth into a number of smaller pieces which fell onto the ground. This disintegration was accompanied by a powerful detonation and a series of smaller shocks accompanied by far reaching rolls.

The photographic instruments, constantly on service at the Astronomical Institute of the Czechoslovak Academy of Sciences, Observatory of Ondřejov, and the Observatory at Prčice 40 km away, recorded, for the first time in the history of meteoritic research, the entire orbit of the bolide as well as parts of the orbits of its fragments. The bolide became extinct at the height of about 13 km. A staff team of the Astronomical Institute of the Czechoslovak Academy of Sciences at Ondřejov, directed by Zd. Ceplecha (23), started at once to measure the observed orbits and to carry out computations inorder to establish the orbit in space. It was found that the bolide penetrated the terrestrial atmosphere above Jihlava with cosmical velocity under an angle of 43°. Its initial weight, according to the computed results, was about 1 ton. From the orbits of the fragments it can be concluded that about 17 pieces fall onto the ground. The measurements of these orbits also allowed to determine, to a great degree of precision, the localities of impact of these pieces as being in the region between Příbram and Kamýk nad Vltavou, SSW and S of Prague. The Ondřejov team, mentioned above, has also the merit of having found up to now with the helpful assistance of the local population four fragments of the original meteorite. The data concerning the finding, dimensions and weight are listed in the attached table. It may be noted that the largest piece, weighing about 100 kg, which must have fallen not far away to the north of Příbram, has not been found up to the present. — The largest of the stones picked up near Luhy fell into cultivated soil, where it excavated only a shallow hole. The other three fragments were found on the surface, and we can therefore conclude that they were submitted to strong braking forces in the atmosphere.

Table of data concerning the stones of the meteoric shower in the region of Příbram, hitherto found

Occurrence	Character of site	Date of finding	Weight in grams	Dimensions in mm	Table
L u h y ESE Příbram WNW Kamýk n. Vlt.	green field	9. IV. 1959	4.250	178×143××115	I. a, b
V e l k á ESE Příbram N Kamýk n. Vlt.	oat field	24. IV. 1959	772	120×87×51	II. a, b
H o j š í n ESE Příbram NNE Kamýk n. Vlt.	clover field	15. VIII. 1959	428	115×56×46	III. d, e
D r a ž k o v ESE Příbram NE Kamýk n. Vlt.	edge of forest on moss near path	24. VIII. 1959	105	64×36×31	III. a—c

1. Shapes of the meteoric stones

A macroscopic observation of the four collected stones reveals a number of common properties, and this fact indicates already common properties of their origin. The shape of the stones is the outcome of the disintegration of the original body of the meteorite. This disintegration proceeded along the corresponding parting surfaces, in analogy with the terrestrial eruptive rocks. It evidently occurred before the meteorite reached the final part of the braking region. This is corroborated by the relatively strong rouding of most of the edges and the smoothing of nearly all surface irregularities, except on the basal parts of the Luhy and Velká stones, i. e., of the two largest pieces. We will later see that these two largest stones differ in a number of other properties from the two smaller ones. The surface effects prove that the surfaces of the fragments are strongly worn down by the atmosphere.

One of the most interesting phenomena is the pronouced relationship between the external shapes of all four stones. All of them have the figure of irregular blunt wedges of polyhedral shape, a shape which is dominant among meteoritic stones. We can classify the stones collectively as irregular pyramids with obliquely chamfered apices. With the exception of the Dražkov stone whose shape is an irregular three - sided pyramid, all the shapes are four-sided pyramids. The stone from Velká is considerably flattened and its shape is similar to that of the Hojšín one While the apex of the Hojšín stone is only rounded, the apices of the three remaining stones are clearly obliquely chamfered. The bases of the pyramidal stones have generally the contour of an irregular hexagon, only that of the Dražkov stone shows the outline of a triangle. The basis of the stone of Velká consists of three small rounded surfaces.

The *magnetism* of the stones was examined by their effect on a magnetic needle and it could be shown that the intensity of this effect changed with the individual stone's contens of nickeliferous iron. It seems that the two smaller stones show a higher magnetic intensity and we have even been able to determine the respective polarity. The slender ends of these stones attract the northern tip of the needle and repulse the southern tip.— A thorough examination of the structure and relief of the surface crust of the stones showed that *all stones are oriented individual pieces*. In every stone we could reliably distinguish the front part (apex) and the basal part. By comparing the four pieces we have found that the larger the stone, the more pronounced is the distinction between front part and basal part. We were therefore at the first glance able to discern at the two larger stones (Luhy and Velká) the basal part from the front part and even from the lateral parts. In these two cases, the basal párts are strikingly uneven and, in comparison with the other parts of the stones, only very little worn down by the atmosphere. By a thorough investigation of the surfaces we can easily distinguish the front part of these stones from the lateral parts, assisted mainly by the classification of the surface types proposed by E. L. Krinov (12, p. 146).

The front part of the two largest stones consists of relatively large surfaces; the stone from Velká shows, moreover, a considerably rounded adjacent apex. The smaller stones (Hojšín, Dražkov), on the other hand, have a front part which consists of strongly rounded edges and neigbouring regions close by. We found that these front parts were everywhere strongly worn down by the atmosphere, sometimes even to perfect smoothness produced by almost complete grinding-off of small surface irregularities, so that a relatively smooth surface of the first order was achieved. On the distal part of the front surface of the Velká stone we observed a clear transition to a surface of the second order. Similar transitions could also be found on the other stones.

The lateral parts of all stones consist of four second order surfaces of unequal size. The irregularities of the surface, which are relatively uniformly distributed, are more dinstinct because they are less worn down by the atmosphere. Almost everywhere we can see gradual transitions to surfaces of the first order. The quality of the lateral surfaces of second order is, however, not of the same character everywhere and this can be considered as an indication that the stones preserved a roughly constant position during the flight or turned only very little.

The basal parts of the two largest stones underwent a conspicuous development. Unfortunately it was just this part that had been torn away and lost from the stone of Hojšín. The basal part of the Dražkov stone is, on the whole, inconspicuous. — The basal parts of the two largest stones (Luhy and Velká) are built by large surfaces of the second order and are essentially systems of scarcely rounded irregularities on the surface. The basal part of the Velká stone is characterized by very sharp edges between itself and the neighbouring surfaces as well as between its own two surfaces. The surface is dotted with various cavities, which are more pronounced with the stone of Luhy than Velká. The basal parts of both stones are very little worn down by the atmosphere. The basal surface of the Dražkov stone has been warped only insignificantly, though its face is much rougher than that of the surfaces of the lateral parts.

Likewise the greater number of very well developed rhegmaglypts can be found on the basal parts of the two largest stones. They can also be found on the lateral parts, though only in a considerably smaller number; their shape is usually much shallower. The basal part of the Luhy stone shows an abundant number of conspicuous rhegmaglypts which are marked by oval, sporadically polygonal perimeters, achieving diameters of 15 mm at the most and a depth of about 5 mm. The stone of Velká has on its basal surface a smaller number of rhegmaglypts, which are also less deep. Flat rhegmaglypts of similar character could also be found on the largest of the lateral surfaces of the Hojšín stone. The smallest and least conspicuous rhegmaglypts have been found on the basal part of the Dražkov stone. Here they show a shallow shape, which is elongated in the direction of the motion. The elongation of the rhegmaglypts indicates the direction of the movement of the stone.

2. Composition and structure of the surface crust

The investigation of the motion ot the stone through the atmosphere and its position during the flight requires a thorough study of the structure and composition of the fusion crust on the surface of the stone. In recent years, a number of contributions have been devoted to the study of the crust of meteoritic stones; the authors are mainly Soviet meteoritists, among them especially I. A. Yudin, who dealt with the meteorites from Vengerov (1954, 7), Pervomaiskij Poselok (1955, 9) and Kunashak (1955, 10).

The whole surface of the four Příbram stones is covered by a fusion crust with the exception of quite frequent small gaps occurring especially on the edges and the apices of the stones. All these gaps have been caused only after the fall of the stones on the surface of the Earth either by the collision or by inconsiderate and inquisitive finders. The Hojšín stone shows an interesting bending of the surface crust close to the gap, which can be considered as proof that the gap was torn on top of a crack of earlier origin.

Another kind of gap can be found on the remaining basal part of the stone of Velká. On the chamfered apex is a fresh gap in the crust and in its neighbourhood there is a second gap of another nature, which undoubtedly originated before the impact of the stone on the surface of the Earth. It could be established that the black fusion crust was torn off mechanically, perhaps by collision with a neighbouring fragment, and the disturbed surface could not be healed by a new crust within the remaining short time interval. The surface was only slightly fused and the uneven and exposed part was only thinly smoothed. The greyish brown colour and the slender fusion crust of this gap distinguish it conspicuously from fresh gaps. Such a gap could be observed only on the preserved part of the Velká stone. The knocking-off of the crust at this part of the stone must have taken place very close to the extinction point.

The colour of the crust is predominantly black to black-grey, occasionally with clear tinges of brown, greyish-brown or reddish-brown; the lustre is dull. Only some larger protuberances show a somewhat brighter lustre, which may however have been produced by mechanical rubbing during handling in the laboratory. The seemingly uniform colouring of the crust might well have indicated a uniform composition of the crust, however, a detailed investigation of the crust by a stereoscopic microscope showed that the crust consist essentially of two components: a silicate and an ore component, the ratio of which is subject to changes. At places of a dominant ore component the colour of the crust is black to black-grey, whereas at places where the silicate component is predominant the colour of the crust is brown or greyish-brown with a tint of red. The ore component is distinctly prevalent in the crust where — especially on the lateral surfaces of the stones — it is sometimes repressed and even reduced to scanty residues in the holllows or on the protuberances. Elsewhere the crust consist primarily of the silicate component, which shows sometimes a greasy lustre. This structure and the composition of the surface crust with black fragments leaves the impression that the ore component of the lateral surfaces was worn off in its fluid condition owing to the influence of atmospheric currents, and wiped off from the surface.

