UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PALLADIUM, PLATINUM, AND RHODIUM CONCENTRATIONS IN MAFIC AND ULTRAMAFIC ROCKS FROM THE KIZILDAG AND GULEMAN AREAS, TURKEY, AND THE FARYAB AND ESFANDAGHEH-ABDASHT AREAS, IRAN[1]

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

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ABSTRACT

The Kizildağ and Guleman areas, Turkey, and the Faryab and Esfandagheh-Abdasht areas, Iran, have produced chromite from ophiolite complexes consisting of harzburgite tectonite, dunite tectonite containing chromitite, pyroxenite, wehrlite, and gabbro. Forty-six samples from these complexes were analyzed in order to investigate the possibility of platinum-group metals being present that could be produced as byproducts. The results, however, indicate concentrations of palladium, platinum, and rhodium ranging up to 46 ppb (parts per billion), 55 ppb, and 24 ppb, respectively. The concentration levels and ratios of these metals are similar to other alpine ultramafic bodies that have been analyzed by modern analytical techniques. Ten samples from massive sulfide deposits in the Günes and Ergani-Maden areas, Turkey, and the Sheikh Ali mine, Iran, were analyzed also. The results of the analysis suggests a low potential for byproduct palladium, platinum, and rhodium production in these ophiolite-associated massive sulfide deposits.

The four ultramafic and mafic areas in Turkey and Iran under consideration have, and are, producing in 1978 chromite from podiform chromitites in alpine-type complexes. Because of the known association of chromitites and platinum-group metals, a collection of chromitites was made to check their palladium, platinum, and rhodium content to determine if economic concentrations might exist. Also, inasmuch as such rocks are thought to represent parts of the oceanic crust and upper mantle, data on platinum-group elements from these rocks can provide information to design geochemical models for the distribution of these elements. During the field excursions of the CENTO Working Group on Volcanic and Intrusive Rocks and Their Associated Ore Deposits, the Kizildağ and Günes areas, Turkey, were sampled in 1974 and the Guleman area, Turkey; Faryab and Esfandagheh-Abdasht areas, Iran, were sampled in 1975. In addition, samples of massive sulfide ores from the Ergani-Maden area, Turkey, were also collected for analysis, and the results included here.

In this report the geologic framework of these areas is briefly examined as a background for interpreting the concentrations of palladium, platinum, and rhodium in the chromitites and ultramafic and mafic rocks. Comparisons of these analyses with analyses from other areas containing similar rocks show few differences in concentration or proportions of these three platinum-group metals.

GEOLOGIC SETTING OF AREAS

The locations of the areas visited and sampled in Turkey and Iran are shown on figure 1. The general geologic setting of each area will be discussed in the following order: Kizildağ, Günes, Guleman, and Ergani-Maden areas, Turkey, and Faryab and Esfandagheh-Abdasht areas, Iran. No attempt is made to discuss the geology of each area in detail, and only those major facets related to interpreting the platinum-group metal analyses are included.

Kizildağ Area, Turkey

The geology and petrology of the ophiolite suite of mafic and ultramafic rocks of the Kizildağ area, south of Iskenderun, Turkey, have been described by Dubertret (1953), Parrot (1973), and Aslaner (1973). Figure 2 shows the distribution of mafic and ultramafic rocks in the ophiolite complex and the location of samples analyzed for palladium, platinum, and rhodium--more detailed location information is given in table 1 where place names and deposit numbers refer to those used by Aslaner (1973).

The Kizildağ complex, which was probably emplaced during the Campanian, consists of dunite and harzburgite tectonites stratigraphically overlain by cumulate ultramafic rocks, including feldspar peridotites. The latter rocks are interlayered with gabbros which in sequence are followed by a layered gabbro unit. Overlying, and in part cutting, the layered gabbro sequence is a sheeted dike complex overlain by pillow basalts. These relations are best exposed in, and described from a coastal section examined by Parrot (1973). More than 100 podiform chromitite occurrences and some larger podiform deposits such as the Asagi Zorkum, reported to have produced 11,000 tonnes of chromite, occur in the dunite and harzburgite tectonites. Aslaner (1973) gives the location of most of the chromitite occurrences and describes them as lenses composed of concentrations of disseminated and massive chromite or as nodular chromite. The chromitites are generally deformed, as are the enclosing ultramafic rocks.

The Günes Area, Turkey

In the Günes area (fig. 1), a northeast-striking belt of peridotite is intruded by a gabbro-syenite complex, which has metamorphosed the peridotite and which contains xenoliths of peridotite. Associated with the peridotite are gabbros which do not contain sulfides and are older than the gabbro-syenite complex which does contain the sulfides (fig. 3). Pyrrhotite-chalcopyrite sulfide veins and veinlets are developed in the xenoliths, and country rocks of the gabbro-syenite complex. This type of mineralization was examined at Agpinar, Karapinar and Handeresi. Samples from Karapinar and Handeresi were analyzed (table 1). Metag (1972) has studied the geology and mineralization of the area.

