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Abstract

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GEOPHYSICS

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ON THE MAGNETIC PROPERTIES OF ULTRABASIC ROCKS

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According to a widely held opinion, ultrabasic rocks belong to the group of the densest and most magnetic formations. On this basis, positive anomalies of the magnetic and gravitational fields are usually interpreted as characteristic of bodies of ultrabasic rocks; moreover, the largest peaks are thought to correspond to the extreme members of the hyperbasite series—dunites—and are for the most part interpreted as zones of feeder channels. Negative anomalies in magnetic and gravitational fields, however, are treated as evidence of the absence of ultrabasic rocks in a given area. Thus, A. A. Nepomnyashchikh, interpreting the low intensity of the magnetic and gravitational fields he obtained over the Kempirsai massif, came to the conclusion that the Kempirsai massif has a small thickness, especially in its northern part (⁀4). However, geological and drilling work carried out on this massif in recent years has shown that even in the part considered by A. A. Nepomnyashchikh to be the thinnest (not more than 250 m), this massif has a depth many times exceeding 1200 m.

Special petrological-geophysical and, in particular, petrophysical investigations of rocks from a number of massifs, including the Kempirsai massif, carried out by us have shown that the incorrectness of A. A. Nepomnyashchikh's conclusions is not accidental and is based on a fundamental error of concept. In the present work only magnetometric data are considered.

In carrying out petrological-geophysical investigations of the Kraka massif, one of the largest and well-exposed hyperbasite bodies of the Urals, it was established (⁀1) that positive magnetic anomalies are characteristic only of the serpentinized varieties of the hyperbasites composing it, whereas fresh ultrabasic rocks—harzburgites and dunites—possess negative values of ΔT, analogous to the weak magnetic fields over the strata of quartz sandstones surrounding the massif. This feature is explained by the fact that the magnetic susceptibility of a rock depends on the presence in it of magnetic minerals, which in the present case is magnetite, whereas the remaining minerals of ultrabasic rocks—olivine, pyroxenes, fresh chromite—do not possess magnetic properties. But magnetite, as is known, is not a primary mineral of hyperbasites and appears in them only in the process of their secondary alteration, during which iron oxides are liberated and combine in the form of magnetite. Such a process is serpentinization.

Further, more detailed petrophysical investigations carried out by the authors on material from the Kraka, Kempirsai, Khabarninskii, and Khalilovskii massifs made it possible to refine the data obtained. It was established that, although serpentinization undoubtedly plays a significant role, there are also other factors affecting the magnitude of magnetic susceptibility. Thus, for example, rocks of some massifs, despite their more intense serpentinization, on the whole possess the same magnetic susceptibility (Kempirsai) as rocks of other, less serpentinized massifs (Kraka). Similarly, within the

within each massif, unevenness of the magnetic properties of rocks is noted despite what would seem to be the same degree of serpentinization, and in individual cases the magnetic susceptibility of rocks serpentinized to different degrees is the same. To clarify these features, we carried out a petrological study of series of samples for which I. F. Zotova had obtained data on physical constants (magnetic susceptibility and density). Table 1 gives the specific values of χ with all variations, rather than arithmetic means for several samples. (Naturally, data on all the samples studied could not be included in the table.)

Table 1

Dependence of magnetic susceptibility on the composition and degree of serpentinization of the rock

Rock name	Degree of serpentinization, %	Value of magnetic susceptibility, $\chi \cdot 10^{-6}$ CGSM
Dunite	20	70
Dunite	30	32; 70
Dunite	40	40
Dunite	45	52
Dunite	50	30; 50; 52; 104
Dunite	60	30; 50; 88; 100
Dunite	70	30; 40; 42; 70; 90
Dunite	80	74; 100
Dunite	90	60
Dunite-harzburgite	30	60
Dunite-harzburgite	40	60; 80; 84; 140
Dunite-harzburgite	50	100; 184; 220; 240; 280
Dunite-harzburgite	60	160; 400; 420; 1800
Dunite-harzburgite	70	100; 500; 600
Dunite-harzburgite	80	330