We observed on some parts of the crust of the two largest stones distinct „*greasy stains*" (Tab. IV.), well known from the surfaces of other meteoric stones. They were produced by fusing chondrules on the stone surface. They are either dull or dark and show generally an oval shape; they are produced by fusing chondrules of fine-fibrous enstatite. Occasionally these stains are circular and one can sometimes discover on them the microporfyritic structure of olivine chondrules. Its particles are usually coated by a black lustrous surface crust. It is important to know the surface structure of the fusion crust, if we want to evaluate the motion of the individual stones through the atmosphere; the nature of the structure becomes clear if we examine it by a stereoscopic microscope. We observe on the front parts of all four stones a conspicuous and characteristic knobby structure (Tab. V., Fig. a), if we use the classification proposed by E. L. Krinov (12). The protuberances are rather small and uniformly distributed on the surface of the stone. They are mainly produced oby agglomerations of nickeliferous iron on stone surfaces not worn down by the strong fusing effect to such a degree as the silicate component. The front parts of the stones show, as a common property, above all the conspicuously strong flattening and rubbing down of these protuberances, due to the grinding effect of the atmosphere. All prot uberances are strongly squeezed to the relatively smooth surface. On some parts of the Luhy stone apex the protuberances disappear completely and the surface crust appears to have a tight-fitting structure, because here the resistance of the air had the greatest effect.

The knobby structure of the crust surface predominates also on the lateral parts of all four stones. On some of them we can establish a gradual transition to a notch structure, such as Luhy and Velká, or a nipple structure like Hojšín, or a strip structure (Dražkov). On the Hojšín stone we find even on several places irregularities arranged in oriented, roughly parallel, rows. The Dražkov stone shows a preserved patch of black crust with distinct, fine, parallel strips in the centre of one of the lateral surfaces. A similar strip structure of the crust surface can be observed, in rare cases, even in the brown silicate crust. This type of structure is one of the characteristics of the lateral parts of chondritic stones. It seems that here we are again dealing with the residue of the initial black surface crust wiped off from the surface by the effect of atmospheric currents. The predominant knobby structure of the surface differs from the same kind of structure of the front part by the fact that the protuberances of nickeliferous iron on the lateral parts protrude more distinctly above the surface and their flattening is smaller than on the front parts.

The surface structure of the crust on the basal parts is roughly identical with that of the lateral parts (Tab. V., Fig. b). It appears that the protuberances on the largest stones protrude sharply above the surface because here the smoothing affect of the atmosphere has been very small. The Dražkov stone shows a crust structure on its basal part which takes the form of fine nipples, sometimes furrowed by shallow pores, so that it has the appearance of something like slag.

If we summarize the observations of the surface structure of the fusion crust of all four Příbram stones we come to the conclusion that the stones rotated to some degree around an axis related to their motion through the atmosphere. This is proved by the fact that the surface structure of the crust on the lateral parts — mainly on the two largest stones — everywhere shows the same character. As for the the two smaller stones, a distinct structural differentiation of the crust could be establised on the lateral surfaces, through sometimes only by indication. This leads us to be conclusion that the stones did not rotace very much on their orbit or that such a rotation during the passage trough the atmosphere was negligible.

Microscopic research of the fusion crust on the surface

Polished sections and thin section taken from the stones of Velká and Hojšín were used for a thorough examination of the inner structure and the mineral composition of the fusion crust on the surface. All the samples examined revealed a composition in which the ore component was predominant. We used a polished section of the Hojšín stone, cut vertically to the stone surface, for measuring the thickness of the crust and found that it varied between 0.35 and 0.25 mm. At a point where the chondrule came close to the surface the thickness of the crust decreased to only 0.15 mm.

This is evidently one of the spots where the observation by a stereoscopic microscope reveals a „greasy stain", mentioned above, and its appearance depends certainly on the structural change of the surface layer below the surface crust, because the chondrules have generally a much finer and more regular structure than the surrounding material of the chondrite. — The thickness of the fusion crust of the Velká stone was measured also by Z. C e p l e c h a. He used a Zeiss instrument for measuring co-ordinates and determined the thickness on 30 surface spots of the chondrite, part of which were situated in the front part and the others in the basal part. He found, first of all, that there is no essential difference between the resulting values of the two parts; the average value was 0.288 mm. If the chondrule approaches the surface of the stone, the crust thickness decreases to 0.180 mm. On the protuberances caused by nickeliferous iron it drops to 0.033 mm only. At places of „greasy stains" the thickness amounts to 0.094 mm.

Under transmitted light the crust is completely opaque and has a deep black colour, caused by the dominance of the ore component. The ore components show sporadically traces of disintegration into rusty limonite, which tinges the neighbouring substances of the chondritic stone. The crust substance of the thin section examined shows, on the whole, the same character in transmitted light as the ore components contained in the proper substance of the chondritic stone. The crust surface is gently undulating and rough; occasionally we observe a number of furrows and shallow pores, the oval section of which can often be seen on thin sections. Their diameter is about 0.030 mm and their depth aproximately 0.08 mm. The pores have the same character as the pores found in the chondrite crusts of the Kunashak stone (Tcheliabinsk region of RSFSR), described and illustrated by I. A. Yudin (8, Fig. 1). The lower border of the crust, as compared with the proper substance of the chondrite, is accentuated by its deep black colour and is therefore conspicuously sharp; it is likewise undulating. Sometimes it produces shallow bends penetrating into the chondrite substance. The description given above makes it clear that the Příbram stones provide, instead of the usual three zones of which the surface crust of chondrites consists, only the third of these zones, i. e., the lowest one, the so-called impregnation zone (if we apply the terminology introduced by G. Tschermak (18), which is based on a detailed examination of the meteorite crust carried out by A. Brezina (2)). The Příbram stones are therefore without the glassy matrix at the surface and the absorption zone below it. However, the occurrence of only one of the usual zones in the surface crust is not quite unusual with chondrites. This phenomenon has already been mentioned by G. Tschermak (18) and, more recently, by E. L. Krinov (12). Tschermak points out that the absence of the second and third zone in the crust of meteorites is characteristic of stones whose porosity is small (e.g. Kňahyňa).

The impregnation zone of the surface crust of the Příbram stones does not differ essentially from the analogous layers on the crusts other chondritic stones. Occasionally it contains inclusions in the form of minute rounded grains of olivine, sometimes also fragments of enstatite, which are always tinted rusty by limonite. No glassy matrix has been found on thin sections.

The examination of the surface crust in reflected light brought some interesting observations. Even at first glance we can see the striking effect of the uneveness of the surface crust and the frequently occurring sections of pores. Especially conspicuous are the inclusions of nickeliferous iron and troilite which differ from the other material of the crust by their higher reflecting power and colouring. The colour of the major part of the surface crust is grey or dark grey; the reflecting power is negligible and there are no inner reflections. It is only by using the greatest magnification that we are able to discern reliably the dark grey silicate material from the relatively brighter ore material. The structure of both components is very fine-grained and, sporadically, fine-striped. The dark grey material corresponds certainly to the silicate component or to the glassy matrix produced by the fusion of silicates on the surface of the stone. It was not possible to identify thoroughly the constitution of this material, because it was completely saturated with the ore component and because of the negligible dimensions of their grains. The second crust component, of very feeble reflection power, clearly dominates over the silicate component and is characterized by a considerable resistance to concentrated acids. It is not even broken by concentrated HNO_3. With respect to these properties it can probably be considered to be a m a g n o m a g n e t i t e, i.e., essentially a magnesium magnetite with a certain ratio of Fe — Mg. Magnomagnetite has also been found in the surface crust of the other meteoritic stones. I. A. Y u d i n (10) found it in the crust of the Kunashak meteorite, mentioned above, the crust character of which corresponds closely to that of the Hojšín chondrite, with the difference that the Kunashak stone surface consists of two zones. The silicate and the ore component of the crust of the Hojšín stone can be discerned only between the crossed nicols of a metallographic microscope, where the magnomagnetite appears as an isotropic dark substance. The difference between the structures of the Hojšín stone and the Kunashak stone rests on the dispersion of both above-mentioned components. The crust of Hojšín stone is a relatively homogenous fine-grained mixture of magnomagnetite with silicate material, while the crust of the Kunashak chondrite is characterized by a field-like micro-structure, where the fields of silicate are surrounded by grains of magnomagnetite.

3. Chondrite substance and its macroscopic description

If we observe the stones with the unaided eye or, better, with a stereoscopic microscope, we find that they have a colour of light grey with a faint tinge of green, which is sometimes quite conspicuous. We see on all refracting surfaces a relatively uniform cloud-like, or spotty, brown to rusty colouring of the stone substance. The spot-like appearance is produced by particles of nickeliferous iron and, to a certain degree, by troilite, both of which are in the beginning state of limonitization. Limonite is a product of the disintegration of these particles and it tinges the close neighbourhood. In the uniformly developed substance of the chondritic stone some particles stand out conspicuously: first of all, the composite agglomeration of nickeliferous iron, mentioned above, forming light metal-grey xenoblasts, as well as smaller grain-shaped accumulations of troilite. The distribution of these components throughout the whole substance of the chondrite is uniform; there are, however, places where nickeliferous iron is predominant over troilite not only in amount but also in the size of agglomerations. Nickeliferous iron and troilite are conspicuous by their colour. Besides these components we observe some oval or circular chondrules, differing from them in size and in structure; their colour is that of the ground-mass of the chondritic stones, but their distribution is irregular. In addition to the chondrules there are finally porphyroblasts of olivine and enstatite of various sizes, which can mostly be seen only with stereoscopic microscope. We come to the conclusion that the chondrules, fragments of chondrules and large individuals constitute the prevailing part of the chondrite material, and at several places their proportion of the total mass can be estimated at nearly 75 per cent (e. g. thin section F).

The structure of chondrites is fine-grained and distinctly holocrystalline, since no glass or glassy matrix have anywhere been found. According to A. N. Z a v a r i c k i j (22), the absence of glass is one of the characteristics of chondrite metamorphosis. We can therefore classify the Příbram stones as c r y s t a l l i n e c h o n d r i t e s. With respect to the presence of larger individuals in the fine-grained ground-mass — if we disregard the chondrules — we can call the structure of the chondrite porphyroblastic. At some places it seems that the porphyroblasts of olivine and enstatite are connected with analogous components of the ground-mass by gradual transitions. However, powerful cataclases often produce an intensive crushing of larger and smaller individuals at various spots and we are therefore not able to follow up reliably such a transition. At some places we find also patchy arrangements of the substance, undoubtedly connected with metamorphic processes, above all, with the disappearance of chondrule borders and the merging with the ground-mass (Tab. VI. a, b).