The Guleman Area, Turkey

Although dunite and harzburgite with tectonite fabrics are the most abundant rock types in the ultramafic and mafic mass exposed in the Guleman area, Turkey, rocks with cumulate textures consisting of interlayered dunite, wehrlite, and pyroxenite with and layered and massive gabbros are present in the southern and the western part of the complex. The chromitite deposits in

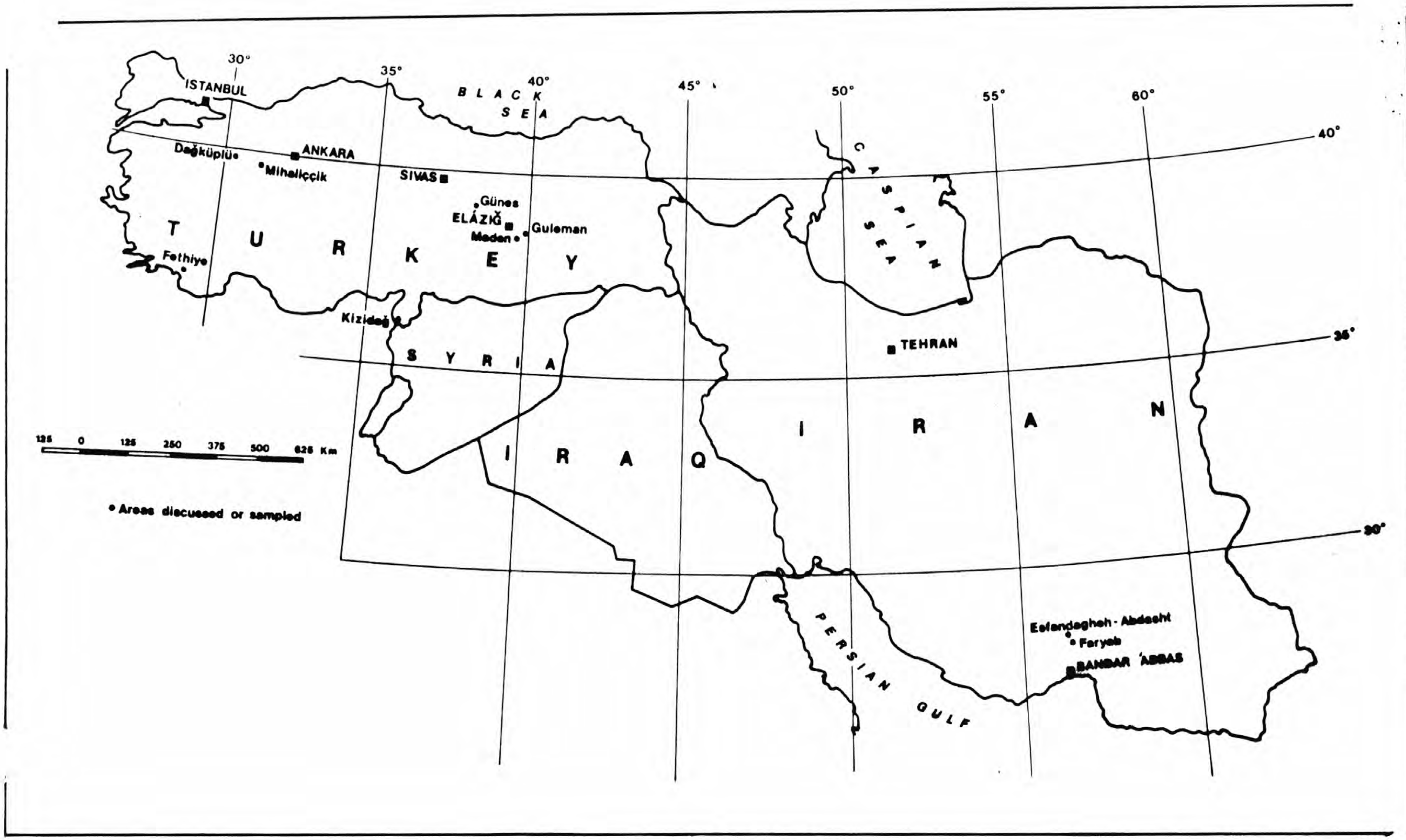

Figure 1.--Map showing location of the areas sampled in Turkey and Iran.

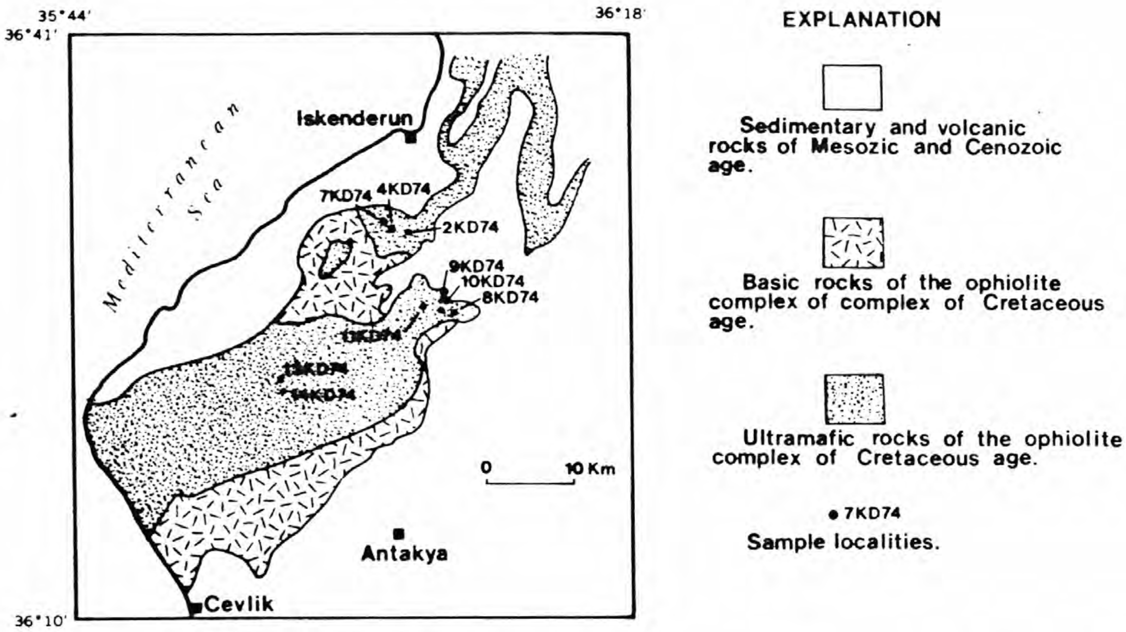

Figure 2.--Geologic sketch map of the Kizildağ area, Turkey, modified after Parrot (1973) showing the location of analyzed samples.

