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Gold in Igneous, Sedimentary, And Metamorphic Rocks

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By Robert S. Jones

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ABSTRACT

Gold analyses were compiled for about 50 rock types of which more than 50 percent are igneous, about 30 percent are sedimentary, and the rest are metamorphic. The analyses for gold made before 1955 tend to be higher than the newer analyses, so separate lists are given. At present, minute amounts of gold in rocks seem to be best determined by neutron-activation methods of analysis, and the following data are based on such analyses:

Igneous rocks contain as little as 0.2 and as much as 73 ppb (parts per billion) gold. The average, calculated on the basis of 50 percent granite and 50 percent basalt, is 3.0 ppb. Averages (in parts per billion) for individual plutonic rock types are: granite, 2.8; syenite, 2.5; diorite, 3.5; gabbro, 5.4; and dunite, 8.2. Averages (in parts per billion) for individual volcanic rock types are: rhyolite, 12; trachyte, 6.5; andesite, 5.2; and basalt, 3.2.

Sedimentary rocks contain as little as 0.3 to as much as 41 ppb gold. The average of 5.0 ppb is based on the average of 7.5 ppb for sandstone, 3.9 ppb for shale, and 3.5 ppb for limestone.

In metamorphic rocks the range of gold content is from 0.86 to 22.4 ppb with an average of 4.3. The average (in parts per billion) for gneiss is 1.8; for schist, 5.0; for quartzite, 4.8; and for marble, 3.1.

In relatively nonauriferous regions, the compiled gold analyses of rocks show only a few parts per billion, whereas in relatively auriferous regions the analyses tend to be one to two magnitudes higher.

INTRODUCTION

This report was prepared as background material for the Heavy Metals program of the U.S. Geological Survey, an intensified program of research on new sources of heavy metals, particularly gold. Data on the occurrence of gold in igneous, sedimentary, and metamorphic rocks are summarized. The number of gold analyses made on common types of rocks is meager compared with analyses of other elements, and many of the data are of questionable quality.

ACCURACY OF ANALYSES

Analyses of the gold content of rocks made prior to 1955 were made by fire-assay, spectrographic, and wet chemical methods. These methods are less sensitive than those used at present, and the results obtained seem to be higher than those given by the newer methods. The gold beads produced by fire assay were measured by gravimetric, colorimetric, or volumetric methods until Hagen (1954) introduced the spectrographic method. Since 1954 a few analyses have been by methods similar to Hagen's, but most have been made by the neutron-activation method. Analyses presented in this report are grouped in tables according to date; analyses made before 1955 are shown in tables 2, 6, and 10, and those made since 1954 are shown in the remaining tables.

Analyses of the U.S. Geological Survey's standard rock samples G-1 and W-1 (Fairbairn and others, 1951) by several methods are given in table 1. The values for G-1 range from 0.002 to 0.0112 ppm (part per million), and those for W-1 range from 0.0048 to 0.010 ppm. All analyses are by neutron-activation methods except for those of Das Sarma, Sen, and Chowdhury (1965), which were made by fire assay followed by spectrographic analysis, and those of Brown and Wolstenholme (1964), which were made by mass spectrometer.

GOLD IN IGNEOUS ROCKS

Gold analyses of igneous rocks are given in tables 2 and 3. The older analyses listed in table 2 for igneous rocks were made by fire assay, and comparison with some of the recent results indicates that the older analyses are very much higher. A major source of error may be gold impurities in blanks, especially in the test lead used in assaying, causing high values. Hillebrand (in Emmons, 1886) and Andrew (1910) warned that it was impossible, at that time, to obtain test lead that did not contain appreciable amounts of gold.

The analyses by Hagen (1954) were made by fire assay followed by spectrographic analysis. He did considerable study on losses that might occur during the assay and applied corrections for them but apparently did not consider the possibility of gold contamination in the reagents. Hagen's values are consistently higher than those given for similar rocks by neutron activation. No comparisons of identical samples are available, but the following comparison may be made for rocks from the same localities.

Rock, locality, and number of samples	Au (ppb)	
	Hagen (1954)	Others
Olivine basalt, Jefferson County, Colo--	116	[1]4.0
Norite, Bushveld complex----------------	4 to 128	[1]2.9
Do------------------------avg of 7--	62	---
Basalt, Hawaii----------------avg of 6--	114	[2]2.6
Do----------------------------------	---	[3]2.8 to 5.9
Do------------------------avg of 3--	---	4.2
Kimberlite, Transvaal-------------------	92	[3]2.6

[1]DeGrazia and Haskin (1964).
[2]Vincent and Crocket (1960b).
[3]Baedecker (1967).

Assuming that the samples were similar in gold content, it would seem that Hagen's results are high by a factor of 20 to 30.

Gold seems to be heterogeneously distributed to a marked degree in some samples. Clifton, Hubert, and Phillips (1967), for example, found that the gold content of splits from a single sample of Oregon beach sand differed by as much as 29 ppm (<0.1 ppm to 29 ppm). De Silva (quoted in Baedecker, 1967) reported large discrepancies in neutron-activation analyses for gold even after the samples had been pulverized to achieve greater homogeneity. He divided one irradiated aliquot into four parts and found that one part contained 90 percent of the total activity of the sample. This lack of homogeneity, rather than analytical errors, is probably the cause of the discrepancies in the analyses of some samples, such as the differences (noted by Baedecker, 1967) in analyses of U.S. Geological Survey standard rocks G-1 and W-1 (table 1) and in four analyses of a diabase dike which showed 3.3, 140, 3.4, and 6.8 ppb gold (Shcherbakov and Perezhogin, 1963).

Clarke and Washington (1924) estimated the gold content of igneous rocks to be in the range 1 to 10 ppb, and this order of magnitude has been substantiated by later workers. The average amount of gold in igneous rocks has been estimated by Berg (1932) to be 6 ppb, by Noddack and Noddack (1934) to be 4 ppb, and by Mason (1952), Rankama and Sahama (1950), Polanski (1948), Anderson (1945), Goldschmidt (1937), and Fersman (1933) to be 5 ppb. Goldschmidt (1954) computed a mean value of 2 ppb gold based on the gold to silver ratio of 20:1; this ratio is based on the proportion of these two elements in important ores. Horn and Adams (1966), with the aid of a computer and assumptions based partly on a modification of Goldschmidt's (1933) material balance, have derived a figure of 3.57 ppb of gold in igneous rocks, which is only slightly higher than the value of 3.0 ppb obtained by averaging the values for granite and basalt in table 5.

Shcherbakov and Perezhogin (1964) reported that, in the Altai-Sayan folded belt in the U.S.S.R., gold is more abundant in extrusive rocks than in their intrusive equivalents. For example, 14 rhyolites and trachytes contain an average of 5.4 ppb gold, compared with the average of 3.8 ppb gold in 33 granites and eight syenites; 19 intrusive basalts average 10 ppb gold compared with the average of 6.4 ppb gold in 14 Altai-Sayan gabbroids. Boyle (1960) reported that the Prosperous Lake granite in the Yellowknife district of Canada contains 10 ppb gold compared with 100 ppb gold in a quartz-feldspar porphyry.

The gold content of the Skaergaard intrusives in Greenland were studied by Vincent and Crocket (1960a), who concluded that they varied little even though the intrusives have undergone strong magmatic differentiation. The initial magma, represented by a chilled border, contained 4.6 ppb gold. Most of the other rocks and minerals contained between half and twice this amount. However, Crocket, Vincent, and Wager (1958) believed that the gold content of the layered gabbros

Table 1.—Gold content of standard granite G-1 and standard diabase W-1

[Analyses by neutron-activation methods unless specified]

Gold content (ppm)		Reference
Granite G-1[1]	Diabase W-1[2]	
0.006	0.010	Vincent and Smales (1956).
.0045	.0084	Vincent and Crocket (1960a).
---	.0049	Hamaguchi and others (1961).
.0046	.005	Shcherbakov and Perezhogin (1963).
[3]<.08	[3]<.08	Brown and Wolstenholme (1964).
.0020	.0048	Baedecker and Ehmann (1965).
[4].0112	[4].0053	Das Sarma, Sen, and Chowdhury (1965).
[5].0057	[5].0064	---

[1]U.S. Geol. Survey standard granite from Westerly, R.I.
[2]U.S. Geol. Survey standard diabase from Centerville, Va.
[3]Analysis by mass spectrometer; not included in average.
[4]Analysis by fire-assay and spectrographic methods.
[5]Average of values except <0.08 ppm.

is constant and tends to be evenly distributed among the various silicate and oxide phases. They thought that the gold is present in uncharged randomly distributed metallic atoms in the magma rather than as charged ions or complexes. In the middle part of the intrusion they found evidence of an appreciable concentration of gold in the immiscible copper sulfide droplets in contrast to the lack of concentration of gold in the iron sulfide droplets which separated later.

The lowest average gold content for granites (1.2 ppb) has been reported by Anoshin and Potap'yev (1966). The granites are from widely separated massifs in the U.S.S.R. (the Kolyvan' massif in the northwestern part of the Altai and the Khangilay-Shilinskii massif in east Transbaikal).

