

*The statement of chemical analyses of stony meteorites  
and the interpretation of the analyses in terms  
of minerals*

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IN earlier analytical work on stony meteorites the analytical results were given in a number of different ways. Not only the principles, but also the methods used in the calculation of the mineral composition as derived from the chemical analyses, were of a different kind in almost every description of a stony meteorite. The same remarks of course apply to a certain extent also to the older descriptions of terrestrial rocks. The publications on the 'Quantitative [(American) system of] classification of igneous rocks' (1) and some publications by Henry S. Washington, especially a paper on 'The statement of analytical results of rock analyses' (2), contributed greatly to the unifying of the methods of representing the results of chemical analyses of rocks and calculating their mineral composition. Later on other systems for the statement and calculation of rock analyses have been introduced by other petrologists, especially by Paul Niggli, and all this work, taken together, has greatly contributed to clarification of the different ways in which the results of rock analyses can be stated and made use of in the petrological study of rocks.

With regard to the analyses of stony meteorites, there still remains to be done much the same work in respect of the establishment of the best ways of stating the results of chemical analyses and the ways of calculating the analyses in order to facilitate petrological comparison of the stony meteorites.

The fact that the abstracting of publications on meteorites has already been carried out for many years according to a well-devised plan has therefore been of very great help in the study of meteorites. It is to Dr. L. J. Spencer's comprehensive and clear abstracts of the meteorite literature during the course of several decades that we owe a good review of almost the whole of this literature during modern times, and this in spite of the very different ways in which a great deal of the original work has been published. Everyone who has studied meteorites during

this period has therefore been greatly indebted to Dr. Spencer for the great amount of work he has devoted to the abstracting of the literature on meteorites.

There has always been a wish to compare the chemical composition of stony meteorites with the composition of ultra-femic igneous rocks. It is therefore desirable that the analytical results for stony meteorites should—as far as possible—be presented in the same manner as the analyses of terrestrial igneous rocks. The principal differences between stony meteorites and igneous rocks arise from the content in stony meteorites of metallic nickel-iron and certain minerals which are chemically stable only in the presence of oxygen amounts insufficient to convert the oxidizable constituents into oxides. We can therefore say that the principal difference between the terrestrial igneous rocks and the stony meteorites is that the meteorites are oxidized in a lesser degree than are the terrestrial rocks.

The occurrence of more or less metallic nickel-iron and of certain minerals, which have so far not been met with in terrestrial igneous rocks, such as lawrencite,  $\text{FeCl}_2$ , oldhamite,  $\text{CaS}$ , daubréelite,  $\text{FeCr}_2\text{S}_4$ , and schreibersite  $(\text{Fe}, \text{Ni}, \text{Co})_3\text{P}$ , however, requires a statement of the analytical results somewhat different from that of the terrestrial igneous rocks. Also chromite,  $\text{FeCr}_2\text{O}_4$ , and troilite,  $\text{FeS}$ , play a much more important part in stony meteorites than in igneous rocks, and phosphorus occurs in stony meteorites, according to our present knowledge, principally as a constituent of the lime-sodium phosphate merrillite,  $3\text{CaO} \cdot \text{Na}_2\text{O} \cdot \text{P}_2\text{O}_5$ , characterized some time ago by Shannon and Larsen (3).

When Berzelius in the early eighteen-thirties published his first analyses of meteorites he introduced the method of a separate determination of the chemical constituents soluble when the finely ground powder of the meteorite is treated with hydrochloric acid. This method was for a long time in quite general use, and is still employed by a great many analysts. It had already been early recognized that most of the stony meteorites are chiefly composed of olivine and rhombic pyroxenes, the olivine being soluble in hydrochloric acid, while this is not the case with the pyroxenes. The treatment with hydrochloric acid was therefore a means of separating the olivine from the pyroxenes, and thus afforded a way of determining the proportions of olivine and of pyroxenes in the rock. As we now know from a great number of analyses, the method is far from a quantitative one. This is due to several circumstances: firstly, an olivine, rich in iron silicate, is attacked by hydro-