Structure and composition of chondrules

As regards the mineral contents, shape and structure of the stones, the Příbram chondrites contain the most usual chondrules built by enstatite and olivine (Tab. VII., Fig. a). The enstatite chondrules are much better preserved and predominate at places over the olivine chondrules. This condition can be explained by the influence of metamorphic processes attacking the less resistent microporphyritic chondrules of olivine, which at some places are completely dissolved in the ground-mass. Similar results have already been published by A. N. Zavarickij and L. G. Kvasha (22). The fine—grained enstatite chondrules, supported by their dense structure, withstand the metamorphosis to a higher degree and retain, on the whole, their identity without essential changes; this is the reason why they now appear more prominently in the structure of chondrules than the olivine chondrules, which were certainly prevalent before the metamorphosis.

The polysomatic enstatite chondrules show their proper characteristic eccentrically radiating fibrous structure; olivine forms rarely monosomatic, skeleton-shaped chondrules, but appears mostly in lamellar and microporphyritic chondrules. The chondrules never dominate over the other chondrite materials, in which they are usually thinly dispersed; only exceptionally we find them is some kind of denser clustering. On the whole, their proportion in the total chondrite mass amounts roughly to approximately 15—20 per cent, generally it ranges below this value. The shape of the chondrules is mostly oval, rarely spherical. Quite often we find pressure deformations, especially on olivine chondrules, and among them extremely elongated shapes. Sporadically we observe a great number of chondrule fragments of predominantly oblong shapes as parts of enstatite chondrules. — The size of chondrules differs considerably, but it may be said that the enstatite chondrules are larger. The relation between the sizes of both kinds of chondrules is shown in a comprehensive table.

Size of the chondrules
(measured on 6 thin sections)

	Enstatite	Olivine
Maximum	3.0 × 2.6	2.4 × 1.05
Average	1.4 × 0.8	0.9 × 0.6
Minimum	0.3 × 0.2	0.5 × 0.5

From the data given above it can be gathered that in our case the chondrules are relatively large and exceed even the average size of 0.5 mm reported by E. L. Krinov (12). This average is roughly that of the olivine chondrules, while the enstatite chondrules are much larger.

Enstatite chondrules

Most of the distinct chondrules are enstatite chondrules of fine fibrous shape. They are built up as polysomatic eccentrically radiating fibrous chondrules, usually formed in fascicles of fibres and arranged fan-like. Sometimes we find chondrules composed of two or more fascicles of fibres. In one case (thin section F) we observed six smallish fascicles of fibres constituting one chondrule, but there are quite often cases where the centre lies on the periphery of the chondrule and even within it (Tab. VII., Fig. b). Enstatite fibres are usually oriented in the same direction. Only in one isolated case (thin section F) we found a double orientation. The section shows the dominating coarser fibres of bluish interference colour in a position, which is roughly parallel with the plane (010). On the other hand, much finer fibres, parallel with the coarse one, of light yellow interference colour, have been found to constitute a plane parallel with the plane of the optical axes, i.e., the plane (100).

The fibrous shape of the enstatite chondrules is always very marked, even when the fibres are very fine. The size of enstatite fibres varies considerably. Some of them reach the length of 1.5 mm and more, and their width averages around 0.015 mm. However, we found among them also fibres, the width of which attained a maximum of 0.075 mm or a minimum of only 0.025 mm. We examined a number of fibre cross sections and measured their dimensions; the minimum value was 0.05×0.0025 mm, the maximum value 0.37×0.15 mm and the average value 0.037×0.020 mm. The ratio in most cases is roughly 2 : 1. — The cross sections of enstatite fibres (though some of them in a very imperfect condition) have been the subject of morphological studies. There are usually strongly rounded and affected by pressure. In most cases it can be established that in the vertical zone the plane (100) is predominant; the columns and fibres are therefore flattened. Occasionally the occurrence of planes (110) and (010) can be inferred to a certain degree of reliability. The bounding of the fibres is always very imperfect and their borders are strongly crushed by cataclase. Very often we observe finely crushed fragments of enstatite between the fibres. Similar observations were made by E. Dittler and J. Schadler (4) when they examined enstatite chondrules of the meteorite stone of Prambachkirchen in Austria.

We recognize the characteristic prismatic cleavage of pyroxenes in the form of very fine, straight, short and sharp cracks only occasionally, mostly on longitudinal sections and rather rarely on cross sections. There are, however, many more coarse transverse cracks on every fibre. We find often great numbers of them. They are produced by the pressure exerted on the long and relatively fragile fibres. — The colour on the enstatite fibres is usually grey to light grey. Sometimes we observe a fine grey obscurity produced by inclusions and fine craks, especially near the fibre borders. A local faint yellowish to yellowish-brown colouring is caused by finely dispersed ferrohydrate, released by the beginning of disintegration of the agglomerations of nickeliferous iron.

Optical research showed very frequently an undulating extinction of the fibres; again proof of an intensive pressure effect. Otherwise, enstatite has a characteristically low positive birefringence, positive elongation and intermediate refraction. The low birefringence indicates the presence of enstatite with a relatively low ratio of the ferro-silite component. — The inclusions in enstatite are very frequent and extremely fine. Occasionally they consist of minute allotriomorphic grains of olivine, and there is also a conspicuous, though tenuous, dispersion of ore pigment, the particles of which attain mostly a diameter of 0.005 mm, not unfrequently only of 0.001 mm, but reaching sometimes agglomerations of 0.015 mm. The grains are black to blackish-brown, in reflected light dark brown, indicating probably chromite and, at places, troilite. Troilite is also indicated by occasional beginning disintegration of the ore grains into limonite. However, the ore grains are dispersed in a too tenuous manner to be able to affect the total colouring of the fibres; they keep, moreover, to a large degree near the periphery of the chondrules.

Clinoenstatite is, on the whole, a rare occurrence in the enstatite chondrules; at some places it forms fine grains or imperfect lamellae and fragments, which adhere parallel to the enstatite fibres. They have roughly the same refraction index as enstatite, a somewhat greater birefringence (yellow interference colour of the first order); they are completely transparent, only rarely twinning, and attain the average size 0.15 × 0.010 mm. A characteristic feature is the fact that its extinction is inclined to the elongation of the lamellae at an angle of c/γ ranging between the values of 18° to 24°. These properties agree with those of the clinoenstatites in chondrites, as has already been pointed out especially by W. Wahl (20) and later by H. Michel (13), who established the presence of clinoenstatite as companion of enstatite in almost all chondrites hitherto known. H. Michel assumed that clinoenstatite was produced mainly by heating and rapid cooling of the meteorites during their flight through the atmosphere. On the other hand, the American scientists E. T. Allen. F. E. Wright and J. K. Clement (1) are of the opinion that the origin of clinoenstatite lies in high temperature. This disagreement between the two presumptions has still to be solved.

Only in exceptional cases we observed, besides the radiating fibrous enstatite chondrules, polysomatic enstatite chondrules consisting of several lobe-like dovetailing grains. They are found only very rare (thin section B). The largest of this kind of chondrules has an oval cross section and a size of 3.04 × 2.60 mm, and the largest enstatite individual inside the chondrule attains the size of 2.1 × 3.0 mm. All its grains are transparent, characterized by frequent fine and short cracks of prismatic cleavage and numerous coarse cracks of irregular course. An interesting feature is the inclusion of olivine in the form of small and large fragments. Only sporadically we could also observe grain agglomeration of troilite.

All enstatite chondrules differ considerably from their vicinity by their structure and can very well be observed in the fine-grained ground-mass, even if they are not marked by a distinct kind of rimming, especially by a ring of fine-grained ore minerals.

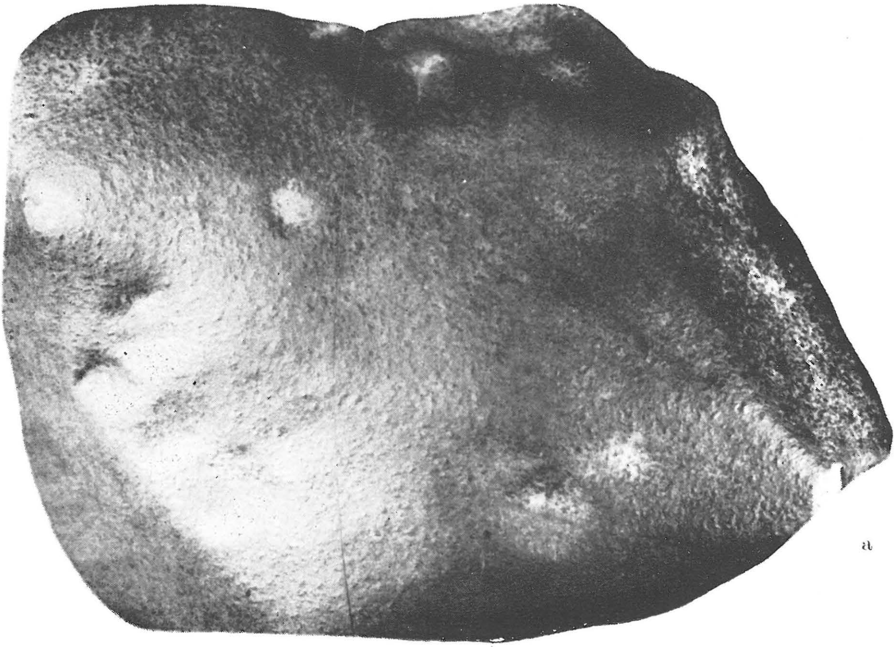
Olivine chondrules

Olivine forms in the Příbram chondritic stones two structural types of chondrules which differ one from another quite distinctly. We find very frequently microporphyritic chondrules (Tab. VII., Fig. c), while lamellar (grate-shaped) chondrules occur only in small numbers. Both kinds of chondrules differ one from another already by their appearance in the ground-mass. While the lamellar chondrules are always clearly visible in the ground-mass, the microporphyritic chondrules are usually disturbed and changed by the metamorphic processes to such a degree that they are mostly lost in the ground-mass. It is, however, most probable that the microporphyritic olivine chondrules substantially dominated in the initial chondrite over the other types of chondrules, perhaps even over the enstatite chondrules.