Shcherbakov and Perezhogin (1963) examined 28 granites and concluded that the gold content of massifs bearing gold deposits are similar to those of barren massifs. The gold content of the younger granite phases, which are considered the source of the gold mineralization in the region, are lower than the gold content of the older mafic rocks.

Mantei and Brownlow (1967) showed that the Marysville quartz diorite stock in Montana has an appreciably higher background value for gold than the rocks of the Altai-Sayan folded belt in Asia (Shcherbakov and Perezhogin, 1963) or those of the Skaergaard intrusives of Greenland (Vincent and Crocket, 1960a). The gold content is greatest in and near the periphery of the stock, where it averages 71 ppb; elsewhere it averages 10 ppb.

Shcherbakov and Perezhogin (1964) used data obtained from igneous rocks of the U.S.S.R. to compare the gold content with the content of iron, magnesium, copper, vanadium, lead, zinc, and some unspecified metals. It is not clear whether they analyzed the same rocks for these metals and for gold or whether they used values furnished by Zavaritskii (1955). The metals and oxides that show correlation with gold, in decreasing order of correlation, are: Cu, Fe_2O_3, MgO, V, and FeO. Shcherbakov and Perezhogin (1964) stated, "It should be noted that the correlation coefficient between the gold content and the content of another cation decreases as the bonding between the cation and oxygen becomes more strongly ionic." In addition they noted that the patterns of gold distribution are different in the intrusive and extrusive rocks so that when the data for the extrusive rocks are introduced, the correlations between gold and all the other components are much lower.

Table 4 gives the average gold content of igneous rocks based on all known published analyses made since 1954. The analyses represented by each average are probably too few to give reliable background values for the igneous rocks. For example, the average for nepheline syenites (1.8 ppb gold) is based on only two analyses, and the value 100 ppb for quartz-feldspar porphyry is a single analysis.

Table 5 shows the average gold content of various igneous rock types as determined by the neutron-activation method only. The value for granites is an average of 13 individual averages of granites from 13 localities in North America and the U.S.S.R.: Algoma District, Ontario; Westerly, R.I.; Wausau, Wis.; Stone Mountain, Ga.; Altai; Turochak, southeast Altai; Aksai, southeast Altai; Kuznetsk, Altai; northwest Altai; east Transbaikal; Tuva, Soviet Asia; Sayan (Mount Sukhaya); and Tashtuzek, southeast Altai. The average gold content of basalts (table 5) was derived from 11 individual averages representing basalts in Jefferson County, Colo.; Cooper Falls, Oreg.; East Pacific Rise; Mauna Loa, Hawaii; Altai, U.S.S.R.; central Altai, U.S.S.R.; Lintz, Germany; Morvern, Scotland; Giant's Causeway, Ireland; and two parts of the mid-Atlantic ridge.

The data for volcanic rocks show a direct relationship between gold and silica, whereas the relationship seems to be inverse for the plutonic rocks (table 5). The relatively large amount of gold in the rhyolites may be the result of selective sampling.

GOLD IN SEDIMENTARY ROCKS

Data on gold in sedimentary rocks are presented in tables 6 and 7. Table 6 gives the analyses made prior to 1955; table 7, the analyses made since 1954.

Reported gold content of sedimentary rocks ranges from at least 82 ppm for conglomeratic ores from the Black Hills, S. Dak., to as little as 0.0003 ppm for a sandstone from Mount Darwin, Tasmania.

Many of the conglomerates represented in table 6 are from ore-producing areas, and some may, in places, contain enough gold to be mined profitably. More than 500 fire-assay-atomic-absorption analyses have been made for gold in conglomerates in northwestern Wyoming (table 7). The average gold content of the Harebell Formation is estimated at 55 ppb, and that for the younger Pinyon Conglomerate is estimated at 80 ppb (Antweiler and Love, 1967).

The analyses for gold in sandstones range from 0.3 ppb in a sandstone from Tasmania (table 7) to 446 ppb for a sandstone from Victoria, Australia (table 6). The average amount of gold detected in sandstones by neutron-activation analysis is 7.5 ppb (table 8). Siltstones are represented by two values (table 8), one of 5.5 ppb and the other 6.2 ppb (Shcherbakov and Perezhogin, 1963).

Amounts of gold reported in shales and lutites range from 2.3 ppb to 374 ppb (tables 6 and 7). The lutites, from shallow cores from the ocean floor, contain variable amounts of gold, but from a depth of 1 to 10.45 meters the gold content increases with depth from 3.1 ppb to 17.2 ppb (DeGrazia and Haskin, 1964).

(Text continues on p. 15.)

Table 2.—Analyses of gold in igneous rocks made before 1955

[Some of these rocks may be metamorphic in origin. All analyses are by fire assay only unless specified]

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	United States:				
Pegmatite	Mojave, Calif.	0.332 to 1.659	---	----------	De Kalb, Courtenay, cited by Lincoln (1911).
Granite	Lake Tenaya (Porcupine Flat), Calif.	.120	2	----------	Wagoner (1901).
Do	American River, Calif.	.115	1	----------	Do.
Do	Candelaria, Nev.	1.130	1	----------	Do.
Do	Pike's Peak, Colo.	.032	1	Fire assay and spectrographic	Hagen (1954).
Do	Antelope Springs, Colo.	<.083	---	Biotite-granite	Hastings, J. B., cited by Lincoln (1911).
Do	Mojave, Calif.	Trace to 0.033	---	----------	De Kalb, Courtenay, cited by Lincoln (1911).
Do	Carson district, Idaho	≥.415	---	----------	Simundi, A., cited by Becker, G. F., in Lincoln (1911).
	South Africa:				
Do	Gröblersdal, Transvaal	.092	1	Fire assay and spectrographic	Hagen (1954).
Do	Janefurse, Transvaal	.059	1	-----do-----	Do.
	British Guiana:				
Do	Mazaruni district	.2	3	Granitite. Method unspecified	Harrison (1905).
	Chile:				
Do	Near Valparaiso	1.000	---	----------	Crosnier, L., cited by Lincoln (1911).
	Australia:				
Do	Timbarra, New South Wales	3.406	10	Silver, 829 ppm	Card, G. W., cited by Lincoln (1911).
	Ecuador:				
Quartz porphyry.	Loja Province	Trace	---	Content probably <0.166 ppm	Wolf, Theodor (abs. by vom Rath) cited by Lincoln (1911).
	Australia:				
Eurite (felsite).	Timbarra, New South Wales	11.607	---	Silver content, 5.0 ppm	Card, G. W., cited by Lincoln (1911).
Do	5 miles from Timbarra, New South Wales.	11.033	4	Silver content, 3.3 ppm	Do.
	South Africa:				
Granophyre	Kalkfontein, Transvaal	.0031(?)	1	Fire assay and spectrographic	Hagen (1954).
	United States:				
Rhyolite	Chalone Peaks, Calif.	Trace	---	Content probably <0.166 ppm	Fairbanks, H. W., cited by Lincoln (1911).
	New Zealand:				
Do	Thames, North Island	.0593	1	----------	Don (1898).
	South Africa:				
Felsite	Rooiberg, Transvaal	.113	1	Fire assay and spectrographic	Hagen (1954).
	United States:				
Aplite	Antelope Springs, Colo.	.041	4	----------	Hastings, J. B., cited by Lincoln (1911).

	British Guiana:				
Do--------	Mazaruni district---------	.3	1	Method unspecified---------------	Harrison (1905).
Do--------	Essequibo River-----------	1.0	2	-----do--------------------------	Do.
	United States:				
Granodiorite--	Dedham, Mass--------------	.079	1	Fire assay and spectrographic----	Hagen (1954).
	Australia:				
Tonalite------	Charters Towers, Queensland.	.080	8	---------------------------------	Don (1898).
	British Guiana:				
Diorite-------	Mazaruni River------------	.3	2	Method unspecified---------------	Harrison (1905).
	Ecuador:				
Diorite porphyry.	Loja Province-------------	Trace	---	---------------------------------	Wolf, Theodor, (abs. by vom Rath), cited by Lincoln (1911).
	New Zealand:				
Andesite------	Thames, North Island------	.042	21	---------------------------------	Don (1898).
Prophylite----	Thames, North Island------	2.42	24	---------------------------------	Do.
	United States:				
Syenite-------	Candelaria, Nev-----------	.72	1	---------------------------------	Wagoner (1901).
	British Guiana:				
Do--------	Mazaruni and Essequibo Rivers.	.5	3	Method unspecified---------------	Harrison (1905).
	Ecuador:				
Porphyry------	Loja Province-------------	Trace	---	---------------------------------	Wolf, Theodor (abs. by vom Rath), cited by Lincoln (1911).
	United States:				
Anthorthosite-	Adirondack, Essex County, N.Y.	.026	1	Fire assay and spectrographic-----	Hagen (1954).
	South Africa:				
Do--------	Transvaal-----------------	.060	2	Fire assay and spectrographic. Bushveld complex.	Do.
	Canada:				
Essexite------	Mount Royal, Montreal, Quebec.	.155	1	Fire assay and spectrographic-----	Do.
	South Africa:				
Gabbro--------	Transvaal-----------------	.087	4	Fire assay and spectrographic. Various parts of Bushveld gabbro.	Do.
	Canada:				
Do--------	Moyie, British Columbia--	.074	1	Fire assay and spectrographic. Purcell sill.	Do.
	United States:				
Do--------	Duluth, Minn--------------	.165	1	-----do--------------------------	Do.
	Canada:				
Norite--------	Sudbury, Ontario----------	.042	2	Fire assay and spectrographic. Levack norite.	Do.
	South Africa:				
Do--------	Transvaal-----------------	.062	7	Fire assay and spectrographic. Bushveld complex. Gold content ranged from 0.004 to 0.128 ppm.	Do.
	United States:				
Diabase-------	Mariposa County, Calif---	.076	1	---------------------------------	Wagoner (1901).
Do--------	Washoe district, Nev-----	As much as 0.66 to 0.83	---	Silver content, 7.2 ppm. Average of two samples.	Becker, G. F., cited by Lincoln (1911).