chloric acid more easily and at a faster rate than an olivine rich in forsterite; secondly, the pyroxenes are not entirely insoluble in hydrochloric acid, the iron silicate also in this case being more readily attacked by the acid. In stones rich in iron silicates the proportion of orthosilicates, as determined by treatment with hydrochloric acid, will therefore appear comparatively larger than in stones poor in iron silicates. And further, the orthosilicates (olivines) are not the only constituents soluble in hydrochloric acid. In fact, in the chondrites rich in chondrules there are almost always considerable amounts of chondrules in which the olivines and the bronzites are embedded in a mesostasis of glass, which contains the residue of the silicates of the 'meteorite-magma', after a certain amount of it has crystallized as olivine or pyroxene, and this residual glass is even more readily soluble in acids than the crystallized olivine. Besides, when the plagioclase is more or less changed into maskelynite it becomes accordingly more or less readily attacked by the acid. The 'soluble portion' will therefore in certain chondrites contain appreciable amounts of other silicates than olivine silicates and it will not be possible to interpret it in terms of olivine silicates alone.

Further, it may be noted that the bulk analysis resulting from the summing up of the two partial analyses in most cases is less exact than when a single bulk analysis has been made of the silicate powder after the metallic portion has been dissolved out by special methods or determined in a separate portion of the powder.

Since the introduction of thin sections, and now that the microscopical-petrographical investigation of these has become the principal way of investigating stony meteorites as well as igneous rocks, it is probable that an approximate quantitative estimate of the amounts of olivine and pyroxene present in a chondrite can be made quite as well in thin section under the microscope as by the chemical method of dividing the material into an insoluble portion and one soluble in hydrochloric acid. The present author is therefore of the opinion that in most cases a single bulk analysis is preferable to the dividing up of the material into a portion soluble in acid and an insoluble portion. It should, however, be pointed out that in certain cases, as for instance the group of black chondrites and in stones containing much very fine-grained or dusty material, a microscopical determination of the character of the constituents cannot be made, and in such cases the chemical method of separation into a soluble and an insoluble portion is of value.

Examples could be given of a great many different ways in which the results of meteorite analyses have been published, but a discussion of

most of these methods seems of little interest and would occupy too much space. It is more practical to give here some examples of analyses of stony meteorites and to discuss in connexion with these examples the ways of stating the results of analyses and the interpretation of the analyses.

TABLE I. Chemical analyses of stony meteorites.