The monosomatic lamellar (grate-shaped) chondrules consists of strongly rounded, spherical or oval skeleton-shaped olivine crystals. Their skeleton-like development can be observed especially on sections roughly vertical to the axis *b*. They attain a maximum size of up to 0.60×0.45 mm, but they are sometimes very small and reach only the size of 0.20×0.16 mm. They are built up from parallel olivine lamellae of a width of 0.025 to 0.012 mm and are sometimes rimmed by fine grains. The thin sections showed so far a parallel orientation with the axis *b*. As a characteristic feature we mention the coincidental extinction of the whole chondrule. The chondrules differ from the ground-mass by their structure, size and the scarcity of ore pigment. Only here and there we observe a thin concentration of ore grains on the periphery. The olivine of these chondrules is quite transparent on thin sections, and only occasionally a faint green tint can be seen or a yellowish-brown colouring by limonite, produced by the disintegration of nickeliferous iron. The olivine lamellae are always highly and irregularly cracked and sometimes also affected by dens, coarse, transverse splits. No cleavage has been observed. Optically they differ clearly from enstatite only by a somewhat higher refractive index and a definitely higher birefringence. Among the unfrequent inclusions we find thinly dispersed grains of black troilite of an average size of 0.015 mm. Between the olivine lamellae we observe again a very fine-grained grey substance, sometimes mixed with minute ore powder of about 0.005 mm diameter. This mixture consists of particles produced by the crushing of olivine lamellae or of transformed glass as a product of cataclases and metamorphoses. Sometimes we discover also in this material distinctly isomorphic particles, undoubtedly belonging to m a s k e l y n i t e. We found only once (thin section F) a composite lamellar chondrule, consisting of three parts. Its size is 1.37×1.017 mm and two of their parts are built of distinctly skeleton-shaped olivine, while the third part consists of irregularly oriented fascicle of fibres. The outline of the chondrule is on the whole egg-shaped and the chondrule itself is considerably flattened.

The microporphyritic chondrules have a spherical or egg-shaped cross section; their maximum size is 2.2×1.7 mm and the minimum size 0.52×0.48 mm. They differ, as a rule, not very much from the ground-mass, with which they not unfrequently coalesce so that they offer an undiscernible aspect. They are sometimes surrounded by a fine-grained olivine rim of 0.04 mm thickness and are built up by grains and/or fragments of olivine, which are either attached one to another or deposited in fine-grain interspace matter. The olivine particles attain a size of 0.9×0.6 mm; they are transparent, always imperfectly bounded and strongly rounded. From a few, but somewhat better bounded outlines of grains we are able to find an indication of columns flattened by (100). Cleavage is not always clearly visible and only occasionally we find cracks of imperfect cleavage by (100) and (001); on the other hand, a great number of coarse irregular cracks are present. Optically there is not a great difference from local lamellar chondrules.

The material between its grains consists usually of very fine-grained grey mixtures of small olivine grains produced by the transformation of the initial glassy matrix, but partly also by the crushing of the peripheral parts of the olivine grains. The inclusions are frequently found to consist again of troilite in the form of minute grains or grain agglomerations having the size of 0.4×0.2 mm. The agglomerations are black, in reflected light they show a light tombac brown colour with metallic



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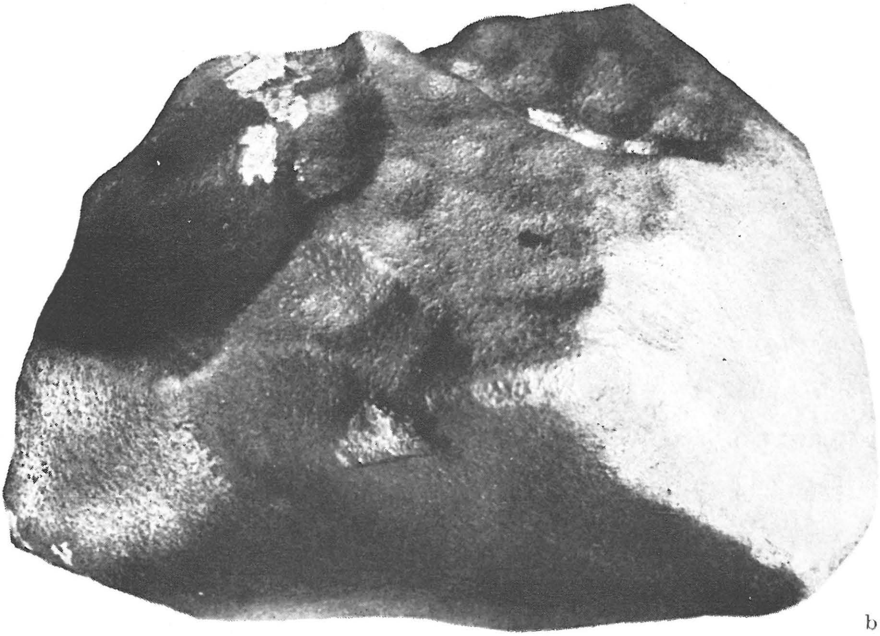

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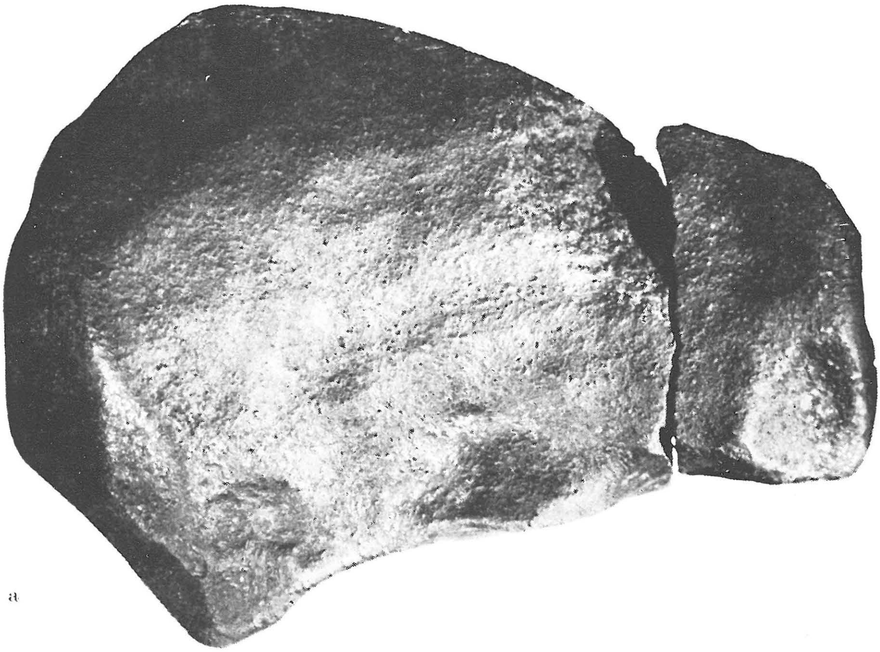

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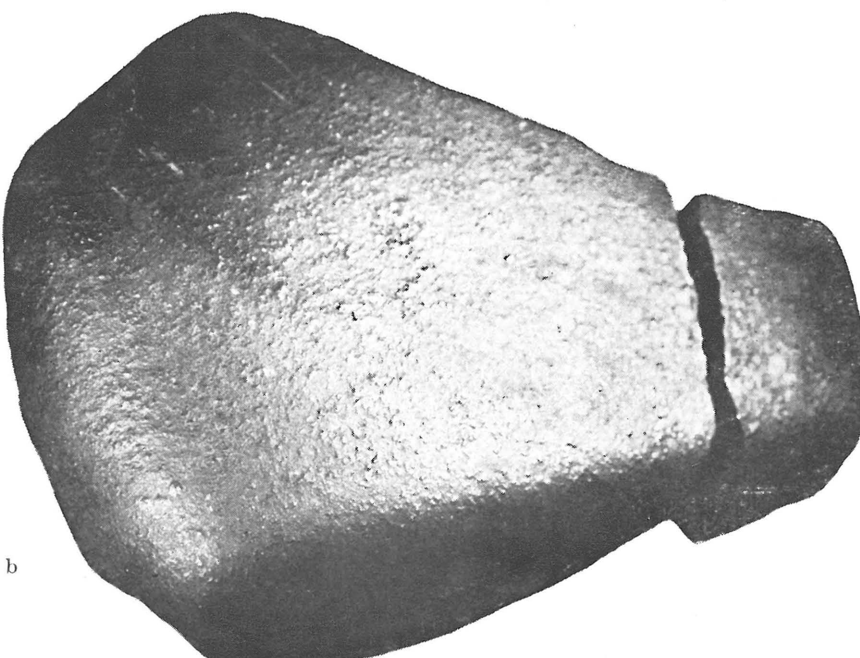

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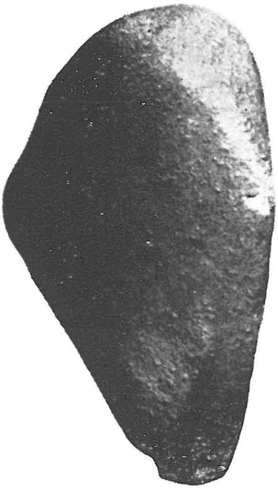