Table 2.—Analyses of gold in igneous rocks made before 1955—Continued

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	British Guiana:				
Diabase-------	Mazaruni River------------	.1	1	Method unspecified. Proterobase--	Harrison (1905).
Do--------	-----do-------------------	.3	1	-----do--------------------------	Do.
Do--------	Omai, Essequibo River-----	.1	1	-----do--------------------------	Do.
Do--------	Cuyuni River--------------	Trace	---	Method unspecified. Some samples yielded less than 0.1 ppm.	Do.
	Surinam:				
Do--------	Victoria placer-----------	0.200 to 0.600	---	--------------------------------	Du Bois (1903).
	Ecuador:				
Diabase porphyry.	Loja Province-------------	Trace	---	--------------------------------	Wolf, Theodor (abs. by vom Rath), cited by Lincoln (1911).
	United States:				
Basalt--------	Cheney, Ritzville, and---- Ellensburg, Wash.	.110	1	Fire assay and spectrographic. Composite sample.	Hagen (1954).
Do--------	Multnomah Falls, Oreg-----	.063	1	-----do--------------------------	Do.
Do--------	Petaluma, Calif-----------	.026	---	Paving stone. Silver content, 0.547 ppm.	Wagoner (1901).
Do--------	Yellowstone National Park, Wyo.	.16	1	Fire assay and spectrographic----	Hagen (1954).
Do--------	Golden, Colo--------------	.116	1	Fire assay and spectrographic. Olivine basalt.	Do.
Do--------	Keweenawan County, Mich---	.127	1	Fire assay and spectrographic. Amygdaloidal basalt.	Do.
	Mexico:				
Do--------	Canteras de Tlalpam, Districto Federal.	.043	1	Fire assay and spectrographic----	Do.
Do--------	Hawaii----------------------	.114	4	-----do--------------------------	Do.
	India:				
Do--------	Bombay--------------------	.126	1	Fire assay and spectrographic. About 35 miles east-southeast of Bombay. Deccan trap. Composite of 20 samples from 18 flows.	Do.
Do--------	-----do-------------------	.098	3	Fire assay and spectrographic. About 80 miles southeast of Bombay. Deccan trap. Three samples aggregating 52 composite samples.	Do.
	South Africa:				
Do--------	Kruger National Park------	.130	1	Fire assay and spectrographic----	Do.
	Azores:				
Do--------	Aria Langa, Pico----------	.077	1	-----do--------------------------	Do.
	New Zealand:				
Basaltic tuff-	Richmond River------------	15.180	---	May be water deposited----------	Schmeisser, Karl, cited by Lincoln (1911).

	South Africa:				
Ijolite (Urtite?).	Spitskop, Sekukuniland, East Transvaal.	.102	1	Fire assay and spectrographic----	Hagen (1954).
	U.S.S.R.:				
Monchiquite---	Krynka River--------------	.739	2	Silver content, 24.74 ppm--------	Morozewics, Józef, cited by Lincoln (1911).
Tilaïte-------	Nizhni Tagil--------------	.012	1	Fire assay and spectrographic. Zoticha, Pavolvski mine.	Hagen (1954).
	United States:				
Pyroxenite----	Cripple Creek, Colo-------	.017	1	Fire assay and spectrographic. From Iron Mountain.	Do.
	Webster County, N.C-------	.037	1	Fire assay and spectrographic----	Do.
	South Africa:				
Do--------	Transvaal-----------------	.063	8	Fire assay and spectrographic. Bushveld complex. Gold content ranged from 0.028 to 0.124 ppm.	Do.
	Germany:				
Do--------	Black Forest--------------	.100	1	Spectrographic-------------------	Leutwein (1939).
	South Africa:				
Kimberlite----	Kimberly, Transvaal-------	.092	1	Fire assay and spectrographic----	Hagen (1954).
	United States:				
Peridotite----	Peekskill (Montrose Point), N.Y.	.028	1	Fire assay and spectrographic----	Do.
Do--------	Murfreesboro, Ark---------	.039	1	Fire assay and spectrographic. Contains biotite and augite.	Do.
	South Africa:				
Harzburgite---	East Transvaal------------	.067	2	Fire assay and spectrographic. Bushveld complex.	Do.
Dunite--------	Transvaal-----------------	.06	1	Fire assay and spectrographic. Mooihoek or Onverwacht mines(?). Outer part of following sample (duplicate analyses).	Do.
Do--------	-----do-------------------	.18	1	Fire assay and spectrographic. Same as preceding sample but an interior part of the rock (triplicate analyses).	Do.
	New Caldonia:				
Serpentinite---	Northern part-------------	7.0 to 8.0	---	-----------------------------	Lacroix, Alfred, cited by Lincoln (1911).

Table 3.—Analyses of gold in igneous rocks made since 1954

[All analyses are by neutron activation unless specified]

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	Canada:				
Pegmatite-----	Yellowknife, Northwest Territories.	<0.01	---	Analysis by fire assay----------	Boyle (1960).
Granite-------	-----do--------------------	.01	1	Fire assay of Prosperous Lake granite.	Do.
Do--------	Algoma district, Ontario--	.0047	1	Bridgeland sill------------------	DeGrazia and Haskin (1964).
	United States:				
Do--------	Westerly, R.I------------	.005	1	U.S. Geol. Survey standard rocks G-1 and G-2. Fire assay, spectrographic, and neutron activation. Value is average of more than 13 analyses. G-1 average, 0.0057 ppm; G-2 average, 0.0011 ppm.	Vincent and Crocket (1960b), Vincent and Smales (1956), Shcherbakov and Perezhogin (1963), Baedecker and Ehmann (1965), Das Sarma, Sen, and Chowdhury (1965), and Baedecker (1967).
Do--------	Wausau, Wis--------------	.0033	1	--------------------------------	DeGrazia and Haskin (1964).
Do--------	Stone Mountain, Ga--------	.0019	1	--------------------------------	Do.
Do--------	Northwest Wyoming---------	.033	3	Precambrian granite. Replicate analyses by fire assay and atomic absorption. Two samples of one rock contained 0.015 ppm each; the second rock contained 0.050 ppm.	Antweiler and Love (1967).
	U.S.S.R.:				
Do--------	Altai--------------------	.0014	3	Sarakokshinsk massif (duplicate analyses). Includes phase II (0.0015 ppm), phase III (0.0015 ppm), and phase IV (0.0012 ppm).	Shcherbakov and Perezhogin (1964).
Do--------	Tashtuzek, southeast Altai.	.0035	1	Duplicate analyses--------------	Shcherbakov and Perezhogin (1963).
Do--------	-----do------------------	.0018	1	Leucocratic (duplicate analyses)-	Do.
Do--------	Turochak, southeast Altai-	.0018	1	Duplicate analyses--------------	Do.
Do--------	Aksai, southeast Altai----	.0020	1	Leucocratic (duplicate analyses)-	Do.
Do--------	Kuznetsk, Altai-----------	.0039	1	Melanocratic, Dudetsk massif (duplicate analyses).	Do.
Do--------	Altai--------------------	.016	2	Duplicate analyses--------------	Shcherbakov and Perezhogin (1964).
Do--------	Northwest Altai----------	.0012	19	Kolyvan' massif (part of Kalba complex). Includes biotite phase I (0.0013 ppm), II (0.0014 ppm), III (0.0011 ppm), and granite porphyry phase IV (0.0011 ppm).	Anoshin and Potap'yev (1966).