|                                | 1.    | 2.    | 3.     | 4.    | 1a.   | 2a.   | 3a.   | 4a.   |
|--------------------------------|-------|-------|--------|-------|-------|-------|-------|-------|
| SiO <sub>2</sub>               | 34.82 | 39.39 | 36.55  | 38.47 | 39.07 | 46.55 | 47.57 | 59.84 |
| TiO <sub>2</sub>               | 0.15  | 0.13  | 0.14   | 0.12  | 0.17  | 0.16  | 0.18  | 0.18  |
| Al <sub>2</sub> O <sub>3</sub> | 2.18  | 2.64  | 1.91   | 1.78  | 2.45  | 3.11  | 2.18  | 2.77  |
| Cr <sub>2</sub> O <sub>3</sub> | 0.58  | 0.49  | 0.52   | 0.23  | 0.65  | 0.58  | 0.68  | 0.35  |
| Fe <sub>2</sub> O <sub>3</sub> | —     | —     | —      | —     | —     | —     | —     | —     |
| FeO                            | 24.34 | 14.13 | 10.21  | 0.23  | 27.30 | 16.71 | 13.29 | 0.35  |
| NiO                            | —     | —     | —      | 0.11  | —     | —     | —     | —     |
| MnO                            | 0.20  | 0.28  | 0.35   | 0.02  | 0.22  | 0.33  | 0.42  | 0.03  |
| MgO                            | 23.57 | 24.21 | 23.47  | 21.63 | 26.44 | 28.60 | 30.54 | 33.64 |
| CaO                            | 2.17  | 1.82  | 2.41   | 1.03  | 2.43  | 2.15  | 3.14  | 1.60  |
| Na <sub>2</sub> O              | 0.69  | 1.09  | 0.78   | 0.64  | 0.78  | 1.29  | 1.01  | 1.00  |
| K <sub>2</sub> O               | 0.23  | 0.20  | 0.20   | 0.15  | 0.27  | 0.24  | 0.26  | 0.24  |
| P <sub>2</sub> O <sub>5</sub>  | 0.20  | 0.24  | 0.30   | tr.   | 0.22  | 0.28  | 0.39  | —     |
| H <sub>2</sub> O +             | 0.10  | —     | 0.15   | 0.34  | —     | —     | —     | —     |
| H <sub>2</sub> O -             | —     | —     | 0.06   |       | —     | —     | —     | —     |
| Silicate                       | 89.23 | 84.62 | 77.05  | 64.75 | 100 % | 100 % | 100 % | 100 % |
|                                |       |       |        |       | 1b.   | 2b.   | 3b.   | 4b.   |
| Fe                             | 4.02  | 7.76  | 15.15  | 23.70 | 72.56 | 85.47 | 88.27 | 92.30 |
| Ni                             | 1.43  | 1.25  | 1.88   | 1.78  | 25.81 | 13.77 | 10.98 | 7.24  |
| Co                             | 0.09  | 0.07  | 0.13   | 0.12  | 1.63  | 0.76  | 0.75  | 0.46  |
| Cu                             | —     | —     | —      | —     | —     | —     | —     | —     |
| Metal                          | 5.54  | 9.08  | 17.16  | 25.60 | 100 % | 100 % | 100 % | 100 % |
| Fe                             | 3.25  | 3.88  | 3.88   | 5.07  |       |       |       |       |
| S                              | 1.87  | 2.25  | 2.23   | 2.89  |       |       |       |       |
| Troilite                       | 5.12  | 6.13  | 6.11   | 7.96  |       |       |       |       |
| C                              | 0.07  | —     | —      | 0.32  |       |       |       |       |
|                                | 99.96 | 99.83 | 100.29 | 99.91 |       |       |       |       |

1. 'Ornansite', Warrenton, Missouri, U.S.A. Unpubl. analysis. H. B. Wiik analyst.

2. Average of twelve 'white chondrites'.

3. 'Crystalline chondrite', Oakley, Kansas, U.S.A. Unpubl. analysis. H. B. Wiik analyst.

4. 'Crystalline enstatite-chondrite', Daniel's Kuil, South Africa. G. T. Prior analyst. Total includes CaS 0.86 %, FeCr<sub>2</sub>S<sub>4</sub> 0.42 %. (Ca = 0.48 %, Cr = 0.22 %.) Total S = 3.51 %. C = 0.10 % according to Church, Chem. News, vol. 18 (1869), p. 258 [but 0.32 % acc. to Prior].

As an instance, an average of all the superior analyses of 'white chondrites', one of the largest 'natural groups' of chondrites, is given in

anal. 2-2a, table I. The analyses of the following white chondrites have been used in computing this average:

- Tenham (Warbreccan), spring, 1879, analysed by G. T. Prior (4).  
 Grossliebenthal, 19.xi.1881, anal. P. Melikov and C. Schwalbe (5).  
 Perpeti, 14.v.1935, anal. E. Spencer and K. B. Sen (6).  
 Varpaisjärvi, found 1914, anal. H. B. Wiik (7).  
 Wittekrantz, 9.xii.1880, anal. G. T. Prior (8).  
 St. Cristophe, 5.xi.1841, anal. F. Pisani; see A. Lacroix (9).  
 St. Michel, 12.vii.1910, anal. L. H. Borgström (10).  
 Baroti, 5.ix.1910, anal. G. T. Prior (11).  
 Lanzenkirchen, 28.viii.1925, anal. E. Dittler (12).  
 Rangala, 29.xii.1937, anal. J. A. Dunn (13).  
 Narellan, 9.iv.1928, anal. T. Hodge-Smith (14).  
 Lundsgård, 3.iv.1889, anal. O. Nordenskiöld (15).