Table 1.--*Analyses, sample descriptions, and location of palladium, platinum, and rhodium from ophiolite suites in Turkey and Iran*

[Rock classification after Streckeisen (1976). < = not determined at that level, tr = trace. In calculation of sums, averages, and ratios Pd=tr, Pt=tr, and Rh=tr were assigned values of 2, 7, and 3 parts per billion, respectively. Analysts: Joseph Haffty and A. W. Hauber]

Sample number	Pd	Pt	Rh	ΣPd+Pt+Rh	Pt/Pt+Pd	Sample description and location
	(parts per billion)					
KIZILDAǦ AREA, TURKEY						
2KD74	<4	<10	<5	<		Harzburgite, road to Soǧukoluk
4KD74	<4	<10	<5	<		Melanogabbro, near Cizmeli Mountain
7KD74	<4	<10	<5	<		Leucogabbro, near Cizmeli
8KD74	4	<10	10	14		Massive chromitite, prospect pit No. 89
9KD74	7	<10	22	29		Nodular and massive chromitite, prospect pit No. 97A
10KD74	<4	<10	17	17		Nodular chromitite, prospect pit No. 97A
11KD74	<4	<10	22	22		Nodular chromitite, prospect pit No. 329
13KD74	<4	<10	18	18		Chromitite, prospect pit No. 576 Asagi Zorkun
14KD74	9	10	tr	22	52.6	Chromitite, prospect pit No. 577, Asagi Zorkun
GÜNES AREA, TURKEY						
15KD74	180	34	<20	214	15.9	Sulfide ore Karapinar tunnel (pyrite, chalcopyrite, arsenopyrite)
16KD74	6	<10	<5	6		Sulfide ore (pyrrhotite, pentlandite gersdoffite, niccolite, cubanite, chalcopyrite) dump samples from Handeresi nickel prospect
GULEMAN AREA, TURKEY						
1GU75	<4	<10	19	19		Chromitite, Lasir Ustu mine
2GU75	6	<10	15	21		Chromitite, Tepebaşi
3GU75	<4	<10	13	13		Chromitite, Uzundamar mine
4GU75	<4	20	12	32		Chromitite, Ayidamar prospect
5GU75	8	12	<5	20	60.0	Peridotite Ayidamar prospect
6GU75	7	<10	7	14		Chromitite, Ayidamar horizon
7GU75	<4	<10	12	12		Chromitite, Kef Dagi open pit
8GU75	<4	<10	10	10		Chromitite, Goladan Chrome mine
9GU75	<4	<10	13	13		Chromitite, near Kelusktepe pit
10GU75	<4	<10	11	11		Chromitite Kapin Chrome prospect
11GU75	9	22	18	49	71.0	Chromitite, Adit above Kapin Chrome prospect
12GU75	<4	16	22	38		Chromitite, Upper Kapin-beneklidamar
ERGANI-MADEN AREA, TURKEY						
13GU75	<4	<10	<5			Massive sulfide (pyrite, chalcopyrite) ore, Hacan area
14GU75	<4	<10	<5			Andesitic dike, Hacan area
15GU75	7	<10	<5	7		Massive sulfide (pyrite chalcopyrite) ore Kisa bekir area
16GU75	<4	<10	<5			Massive sulfide (pyrite chalcopyrite) ore, Anayatak open-pit
17GU75	<4	<10	<5			Massive sulfide (magnetite, pyrrhotite, chalcopyrite) ore, Anayatak open-pit
[1]18GU75	<20	<50	<25			Banded massive sulfide ore, Weiss open-pit
19GU75	tr	<10	<5	2		Massive sulfide (pyrite, chalcopyrite) ore, Mizirtepe area
FARYAB AREA, IRAN						
1FY75	8	19	18	45	70.4	Chromitite, Dovis pit
2FY75	46	55	24	125	54.5	Chromitite, lower Dovis pit
3FY75	tr	tr	<5	9		Dunite, lower Dovis pit
4FY75	<4	<10	18	18		Chromitite, Shahin pit
5FY75	<4	<10	11	11		Layered chromitite, Yasamin pit
6FY75	<4	23	24	47		Massive chromitite, Yasamin pit
7FY75	<4	<10	20	20		Friable chromitite, Reza mine area
8FY75	<4	<10	9	9		Chromitite, Amin mine
9FY75	tr	<10	18	20		Disseminated chromitite, Shahriar pit
10FY75	<4	<10	<5	<		Peridotite, Shahriar area
ESFANDAGHEH-ABDASHT AREA, IRAN						
1ES75	8	tr	<5	15	46.7	Peridotite
2ES75	<4	<10	18	18		Chromitite
3ES75	<4	<10	<5	<		Dunite
4ES75	<4	<10	10	10		Layered chromitite, Sikhoran mine
5ES75	26	27	10	63	50.9	Nodular chromitite, Sikhoran mine
6ES75	18	14	<5	32	43.8	Pyroxenite
7ES75	<4	<10	<5	<		Clinopyroxenite
8ES75	tr	10	<5	12	83.3	Troctolite
9ES75	<4	<10	<5	<		Dunite with orthopyroxene oikiocrysts, probably cumulate
10ES75	33	17	<5	50	34.0	Pyroxenite, fine-grained
11ES75	<4	<10	<5	<		Pyroxenite, coarse-grained
12ES75	<4	<10	<5	<		Layered gabbro
13ES75	<4	<10	6	6		Chromitite, Suluiyeh Chrome mine
14ES75	<4	<10	6	6		Chromitite, Soghan mine
15ES75	<4	<10	tr	3		Chromitite, Abdasht mine
16ES75	<4	<10	<5	<		Massive sulfide, pyrite-chalcopyrite, Sheikh Ali mine, 24 km south of Abdasht