Do--------	East Transbaikal, central part of Aga area.	.0012	7	Khangilay-Shilinskiy massif------	Do.
Do--------	-----do-------------------	.0020	9	Khangilay-Shilinskiy massif. Average of three hydrothermally altered granites: 1. Biotite-muscovite granite (0.0028 ppm), 2. Muscovite-albite granite (0.0018 ppm), 3. Muscovite-albite-lepidolite granite (0.0014 ppm).	Do.
Do--------	Gornaya Shoriya-----------	.039	2	Duplicate analyses---------------	Shcherbakov and Perezhogin (1964).
Do--------	Tuva----------------------	.0037	1	Chingekat granite (duplicate analyses.	Shcherbakov and Perezhogin (1963).
Do--------	Sayan (Mount Sukhaya)-----	.0042	1	Duplicate analyses---------------	Do.
Do--------	Altai-Sayan folded belt (mostly).	.0032	33	This average includes probably most of or all the foregoing analyses.	Do.
	U.S.S.R.:				
Quartz porphyry.	Southeast Altai-----------	.012	1	D_2 (duplicate analyses)----------	Shcherbakov and Perezhogin (1964).
	Canada:				
Quartz feld-spar porphyry.	Yellowknife, Northwest Territories.	.10	1	Fire assay-----------------------	Boyle (1960).
Granophyre----	Greenland (southeast)------	.0036	3	Acid, Skaergaard massif (duplicate analyses).	Vincent and Crocket (1960a).
Do--------	-----do--------------------	.073	1	-----do--------------------------	Do.
Do--------	-----do--------------------	.0085	1	Basic, Skaergaard massif (duplicate analyses).	Do.
	U.S.S.R.:				
Do--------	Nizhnyaya Tunguska River--	.0043	3	Anakita massif-------------------	Shcherbakov and Perezhogin (1964).
Aplite--------	Northwest Altai-----------	.0012	1	Kolyvan' massif (part of Kalba complex) phase IV—see "Granite."	Anoshin and Potap'yev (1966).
Do--------	?	.0019	1	Kundatsk massif (duplicate analyses).	Shcherbakov and Perezhogin (1963).
Do--------	Kuznetsk, Ala-Tau---------	.0048	2	Duplicate analyses---------------	Do.
	United States:				
Do--------	Boulder County, Colo------	.0033	1	--------------------------------	DeGrazia and Haskin (1964).
	U.S.S.R.:				
Rhyolite------	Altai---------------------	.012	1	Duplicate analyses, possibly also referred to as "trachyte," sample No. 480.	Shcherbakov and Perezhogin (1964).
Felsite------	Northeast Altai-----------	.0055	1	Duplicate analyses---------------	Shcherbakov and Perezhogin (1963).
Rhyolites and trachytes.	Altai-Sayan folded belt---	.0054	14	--------------------------------	Shcherbakov and Perezhogin (1964).
	New Zealand:				
Obsidian-----	Rotorua-------------------	.021	1	--------------------------------	DeGrazia and Haskin (1964).

Table 3.—Analyses of gold in igneous rocks made since 1954—Continued

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	Australia:				
Perlite-------	Queensland----------------	0.0015	1	---------------------------------	DeGrazia and Haskin (1964).
	U.S.S.R.:				
Tuff lava-----	Central Altai-------------	.0052	1	Duplicate analyses---------------	Shcherbakov and Perezhogin (1963).
	Canada:				
Granodiorite--	Yellowknife, Northwest Territories.	<.01	---	Western granodiorite, analyses by fire assay.	Boyle (1960).
	United States:				
Do--------	Silver Plume, Colo--------	.0013	1	U.S. Geol. Survey standard GSP-1. Triplicate analyses reported as 1.3 ppm. Iridium content 0.0007 ppm, reported as 0.7 ppm.	Baedecker (1967).
	U.S.S.R.:				
Do--------	Ala-Tau-------------------	.0031	1	Dudetsk massif (duplicate analyses).	Shcherbakov and Perezhogin (1963).
Do--------	Central Altai-------------	.0048	1	Yalomanskii massif (duplicate analyses).	Do.
Do--------	Altai-Sayan folded belt---	.0040	8	---------------------------------	Shcherbakov and Perezhogin (1964).
Do--------	Sultanuizdag (Uzbekistan)-	.0056	5	Aktausk intrusive. Values of 11 analyses range from 0.0013 to 0.0320 ppm.	Paleĭ, Murovtsev, and Borozenets (1967).
	United States:				
Quartz diorite.	Helena, Mont. (20 miles northwest).	.034	5	Marysville quartz diorite stock. Range: 0.004 to 0.089 ppm.	Mantei and Brownlow (1967).
	U.S.S.R.:				
Diorite-------	Altai---------------------	.0010	1	Phase I (duplicate analyses)-----	Shcherbakov and Perezhogin (1963).
Do--------	-----do-------------------	.0045	1	-----do--------------------------	Do.
Do--------	East Sayan Mountains------	.0032	2	Kanatinsk diorite (duplicate analyses).	Do.
Do--------	Altai-Sayan folded belt (mostly).	.0035	14	---------------------------------	Shcherbakov and Perezhogin (1964).
Do--------	Central Kuznetsk, Ala-Tau-	.0046	2	Duplicate analyses---------------	Shcherbakov and Perezhogin (1963).
Do--------	Kuznetsk, Ala-Tau---------	.0034	1	Tikhvinsk diorite (duplicate analyses).	Do.
Do--------	Sultanuizdag (Uzbekistan)-	.009	1 1	Diorite porphyrite vein----------	Paleĭ, Murovtsev, and Borozenets (1967).
	United States:				
Andesite------	Guano Valley, Lake County, Oreg.	.0006	1	U.S. Geol. Survey standard AGV-1 (triplicate analyses reported as 0.6 ppm). Iridium content reported as 0.5 ppm, probably is 0.0005 ppm.	Baedecker (1967).
	U.S.S.R.:				
Do--------	Northeast Altai-----------	.01	1	Duplicate analyses---------------	Shcherbakov and Perezhogin (1963).

Do--------	Kuznetsk, Ala-Tau---------	.0055	3	-----do--------------------------	Do.
Do--------	-----do---------------------	.0047	1	Basaltic (duplicate analyses)----	Do.
Syenite-diorite.	Sultanuizdag (Uzbekistan)-	.034	5	Leucocratic. From Dzhamansaĭ intrusive. Values range from 0.0028 to 0.0660 ppm.	Paleĭ, Murovtsev, and Borozenets (1967).
	United States:				
Syenite-------	Wausau, Wis---------------	.00064	1	--------------------------------	DeGrazia and Haskin (1964).
	U.S.S.R.:				
Do--------	Altai-Sayan folded belt---	.0044	8	--------------------------------	Shcherbakov and Perezhogin (1964).
Trachyte------	Southeast Altai-----------	.0051	1	D_2. Duplicate analyses-----------	Shcherbakov and Perezhogin (1963).
Do--------	Northeast Altai-----------	.012	1	Pillow structure. Duplicate analyses (possibly also called "rhyolite"), samples No. 480.	Do.
Do--------	Central Altai-------------	.0080	1	D. Quartz bearing. Duplicate analyses.	Do.
Do--------	-----do---------------------	.0011	1	D_2. Quartz bearing. Duplicate analyses.	Do.
Do--------	Northeast Altai-----------	.0065	2	Felsitic. Duplicate analyses-----	Do.
Diorite-gabbro.	Kuznetsk, Ala-Tau---------	.015	1	Dudetsk massif. Duplicate analyses.	Do.
Gabbro--------	East Greenland-------------	.0024	1	Skaergaard intrusion. Olivine free. Duplicate analyses.	Vincent and Crocket (1960a).
Do--------	-----do---------------------	.0046	1	Skaergaard intrusion. Chilled margin. Duplicate analyses.	Do.
Do--------	-----do---------------------	.011	1	Skaergaard intrusion. Olivine-bearing. Duplicate analyses.	Do.
Do--------	-----do---------------------	.014	3	Skaergaard intrusion. Ferro-gabbro (hortonolite). Duplicate analyses.	Do.
Do--------	-----do---------------------	.0029	1	Skaergaard intrusion. Ferro-gabbro (fayalite). Duplicate analyses.	Do.
	United States:				
Do--------	Ironton, Mo---------------	.0024	1	--------------------------------	DeGrazia and Haskin (1964).
	U.S.S.R.:				
Do--------	Kuznetsk, Ala-Tau---------	.0066	1	Dudetsk massif. Duplicate analyses.	Shcherbakov and Perezhogin (1963).
Do--------	Altai--------------------	.0044	2	Sarakokshinsk massif. Duplicate analyses.	Do.
Do--------	Taskyl ------------------	.0063	1	Taskyl' gabbro. Duplicate analyses.	Do.
Do--------	Altai-Sayan folded belt---	.0055	1	Kanatinsk gabbro-----------------	Do.
Do--------	-----do---------------------	.0064	14	The rocks are referred to as "gabbroids."	Shcherbakov and Perezhogin (1964).
Do--------	-----do---------------------	.0087	33	The rocks are referred to as "gabbroids" and have originated in the Altai-Sayan folded belt and elsewhere.	Do.