When occurring all  $\text{Fe}_2\text{O}_3$  of these analyses has been calculated as  $\text{FeO}$ .  $\text{H}_2\text{O}$  has been left out in calculating this average composition. Nearly all the figures of these analyses vary only slightly from the corresponding figures of the average 2, table I.

Water,  $\text{Fe}_2\text{O}_3$ , and  $\text{NiO}$  as determined in the analyses are given in the statement of the analytical results 1, 3, and 4, table I. Water and  $\text{Fe}_2\text{O}_3$  if occurring in considerable amount indicate that the stone is much altered by weathering as is the case with many stony meteorites ploughed up from the soil years after they have fallen.  $\text{NiO}$  together with  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}$  in an analysis indicates a far-reaching decomposition of the nickel-iron of the stone. In stony meteorites which are not decomposed  $\text{NiO}$  in an analysis indicates that the magnetic separation of nickel-iron has not been complete and that some nickel-iron has remained in the material used for the analysis of the silicate portion.

Although analysis 2 in table I represents fairly well also the average chondrite, since most of the intermediate chondrites, the grey chondrites, and many of the spherical chondrites are of chemical compositions not differing much from that of the white chondrites, the variation in chemical composition of the chondrites is fairly wide. For comparison, therefore, analyses are here given of representatives of the group of chondrites with the lowest amount of silica, anal. 1, table I, the ornansite of Warrenton and of the group of chondrites with the highest amount of silica, the crystalline enstatite-oligooclase chondrite of Daniel's Kuil, anal. 4, table I. The ornansites have not only the lowest contents of silica among the chondrites, but also the lowest contents of metallic nickel-iron and the highest contents of ferrous silicate and ortho-silicates. The crystalline enstatite-chondrites have the highest amounts of silica, of metallic nickel-iron, and of metasilicates, and the lowest amount of

ferrous silicates. All the other chondrites vary in composition between the ornansites and the enstatite-chondrites of the Hvittis-type to which Daniel's Kuil belongs. In addition, as an example of the chondrites rich in nickel-iron, the crystalline chondrite of Oakley is given as anal. 3 of table I. These four analyses in table I are thus fairly well suited to illustrate here the statement of analytical results with regard to chondrites.

In the following calculations the  $H_2O$  of analyses 1, 3, and 4 has been left out as not forming an original constituent of the meteorites.  $Fe_2O_3$  occurring in small amounts in some of the analyses of the 'white chondrites' has been—as mentioned above—calculated as FeO. Small amounts of NiO, calculated as Ni, may, together with an amount of FeO corresponding to the proportion between Ni and Fe in the metallic portion, the FeO calculated as Fe, be added to the nickel-iron. Rare elements in small amounts determined in the analysis are preferably not included in the table but are mentioned in the text after the locality and name of the analyst. Here also the figures for the rare sulphides occurring in some stony meteorites, for instance in Daniel's Kuil, anal. 4, table I, may be given in detail.

In order to facilitate calculations and comparisons table I has been divided horizontally in such a way that the silicate portion, the metallic portion, and the sulphide portion of the meteorite are each summed up separately. In this way a comparison between the relative amounts of silicate, metal, and sulphide in different kinds of meteorites is facilitated, a comparison which is of importance also with regard to the possible occurrence of distinct silicate, sulphide, and metal shells in the body of the earth.

In cases where the amount of nickel-iron varies as much as in these four analyses in table I it is of interest to compare the composition of the silicate portions of the chondrites. Therefore the silicate portions of the four analyses, as calculated to 100 %, are given in 1*a*, 2*a*, 3*a*, and 4*a*, table I; also the nickel-iron portions as calculated to 100 % are given in 1*b*, 2*b*, 3*b*, and 4*b*.

The variation in composition of the silicate portions of stony meteorites is more distinctly seen from these analyses 1*a*–4*a* than from the bulk analyses 1–4. Especially the big difference in  $SiO_2$  content between the different 'natural groups' of chondrites is well shown. We see further that MgO increases in proportion to the increase in the  $SiO_2$ , although much less than  $SiO_2$ . With the rise of  $SiO_2$  the amount of FeO falls, becoming zero in the group of 'crystalline enstatite chondrites'. This

decrease in FeO is of course a result of the simultaneous and corresponding increase of metallic iron as seen from the analyses 1 to 4, table I. We see further from the analyses 1a-4a, table I, that while MgO increases with SiO<sub>2</sub> and FeO decreases, the other chemical components are not affected by this change, but remain fairly constant in all groups of chondrites.