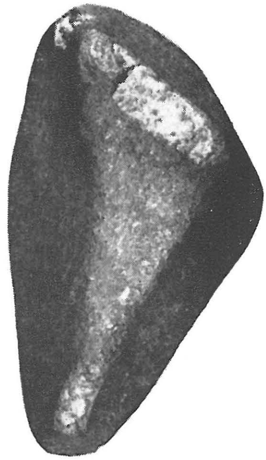

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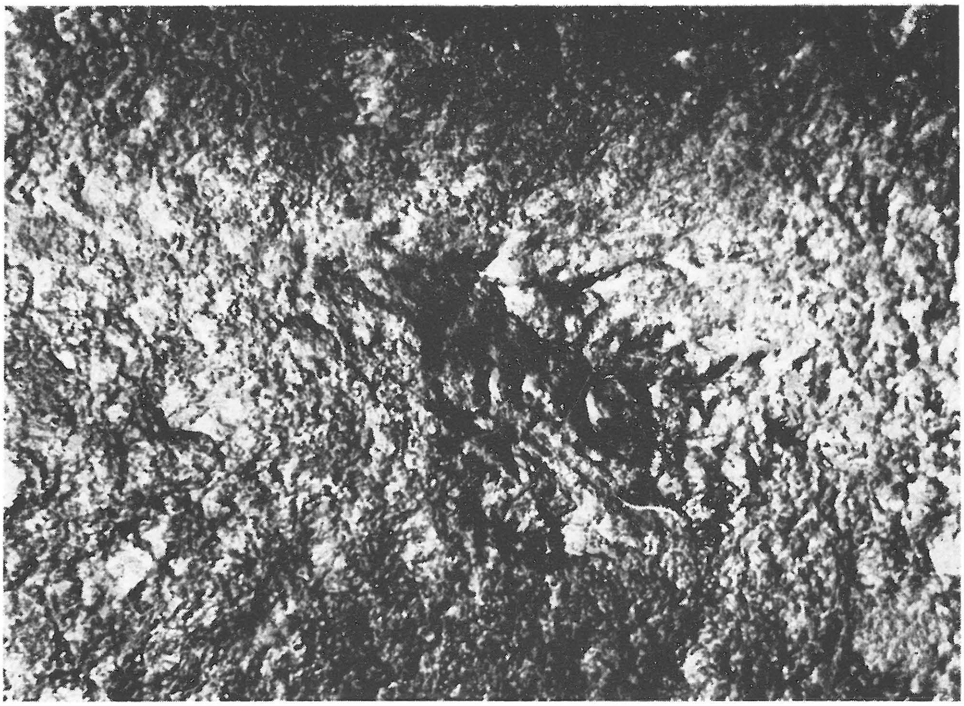

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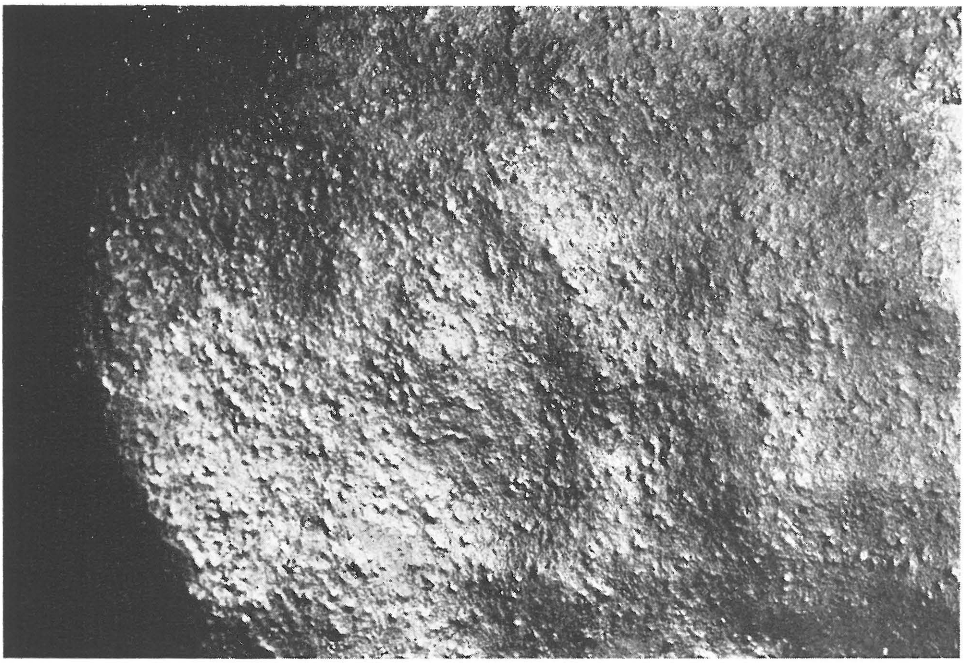

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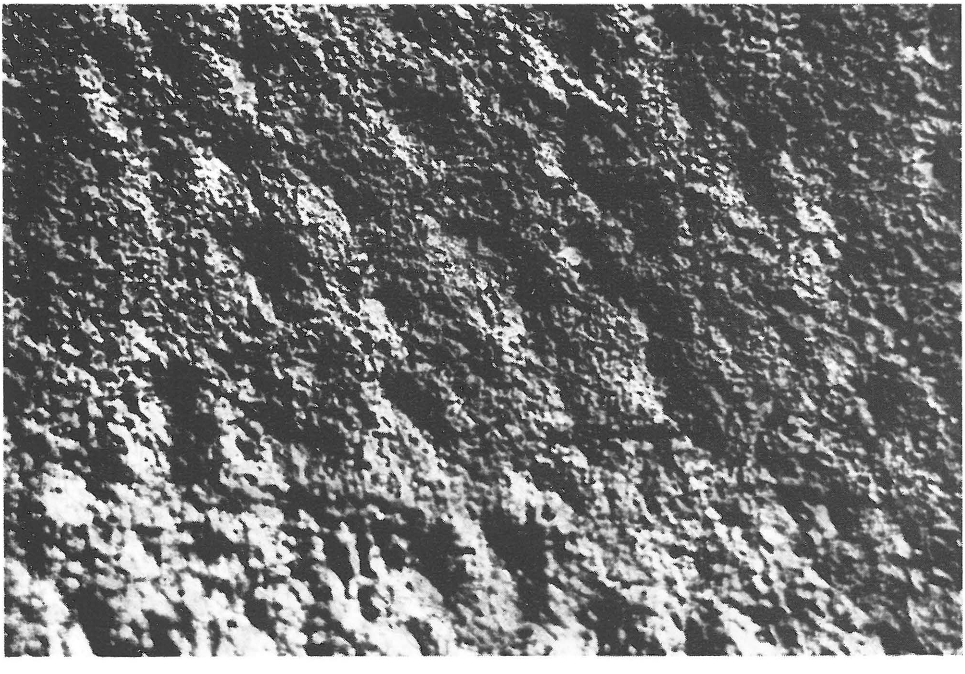

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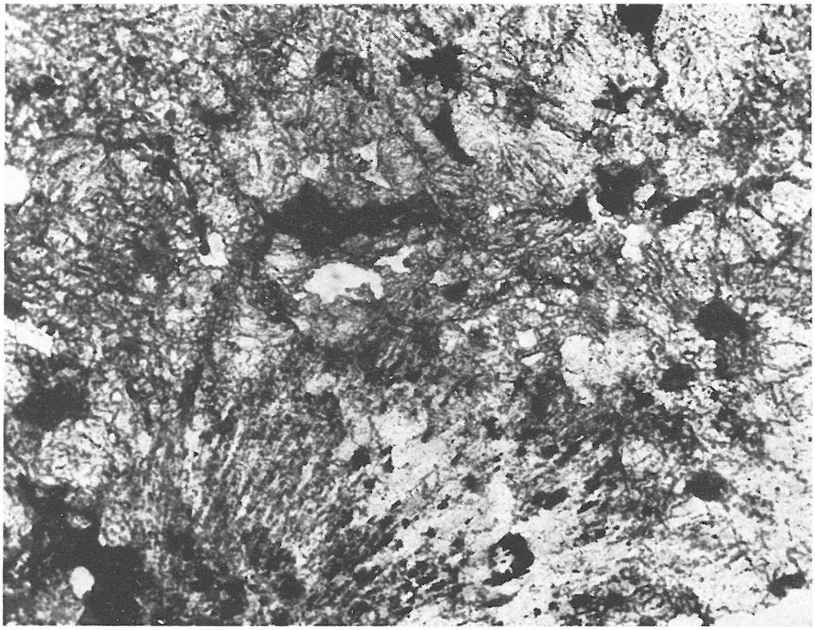

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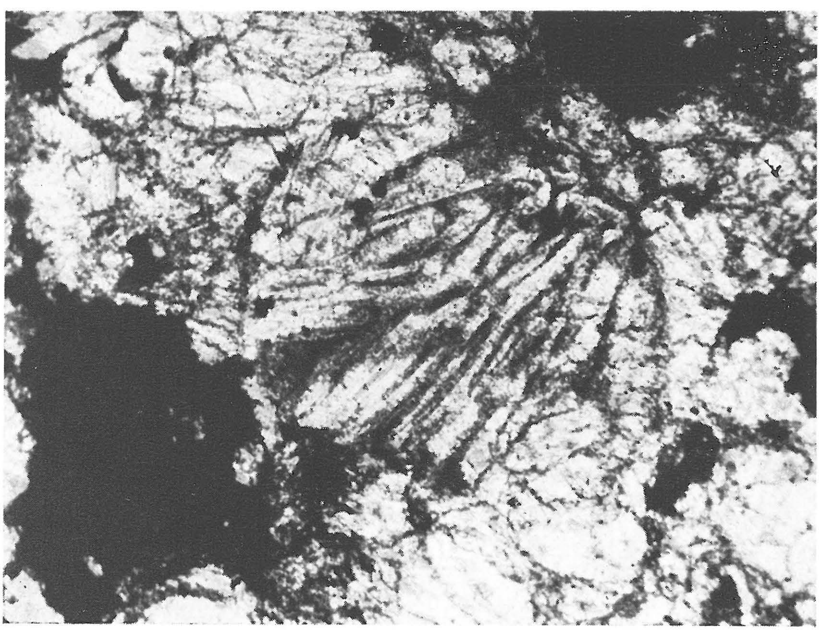

