CHILEAN HEXAHEDRITES AND THE COMPOSITION OF ALL HEXAHEDRITES

EDWARD P. HENDERSON,[1]
U. S. National Museum, Washington, D. C.

ABSTRACT

Many hexahedrites have been reported from Chile and since they are found over a rather limited geographical area, are most likely not all separate falls. Chemical investigations were made in the hope that some significant differences in composition would be found in them, but all have proven to be very similar. Chilean hexahedrites when compared with others from all parts of the world, are likewise found to be chemically similar. The composition of hexahedrites is now well established. Their position in the equilibrium diagram of the iron-nickel system is discussed. Kamacite in octahedrites is shown to be similar to hexahedrites.

According to the records of the U. S. National Museum, ten hexahedrite irons are known from Chile, most of them having been discovered within a rather limited geographical area. Hexahedrites are an uncommon type of iron meteorite and the finding of ten separate falls of this class in such a restricted area is more than can be considered logical.

In the following table the names of all hexahedrites, together with the latitudes and longitudes of those which can definitely be located, are given. As meteorites are named after the town or other well known geographical feature near the point of their discovery, the latitude and longitude denotes the geographical spot for which the meteorite was named. Since the area in Chile is very sparsely populated, with few towns, the localities given usually represent the town to which the meteorite was carried, and the distribution of the meteoritic material may be more limited than the table indicates. The extreme differences in latitude between them is 8°54′, while the maximum difference in longitude is 1°56′.

It is evident from Table 1 that these meteorites are, with the exception of San Martin, rather closely grouped geographically, and most likely represent a shower of iron falls.

All of these hexahedrites are homogeneous in structure and large polished and etched faces show a continuous, unbroken structure throughout. A few small inclusions of troilite are present and around an occasional troilite mass there are some thin zones of schreibersite. At times a rectangular area of schreibersite is included within the troilite. Delicate needles of rhabdite are present and rather evenly distributed but are not particularly numerous. The areas selected for analyses were free from

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TABLE 1. CHILEAN HEXAHEDRITES

Name	Latitude	Longitude	Known weights
Cerros del Buei Muerto	22°40′ S	69°50′ W	75 kilograms
Coya Norte[1]	22°20′ S	69°40′ W	17.9 kilograms
Mejillones	23° 7′ S	70°30′ W	1185 grams[2]
Negrillos[1]	On the Iquique Pampa		28.5 kilograms
Puripica[1]	Province of Antofagasta		19 kilograms
Rio Loa[1]	21°26′ S	70° 5′ W	4 kilograms
San Martin[3]	30° 0′ S	71°18′ W	
Sierra Gorda[1]	22°53′ S	69°18′ W	22 kilograms
Union	23° 3′ S	69°30′ W	22 kilograms
Filomena[1]	23° 0′ S	69°26′ W	21.1 kilograms

[1] Described for first time.

[2] Weight reported in collections. Original find must have been much greater, but location of main mass is now unknown.

[3] Main mass in Kiel, Germany. Weight is not listed.

any conspicuous inclusions, save the needles of rhabdite. Therefore, these analyses express as nearly as possible the composition of the main mass.

Table 2 contains the analyses of the newly reported meteorites and indicates how strikingly similar they are. It is impossible to find any distinguishing differences between any of these meteorites.

After determining the definite proportion between iron and nickel in the Chilean material, it was then desirable to compare these results with those published for other hexahedrites. Farrington[2] compiled a list of

TABLE 2. NEW CHILEAN HEXAHEDRITES

Name	Fe	Ni	Co	P	S	Cr	Ins.	Total
Coya Norte	93.74	5.51	.37	.30	trace	.03	.03	99.95
Negrillos	93.94	5.32	.35	.22	trace	.02	.02	99.87
Puripica	93.83	5.77	.26	.19	trace	trace	.03	100.08
Rio Loa	93.33	5.70	N.D.	.28	trace	trace	.01	99.32
Sierra Gorda	93.44	5.58	.25	.23	trace	trace	.01	99.51
Union[1]	93.09	5.63	N.D.	N.D.				
Filomena	N.D.	5.73	.21	.30	trace		.01	

Average Fe content 93.56
Average Ni content 5.60

[1] *Bull. Suiesse. de Min. et Petr.*, **17** (1937). Ni was originally reported as 4.66%. Private communication from J. Buffle reports the redetermination of Ni to be 5.63%.