The variation in the composition of the metallic nickel-iron in the different natural groups of chondrites is seen from the analyses 1b-4b, table I, as well as from the bulk analyses 1-4. We see clearly that with the decrease in the amount of nickel-iron, the nickel amount increases very considerably, as pointed out earlier by Prior (16).

In a previous paper on the chemistry of the meteorites (17) the present author pointed out that if the bulk analyses are calculated as free of oxygen and the metal atoms to 100 %, one finds that the difference in the metal atom composition of the several kinds of chondrites is but small. It was also pointed out that the difference in chemical and mineralogical composition of the different types of chondrites is therefore in reality a case of a different degree of oxidation. The proportion between all the metal atoms taken together and the number of the oxygen atoms present in a meteorite is a measure of the degree of oxidation of the meteorite and is an important means of comparison of meteorites amongst themselves and of meteorites with terrestrial rocks, which are to a much higher degree oxidized than the meteorites containing metallic nickel-iron. Such a comparison is, however, beyond the scope of this paper and will be dealt with in a separate publication.

*Calculation of the mineral composition of stony meteorites from the analytical results.*

Just as the analytical results have been published in many different ways—and not always in such a way as to allow of a bulk analysis of the meteorite being derived from the figures given—also the calculation of the mineral composition from the analytical results has been given in many different ways. As is well known, the calculation of the mineral composition of an igneous rock from the analysis is a complicated matter and has led to the introduction by American petrographers of a 'norm' calculation. Farrington tried to introduce a similar quantitative classification for stony meteorites (18), but his attempt cannot be regarded as successful, mostly on account of the small number of sufficiently accurate chemical analyses available at the time of his

publication, and also because Farrington in his calculations used a great number of inferior analyses.

On account of the non-existence in meteorites of the complicated silicates of the mica- and hornblende-groups, a calculation of the mineral composition of a stony meteorite is less complicated than the calculation of the 'mode' of an igneous rock. In most cases a kind of 'norm' of a meteorite, which at least approximately corresponds to its 'mode' or actual mineralogical composition, can be calculated from the analysis. In table II such examples are given of the calculation of the mineral composition from analyses 1, 2, 3 and 4, table I.

TABLE II. Mineral 'norms'.

|   | 1.     | 2.     | 3.    | 4.    |
|---|--------|--------|-------|-------|
| Na <sub>2</sub> O.Al <sub>2</sub> O <sub>3</sub> .6SiO <sub>2</sub> ... | 5.11   | 8.38   | 5.50  | 5.27  |
| K <sub>2</sub> O.Al <sub>2</sub> O <sub>3</sub> .6SiO <sub>2</sub> ...  | 1.34   | 1.16   | 1.16  | 0.89  |
| CaO.Al <sub>2</sub> O <sub>3</sub> .2SiO <sub>2</sub> ...               | 2.55   | 2.20   | 1.69  | 1.53  |
| FeO.SiO <sub>2</sub> ...  | 0.12   | 7.36   | 6.31  | 0.03  |
| FeO.TiO <sub>2</sub> ...  | 0.28   | 0.24   | 0.33  | 0.23  |
| MnO.SiO <sub>2</sub> ...  | 0.37   | 0.51   | 0.45  | 0.04  |
| CaO.SiO <sub>2</sub> ...  | 2.94   | 2.26   | 3.58  | 2.21  |
| MgO.SiO <sub>2</sub> ...  | 0.16   | 16.50  | 20.63 | 53.85 |
| 2FeO.SiO <sub>2</sub> ...   | 33.91  | 13.85  | 8.95  | —     |
| 2MgO.SiO <sub>2</sub> ...   | 41.12  | 30.67  | 26.47 | —     |
| FeO.Cr <sub>2</sub> O <sub>3</sub> ...                                  | 0.85   | 0.71   | 0.76  | 0.33  |
| 3CaO.Na <sub>2</sub> O.P <sub>2</sub> O <sub>5</sub> ...                | 0.52   | 0.63   | 0.79  | —     |
| SiO <sub>2</sub> ...  | —      | —      | —     | 0.34  |
| Fe ...  | 4.02   | 7.76   | 15.15 | 23.70 |
| Ni ...  | 1.43   | 1.25   | 1.88  | 1.78  |
| Co ...  | 0.09   | 0.07   | 0.13  | 0.12  |
| FeS ...   | 5.12   | 6.97   | 6.11  | 8.09  |
| CaS ...   | —      | —      | —     | 0.86  |
| FeCr <sub>2</sub> S <sub>4</sub> ...                                    | —      | —      | —     | 0.40  |
| C ...   | 0.07   | —      | —     | 0.10  |
|   | 100.00 | 100.52 | 99.89 | 99.77 |