[1]The higher limits of determination are due to the dilution factor.

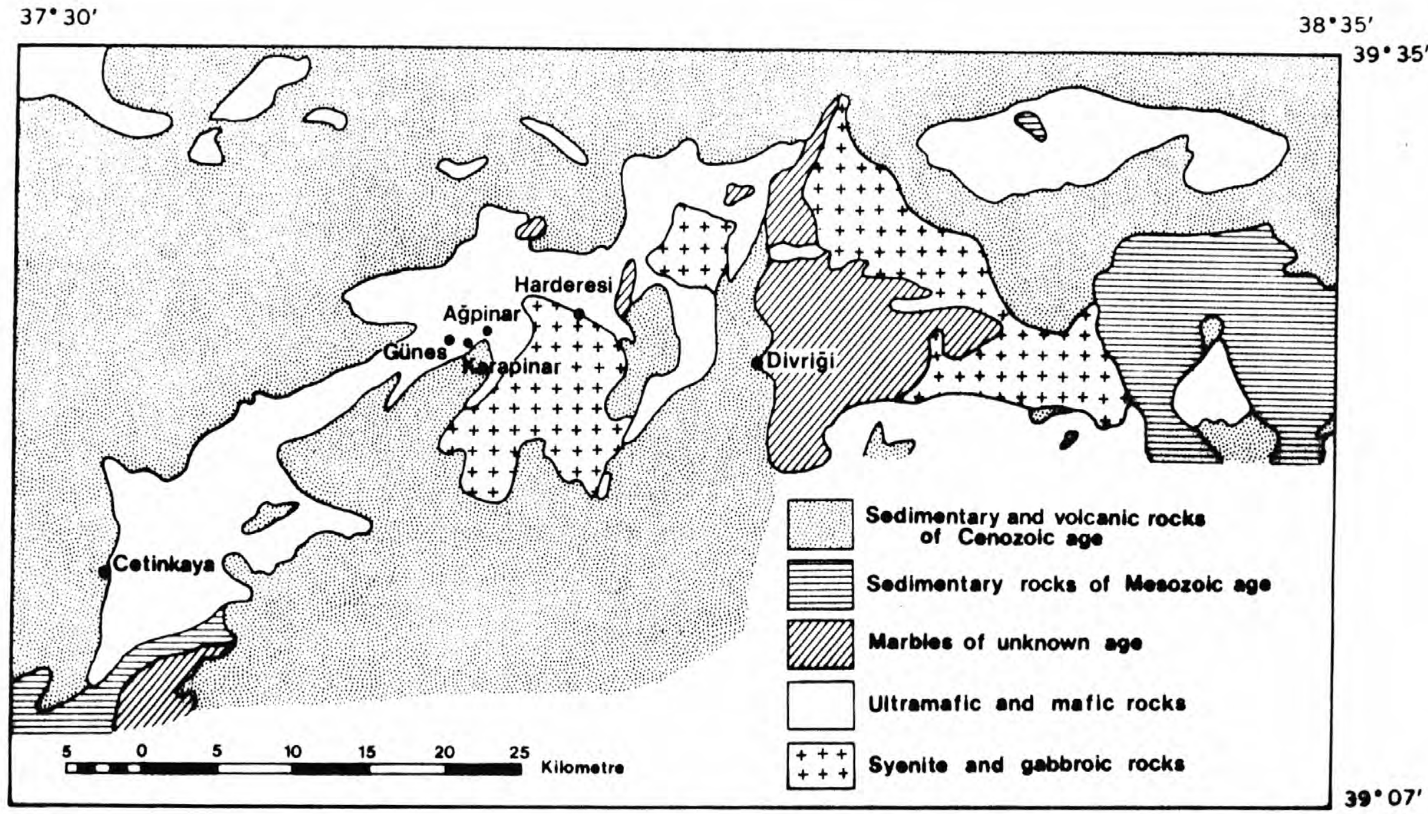

Figure 3.--Geologic setting of the Günes area, Turkey, modified from the Geological map of Turkey (1961).

this district have been an important source of high-chromium metallurgical grade chromite. Some of the deposits are tabular-shaped lenses up to 1.5 km in strike length, over 200 m in dip direction, and 4 m in thickness (Petrascheck, 1958); others are podiform in shape. Wijkerslooth (1947), Kovenko (1949), Helke (1961, 1962), Thayer (1969), Engin and Sumer (1978), Balci, Durak, Açan, and Pinar (1978), Erden, Ortalan, and Seçer (1978), and Izmin and Koç (1978) have described various aspects of the areal geology and details of the chromite deposits.

Figure 4 shows a sketch map of part of the area and the location of samples analyzed for palladium, platinum, and rhodium; names of the chromitite deposits are given in table 1 and may be correlated with maps of Helke (1961).