Rock name	Degree of serpentinization, %	Value of magnetic susceptibility, $\chi \cdot 10^{-6}$ CGSM
Dunite-harzburgite	90	100; 940
Dunite-lherzolite	5	40
Dunite-lherzolite	30	810; 1300
Dunite-lherzolite	40	600; 1200
Dunite-lherzolite	60	400
Dunite-lherzolite	70	2000
Dunite-lherzolite	90	1800; 2000
Lherzolite	15	640
Lherzolite	20	780; 840
Lherzolite	40	1060
Lherzolite	100	2600
Harzburgite	0	47; 70
Harzburgite	5	600; 600; 100
Harzburgite	10	82; 270; 300 800; 1200
Harzburgite	20	260; 400; 590; 800; 920; 1000; 1760; 2100
Harzburgite	30	120; 360; 380; 1160; 2500; 3000
Harzburgite	40	1060; 1300; 2200; 3000
Harzburgite	50	1400; 1800
Harzburgite	60	1700; 1900; 3600
Harzburgite	90	3600; 4000; 5000

As is evident from the table, dunites generally have the lowest magnetic susceptibility, not exceeding 100^{-10} units; dunite-harzburgites and dunite-lherzolites have higher values (up to 2000), and the highest values (up to 5000) are typical of harzburgites.

In studies of the hyperbasites of the massifs mentioned, we established that the chemical composition of both rock-forming and accessory minerals in the listed varieties of hyperbasites is not the same. In harzburgites and lherzolites, olivine and pyroxenes are represented by more ferruginous varieties, and as olivine increases in the rock and pyroxene decreases, as a result of which harzburgites pass into

dunite-harzburgites are replaced by dunites; the olivine and, partly, the pyroxene of the rocks gradually acquire an essentially magnesian composition, with the most insignificant presence of iron in them ([2]). In the accessory chrom-spinelid, on the contrary, as the rock progresses from harzburgite to dunite, iron acquires the predominant importance ([3]). That is, the initial rocks are represented by the following series: relatively ferruginous harzburgites—less ironbearing, more magnesian dunite-harzburgites—essentially magnesian dunites. In the latter, iron is present mainly in chromite, i.e., an accessory mineral, the amount of which is negligible.

It is quite natural that, during serpentinization of hyperbasites, which promotes the release of iron, its oxidation, and its binding in magnetite, the greatest amount of iron will be liberated in harzburgites, less in dunite-harzburgites, and practically negligible in dunites (Table 1). It is precisely for this reason that dunites, even when very intensely serpentinized, cannot be magnetic. And indeed, as is known, apodunite serpentinites are practically nonmagnetic ([5]). Dunite-harzburgites and harzburgites, however, prove to be considerably more magnetic (Table 1), and the degree of their magnetism is the greater, the higher their content of rhombic pyroxene; and, at the same content of this mineral, the more strongly the serpentinization of the rock is developed.

The data presented lead to the conclusion that the amount of magnetite released and, consequently, the magnetic susceptibility of the rock are affected not only by the degree of development of the process in which the magnetic mineral (magnetite) arises, i.e., serpentinization, but also by the composition of the initial rock, which determines the potential amounts of iron that can be released in this process.