TABLE IIa.

|                 | 1.    | 2.     | 3.    | 4.    |
|-----------------|-------|--------|-------|-------|
| Feldspars ...   | 9.00  | 11.70  | 8.35  | 7.69  |
| Pyroxenes ...   | 3.85  | 26.87  | 31.30 | 56.36 |
| Olivine ...     | 75.03 | 44.52  | 35.42 | —     |
| Chromite ...    | 0.85  | 0.71   | 0.76  | 0.34  |
| Merrillite ...  | 0.52  | 0.63   | 0.79  | —     |
| Quartz ...      | —     | —      | —     | 0.34  |
| Nickel-iron ... | 5.54  | 9.08   | 17.16 | 25.60 |
| Troilite ...    | 5.12  | 6.97   | 6.11  | 8.09  |
| Oldhamite ...   | —     | —      | —     | 0.86  |
| Daubréelite ... | —     | —      | —     | 0.40  |
| Carbon ...      | 0.07  | —      | —     | 0.10  |
|                 | 99.98 | 100.48 | 99.89 | 99.78 |

In these calculations the following rules have been followed:

1. After the molecular proportions have been ascertained in the usual way an amount of  $\text{Na}_2\text{O}$  and  $\text{CaO}$  necessary to bind all the  $\text{P}_2\text{O}_5$  of the analysis as merrillite,  $3\text{CaO} \cdot \text{Na}_2\text{O} \cdot \text{P}_2\text{O}_5$ , is deducted from the bulk of  $\text{CaO}$  and  $\text{Na}_2\text{O}$ .

2. The remaining  $\text{Na}_2\text{O}$  is combined with the corresponding amount of  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  to form the albite molecule. All  $\text{K}_2\text{O}$  is combined with  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  to form the orthoclase molecule. The remaining  $\text{Al}_2\text{O}_3$  is combined with a corresponding amount of  $\text{CaO}$  and  $\text{SiO}_2$  to form anorthite. In this way the amount of feldspar (and maskelynite) silicates, crystallized as well as contained in the glassy portion of the chondrules and of the meteorites, is determined by the analytical figure for  $\text{Al}_2\text{O}_3$ . It is therefore necessary that  $\text{TiO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{MnO}$ , and  $\text{P}_2\text{O}_5$  be determined in the analysis, otherwise an omission of the determination of one or more of these minor constituents will lead to too high a figure for  $\text{Al}_2\text{O}_3$  and too high an amount of anorthite with a correspondingly too low figure for the pyroxene component  $\text{CaSiO}_3$ .

3. If the stone contains oldhamite,  $\text{CaS}$ , a corresponding amount of calcium is obtained in solution after digesting a portion of the powder in water slightly acidified with acetic acid. After deducting an amount of  $\text{CaO}$  corresponding to the oldhamite, any remaining  $\text{CaO}$  is combined with  $\text{SiO}_2$  to form  $\text{CaSiO}_3$  which is counted as belonging to the pyroxenes of the meteorite.

