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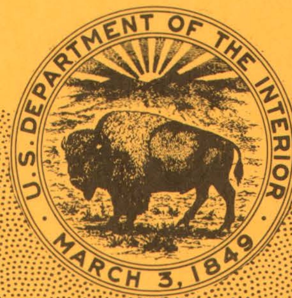

Gold in Meteorites And in the Earth's Crust

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By Robert S. Jones

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By ROBERT S. JONES

ABSTRACT

The reported gold contents of meteorites range from 0.0003 to 8.74 parts per million. Gold is siderophilic, and the greatest amounts in meteorites are in the iron phases.

Estimates of the gold content of the earth's crust are in the range of 0.001 to 0.006 parts per million.

INTRODUCTION

This report is one of several that summarize available data on the occurrence of gold. They have been prepared as background material for the Heavy Metals program of the U.S. Geological Survey, an intensified program of search for new sources of heavy metals, including gold.

Data on the occurrence of gold in meteorites and tektites are summarized, and recent estimates of the abundance of gold in the earth's crust are compiled.

GOLD IN METEORITES

Table 1 shows reported gold contents of tektites, aerolites, siderolites, and siderites. The table is arranged so that the data on tektites, which have the lowest iron contents, are at the top of the table and the data on siderites, which have the highest iron contents, are at the bottom. The other meteorite groups are intermediate in iron contents except for the siderolites. Gold is most abundant in the siderites and least abundant in the tektites; therefore, meteorites supply good evidence of the siderophilic character of gold. The tektites and the achondrites are relatively low in gold contents and are distinct from the other groups of meteorites in this respect. The gold contents of tektites and achondrites are of the same order of magnitude as those of terrestrial rocks. The other meteorites, on the average, contain appreciably more gold.

Although the iron contents of meteorites are similar in many respects to those of mafic and ultramafic rocks, the meteorites tend to contain much more gold. In chondrites, the gold seems to be almost entirely in the dispersed metallic phase (Vincent and Crocket, 1960), and this is probably true of the other meteorites. The gold content of the metallic phase of the chondrites is about 1.4 ppm (parts per million), which is similar to the gold contents of siderolites, octahedrites, and ataxites (Vincent and Crocket, 1960; Goldberg and others, 1951).

The carbonaceous chondrites are primitive, relatively undifferentiated matter from which the other meteoritic types have evolved (Mason, 1962; Baedecker and Ehmann, 1965). The occurrence of gold in such primitive types may be of special interest. The average gold content for 13 carbonaceous chondrites is 0.16 ppm, an amount greater than that in the average terrestrial rock by a ratio of about 40 to 1.

It has been suggested (Aller, 1961) that the best approximation to the average composition of the earth's mantle or even the entire earth is provided by the composition of the chondrites. They are similar in chemical composition to the ultramafic rocks, and their isotopic constitution for several elements is basically the same as that for the rocks of the mantle.

Baedecker and Ehmann (1965) show the abundances of gold, iridium, and platinum in four groups of chondrites. In the olivine-bronzite (H group), the olivine-hypersthene (L group), and the carbonaceous chondrites, the abundance ratio of Pt:Ir:Au is approximately 7–9:2:1; but for the enstatite chondrites, gold is more abundant and the Pt:Ir:Au ratio is 3.5:0.2:1. The iridium shows a relatively large decrease with respect to gold. These values, however, represent only analysis of the Abee enstatite chondrite made by Baedecker and Ehmann (1965) by neutron-activation methods. Analysis of this same meteorite by Crocket and