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[2] Farrington, O. C., *Field Museum Publication 120*, **3**, No. 5 (1907).

analyses of hexahedrites which showed some variation in the percentages of iron and nickel. In the 38 analyses given by Farrington, the percentages of iron varies from a low of 91.86% to a high of 97.90%, and likewise the range of nickel lies between 2.10% and 7.42%. It is interesting to note that the higher value for the iron is in the same analysis as the low nickel determination. It has been found that the determination of nickel in the presence of much iron leads to analytical difficulties and low nickel percentages in so many old analyses are incorrect.[3]

TABLE 3. ANALYSES OF HEXAHEDRITE METEORITES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fe	93.36	94.14	93.75	93.30	93.93	94.02	93.39	94.03	93.39	93.47	93.59	93.62	93.06	93.75	93.59	94.05
Ni	5.78	5.30	5.51	5.79	5.52	5.48	5.62	5.33	5.69	5.55	5.68	5.21	5.35	5.43	5.59	5.48
Co	.75	.63	.51	.29	.61	.22	.58	.95	.78	.52	.66	.92	1.00	.58	.78	
S		.19		.18		.04		.07	trace	none	.08	.08	.08	.08	trace	
P	.25	.28	.20	.20	.34	.30	.31	.23	.22	.27	.25	.24	.31	.19	.32	
C	.03		.06		.04				.12	.03		.09				
Cr		.05		.04		.02		.02			.02	.05	.23			
Cu		.05		trace	.02			.04	trace	trace	.04	.07				
Ins.				.08				.01					.08		.07	
Cl					.06											

Average Fe content 93.652
Average Ni content 5.519

Col.	1—Uwet, Africa	*Min. Mag.*, **17,** 127 (1914).
	2—Walker Co., Alabama	*Meteoritenkunde*, **3,** 173 (1897).
	3—Iredell, Texas	*Am. Jour. Sci.*, **8,** 415 (1899).
	4—Bruno, Sask., Canada	*Am. Jour. Sci.*, **31,** 209 (1936).
	5—Murphy, North Carolina	*Meteoritenkunde*, **3,** 227 (1905).
	6—Cedartown, Georgia	To be described by S. H. Perry.
	7—Summit, Alabama	*Am. Jour. Sci.*, **40,** 322 (1890).
	8—Scottsville, Kentucky	*Meteoritenkunde*, **3,** 218 (1905).
	9—Warialda, Australia	*Rec. Geol. Surv., N. S. W.*, **10,** 75 (1921).
	10—Barraba, Australia	*Rec. Geol. Surv., N. S. W.*, **10,** 75 (1921).
	11—Hex River, Africa	*Meteoritenkunde*, **3,** 225 (1905).
	12—Braunau, Bohemia	*Meteoritenkunde*, **3,** 207 (1905).
	13—Holland's Store, Georgia	*Meteoritenkunde*, **3,** 240 (1905).
	14—Cerros del Buei Muerto, Chile	*Chemie der Erde*, **7,** (3) 499, (1932).
	15—Coahuila, Mexico[1]	New analysis, unpublished (E. P. H.)
	16—Boguslavkia, Siberia, USSR	New analysis, unpublished (E. P. H.)

[1] Of the 3 best analyses for this meteorite, the nickel content was reported as 5.62; 6.62; 7.42. Reanalysis by E. P. Henderson was made to establish the correct value.

Sixteen different analyses are listed in Table 3 which agree with the findings given above for the Chilean hexahedrites. Such consistent agreement between all of these results must have some fundamental significance. The average value for iron in the Chilean meteorites here reported for the first time is 93.56% and for the other 16 hexahedrites here re-

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[3] Henderson, E. P., Methods of determining nickel and cobalt in meteoric iron: *Am. Jour. Sci.*, **239,** 372 (1941).

ferred to is 93.65%. The percentage of nickel is 5.60% in the Chilean material against 5.519% in the other table.

Hexahedrites are similar in structure to kamacite, the principal alloy in octahedrites. Table 4 offers a comparison between some analyses of kamacite and the average analysis for hexahedrites.