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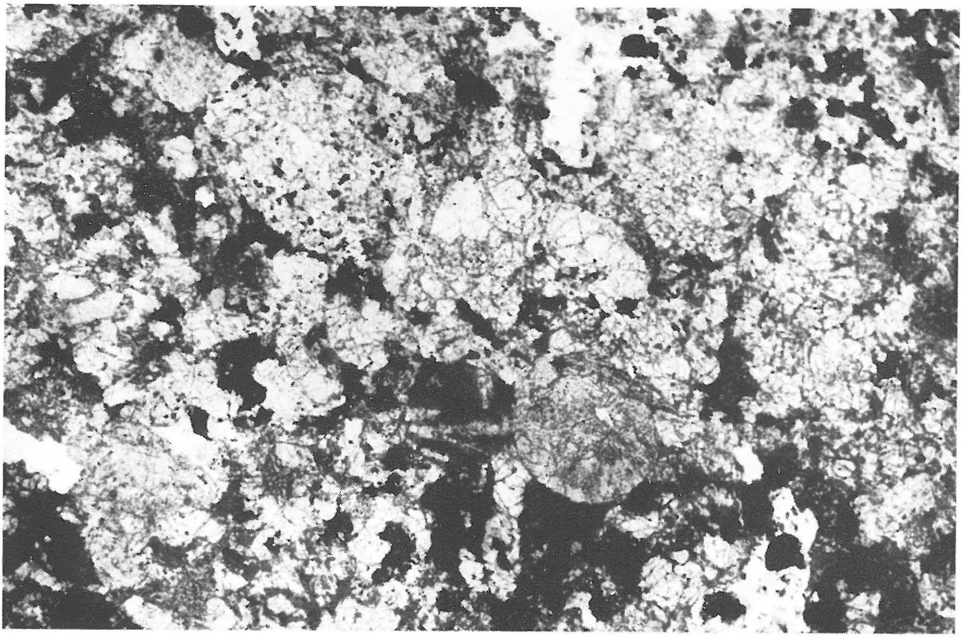

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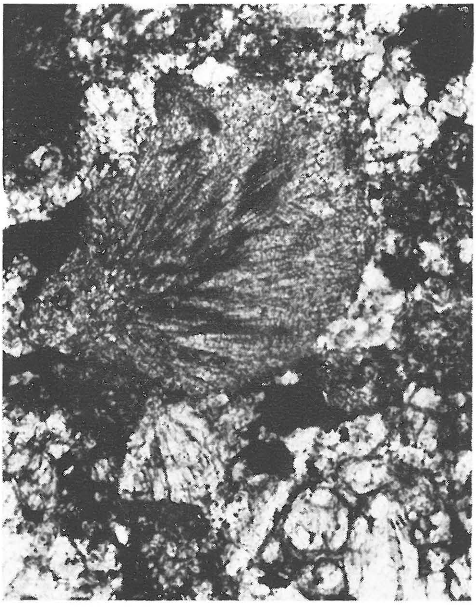

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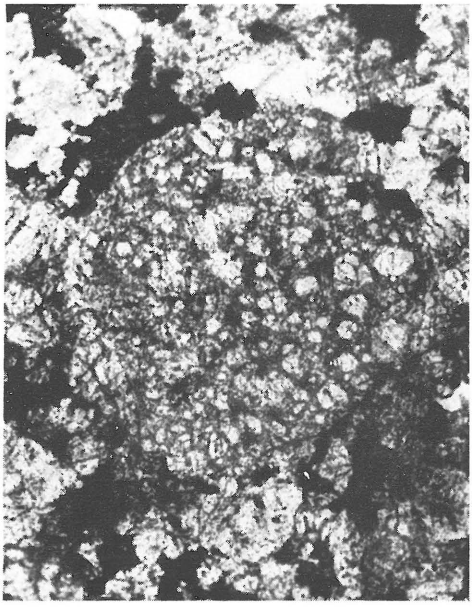

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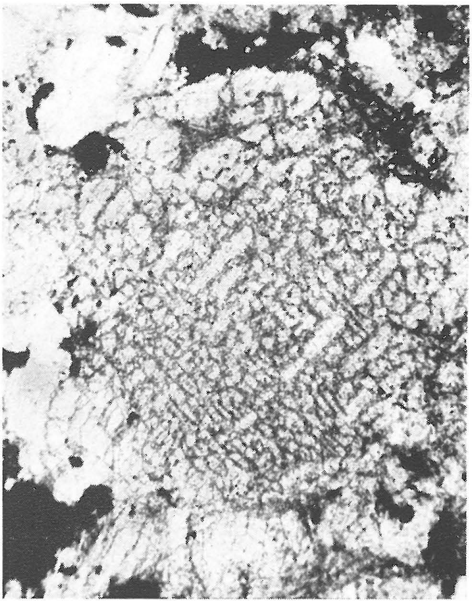

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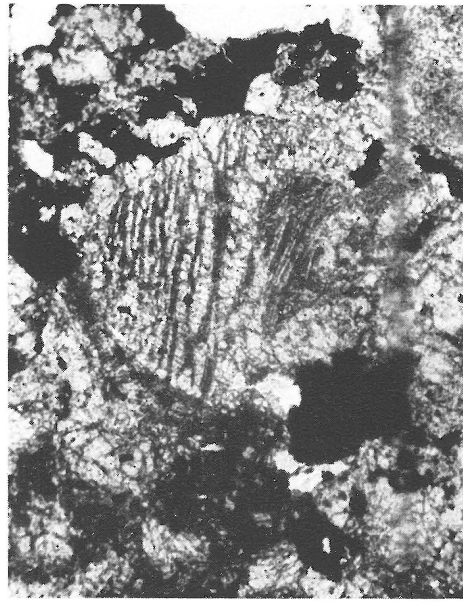

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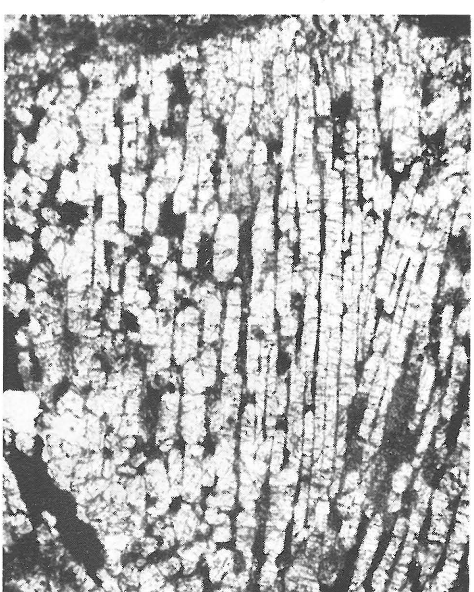

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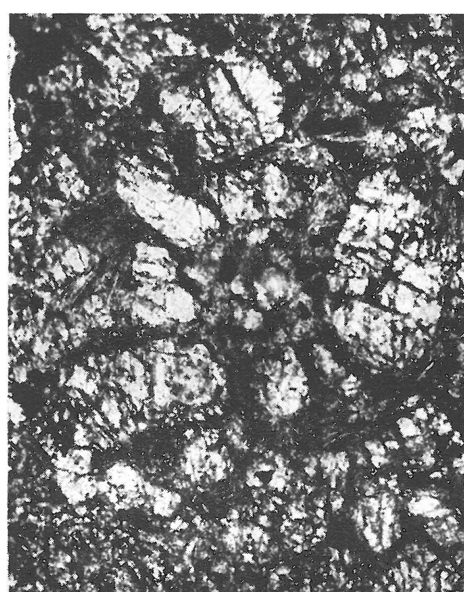

d

lustre, and they are always remarkably composite. The smaller grains are evidently more readily subject to hydratration and change gradually into limonite, which tinges its vicinity with faintly yellowish-brown colour.

Mixed chondrules

We could only rarely establish the presence of chondrules consisting besides the predominant enstatite also olivine. They attain a size of 2.2 × 1.7 mm (thin section F). The first chondrule that was examined had an oval outline and consisted of an aggregate of enstatite grains of an approximate size of 0.6 × 0.3 mm each, containing also olivine grain in its core. It was separated by a fine rim of olivine grains from the ground-mass; the rim had a thickness of 0.030 mm. All grains were allotriomorphic, there were no gaps between them, and they showed clearly cleavages by both pinacoides.

The other singular chondrule was round and consisted of eccentrically radiating fibrous enstatite (thin section B), in which imperfect columns of olivine were deposited; their size was 0.60 × 0.045 mm. A conspicuous feature was the occurrence of strong, imperfectly bounded, cracked, but transparent olivine columns in a fine fibrous grey enstatite material. Only these two cases on thin sections have been examined and described, although olivine grains are quite often included in enstatite chondrules.

4. Description of the individual components

The material of chondrites, apart from the chondrules, consists of a holocrystalline mixture of olivine and enstatite grains with uniformly dispersed particles of nickeliferous iron, troilite and chromite. It has a light grey colour, occasionally tinted faintly green. As a rule, we find also everywhere the effect of coarse pigment, especially of limonite produced by the beginning of hydratation of nickeliferous iron, which colours the chondritic stone yellowish brown, macroscopically perceptible as light rusty stains. The fine-grained ground-mass contains porphyroblasts of olivine and enstatite, which are quite often connected with the components of both minerals in the ground-mass by gradual transitions.

The bounding of the components is always allotriomorphic; only the porphyroblasts show sometimes imperfect outlines of crystals. The morphology of all components is strongly affected by the influence of strong pressure and partial resorption. In most cases, the proportion of olivine and enstatite shows a rough balance, occasionally one of them predominates, sometimes olivine is more frequent in porphyroblasts and enstatite in the ground-mass, or the other way round.

It has already been mentioned that everywhere we can observe traces of the effect of strong pressure; proof of this are not only the strong cataclases of the components, and the deformation of the chondrules, but also the very frequent undulating extinction which is shown by nearly every grain. The metamorphic processes affect moreover the mineralogical constitution of the chondritic stones to a high degree; the glassy matrix is already missing and has been replaced by a fine-grained aggregate of olivine or plagioclase with maskelynite.