TABLE 1.—*Gold content of meteorites*

Type	No. of meteorites analyzed	Gold content (ppm) Range	Gold content (ppm) Average	Method	References
Tektites [1]	12	[2]0.0003– 0.0242	0.0074	Neutron activation.	Baedecker and Ehmann (1965).
Aerolites:					
Achondrites:					
Calcium poor	3	.0040– .030	.014	do	Baedecker and Ehmann (1965); Baedecker (1967).
Calcium rich	4	.0019– .0078	.0037	do	Do.
Chondrites:					
Carbonaceous	13	[3] .10 – .23	.16	do	Shcherbakov and Perezhogin (1964); Baedecker and Ehmann (1965); Baedecker (1967); Crocket and others (1967).
Hypersthene-olivine	8	[4] .10 – .19	.15	do	Vincent and Crocket (1960); Shcherbakov and Perezhogin (1964); Baedecker and Ehmann (1965).
Bronzite	9	[5] .14 – .29	.21	do	Do.
Enstatite	7	[6] .13 – .37	.27	do	Baedecker and Ehmann (1965); Baedecker (1967); Crocket and others (1967).
Siderolites	3	[7]1.3 – 2.0	1.5	do	Cobb (1967).
	--	[8]5 –10	-----	Other	Goldschmidt and Peters (1932).
Siderites:					
Hexahedrites	17	.43 – 1.17	.67	Neutron activation.	Goldberg and others (1951); Fouché and Smales (1966); Cobb (1967).
	1	1 – 5	-----	Other	Goldschmidt and Peters (1932).
Octahedrites	92	[9] .43 – 8.74	1.3	Neutron activation.	Goldberg and others (1951); Fouché and Smales (1966); Cobb (1967).
	15	0 –10	[10]4.7	Other	Noddack and Noddack (1930); Goldschmidt and Peters (1932).
Ataxites	20	[11] .05 – 3.8	1.2	Neutron activation.	Goldberg and others (1951); Fouché and Smales (1966); Cobb (1967).
	5	.5 –10	[12]2.9	Other	Goldschmidt and Peters (1932).

[1] The origin of tektites is in doubt.
[2] A tektite spherule contained 8 ppm Au (Baedecker, 1967).
[3] A chondrule contained 0.11 ppm Au, and the matrix contained 0.13 ppm Au (Baedecker, 1967).
[4] The metallic fraction of two meteorites contained 1.52 ppm Au, and the silicate fraction contained 0.0052 ppm Au (Baedecker 1967).
[5] The metallic fraction of two meteorites contained 1.00 ppm Au, and the silicate fraction contained 0.025 ppm Au (Baedecker, 1967).
[6] The metallic fraction of two meteorites contained 0.95 ppm Au, and the silicate fraction contained 0.029 ppm Au (Baedecker, 1967).
[7] The metallic fraction of two pallasites contained 1.9 ppm Au, and the silicate phase of three pallasites contained 0.046 ppm Au (Baedecker, 1967).
[8] Iron parts only.
[9] The maximum value "probably gravely high" (Hey, 1966).
[10] In obtaining the average, "–" was assumed to be 0.5 ppm Au, and several values reported as 5–10 ppm Au were assumed to be 7.5 ppm Au.
[11] Value of < 0.1 ppm Au assumed to be 0.05 ppm Au.
[12] Value of 5–10 ppm Au assumed to be 7.5 ppm Au.

others (1967), who also used neutron-activation methods, gives a somewhat different relationship. Their ratio for Pt:Ir:Au is 5.9:1.5:1. The amount of platinum, iridium, and gold reported by Baedecker and Ehmann is 1.3, 0.083, and 0.37 ppm, respectively; Crocket and others reported 1.3, 0.32, and 0.22 ppm, respectively. The iridium–gold ratio of terrestrial rocks is more like that of tektites than it is like the ratios of the other meteorites (Baedecker and Ehmann, 1965).

The gold contents of the octahedrites do not seem to vary with the coarseness of the octahedrites. Cobb (1967) noted that most of his values for gold in meteorites were in the range of 0.2 to 2.5 ppm. Cobb (1967) and Goldberg, Uchiyama, and Brown (1951) analyzed parts (three in all) of the same meteorite, and Cobb obtained lower values. The average values of gold in hexahedrites were also low compared with those of Goldberg, Uchiyama, and Brown (1951). For the same 11 meteorites analyzed by neutron-activation methods by Goldberg, Uchiyama, and Brown (1951) and Fouché and Smales (1966), the average contents were 1.1 ppm gold and 0.9 ppm gold, respectively.