Table 3.—Analyses of gold in igneous rocks made since 1954—Continued

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	South Africa:				
Norite	Transvaal	0.0029	1	Bushveld complex	DeGrazia and Haskin (1964).
	Canada:				
Diabase	Yellowknife, Northwest Territories.	<.01	---	Late diabase dikes. Analyses by fire assay.	Boyle (1960).
	United States:				
Do	Centerville, Va	.0065	1	U.S. Geol. Survey standard rock W-1. Fire assay, spectrographic, and neutron activation. Value is average of more than 10 analyses.	Vincent and Smales (1956), Vincent and Crocket (1960a), Hamaguchi and others (1961), Shcherbakov and Perezhogin (1963), Baedecker and Ehmann (1965), and Das Sarma, Sen, and Chowdhury (1965).
	U.S.S.R.:				
Do	Altai	.0058	2	Sarakokshinsk massif. Phase V. Duplicate analyses.	Shcherbakov and Perezhogin (1963).
Do	Nizhnyaya Tunguska River	.0080	1	Anakita massif, fine-grained part of the chilled border (duplicate analyses).	Shcherbakov and Perezhogin (1964).
Do	Kuznetsk, Ala-Tau	.0384	1	Cm_1. Quadruplicate analyses, with values of 0.0033, 0.0034, 0.0068, and 0.14 ppm.	Shcherbakov and Perezhogin (1963).
	United States:				
Basalt	Jefferson County, Colo	.0040	1	Contains olivine	DeGrazia and Haskin (1964).
Do	Cooper Falls, Bridal Veil quadrangle, Oregon.	.0006	1	U.S. Geol. Survey standard BCR-1 (triplicate analyses reported as 0.6 ppm). Iridium content reported as 0.5 ppm, probably is 0.0005 ppm.	Baedecker (1967).
Do	East Pacific Rise	.0004	1	Iridium content, 0.0002 ppm	Do.
	Hawaii:				
Do	Mauna Loa	.0026	1	Tholeiitic; olivine present (duplicate analyses).	Vincent and Crocket (1960b).
Do	-----do	.0059	1	Flow of 1859. Tholeiitic	Baedecker (1967).
Do	-----do	.0028	1	Flow of 1868. Tholeiitic-picrite	Do.
Do	-----do	.0039	1	Flow of 1881 near Hilo. Tholeiitic, hypersthene present. Iridium content, 0.0021 ppm.	Do.
	U.S.S.R.:				
Do	Altai	.0006	1	Duplicate analyses	Shcherbakov and Perezhogin (1963).
Do	Central Altai	.0089	1	Duplicate analyses. Basalt flow	Do.
Do	Altai-Sayan folded belt (mainly).	.010	19	These are all intrusive	Shcherbakov and Perezhogin (1964).
Do	Germany:				
	Lintz, Rhenish Prussia	.0026	1	------------------------------	DeGrazia and Haskin (1964).

	Scotland:				
Do--------	Morvern------------------	.0022	1	Duplicate analyses---------------	Vincent and Crocket (1960b).
	Ireland:				
Do--------	Giant's Causeway----------	.0020	1	Tholeiitic (duplicate analyses)--	Do.
	Middle Atlantic Ocean:				
Do--------	Mid-Atlantic ridge--------	.010	3	Values of 0.0063, 0.0106, and 0.014 ppm.	DeGrazia and Haskin (1964).
Do--------	-----do--------------------	.0003	3	Values range from 0.0002 to 0.0003 ppm; depth of collection ranges from 10,200 to 14,040 ft. Iridium content, 0.0039 ppm.	Baedecker (1967).
	U.S.S.R.:				
Basalts and andesites.	Altai-Sayan folded belt (mainly).	.0065	29	These samples include some shown elsewhere in this table.	Shcherbakov and Perezhogin (1964).
Gabbro-picrite.	Greenland (eastern)---------	.0035	1	Skaergaard massif (triplicate analyses).	Vincent and Crocket (1960a).
	U.S.S.R.:				
Gabbro-pyroxenite.	Altai----------------------	.0028	1	Sarakokshinsk massif. Duplicate analyses.	Shcherbakov and Perezhogin (1963).
	Canada:				
Nepheline syenite.	Bancroft, Ontario---------	.0026	1	--------------------------------	DeGrazia and Haskin (1964).
	United States:				
Do--------	Red Hill, N.H-------------	.00098	1	Contains sodalite----------------	Do.
	U.S.S.R.:				
Picrite-------	Southern Fergana and northern Nuratau.	.02	---	Picrite porphyrite. Replicate spectral analyses.	Gamaleev and others (1967).
	South Africa:				
Kimberlite----	Kimberly, Transvaal-------	.0026	1	From Kimberly mine---------------	Baedecker (1967).
	United States:				
Peridotite----	Cazadero quadrangle, Sonoma County, Calif.	.0007	1	U.S. Geol. Survey standard PCC-1 (triplicate analyses reported as 0.7 ppm). Iridium content reported as 2.5 ppm, probably is 0.0025 ppm.	Do.
	U.S.S.R.:				
Do--------	Eastern Sayan-------------	.0060	1	Ospinskii massif-----------------	Shcherbakov and Perezhogin (1964).
	Hebrides:				
Do--------	Rhum, Inner Hebrides------	.011	1	Autochthonous olivine cumulite---	Vincent and Crocket (1960b).
	South Africa:				
Do--------	Kimberly, Transvaal-------	.0008	2	Garnet present. Xenolith in kimberlite from Bulfontein mine. Iridium averages 0.0025 ppm.	Baedecker (1967).
	United States:				
Dunite--------	Balsam, N.C---------------	.0022	1	Duplicate analyses---------------	Vincent and Crocket (1960b).
Do--------	Twin Sisters Mountains, Wash.	.0008	1	U.S. Geol. Survey standard DTS-1 (triplicate analyses reported as 0.8 ppm). Iridium content reported as 0.4 ppm, probably is 0.0004 ppm.	Baedecker (1967).

Table 3.—Analyses of gold in igneous rocks made since 1954—Continued

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
Dunite--------	China----------------------	0.014	3	Duplicate analyses----------------	Shcherbakov and Perezhogin (1964).
	U.S.S.R.:				
Do--------	Urals--------------------	.009	4	From Ray-12, Uktussk, and Elizaveta massifs and Solov'yeva. Range, 0.0052 to 0.015 ppm (duplicate analyses).	Do.
Do--------	Polar Urals--------------	.022	1	Sabskovaykarskii massif. Duplicate analyses.	Do.
Do--------	Khatanga River basin------	.0056	1	Gula intrusive (duplicate analyses).	Do.
Do--------	Albania--------------------	.0037	1	Bulchiz massif. Duplicate analyses.	Do.
	U.S.S.R.:				
Ultramafic rocks.	Altai-Sayan folded belt---	.0094	27	These samples include some shown elsewhere in this table. (replicate analyses).	Do.

Table 4.—Average gold content of igneous rocks based on all known published analyses made since 1954

[Data from table 3. Average Au: First figure in brackets is the number of areas from which the samples were taken, and the second figure is the number of neutron-activation analyses made on these samples]

Rock type	Average Au (ppb)	Rock type	Average Au (ppb)
Pegmatite-------------------	<0.01 [1, 1]	Syenite-diorite----	3.4 [5, 5]
Granite---------------------	7.1 [20, 87]	Syenite------------	2.5 [2, 9]
Quartz porphyry-------------	12.0 [1, 2]	Trachyte-----------	6.5 [5, 12]
Quartz feldspar porphyry----	100.0 [1, 1]	Diorite-gabbro-----	15.0 [1, 2]
Granophyre------------------	16.3 [2, 13]	Gabbro-------------	5.4 [5, 23]
Felsite---------------------	5.5 [1, 2]	Norite-------------	2.9 [1, 1]
Aplite----------------------	2.8 [4, 8]	Diabase------------	[1]14.7 [4, 20]
Rhyolite--------------------	12.0 [1, 2]	Basalt-------------	3.6 [10, 40]
Obsidian--------------------	21.0 [1, 1]	Gabbro-picrite-----	3.5 [1, 3]
Perlite---------------------	1.5 [1, 1]	Gabbro-pyroxenite--	2.8 [1, 2]
Tuff lava-------------------	5.2 [1, 2]	Nepheline syenite--	1.8 [2, 2]
Granodiorite----------------	3.5 [4, 24]	Peridotite---------	4.6 [4, 7]
Quartz diorite--------------	34.0 [1, 5]	Picrite------------	20.0 [1, 2]
Diorite---------------------	4.3 [6, 15]	Kimberlite---------	2.6 [1, 1]
Andesite--------------------	5.2 [4, 13]	Dunite-------------	8.2 [7, 25]

[1]A value of 6.2 ppb Au is obtained if the anomalous value of 140 ppb is not included (see table 3).

Table 5.—Average gold content of plutonic and volcanic rocks

[Analyses by neutron activation only]

Plutonic rocks	Average Au (ppb)	Volcanic rocks	Average Au (ppb)
Granite--	[1]2.8	Rhyolite--	12.0
Syenite--	2.5	Trachyte--	6.5
Diorite--	[2]3.5	Andesite--	5.2
Gabbro---	5.4	Basalt----	3.2
Dunite---	8.2		

[1]This value is increased to 5.7 if the anomalous figures (Shcherbakov and Perezhogin, 1964) of 39 and 16 ppb Au are used in the calculation.
[2]Value given by Shcherbakov and Perezhogin (1964).

Leutwein (1951) made spectrographic analyses of 11 Thuringian alum- and silica-rich shales. The median amount of gold in these shales was 100 ppb. Pyrite separated from them contained no detectable gold, but gold was found in the hydrocarbon fraction. Seven sediments of Holocene age taken from the Baltic and North Seas, also analyzed by Leutwein, contained 500 to 2,500 ppb gold, which seems high. (See "sapropel," table 6).