The Ergani-Maden Area, Turkey

Copper has been mined in this area for over 4,000 years from massive sulfide deposits related to volcanic rocks of an ophiolitic assemblage, which is believed to be part of a melange. Griffitts, Albers, and Öner (1972) and Bamba (1976), describe the geology, petrology, and mineralogy of these deposits. Because these massive sulfide deposits are associated with the other ophiolitic rocks, some samples were collected to test for platinum-group metal contents. The individual localities sampled are given in table 1.

Other Areas, Turkey

Apart from those areas examined in this report, Baştürk (1974) analyzed samples of pyroxenite, peridotite, dunite, and serpentinites from other ultramafic rock complexes located near Dagküplü, Mihaliççik (Eskişehir), Fethiye (Mugla), and Kizildağ (Antakya). These areas are located on figure 1. Baştürk (1974) analyzed only for platinum and his results range from 0.5 to 58.2 ppb for 122 analyses of 55 rocks.

Faryab Area, Iran

The Faryab area, northeast of Bandar Abbas, Iran, contains chromitite deposits in a body of harzburgite and dunite with tectonite fabrics. The body of ultramafic rock is elliptical in plan, with a long axis of about 7-8 km trending northwest and a short axis of about 4-5 km (see British Petroleum Company, LTD., 1963). The chromitite deposits are distributed from approximately northwest to southeast in the mass and in order are named Dovis, Shahin, Yasamin, Amin, Shahriar, and Reza mines.

Esfandagheh-Abdasht Area, Iran

The ultramafic and mafic rocks in Esfandagheh-Abdasht area are situated at the convergence of two, complex, major structural units, the Sanandaj-Sirjan and the Zagros tectonic provinces (Sabzehei, 1974). These stratigraphic and structural complexities are not shown on figure 5, a sketch map showing locations of samples analyzed for palladium, platinum, and rhodium. However, Sabzehei (1974) prepared a more detailed geological map than that in figure 5 and discusses the geological complexities of the area.

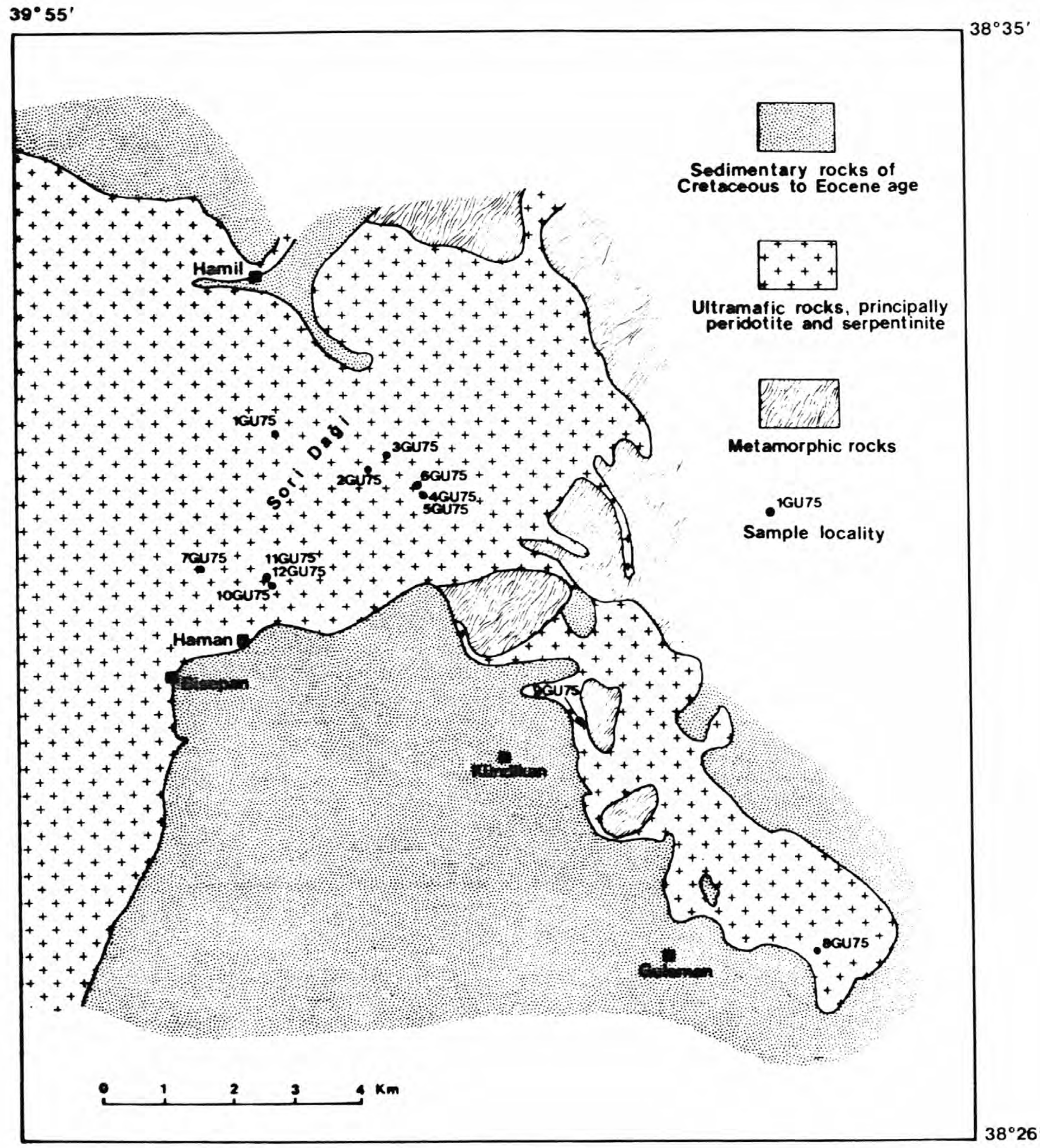

Figure 4.--Geologic sketch map of the Guleman modified after Helke (1961).