The various types of siderites have differing amounts of gold. Ataxites and octahedrites have an average gold content of about 1.3 ppm, which is about twice that for hexahedrites (0.64 ppm). The hexahedrites usually have less nickel than either the ataxites or the octahedrites. The Santa Catharina ataxite contained the most nickel (38.5 percent) and also the most gold (4.0 ppm), but the Deep Springs ataxite (13.4 percent nickel) contained the least amount of gold (less than 0.1 ppm, but considered as 0.05 ppm for table 1).

Fouché and Smales (1966) analyzed 70 siderites and found gold contents that ranged from 0.055 to 3.61 ppm. The correlation coefficients between gold and rhenium and between gold and chromium were low and negative, giving values of −0.41 and −0.31, respectively, but the correlation between gold and arsenic was +0.82 and between gold and palladium +0.68.

Goldschmidt and Peters (1932) analyzed the Coahuila, Mexico, meteorite and reported that it contained 1 to 5 ppm gold, whereas analysis by the neutron-activation method by Goldberg, Uchiyama, and Brown (1951) gave 0.743 ppm gold; by Fouché and Smales (1966), 0.70 ppm gold; and by Cobb (1967), 0.43 ppm gold. Goldschmidt and Peters (1932), analyzed the Mount Joy, Pa., meteorite and reported that it contained 5 to 10 ppm gold, whereas analysis by the neutron-activation method by Goldberg, Uchiyama, and Brown (1951) gave 0.994 ppm gold. These comparative values along with others in this report seem to indicate that lower values are obtained for gold when neutron-activation methods are used.

ESTIMATES OF GOLD IN THE EARTH'S CRUST

Parker (1967) has pointed out the difficulty in estimating the composition of the earth's crust, which forms less than 1 percent of the earth's mass (Aller, 1961). Differences among the estimates given by various authors since Clarke and Washington (1924) are due partly to different concepts of what constitutes the earth's crust, the depth to the Mohorovičić discontinuity, the composition of the oceanic crust compared with the continental crust, and the changes in crustal composition with depth. Also, with respect to gold specifically, the newer method of analysis, that of neutron activation, has resulted in a general downward revision of gold values.

TABLE 2.—*Abundance of precious metals in the earth's crust*

[n, first significant though unknown integer]

Amount, in parts per million			
Ag	Au	Pt	Reference and sample source
0.0n	0.00n	0.00n	Clarke and Washington (1924); igneous rocks.
.04	.0015	.00012	Berg (1929, p. 11).
.1	.005(?)	.05	Fersman (1933); 10-mile crust.
.06	.006	.05	Schneiderhöhn (1934); 16-km crust.
.1	.005	.005	Goldschmidt (1934, 1937) and Rankama and Sahama (1950); igneous rocks.
.04	.0015	.05	Anderson (1945); crust.
.1	.005	.005	Polański (1948); 35-km crust.
.1	.005	.005	Mason (1952, 1958); crust.
.2	.00n	.005	Vinogradov (1956); crust.
.07	.0043	------	Vinogradov (1962); crust.
----	.0025	------	DeGrazia and Haskin (1964); igneous rocks.
.075	.0035	.046	Tung and Chi-Lung (1966); crust.

TABLE 3.—*Abundance of precious metals in parts of the earth's crust*

[From Tung and Chi-Lung, 1966]

Source	Amount, in parts per million		
	Ag	Au	Pt
Deep oceanic region	0.098	0.004	0.095
Suboceanic region	.082	.0029	.05
Continental shield region	.067	.0034	.031
Folded belt region	.062	.0038	.022
Oceanic crust	.091	.0035	.075
Continental crust	.065	.0035	.028
Earth's crust	.075	.0035	.046
Crystalline rocks	.077	.0036	.049
Sedimentary rocks	.065	.0051	---

Table 2 gives the various estimates for the abundance of the precious metals, gold, platinum, and silver, in the earth's crust. Precious-metal contents of various parts of the earth's crust has been noted by Tung and Chi-Lung (1966). These data are given in table 3.

The estimates of gold and silver in the earth's crust have varied little since those of Clarke and Washington in 1924, although the estimates for platinum have varied substantially. The Ag:Pt:Au ratios, based on Tung and Chi-Lung's (1966) figures, are 21:13:1.

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