Tischendorf (1959) found that black graptolitic shales near Tilkerode, Harz, Germany, contained 300 to 1,300 ppb gold, whereas bleached shales from the same area contained from less than 50 to 800 ppb (table 7). Six shales from the Harebell Formation in northwest Wyoming had an average of 72 ppb gold, and 18 shales from the Pinyon Conglomerate averaged 52 ppb gold (Antweiler and Love, 1967). Noddack and Noddack (1931) reported 10 ppm gold in a cupriferous shale from Germany. Gold values for clay range from 3.12 ppb (computer-derived geochemical balance, Horn and Adams, 1966) to 817 ppb.

Gold in lateritic ores of Ity, Ivory Coast, is finely dispersed in amounts up to 18.3 ppm according to available data. Bacteria may have played a role in the deposition of this gold (Parès and Martinet, 1964), as indicated by the results of the treatment of the ores and by the gold precipitated with cultures of microorganisms from streams and soils of the region. Experiments have shown that the initial solubility of the gold up to concentrations of 6 ppm is followed by slow reprecipitation.

Gold occurs in coal of all geological periods (Babička, 1943). Goldschmidt (1935) considered that the maximum factor of enrichment of gold in coal ash over the average gold content of the earth's crust is between 40 and 100 times. Thyssen-Bornemisza (1942) reported that some plants have the ability to concentrate gold.

Widely separated coals have yielded appreciable amounts of gold. Gold has been reported in coals from Pleasant Valley, Utah, and Kemmerer and Cambria, Wyo. (Gibson and Selvig, 1944; Jenney, 1903; Stone, 1912). Stone reported that samples from 31 carloads of coke (estimated one-third ash) from Cambria contained from 0.10 to 0.28 oz per ton (4 to 11 ppm) of gold, but more recent analyses have not confirmed these high figures. The split and boney coal from Cambria contained more gold than that with lower ash contents. The gold may be associated with pyrite and possibly derived from a slightly auriferous sandstone roof above the coal. (Text continues on p. 22.)

Table 6.—Analyses of gold in sedimentary rocks made before 1955

[Analyses are by fire assay unless specified]

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	United States:				
Conglomerate	Black Hills, S. Dak	Up to 82.950	---	Cambrian	Devereux, W. B., cited by Lincoln (1911).
Do	Klamath River, Calif	6.636 to 10.220	---	Cretaceous	Dunn, R. L., cited by Lincoln (1911).
Do	Calaveras County, Calif	Trace to 0.597	---	Jurassic	Lindgren (1894).
	Australia:				
Do	Gympie, Queensland	.043	2		Don (1898).
Do	Peak Downs, Queensland	7.680 to 9.216	---	Permian	Maclaren (1908).
Do	Tallawang, New South Wales.	1.536 to 23.040	---	do	Do.
Do	Nullagine, Western Australia.	18.980	---	Precambrian	Do.
	England:				
Do	Gloucester	7.680	---	Carboniferous	Do.
	South Africa:				
Do	Witwatersrand	7.500 to 15.000	---	Precambrian	Lincoln (1911).
	United States:				
Sandstone	Angel Island, Calif	.024	---		Wagoner (1901).
Do	Colusa County, Calif	.039	---		Do.
Do	San Francisco (Russian Hill), Calif.	.021	---		Do.
	Australia:				
Do	Bendigo, Victoria	.008	19	Maximum, 0.085 ppm	Don (1898).
Do	Ballarat, Victoria	.047	27	Maximum, 0.446 ppm	Do.
Do	Gippsland, Victoria	.039	13	Maximum, 0.224 ppm	Do.
Sandstone and slate.	Ballarat and Gippsland, Victoria.	.637	8		Do.
	United States:				
Shale	Braintree, Mass	About 0.008	---	Gray Cambrian shale	Lincoln (1911).
Do	Pennsylvania	About 0.008	---	Black Pennsylvanian shale	Do.
Do	Western Kansas	.037	---	Benton Shale. Silver content, 2.820 ppm.	Lindgren (1902).
	Australia:				
Do	Gympie, Queensland	.374	8	Maximum amount, 0.870 ppm	Don (1898).
	Germany:				
Do	Thuringia	<0.005 to 0.8	11	Silver ranged from 5 to 30 ppm. Analyzed by spectrochemical method.	Leutwein (1951).
Do	Mansfeld (Saxony)	10.0	---	Cupriferous	Noddack and Noddack (1931).

Do--------	Norway and Sweden-----------	0.05 to 0.1	---	Lower Ordovician black shale. Analytical method unspecified.	Goldschmidt (1954).
	United States:				
Coal----------	Pleasant Valley, Utah-----	1.0 to 1.4	---	Values given as $0.60 to $0.80 per ton with gold at $20 per ounce.	Jenney (1903).
Do--------	Kemmerer, Wyo-------------	1.0 to 1.4	---	-----do-------------------------	Do.
Do--------	Cambria, Wyo--------------	4.0 to 11.0	---	From coke only. The coke is estimated to be about one-third ash.	Stone (1912).
Do--------	Poland:				
	Rudolph, Koppich near Neurode.	0.5 to 1.0	---	--------------------------------	Goldschmidt and Peters (1933).
	Germany:				
Do--------	Brassert, Westphalia------	.5	---	From clarain--------------------	Do.
Do--------	Grube Fortuna, Cologne----	0.01 to 0.1	---	From the ash of brown coal. Spectrophotographic analyses.	Fuchs (1935).
	England:				
Do--------	Hartley-------------------	.5	---	--------------------------------	Goldschmidt and Peters (1933).
Limestone-----	Whalton, Somerset---------	.26	---	Carboniferous. Silver content, 18.7 ppm.	Maclaren (1908).
	United States:				
Gypsum -------	Salina, N.Y---------------	.083	---	Red Silurian gypsum-------------	Lincoln (1911).
Do--------	Grand Rapids, Mich--------	.083	---	Red Mississippian gypsum---------	Do.
	Germany:				
Anhydrite-----	Plõmnitz------------------	.007	---	--------------------------------	Friedrich, K., cited by Lincoln (1911).
	England:				
Rock salt, and some associated minerals.	Cheshire------------------	0.095 and 0.100	---	--------------------------------	Liversidge (1897).
	Germany:				
Do--------	Strassfurt----------------	.1	4	Includes sylvite, kainite, carnallite, and red rock salt.	Do.
Do--------	Strassfurt, Neindorf, Bernburg, and Mecklenburg.	<.003	13	Includes red rock salt, white rock salt, sylvite, boracite, "older" and "younger" rock salt, carnallite, kainite, langbeinite, and kieserite with rock salt.	Friedrich, K., cited by Lincoln (1911).
Do--------	Bernburg-----------------	.012	1	Red carnallite--------------------	Do.
	France:				
Marl----------	Rancourt------------------	4.000	---	Keuper variegated marl. Drill hole, 250.5 m. Silver content, 6.000 ppm.	Laur, Francis, cited by Lincoln (1911).
Do--------	-----do--------------------	36.000	---	Muschelkalk sandy marl. Drill hole, 382 m. Silver content, 245.00 ppm.	Do.
Do--------	-----do--------------------	6.000	---	Muschelkalk marl. Drill hole, 465 m. Silver content, 1,000 ppm.	Do.

Table 6.—Analyses of gold in sedimentary rocks made before 1955—Continued

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	France:				
Marl----------	Rancourt------------------	4.000	---	Muschelkalk marl. Drill hole, 467 m. Silver content, trace.	Laur, Francis, cited by Lincoln (1911).
	United States:				
Clay----------	Philadelphia, Pa----------	.817	---	Columbian clay------------------	Eckfeldt, cited by Lincoln (1911).
	Australia:				
Do--------	Ballarat, Victoria--------	.062	2	--------------------------------	Don (1898).
	Germany:				
Do--------	Plömnitz------------------	.013	---	Salt clay-----------------------	Friedrich, K., cited by Lincoln (1911).
	Western North Atlantic Ocean:				
Mud-----------	East of Georges Bank------	.257	---	Dredging, 677 fathoms deep. Silver content, 1.96 ppm.	Wagoner (1908).
Do--------	Southeast of Georges Bank.	.125	---	Dredging, 1,769 fathoms deep. Silver content, 0.38 ppm.	Do.
	United States:				
Do--------	South of Nantucket--------	.066	---	Dredging, 990 fathoms deep. Silver content, 0.41 ppm.	Do.
Do--------	Off Delaware Bay----------	.145	---	Dredging, 1,091 fathoms deep. Silver content, 1.0 ppm.	Do.
Do--------	Off Chesapeake Bay--------	.015	---	Dredging, 104 fathoms deep. Silver content, 0.35 ppm.	Do.
Do--------	Between Chesapeake Bay and Hatteras.	.044	---	Dredging, 49 to 70 fathoms deep. Silver content, 0.30 ppm.	Do.
Do--------	San Francisco Bay---------	0.045 to 0.271	---	Holocene------------------------	Do.
Sapropel------	Baltic Sea------------------	0.5 to 0.7	3	Depth of samples, 67 to 180 m. Spectrographic analyses.	Leutwein (1951).
	North Sea:				
Do--------	Norwegian coast (Nord Fjord, Ulvesünd, Drontheim Fjord, and Nord-Rauen).	0.7 to 2.5	4	Depth of samples, 58 to 517 m. Spectrographic analyses.	Do.
Laterite------	Surinam--------------------	3.0 to 10.0	---	Analytical method unspecified----	Du Bois (1903).
	Atlantic Ocean:				
Manganese nodule.	Station 286, H.M.S. *Challenger* Expedition.	.2	---	Spectrographic analyses----------	Goldschmidt and Peters (1932).