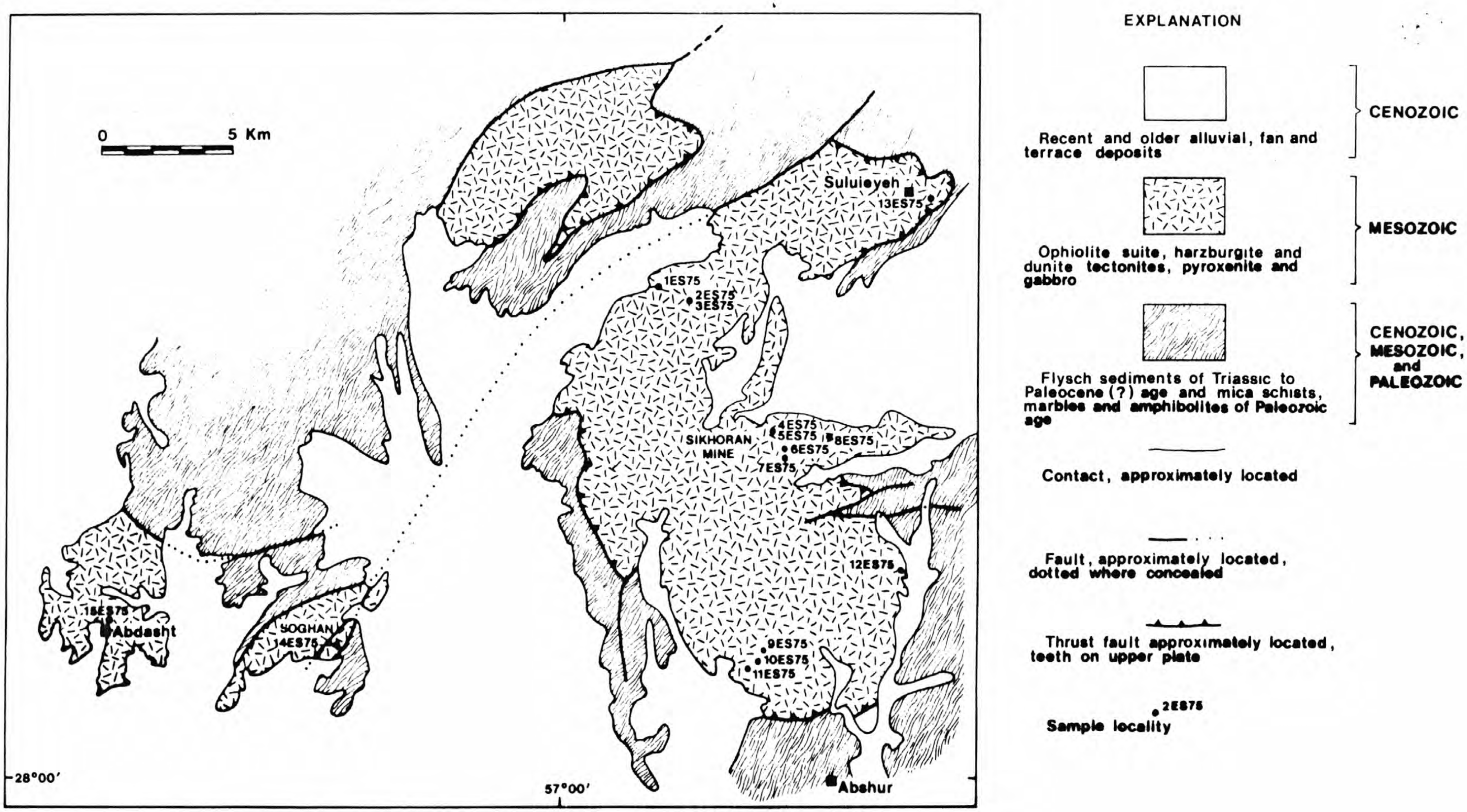

Figure 5.--Simplified geologic sketch map of the Esfandagheh-Abdasht area, Iran, showing location of analyzed samples. Modified after Sabzehie (1974).

Included in the ophiolite suite (fig. 5) is a variety of ultramafic and mafic rocks. The relations between the rock types, especially field relations, have not been established in detail. Harzburgite and dunite tectonites that contain the chromitite deposits are the most abundant rock types. Some areas of tectonite, for example-near the locality for 1ES75, appear to have a metamorphic event superimposed on them, because the mineral assemblages present in the rocks include antigorite, talc, anthophyllite, and olivine. Other areas are highly serpentinized, such as the area around Suluieyeh. Interlayered dunite and pyroxenites are also present, and near locality 9ES75, the dunite contains poikilitic orthopyroxenes which suggest typical cumulate textures. Layered gabbros appear to lie stratigraphically above the dunite-pyroxenite sequences and are present around locality 12ES75. Around, and south of, locality 10ES75, the ophiolite sequence contains crosscutting intrusive gabbro and hornblende gabbro, which locally display comb layering. The intrusive gabbros contain inclusions of the layered gabbro and amphibolite. This gabbro is in turn cut by quartz-plagioclase dikes.