Olivine

A conspicuous feature on all thin sections is the frequent occurrence of olivine grains in the form of porphyroblasts as well as of minute allotriomorphic grains and fragments in the ground-mass. The maximum size of the porphyroblasts is 0.9 $\times$ 0.7 mm, the average size ranges at about 0.3 $\times$ 0.2 mm and the smallest grains attain only 0.03 $\times$ 0.015 mm. The morphological character is clearly dominated by the usual low column habit of the large and intermediary individuals, which are flattened by (100), occasionally also by (010). The bounding of these shapes in the vertical zone is represented by the planes (100), (010) and (110) and at the tips by (001), (011) and (101). These planes have been determined by estimates based on the examination of a number of sections which were, at least partially, crystallographically better bounded. Only the large and intermediate porphyroblasts are somewhat better bounded; in the ground-mass there are only allotriomorphic grains and fragments. At some places the morphological variability is comparatively great. In the vertical zone, one or the other pinacoide is not unfrequently suppressed and planes (110) are developed instead of them (sometimes quite irregularly), which usually cut off the edges of both pinacoides uniformly. Similarly, the planes (001) give way to planes (011) in the tips of the olivine crystals; they decrease and disappear finally. In such a case, too, an irregular development of the planes (011) takes place. Sometimes the planes (101) dominate in the tips. Similar shapes of olivine with somewhat steeper planes (101) have already been described in 1870 by N. Koksharov (11) with respect to Pallas' iron. They are also mentioned in V. Goldschmidt's (5) large compendium on crystal shapes.

The olivine of the thin sections is transparent; only occasionally we can observe a faint shade of green. On the other hand, the polished sections show clearly patches of greenish colour which sometimes changes into yellowish green. At some places olivine is coloured faintly yellowish-brown by limonite. Limonite also penetrates quite often into the coarse irregular cracks. Cleavages are not very distinct; each grain is clearly marked by dominant coarse cracks produced undoubtedly by pressure. They mostly pass in an irregular course across the columns and are not unfrequently filled by a fine olivine pulp, which is proof of their genesis. Real cracks of imperfect cleavage are rare. Perfect cleavage by (010) is proved by short, sharp, straight cracks, but frequently we observe perfect cleavage by (001) and imperfect cleavage by (100). Optically, olivine can, on the whole, be easily distinguished from enstatite, which is otherwise very similar. It differs above all by a higher refractive index. The determination of the refractive index of sodium light by the immersion method yielded the value : $\gamma = 1.692$, $\alpha' = 1.670$; the resulting birefringence is therefore 0.022. The birefringence is positive, the elongation oscillates, and at several places we find large angles of the optical axes. All these properties indicate that olivine contains only about 10 per cent of the fayalite component. This may also explain its very light colour and a faint greenish tinge.

There are not very many inclusions in olivine. We find there only very thinly dispersed grains of black-brown troilite in the initial stage of hydratation. Otherwise we find ore powder consisting of minute black grains, which by their sections remind us of either chromite or magnetite. The insignificant amount of inclusions does not affect at all the colour of the mineral.

Enstatite

The properties of enstatite, as far as the size of the individuals, their shape and relative number are concerned, are roughly the same as those of olivine. It seems, however, that its portion within the chondrite material is not so regularly distributed. At some places it gives distinctly ground to olivine, at others it is locally accumulating in greater numbers, especially with regard to porphyroblasts. The bounding of enstatite porphyroblasts appears to be still more imperfect than that of olivine. Everywhere the effect of resorption on the rounding of individuals and the strong influence of cataclases are prominent. Also, the habit of the crystals is shown by low columns with a dominant plane (100) in the prismatic zone. The bounding is mostly given by the three basic pinacoides, and very rarely we can observe cutting of the edges built by the planes (100) and (010) by narrow planes (110). The plane (010) is sometimes pushed back to a large degree by the planes (110) until it disappears completely; the crystals show then spindle-shaped sections on the sections perpendicular to the vertical. The prismatic planes are usually unevenly developed and, as a rule, strongly rounded. The terminal planes are developed only in exceptional cases; they are mostly (101). Notwithstanding the fact that it is just the terminal part of the crystals which is usually strongly rounded, we are able to conclude from the rounded edges of the sections that the bounding is most likely provided by planes of low dipyramids and prisms by the axis a of (012) and (021).

Porphyroblasts attain a size of up to 1.67×0.5 mm, but their average value is 0.4×0.25 mm. The colour of enstatite is occasionally faintly green, the sections are however, as a rule, transparent and only occasionally yellowish or yellowish-brown. The prismatic cleavage, characteristic of pyroxene, is only rarely recognizable in the shape of short, sharp cracks on sections perpendicular to the vertical. Only exceptionally we can observe parting by (010). Similar to olivine, the enstatite shows irregular and coarse cracks on every individual, running obliquely across the crystal. The cracks are however not so frequent as with olivine.

Optical investigation showed, above all, very frequent undulating extinction, which appears to be more abundant than in olivine. Pleochroism was nowhere observed. The refractive index as well as birefringence are lower than with olivine. The refractive indices of sodium light were determined by the immersion method and yielded the following values : $\gamma = 1.674$, $\alpha = 1.665$, $\gamma - \alpha = 0.009$. Birefringence and elongation are positive, the angle of the optical axes is much smaller than with olivine (the distance of the hyperbolae lies always within the field of the microscope). The facts, so far determined, indicate a relatively clean enstatite with a minimum admixture of ferrosilite components.

The inclusions in enstatite are very thinly dispersed and nowhere oriented. We find among them mostly blackish-brown grains of troilite of an average size of 0.015 mm. Occasionally there are also minute black grains most likely of chromite or probably of magnetite. An interesting inclusion is represented by a relatively great number of rounded grains of olivine of from 0.15×0.10 mm to 0.03×0.02 mm. Inclusions of olivine in enstatite were also established in a number of other chondrite stones; this can be considered as proof that olivine is paragenetically the older component than enstatite. Finally, among the very rare inclusions in enstatite are those of a mineral of low birefringence, which is most likely re-crystallized glassy matrix.

In order to prove and complement the knowledge gained from the optical research of olivine and enstatite we carried out a roentgenometric investigation as well as a qualitative spectroscopic analysis. First of all, the chondrite powder was freed of nickeliferous iron by a strong magnet and the troilite was dissolved in HCl. After thorough washing, the residue contained only olivine, enstatite and accessory maskelynite, besides a small amount of chromite. This compound was submitted to a roentgenometric investigation in the laboratory of the Mining Institute of the Czechoslovak Academy of Sciences in Prague (V. Čáslavská) under the following conditions:

Apparatus Chirana, diameter of the camera 64 mm, Cr-radiation filtered through V 30 KV — 20 mA, exposure 3 hours, thickness of the preparate 0.4 mm, film used Agfa Laue, method powder-Debye-Scherrer. The resulting data are contained in the attached table and compared with the data for *d* of olivine and enstatite. The comparison shows that the Debye-Scherrerogram includes lines of olivine as well as of enstatite, and the resulting values agree well with the data for both minerals listed in the table. The intensities of the lines are on the same level and this corroborates the correctness of the estimates derived from the thin sections, namely, that the two minerals are roughly in balance although, in fact, there is a slight preponderance of olivine.

The qualitative spectrographic analysis was carried out in the same institute (M. Soudný) under the following conditions: Spectrograph ISP—22, 0.008 mm slit, electrode gap 2 mm, arc 6 A, generator DG—1, time of exposure 90 sec., range 2300—4500 A, photographic plate Foma-Spectro-blue 220. The estimates of the elements (in orders of magnitude) are listed in the following table. This table shows that we have here to deal with a mixture of considerably predominating silicates (olivine and enstatite, ev. maskelynite) with a small contribution of chromite and traces of pure copper. The main share falls predominantly to Fe, Mg, Ca and Si. Ca, Al, Mn and Ni can be considered as isomorphic admixtures of olivine, enstatite and chromite. It must however be pointed out that Ni appears very rarely in olivine and then only in negligible amounts. Part of Ni and Fe probably also belongs to the unresolved and unseparated small amounts of nickeliferous iron. The larger part of Ca and Al and a small amount of Na are components of accessory maskelynite where doubtlessly Ca prevails, because the microscopic examination indicates that it is produced by re-melting anorthite. Pure copper is present only in traces; it was frequently found in chondrites, e.g. in the chondrites of Saratov and Ochansk in the Soviet Union.

Element	Est. amount	Olivine	Enstatite	Chromite	Maskelynite	Pure copper
Fe	H	/	.	/		
Mg	m	/	/			
Si	m	/	/		/	
Ca	m	.	.	.	/	
Al	m—s	.	.	.	/	
Mn	m—s	.	.	.		
Ni	m—s	.	.	.		
Cr	s			/		
Na	s				/	
Cu						/

H = main component (more than 10 per cent), m = minor component (10—0.01 per cent), s = traces (less than 0.01 per cent).

Clinoenstatite

Clinoenstatite can very rarely be found on the periphery of some large individuals. It is attached parallel to enstatite (thin section E), the column of which is rimmed by lamellae on both planes parallel to the vertical. Clinoenstatite can be identified by its higher birefringence as well as by its inclined extinction : $c/\gamma = 39°$. The great differences between the value of the extinction angle of clinoenstatite in chondrules and clinoenstatite in the ground-mass agree well with the results of various observations. C. Hintze (6) quotes 30°—40° as the extinction angle of clinoenstatite. This difference may be caused by differences of the chemical constitution of the mineral, which affect also the optical properties. Enstatite with its rim of clinoenstatite has a size of 0.17 × 0.048 mm, the clinoenstatite rim on its periphery has a thickness of 0.007—0.005 mm only and a length of 0.16 mm. The clinoenstatite is fainty turbid, the enstatite itself is comparatively transparent.

We have mentioned already H. Michel's (13) supposition that the origin of clinoenstatite on the periphery of enstatite is due to the heating of the chondritic stone and its rapid cooling during its flight through the atmosphere. R. W. G. Wyckoff, H. E. Merwin and H. S. Washington (21) have succeeded in proving artificially the creation of clinoenstatite by heating enstatite up to a temperature of 1400° for several days. The clinoenstatite of the Příbram chondrites actually indicates only a short time interval favourable for its creation. Here we have to deal only with a change on the surface of the enstatite into clinoenstatite.