Table 7.--Analyses of gold in sedimentary rocks made since 1954

[All analyses are by neutron activation unless specified]

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	United States:				
Conglomerate--	Northwest Wyoming---------	0.055	56	Harebell Formation (Upper Cretaceous). Replicate analyses by fire assay-atomic absorption.	Antweiler and Love (1967).
Do--------	-----do-------------------	.080	225	Pinyon Conglomerate (Paleocene). Replicate analyses by fire assay-atomic absorption.	Do.
	Canada:				
Sandstone-----	Elbow Lake, Ontario-------	.0023	1	Graywacke, Gowganda Formation----	DeGrazia and Haskin (1964).
Do--------	Yellowknife, Northwest Territories.	.01	---	Graywacke. Analyses by fire assay.	Boyle (1960).
	United States:				
Do--------	Bayfield County, Wis.	.0116	1	Keweenawan----------------------	DeGrazia and Haskin (1964).
Do--------	Vanceburg, Ky-------------	.0026	1	Berea Sandstone-----------------	Do.
Do--------	Kettleman Hills, Calif----	.041	1	--------------------------------	Do.
Do--------	Northwest Wyoming---------	.064	11	Flathead Sandstone (Cambrian). Replicate analyses by fire assay-atomic absorption. Range, 0.015 to 0.150 ppm Au.	Antweiler and Love (1967).
Do--------	-----do-------------------	.081	55	Harebell Formation (Upper Cretaceous). Replicate analyses by fire assay-atomic absorption.	Do.
Do--------	-----do-------------------	.122	152	Pinyon Conglomerate (Paleocene). Replicate analyses by fire assay-atomic absorption.	Do.
	Australia:				
Do--------	Henbury, central Australia.	.0006	1	Henbury subgraywacke. Gold reported as 0.6 ppm. Iridium reported as 0.9 ppm, probably is 0.0009 ppm.	Baedecker (1967).
	Tasmania:				
Do--------	Western slope, Mount Darwin.	.0003	1	Owen sandstone. Gold reported as 0.3 ppm. Iridium reported as 1.1 ppm, probably is 0.0011 ppm.	Do.
	U.S.S.R.:				
Do--------	Northeast Altai-----------	.0026	1	Cm$_2$. Duplicate analyses----------	Shcherbakov and Perezhogin (1963).
Do--------	Central Altai-------------	.0053	1	S. Duplicate analyses------------	Do.
Do--------	-----do-------------------	.0027	1	D$_3$. Quadruplicate analyses-------	Do.
Do--------	-----do-------------------	.0029	1	D$_2$. Quadruplicate analyses-------	Do.
Do--------	Southeast Altai-----------	.0043	1	D$_3$. Duplicate analyses-----------	Do.
Do--------	-----do-------------------	.0023	1	Cm$_3$. Duplicate analyses----------	Do.

Table 7.—Analyses of gold in sedimentary rocks made since 1954—Continued

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	U.S.S.R.:				
Sandstone-----	Southeast Altai-----------	0.0016	1	O. Duplicate analyses------------	Shcherbakov and Perezhogin (1963).
Sandstones and shales.	Altai-Sayan folded belt (mainly).	.0036	39	These samples may be represented by some of the foregoing analyses.	Shcherbakov and Perezhogin (1964).
Siltstone-----	Central Altai-------------	.0055	1	O. Duplicate analyses------------	Shcherbakov and Perezhogin (1963).
Do--------	Southeast Altai-----------	.0062	1	D_3------------------------------	Do.
	United States:				
Shale---------	Wyandotte County, Kans----	.0072	---	Muncie Creek Shale Member of Iola Limestone.	DeGrazia and Haskin (1964).
Do--------	South Dakota--------------	.0047	---	Homestake Formation---------------	Do.
Do--------	Northwest Wyoming---------	.072	6	Harebell Formation (Upper Cretaceous). Replicate analyses by fire assay-atomic absorption.	Antweiler and Love (1967).
Do--------	-----do-------------------	.052	18	Pinyon Conglomerate (Paleocene). Replicate analyses by fire assay-atomic absorption.	Do.
	U.S.S.R.:				
Do--------	Gornaya Shoriya-----------	.0026	1	O. Duplicate analyses------------	Shcherbakov and Perezhogin (1963).
Do--------	Southeast Altai-----------	.0023	2	D_3. Duplicate analyses-----------	Do.
Do--------	Kuznetsk, Ala-Tau---------	.0028	1	Sn. Calcareous and carbonaceous (duplicate analyses).	Do.
	Germany:				
Do--------	Tilkerode, Harz-----------	0.3 to 1.3	---	Black shale. Spectrochemical analyses.	Tischendorf (1959).
Do--------	-----do--------------------	0.05 to 0.8	---	Bleached shale. Spectrochemical analyses.	Do.
	Canada:				
Tuff----------	Yellowknife, Northwest Territories.	0.01 to 0.07	---	This fine-grained rock considered a sediment by Boyle (1960). Graphitic, cherty, and calcareous. Analyses by fire assay.	Boyle (1960).
	Southwest Atlantic Ocean area:				
Lutite--------	Argentine Basin-------------	.0106	---	Depth of core below ocean bottom, 1 m.	DeGrazia and Haskin (1964).
Do--------	-----do--------------------	.0031	---	Depth of core below ocean bottom, 3.55 m.	Do.
Do--------	-----do--------------------	.0052	---	Depth of core below ocean bottom, 6.75 m.	Do.
Do--------	-----do--------------------	.0173	---	Depth of core below ocean bottom, 10.45 m.	Do.
	United States:				
Limestone-----	Wyandotte County, Kans----	.0048	---	Paola Limestone Member of Iola Limestone.	Do.

Do--------	Northwest Wyoming---------	.020	2	Harebell Formation (Upper Cretaceous). Replicate analyses by fire assay—atomic absorption.	Antweiler and Love (1967).
Do--------	-----do---------------------	.041	11	Pinyon Conglomerate (Paleocene). Replicate analyses by fire assay—atomic absorption.	Do.
	U.S.S.R.:				
Limestone-----	Southeast Altai-----------	0.0025	---	Sn. Duplicate analyses-----------	Shcherbakov and Perezhogin (1963).
Do--------	Central Altai-------------	.0018	---	S. Duplicate analyses------------	Do.
	England:				
Oolite--------	Cleeve Hill, Cheltenham---	.0023	---	----------------------------------	DeGrazia and Haskin (1964).
	United States:				
Carbonate-----	Florida coast-------------	.0039	---	Holocene-------------------------	Do.
Coral---------	Florida Keys--------------	.0008	---	Holocene-------------------------	Do.
	Southwest Atlantic Ocean area:				
Clay----------	Brazil Basin--------------	.031	---	Depth of core below ocean bottom, 3.43 m. Red.	Do.
Do--------	-----do---------------------	.016	---	Depth of core below ocean bottom, 6.64 m. Red.	Do.
Do--------	-----do---------------------	.0042	---	Depth of core below ocean bottom, 8.87 m. Red.	Do.

Bouska, Havlena, and Sulcek (1963) concluded that gold is bound predominantly to the organic part of coal. The coals they studied were found in fresh-water Cenomanian deposits in Bohemia and Moravia. Deul (1958) found gold in the ash of the humic acid fractions of peat. He did not detect it in plant ashes, in the whole peat ash, or in any other fraction that he separated from the peat. In seven samples, Deul obtained from 1 to 10 ppm gold in the ash of the humic acid extract.

Goldschmidt and Peters (1933) gave the gold content of the ash of coal as 0.5 to 1 ppm and the gold content of clarain, a constituent of coal, as 0.5 ppm (table 6). Trace amounts of gold have been detected in the ash of crude oils from Poland (Kisielow and Gregorowicz, 1955).

Most carbonate rocks contain less gold than sandstones and shales (table 8). The amount of gold reported in carbonate rocks ranges from 0.8 ppb for a coral from the Florida Keys (table 7) to 256 ppb for a limestone from England (table 6). Two limestones from the Harebell Formation in northwest Wyoming had 20 ppb gold, and 11 limestones from the Pinyon Conglomerate in the same area contained 41 ppb gold (Antweiler and Love, 1967). Horn and Adams (1966) estimated the average gold content for carbonate rocks at 1.79 ppb.

Early analyses show that marl from the Keuper and Muschelkalk at Rancourt, France, contains a large amount of gold (ranging from 4 to 36 ppm) and also appreciable silver (table 6). The analyses for gold in gypsum and rock salt (table 6) are suspiciously high. An analysis for gold in anhydrite, however, seems reasonable (Lincoln, 1911). A manganese nodule obtained by the H. M. S. Challenger Expedition was found to have 0.2 ppm gold (Goldschmidt and Peters, 1932).

Of the sedimentary rocks, carbonates probably contain on the average the least gold, and sandstones contain the most (table 9). This conclusion is based on the neutron-activation analyses of Shcherbakov and Perezhogin (1963) and DeGrazia and Haskin (1964) and on the computer-derived geochemical balance of Horn and Adams (1966).