To the south of the area shown on figure 5 is a sequence of Upper Cretaceous-to-Paleocene rocks of the Colored Melange Zone (Sabzehei, 1974). They contain basic pillow lavas, pelagic limestone, calcareous mudstone, and some radiolarite. Within this sequence the mined-out Sheikh Ali massive sulfide body occurred. A piece of ore found in dump materials was analyzed.

PALLADIUM, PLATINUM, AND RHODIUM ANALYSIS

The analyses of rocks from different areas given in table 1 were performed by the method of Haffty and Riley (1968). Those samples analyzed from massive sulfide deposits contain spotty but uniformly low to below-detectable concentrations of palladium, and platinum and no detectable rhodium. Therefore most of this discussion focuses on the ophiolitic assemblages. Sixty-seven percent of the ultramafic and mafic samples contain detectable rhodium (results listed as tr or >5 ppb), 35 percent contain detectable palladium (results listed as tr or >4 ppb), and 30 percent contain detectable platinum (results listed as tr or >10 ppb). In the ultramafic and mafic samples, palladium ranges up to 46 ppb and averages 12 ppb, platinum up to 55 ppb and averages 19 ppb, and rhodium up to 24 ppb and averages 14 ppb. The average Pt/Pt+Pd x100 ratio is 54.5 and ranges between 34 and 83. Significant characteristics of the distribution of palladium, platinum, and rhodium in the various rock types of the ultramafic and mafic complexes include (1) higher concentrations of rhodium found in the chromitites, (2) no dunites, peridotites, pyroxenites, or gabbros containing detectable rhodium, and (3) no anomalously high concentrations of the three platinum-group elements occurring in any rock type except the sulfide-bearing samples (table 1).

Average palladium, platinum, and rhodium concentrations in the mafic and ultramafic rocks from Turkey and Iran appear similar to those in rocks from other alpine-type ultramafic complexes (table 2). Baştürk's (1974) data on platinum are summarized as averages of each of the rock types in the four different areas for comparison with the results of this report. The small number of samples from the four areas sampled in this report makes detailed comparisons invalid; nevertheless, the average rhodium content of the chromitites varies over a narrow range, which is comparable to the average range of other alpine complexes (see Page and others, 1978). Baştürk's (1974)

Table 2.--*Comparison of average palladium, platinum, and rhodium contents between areas in Turkey and Iran with an average from other alpine-type ultramafic localities*

[Numbers in parentheses refer to number of samples included in averages; weighted average from Page and others, 1978]

Description	Location	Average Pd	Average Pt	Average Rh	Sum of averages	Pt/Pt+Pdx100
			(in ppb)			
Chromitite	Faryab, Iran	15 (4)	26 (4)	18 (8)	59	63.4
	Esfandagheh-Abdasht, Iran	26 (1)	27 (1)	9 (6)	62	50.9
	Kizildağ, Turkey	7 (3)	10 (1)	14 (6)	31	58.8
	Guleman, Turkey	7 (3)	19 (3)	14(11)	40	73.1
	Average, other alpine-type chromitites	11(16)	22 (14)	17(50)	50	66.7
Dunite, peridotite and serpentinized equivalent	Faryab, Iran	<4	<10	<5	--	--
	Esfandagheh-Abdasht, Iran	8 (1)	7 (1)	<5	15	46.7
	Kizildağ, Turkey	<4	<10	<5	--	--
	Guleman, Turkey	8 (1)	12 (1)	<5	20	60.0
	Mihaliççik, Turkey[1]					
	peridotite	--	12.2(10)	--	--	--
	dunite	--	10.6 (7)	--	--	--
	Fethiye, Turkey[1]					
	peridotite	--	9.7(10)	--	--	--
	dunite	--	9.7 (8)	--	--	--
	Dagkulplu, Turkey[1]					
	peridotite	--	15.1 (4)	--	--	--
	dunite	--	17.9 (1)	--	--	--
	serpentinite	--	3.2 (1)	--	--	--
	Kizildağ, Turkey[1]					
	dunite	--	13 (1)	--	--	--
	serpentinite	--	7.6 (2)	--	--	--
	Average, other alpine-type ultramafic rocks	29(75)	28 (54)	2(10)	59	49.1
Pyroxenite and gabbroic rocks	Faryab, Iran	<4	<10	<5	--	--
	Esfandagheh-Abdasht, Iran	18 (3)	14 (3)	<5	32	43.8
	Kizildağ, Turkey	<4	<10	<5	--	--
	Guleman, Turkey	<4	<10	<5	--	--
	Mahaliççik, Turkey[1]	--	10.8 (5)	--	--	--
	Fethiye, Turkey[1]	--	16.8 (1)	--	--	--
	Dagkulplu, Turkey[1]	--	40.6 (3)	--	--	--
	Kizildağ, Turkey[1]	--	10.2 (2)	--	--	--
	Average, other alpine-type mafic rocks	36 (7)	43 (8)	<5	34	54.4

[1]Average values from Baştürk (1974, table xxiv, p. 189).

average contents for platinum are well within the ranges of averages found in this report. In other alpine complexes, for example southwestern Oregon (Page and others, 1975), some chromitite samples contain 10-20 times higher concentrations of platinum-group metals than the average chromitite; these levels of concentrations were not found in samples from Turkey and Iran, which may be only an artifact of the number of samples analyzed. Proportions of the three platinum-group metals in the dunite, peridotite, and serpentinized equivalent samples, and in the pyroxenite and gabbroic rocks are similar to other alpine-type complexes (fig. 6A). However, the proportions of the three metals are different from stratiform complexes, as represented by the Stillwater Complex, in not having a higher fraction of rhodium. Average proportions of the three metals for the chromitite samples (fig. 6B) indicate that each area appears distinguishable on the basis of palladium, platinum, and rhodium ratios and that these ratios overlap the range for chromitites from the Stillwater Complex.