When considering the data of Table 1, one may also note that in some cases rocks of identical mineralogical composition and serpentinized to the same degree exhibit very different magnetic susceptibility. Petrographic study of such samples showed that the distribution of the mineral components of the rock in them is uneven, for the most part banded, and often essentially olivine bands alternate with essentially enstatite bands. In those cases where serpentinization is uneven and embraces areas of predominantly olivine composition, very weakly affecting, and sometimes almost not affecting, the enstatite areas, the rock contains relatively insignificant amounts of magnetite and its magnetic susceptibility is small. In those cases, however, where serpentinization embraces the rock, uniformly altering both minerals—olivine and, especially, pyroxene—the amount of magnetite released is high and the magnetic susceptibility of the rock reaches its maximum value. This observation once again emphasizes the influence of the composition of the serpentinized rock on its magnetic susceptibility. The mode of occurrence of magnetite undoubtedly affects the magnitude of magnetic susceptibility. Petrographic studies show that the presence of large crystals of magnetite always increases magnetic susceptibility less than the presence of widely disseminated large accumulations of powdery magnetite.

Thus, under conditions of the same quantitative mineralogical initial composition, the magnetic susceptibility of a rock is influenced by the character of serpentinization, as well as by the mode of occurrence of the magnetic mineral. With the same composition of the initial rock and the same mode of occurrence of magnetite, the magnitude of magnetic susceptibility is the higher, the more intense the serpentinization of the rock. Undoubtedly, this applies mainly to harzburgites, lherzolites, dunite-harzburgites, and dunite-lherzolites, and very little to dunites proper, which, as indicated above, are of little promise for the release of magnetite.

The material presented above does not allow agreement with the opinion ([6]),

that the magnetism of the rock is determined by the stage of allo- or autoserpentinization. Obviously, a weakly ferruginous dunite, whatever auto- or alloserpentinization it may have undergone, will always be a smaller potential supplier of iron than a more ferruginous harzburgite, and it is precisely this, and not the crystallization of one or another modification of serpentine (chrysotile or antigorite), that determines the magnitude of the magnetic susceptibility of the serpentinized rock.

It also follows from what has been said that, in studying the behavior of iron during serpentinization, it is necessary to approach this question with regard to the specific petrographic features and, above all, to the composition of the rock being serpentinized, and not to take the arithmetic mean from a large number of heterogeneous values for different petrographic varieties of hyperbasites ([6]), since in such cases the arithmetic mean does not reveal the features of the process but levels them out.

On the basis of the above, the difference in the magnitude of the magnetic fields observed both for different massifs of one formation and for different parts of one massif becomes understandable. A detailed survey of the Kraka massif, carried out by S. V. Moskaleva, showed that this massif consists predominantly of harzburgites interbedded with less thick bands of dunites and dunite-harzburgites. The main volume of the Kempirsai massif, however, is composed of harzburgite-dunites and dunite-harzburgites, interbedded with large fields of dunites. It is quite natural that even intense serpentinization of these rocks cannot promote the crystallization of significant masses of magnetite, and this accounts for the low value of the magnetic field for this massif, noted by all investigators. The Kraka massif, on the other hand, by virtue of the peculiarities of its composition, possesses greater potential possibilities, and therefore the amount of magnetite released during the serpentinization of the rocks composing it is considerably greater, which also contributes to the higher value of its magnetic field in those areas that have undergone serpentinization.

The results obtained make it possible to draw a number of practical conclusions.

1. The magnetism of ultrabasic rocks should be regarded as a property not inherent in them initially, but appearing in them only as a result of secondary changes. Therefore, in carrying out magnetometric studies, only altered ultrabasic rocks are recorded, whereas fresh ones are not detected by them.

2. The degree of magnetism is determined not only by the intensity of serpentinization of the rock, but no less by the composition of the original rocks —the potential suppliers of iron for the crystallizing magnetite—as well as by their texture and the character of the separation of magnetite. There-

fore, not all, even serpentinized, rocks can be detected by magnetometric studies.

On this basis it is quite obvious that magnetometry data can indicate only the presence of secondary changes in hyperbasites, outline the areas in which they occur, but cannot reflect either the dimensions, or the forms, or the thicknesses of bodies of weakly altered or unaltered ultrabasic rocks, or such parts of them which, by the chemical composition of the altered rocks (dunites), are unfavorable for the separation in them of free magnetite.

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Note: Figure translations are in progress. See original paper for figures.