5. Characteristics of the ground-mass

Generally speaking, the ground-mass represents the predominant component of the chondritic stone. It is a holocrystalline mixture of very minute grains and fragments of olivine and enstatite with ore minerals. The average size of the olivine grains is 0.04 × 0.025 mm, that of the enstatite grains only 0.015 mm. The minimum dimensions of the both minerals in the ground-mass attain however only the average size of about 0.005 mm. On thin sections the ground-mass is transparent, only occasionally it is turbid. The distribution of the components of the ground-mass is on the whole uniform, only occasionally olivine predominates somewhat over enstatite and very rarely the opposite is the case. The bounding of the components is mostly allotriomorphic; only several somewhat larger grains of olivine indicate traces of bounding planes which can be fairly well estimated. All components show the effect of high pressure, evidenced not only by strong cataclase of many individuals but also by undulating extinction quite often shown by grains. No glassy matrix has been established on thin sections of the ground-mass, which can be considered as the most reliable proof of metamorphic processes.

Besides olivine and enstatite, the presence of fine-grained plagioclase was established, though only in very rare cases. It constitutes lobe-shaped grains of low birefringence; its refractive index is similar to that of Canada balsam. It can therefore be concluded that the constitution of this plagioclase is similar to that of oligoclase which, according to E. L. Krinov (12), represents a characteristic admixture of crystalline chondritic stones.

There are two kinds of ground-mass pigmentation: a coarse one, consisting of large agglomerations of nickeliferous iron and troilite, and a fine one, produced by very thinly dispersed ore powder. The effect of fine pigmentation on the colouring of the ground-mass is not very great. As for the coarse pigmentation, the nickeliferous iron is present, as a rule, in particles of larger size, while troilite occurs only in finer accumulations of grains. Ore minerals fill up the gaps between the other components of the ground-mass and present therefore a considerably irregular and composite shape. Viewed in transmitted light, they are black to blackish-brown, in reflected light they can easily be distinguished. The largest agglomerations of ore minerals achieve the size of about 1.3 mm, while the particles of ore powder are restricted to only 0.002 mm. The colour of the ground-mass is very much affected by the beginning of hydratation especialy of nickeliferous iron; the limonite produced by hydratation colours the ground-mass yellowish-brown.

Nickeliferous iron

The preponderant ore component of the chondritic stone consists of very composite and tipped particles of nickeliferous iron. Its largest particles in a thin section show the size of 1.5 × 0.6 mm, the smallest ones only of 0.30 × 0.015 mm. In transmitted light its colour is deep black with a brown rim, in reflected light it is characteristically steel-gray showing semi-metallic to metallic lustre. At some places it is evident that the agglomerations are aggregates of several smallish grains. In a metallographic microscope its colour is clear light yellow; it has a large or medium reflecting power without inner reflections; between crossed nicols it appears isotropic. Nearly every agglomeration is in the initial stage of hydratation. The limonite produced hereby colours the surrounding ground-mass yellowish-brown and penetrates into the cracks of the other components. The border between nickeliferous iron and the limonite is always very sharply marked and it can therefore be concluded that the disintegration did not exceed the initial stages.

Troilite

As far as the amount and size of the particles and agglomerations are concerned, troilite falls far behind nickeliferous iron. We observed on thin sections only very rarely places where both minerals were in rough balance. Not unfrequently troilite is changing into finely dispersed ore pigment. Its agglomerations have the size of 0.64 to 0.043 mm, while the powder components attain only the size of 0.002 mm and less. Its fine-grained agglomerations are again very composite. Troilite occurs in the ground-mass as well as in porphyroblasts and in chondrules. In the last two components it is very thinly dispersed. Occasionally it is present in the fine rim of some chondrules in great numbers. In transmitted light its colour does not differ very much from that of nickeliferous iron. However, even in the faint reflected light of the polarization microscope the troilite differs from nickeliferous iron by a characteristic dark tombac colour and at some places by metallic lustre, which is however fainter than the lustre of nickeliferous iron. Its colour in the metallographic microscope is bright bronze yellow to yellowish-brown, its reflecting power is smaller than that of nickeliferous iron and occasionally shows evidence of anisotropy. Only in rare cases we can observe on troilite the beginning of disintegration into limonite, which never reaches the intensity of nickeliferous iron.

As a rule, troilite does not occur together with nickeliferous iron, common occurrence of both in agglomerations on thin sections so far examined is a rare event.

Chromite

Still very much less than that of troilite is the occurrence of isolated grains of chromite or their small accumulations in the ground-mass. Frequently they present quadratic or triangular cross sections and their size amounts to 0.15 to 0.021 mm. They are sometimes included in olivine grains as minute powder, and the size of these particles ranges between 0.007 and 0.005 mm. These particles are velvet black in transmitted light and have translucent yellowish-brown borders. They are therefore doubtlessly chromite, which is frequently a component of chondritic stones. Its colour in a metallographic microscope is grey with a brown tinge; it is distinctly isotropic and its reflecting power is very low. In contradistinction to the two earlier components it never suffers the beginning of disintegration.

Chromite remained also preserved in the form of small black grains, when the powder compound for roentgenometric research of olivine and enstatite was prepared. After the removal of iron by a strong magnet and the dissolution by hydrochloric acid of troilite the remaining silicate powder still contained some minute grains of chromite.

Maskelynite

One of the accessory components of the ground-mass is maskelynite, which today is generaly considered to be a re-fused plagioclase and a proof of the crystalline character of the chondrite. It is very rarely in the Příbram chondrites and we can therefore assume that plagioclase, too, was an accessory in the original chondritic stone. We found it only on two of the six thin sections examined (D and F). It occurs in the form of xenomorphic lobe-shaped grains attaining a maximum size of $0.75 \times \times 0.45$ mm. Otherwise it was present in enstatite chondrules as very fine particles between the columns. No cleavage was observed, but at different places fine irregular cracks were present. It is strikingly transparent and fills always the gaps between the minerals. Sometimes it is faintly coloured by limonite. It is optical isotropic and characterized by faint anomalous birefringence with a bluish-grey interference colour, indicating 0.001 as the value of birefringence. It was just this anomalous birefringence which induced A. Brezina (3) to suggest that maskelynite is a cubic instead of an amorphous mineral, as had been stated by G. Tschermak (16,17). A. Brezina assumed that maskelynite was produced from an original cubic felspar by molecular transformations, because cubic modifications are more stable at high temperature. — The refraction of maskelynite is higher than that of Canada balsam, though distinctly lower than that of olivine and enstatite. Unfortunately we could not determine correctly the refractive index, because the dimensions of maskelynite in our thin sections were too small.

The relative refractive index indicates however that we have very likely to deal with fused anorthite. According to a proposal by H. Michel (13) it could be designated as an anorthite-maskelynite. — The inclusions in maskelynite consist of small, strongly rounded grains of olivine of maximum size of 0.045 mm and, though rarely, of grains of enstatite. Troilite is frequently found in the form of black allotriomorphic grains, usually elongated in one direction; they attain a maximum size of 0.075×0.030 mm. — Paragenetically, maskelynite is evidently the youngest mineral and represents, according to E. L. Krinov (12) a characteristic symptom of chondrite metamorphosis.

Finally, I should like to express my gratitude to all those who co-operated and discussed with me, especially to Z. Ceplecha, Astronomical Institute, Ondřejov, R. Rost, Professor of Mineralogy of Charles University, Prague, J. Kouřimský and V. Šípek of Department of Mineralogy, National Museum, Prague. My sincere thanks go to Mrs. V. Čáslavská for providing the roentgenometric exposures of the silicate mixture and to M. Soudný for carrying out the necessary qualitative spectrographic analysis.

Table of the roentgenometric data

Olivine, Sorrento, Italy Micheev — 750		Silicates of the chondrite, Velká near Příbram		Enstatite, Bamle, Norway Micheev — 780	
I.	d.	I.	d.	I.	d.
				3	4.405
1	(4.39)				
4	3.95				
2	3,79				
3	3.53	2	3.457	5	3.298
		7	3.149	10	3.158
2	(3.08)				
2	3.02	4	2.982	5	2.945
		4	2.864	7	2.864
7	2.792				
3	2.734	4	2.736	5	2.701
				1	
7	2.516	8	2.516	6	2.526
8	2.466	8	2.455	6	2.472
3	2.356	2	2.351		
				2	
8	2.261	3	2.258		
5	2.162			2	
2	2.044	2	2.064	6	2.105
				2	2.054
				1	
				2	1.974
		1	1.966	4	1.955
2	1.878			1	
2	1.806			1	
1	1.786			3	1.782
10	1.744	7	1.745		
				2	1.731
		1	1.696	2	1.699
3	1.667	1	1.668	1	
5	(1.633)	1	1.646		
2	1.617	1	1.612	5	1.601
3	1.569				
1	(1.535)				
				4	1.520
6	1.495	2	1.500		
8	1.478	8	1.482	6	1.483
				3	1.467
2	1.431				
		1	1.417	2	1.417
8	1.393	6	1.395	5	1.391
7	1.349	5	1.351	2	1.357
				2	1.336
6	1.314	4	1.317		
				3	1.305
3	1.295	3	1.294	3	1.292

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EXPLANATION TO THE TABLES

(All photos by Rudolf Rost. Dimensions of the stones in the survey of data in the text)

Table I. The largest chondritic stone founded in the vicinity of Luhy near Příbram; a) Front part (apex), b) Basal part

Table II. Chondritic stone from the vinicity of Velká, ESE Příbram; a) Basal part, b) Apex

Table III. Chondritic stones from the vinicity of Dražkov (a—c) and of Hojšín (d—e).

Table IV. The surface details of chondrite from Luhy with so-called „greasy stain" (Magnification ca 12×).

Table V. The surface details of chondritic stone from Velká; a) Knobby structure on the apex, b) Structure on the basal part (Magnification 6×)

Table VI. Parts of thin sections of chondrite from Velká with indistinct chondrules partly dissolved in the ground-mass (Magnification a) 80×, b) 120×)

Table VII. Chondrite from Velká; a) Part of thin section of chondrite (Magnification 35×), b) Enstatite chondrule, c) Microporphyritic chondrule of olivine with largest agglomerations of nickeliferous iron in its vicinity (Magnification 120×)

Table VIII. Chondrite from Velká near Příbram; a) Chondrule with unsharp boundary, b), c) Chondrules of lamellar structure, d) Part of thin section with prevailing squashed porphyroblasts of olivine. Dark ground-mass around the olivine grains is in the fact rather transparent (Magnification 120×)

CONTENS

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