4.  $\text{TiO}_2$  is combined with  $\text{FeO}$  to form  $\text{FeTiO}_3$ , which is added to the pyroxene silicates replacing  $\text{FeSiO}_3$ . Ilmenite has so far not been proved to occur in stony meteorites. Titanium, however, is possibly present as  $\text{Ti}_2\text{O}_3$  in the pyroxenes, and admittedly the whole question of how the titanium occurs has to be solved by future research.

5.  $\text{Cr}_2\text{O}_3$  is combined with  $\text{FeO}$  to form chromite  $\text{FeCr}_2\text{O}_4$ , except in stones like Daniel's Kuil, anal. 4, table I, where part of the  $\text{Cr}_2\text{O}_3$  occurs in the soluble portion of the meteorite. In such a case this portion of the  $\text{Cr}_2\text{O}_3$  should be calculated as daubréelite,  $\text{FeCr}_2\text{S}_4$ .

6. All  $\text{Fe}_2\text{O}_3$  of the analyses is calculated as  $\text{FeO}$  and added to the quantity of  $\text{FeO}$  found, since it is very uncertain whether any magnetite occurs, or theoretically could at all exist in a chondrite containing metallic nickel-iron. The only instances where one could expect to find magnetite or where magnetite has been reported to occur seem to be in the almost totally oxidized achondrites which do not contain any metallic nickel-iron. But this problem also has to be clarified by further research.

All MgO and FeO are combined with SiO<sub>2</sub> to form MgSiO<sub>3</sub>, Mg<sub>2</sub>SiO<sub>4</sub>, FeSiO<sub>3</sub>, and Fe<sub>2</sub>SiO<sub>4</sub>, the proportion of metasilicates to orthosilicates being calculated in the same way as in the 'Quantitative classification of igneous rocks' (1), p. 193, paragr. 18a, to p. 199.

This calculation based on the proportion between available SiO<sub>2</sub> molecules and FeO+MnO+MgO molecules gives us the proportion between the FeO and MgO metasilicates contained in the pyroxenes and FeO and MgO orthosilicates contained in the olivine, and thus, if FeTiO<sub>3</sub> and CaSiO<sub>3</sub> are added to the FeSiO<sub>3</sub> and MgSiO<sub>3</sub> pyroxene silicates, the proportion between pyroxenes and olivine contained in the stone. However, in this norm calculation the Mg and Fe silicates are allotted to the pyroxene and the olivine in the same proportion and do not give any information as to the actual distribution of iron and magnesium silicates in these minerals. From investigations on achondrites we know that the proportions between FeO and MgO are not the same in pyroxenes and olivines contained in the same stone, and where these minerals have crystallized from a melt we must expect that the proportions between FeO and MgO will be different in the two mineral series. The actual equilibrium conditions, however, are not known, but further studies of certain of the achondrites may throw light on these interesting relations concerning the distribution of FeO and MgO silicates between the pyroxenes and the olivines. Where optical determinations on achondrites are possible the results can be used in calculating the 'norm' and thus include a calculation of the actual proportions of the FeO and MgO silicates contained in the pyroxenes and olivines. In the chondrites conditions are more complicated and it seems that in many stones both enstatite chondrules and bronzite and hypersthene chondrules occur, while the olivines of different chondrules may perhaps also have a different composition; but these questions need further investigation. Prior has proposed to designate the ratio MgO : FeO in the silicate portion of a stony meteorite by *m* and the ratio of percentage weight of Fe : Ni in the metallic portion of the stones by *n*.

The figures of a table of mineral constituents such as table II are, however, greatly influenced by the quality of the analyses and especially by the exactness of the determination of the amount of metallic nickel-iron present, and the proportion between metallic iron and FeO, which is the most difficult determination in the analyses of stony meteorites and siderolites.

A similar way of calculating the mineral composition of the Suwahib meteorite has been used by Campbell Smith (19) and modifications of

such methods have been used by Prior and also by some other authors. Were the 'rules' according to which the mineral compositions in table II have been calculated to be generally accepted, we would obtain 'norms' which probably would be very close to the actual mineralogical composition and could better serve as a basis for petrological comparison than some of the earlier methods of calculating the mineral composition which in some points vary amongst themselves.

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