The agreement is very close between these kamacite and hexahedrite analyses. Perhaps the reason for the kamacite from octahedrites averaging more nickel than the hexahedrites is that it is very difficult to remove a sample of kamacite from an octahedrite and be certain that no taenite is included.

TABLE 4. KAMACITE ANALYSES

	Bendigo	Welland	Glorietta	Canyon Diablo	Magura	Magura	Magura	Staunton	Toluca	Canyon Diablo	Santa[1] Luzia	Average for kamacite and hexahedrite	
												Kamacite	Hexahedrite
Fe	93.01	93.09	92.62	92.62	93.01	92.94	93.27	93.89	94.05	94.09	93.88	93.35	93.65
Ni	6.22	6.69	6.55	6.81	6.25	6.18	6.04	5.30	5.26	5.51	6.14	6.07	5.52
Co	.77	.25	.83	.57	.74	.88	.64	.61	.57	—	.096	.56	.59

[1] V. B. Meen, Santa Luzia de Goyaz meteorite; *Am. Mineral.*, **24,** 600 (1939).
All other kamacite analyses taken from O. C. Farrington, *Meteorites*, privately published **(1915).**

The compositions of hexahedrites agree with data of the equilibrium diagram of Owen and Sulley for the iron-nickel system.[4]

In this diagram the α-$\alpha\gamma$ boundary shows a maximum solubility of 5.6% Ni in Fe at about 400° C. The solubility decreases as the temperature is lowered. If the α-$\alpha\gamma$ boundary line in this diagram is extended down to 200° C., the nickel content would be 5.3 %.This lowering of the solubility of Ni between the temperatures of 400° C. and 200° C. may not decrease quite as rapidly as they indicate and the boundary should be more nearly straight. In Table 2 the average Ni for the hexahedrites is 5.60% while in Table 3 it is 5.519%.

Hexahedrites therefore fall near the α-$\alpha\gamma$ boundary and being composed essentially of one compound, kamacite or α-iron, should contain about 5.5% Ni. Kamacite from octahedrites has been analyzed and its Ni content should lie on the α-$\alpha\gamma$ boundary and none should fall into the α-iron field. Coarsest octahedrites, consisting essentially of kamacite (α-iron) with a very little taenite (γ-iron) should lie immediately within the $\alpha\gamma$ field.

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[4] Owen, E. A., and Sulley, A. H., Equilibrium diagram of iron-nickel alloys· *Phil. Mag. and Jour. Sci.*, **27,** No. 184, 633, May (1939).

Of the kamacite analysis in Table 4, two have nickel values (5.30% and 5.26% respectively) that are below the average of hexahedrites or α-iron; three have nickel values (6.69%, 6.55% and 6.81% respectively) which are higher than would be expected for a true homogeneous kamacite and these may be contaminated with taenite inclusions.

The list is only of qualitative value and is repeated here to show how the average kamacite compositions compares with the hexahedrite, as well as agrees with the equilibrium diagram for iron and nickel. The average for kamacite is 6.07% Ni which is located on the diagram, as it should be, just within the $\alpha+\gamma$ field. The composition for hexahedrites is given with some degree of confidence. The discussion of the composition of kamacite from octahedrites is introduced to show relationship. The marginal boundary between hexahedrites and octahedrites (coarse octahedrites) is perhaps somewhere between these values. Analyses of the coarsest octahedrites are being made in the hope of further defining the boundary between hexahedrites (α-iron) and octahedrites ($\alpha+\gamma$-iron).

CONCLUSIONS

1. Chilean hexahedrites have identical compositions and are recovered from a long, narrow strip of country in northern Chile. Very likely most, but perhaps not all, of these are related to a single shower. It is suggested that the named meteorites in this paper be referred to as North Chilean hexahedrites, while all other names now in the literature be regarded as synonyms.

(2) The composition of all hexahedrites is very definite. The nickel content lies between 5.5% and 5.6%.

(3) Relationship between hexahedrites and octahedrites is discussed and the lower nickel range for octahedrites seems somewhat definitely established somewhere between 5.52% and 6%. The coarsest of the octahedrites should contain slightly higher than 5.60% nickel and taenite would be scarcely detectable in octahedrites of less than 6% nickel.