INTERPRETATION AND CONCLUSIONS

The limited number of analyzed samples from the Faryab, Esfandagheh-Abdasht, Kizildağ, and Guleman areas of Iran and Turkey suggest that the potential for recovering byproduct palladium, platinum, and rhodium from chromite mining in these areas is low. However, the occurrences of platinum group metals associated with the gabbro-syenite intrusive rocks in the Günes area, Turkey, warrant further sampling and analysis. The massive sulfide deposits in the Ergani-Maden area, Turkey, and the Sheikh Ali mine, Iran, apparently have a low potential for byproduct palladium, platinum, and rhodium based on the few samples analyzed in our study.

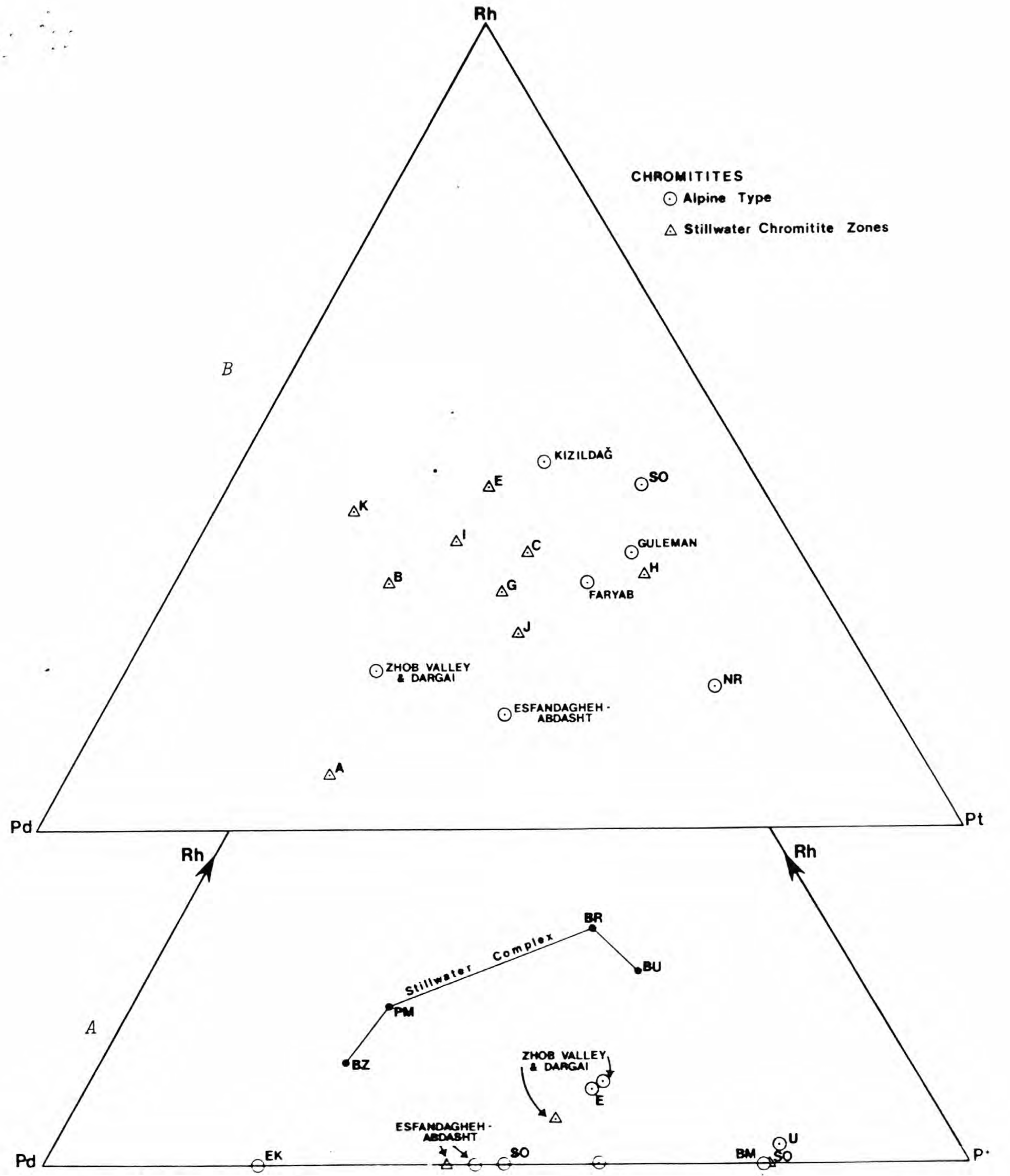

Figure 6.--Average proportions of palladium, platinum, and rhodium in rocks from Turkey and Iran compared with other alpine-type and stratifrom complexes. *A*, Mafic and ultrmafic rocks. *B*, Mafic and ultramafic rocks. BZ, norites, gabbros, and cumulates from the Basal zone; PM, silicate cumulates from the Peridotite member of the Ultramafic zone; BR, cumulates from the Bronzitite member of the Ultramafic zone; BU, banded and upper zone cumulates; A through J, Chromitite zones Stillwater Complex, Montana. EK, Eklutna area, Alaska; BM, Burro Mountain area, California; SO, Medford quadrangle, southwestern Oregon; E, serpentinized ultramafic rocks, Eagle quadrangle, Alaska; NR, New Idria and Red Mountain area, California; U, dunite and peridotite, Urals, Russia.

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