GOLD IN METAMORPHIC ROCKS

Fewer metamorphic rocks have been analyzed for gold than either sedimentary or igneous rocks. The amounts detected range from 0.86 ppb in a marble (DeGrazia and Haskin, 1964; table 11), determined by neutron-activation methods, to 24 ppm in a schist (Levat, cited by Lincoln, 1911; table 10). Estimates of the average amounts of gold in various metamorphic rock types are given in table 12.

One analysis of a mica-garnet gneiss showed 1.8 ppb gold (DeGrazia and Haskin, 1964). Older analyses of gneisses gave 0.830 to 23 ppm gold (table 10).

Slates from gold mining regions in New Zealand and Australia had almost equal average amounts of gold: New Zealand, 111 ppb, and Australia 124 ppb (Don, 1898). Composite samples of slates and argillites from the Yellowknife district, Northwest Territories, Canada, averaged 10 ppb gold (Boyle, 1960). An argillite from Asia contained 8.3 ppb gold (Shcherbakov and Perezhogin, 1963).

Shcherbakov and Perezhogin (1963) detected 1.2 ppb gold in a phyllite. Chlorite schists from widely separated areas analyzed by the same workers contained about the same amount of gold (5.3 and 6.7 ppb). Don (1898) found an average of 89 ppb gold in 79 schists from New Zealand. Shear zones at Yellowknife, Northwest Territories, Canada, yielded 17 ppb gold in chlorite schist and 632 ppb gold in a carbonate-sericite schist (Boyle, 1960). Levat, cited by Lincoln (1911), reported large amounts of gold and silver in hornblende schists (table 10). Paleč and others (1967) analyzed eight schists for gold. The amounts found range from 0.8 to 9 ppb and averaged 3.1 ppb. Hornfels from the Altai in the U.S.S.R. had a gold content ranging from 1.8 to 22.3 ppb.

Both the lowest and the highest gold values given in this report for metamorphic rocks as analyzed by neutron-activation methods are for marble: 0.9 ppb and 22.4 ppb (table 11). One quartzite sample from near Wausau, Wis., contained 7.3 ppb gold, and another from near Baraboo, Wis., contained 2.4 ppb gold (DeGrazia and Haskin, 1964). These values are in the same order of magnitude as most values reported for gold in sandstones in tables 8 and 9.

Table 8.—Average gold content of sedimentary rocks

[Data from table 7. Average Au: First figure in brackets is the number of areas from which the samples were taken, and the second figure is the number of neutron-activation analyses made on these samples]

Rock type	Average Au (ppb)
Sandstone	7.5 [9, 24]
Siltstone	5.8 [2, 3]
Shale	[1]3.9 [5, 8]
Sandstone and shale	[2]3.6 [?, 39]
Lutite	9.0 [1, 4]
Clay	17.1 [2, 5]
Limestone	[3]3.5 [3, 5]
Oolite	2.3 [1, 1]
Carbonate	3.9 [1, 1]
Coral	.8 [1, 1]

[1]Average including lutite and clay, 8.6 ppb.
[2]39 samples from the U.S.S.R.
[3]Average including oolite, carbonate, and coral, 3.0 ppb.

Table 9.—Average gold content of sedimentary rocks, from recent data

[Data in parts per billion]

Rock type	Shcherbakov and Perezhogin (1963); this report, table 7	DeGrazia and Haskin (1964); this report, table 7	Horn and Adams (1966) estimate; this report, text
Sandstone------	3.1	14.4	4.57
Shale----------	2.6	6.0	3.45
Carbonate------	2.2	3.0	1.79

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Table 10.—Analyses of gold in metamorphic rocks made before 1955

[Analyses are probably by fire assay unless specified]

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
	New Zealand:				
Slate----------	Reefton--------------------	0.111	12	Maximum amount, 0.540 ppm--------	Don (1898).
	Australia:				
Do---------	Bendigo, Ballarat, and Gippsland, Victoria.	.124	64	Maximum amount, 1.656 ppm--------	Do.
	French Guiana:				
Schist--------	Roche Creek, Awa----------	2.000	---	Hornblende schist. Silver content, 6.000 ppm.	Levat, E. D., cited by Lincoln (1911).
Do---------	Pichevin Creek, Awa--------	1.500	---	Hornblende schist. Silver content, 2.000 ppm.	Do.
Do---------	Oyapock Creek, Inini-------	24.000	---	Hornblende schist. Silver content, 4.000 ppm. Gold is visible.	Do.
	New Zealand:				
Do---------	Macetown------------------	.089	79	Mica schist. Maximum amount, 2.074 ppm.	Don (1898).
	Canada:				
Gneiss--------	Western Ontario------------	Trace to 0.830	---	Method of analyses unspecified--	Young (1909).
	Brazil:				
Do---------	Southern Minas Gerais------	5.0 to 10.0	---	Granitelle gneiss. Method of analyses specified.	Derby (1903).
	Southern Rhodesia:				
Do---------	Ayrshire mine, Mashonaland.	23.000	---	Visible gold---------------------	Spurr, J. E., cited by Lincoln (1911).
	United States:				
Marble--------	Tuolumne County, Calif----	.005	---	---------------------------------	Wagoner (1901).
	Italy:				
Do---------	Carrara--------------------	.0086	---	---------------------------------	Do.

Table 11.—Analyses of gold in metamorphic rocks made since 1954

[All analyses by neutron activation unless specified]

Rock	Location	Gold content (ppm)	Number of samples	Remarks	Reference
Argillite	U.S.S.R.: Southeast Altai	0.0083	1	Duplicate analyses	Shcherbakov and Perezhogin (1963).
Argillites and slates.	Canada: Yellowknife, Northwest Territories.	.01	---	Analyses by fire assay	Boyle (1960).
Phyllite	U.S.S.R.: Yenisei Range	.0012	1	Duplicate analyses	Shcherbakov and Perezhogin (1963).
Schist	Canada: Yellowknife, Northwest Territories.	.017	---	Average of chlorite-schist phase of shear zones. Analyses by fire assay.	Boyle (1960).
Do	do	.632	---	Average of carbonate-sericite schist phase of shear zones. Analyses by fire assay.	Do.
Do	do	.01	---	Knotted quartz-mica schist. Analyses by fire assay.	Do.
Do	U.S.S.R.: Northeast Altai	.0053	1	Chlorite schists (duplicate analyses).	Shcherbakov and Perezhogin (1963).
Do	Kuznetsk, Ala-Tau	.0067	1	do	Do.
Do	Sultanuizdag (Uzbekistan)	.0031	8	Schists with two or more of the following minerals: quartz, mica, chlorite, plagioclase, and unspecified carbonate mineral(s). Range, 0.0008 to 0.009 ppm Au.	Paleĭ, Murovtsev, and Borozenets (1967).
Gneiss	United States: New York, N.Y	.0018	---	Mica-garnet gneiss	DeGrazia and Haskin (1964).
Hornfels	U.S.S.R.: Central Altai	.0070	1	Duplicate analyses	Shcherbakov and Perezhogin (1963).
Do	do	.0223	1	Amphibole hornfels formed from basalt (duplicate analyses).	Do.
Do	Southeast Altai	.0018	1	Formed from shale (duplicate analyses).	Do.
Do	do	.0027	1	do	Do.
Quartzite	United States: Rib Mountain, Wausau, Wis.	.0073	---	---	DeGrazia and Haskin (1964).
Do	Devil's Lake, Baraboo, Wis.	.0024	---	---	Do.
Marble	United States: Rutland (Belden's Farm), Vt.	.00086	---	---	Do.

	U.S.S.R.:				
Do--------	Central Altai-------------	.0053	1	Duplicate analyses---------------	Shcherbakov and Perezhogin (1963).
Do--------	Sultanuizdag (Uzbekistan)-	.0224	1	Triplicate analyses. Range, 0.0082 to 0.0370 ppm Au.	Paleĭ, Murovtsev, and Borozenets (1967).
	Canada:				
Amphibolite---	Yellowknife, Northwest Territories.	.01	---	Analysis by fire assay-----------	Boyle (1960).
Do--------	-----do---------------------	.008	---	Analyses by fire assay. Epidote amphibolite.	Do.
	South Africa:				
Eclogite------	Orange Free State (Roberts Victor mine).	.0022	2	Xenolith in kimberlite. Iridium averages 0.0009 ppm.	Baedecker (1967).

Table 12.—Average gold content of metamorphic rocks

[Data from table 11. Average Au: First figure in brackets is the number of areas from which the samples were taken, and the second figure is the number of neutron-activation analyses made on these samples]

Rock type	Average Au (ppb)
Argillite	8.3 [1, 2]
Phyllite	1.2 [1, 2]
Schist	5.0 [3, 12]
Gneiss	1.8 [1, 1]
Hornfels	8.4 [2, 8]
Quartzite	4.8 [2, 2]
Marble	[1]3.1 [2, 3]
Eclogite	2.2 [1, 2]

[1]If the anomalous value of 22.4 ppb Au (table 11) is included in the calculations, the gold content becomes 9.6 ppb.

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