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ZONING IN Os-Ir ALLOYS AND THE RELATION OF THE GEOLOGICAL AND TECTONIC ENVIRONMENT OF THE SOURCE ROCKS TO THE BULK Pt: Pt + Ir + Os RATIO FOR PLACERS

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ABSTRACT

Osmiridium samples from Tasmania have been found to include iridosmine, rutheniridosmine, osmiridium, ruthenosmiridium, and irarsite. Compositional zoning was determined in three of the fifteen Tasmanian grains and in nine of the thirty grains from British Columbia. The zoning in the Os-Ir alloys is considered to be the result of non-equilibration during primary crystallization rather than "element agglutination".

Alluvial and eluvial platinum-group alloy occurrences from pre-Late Tertiary to the Precambrian are reviewed in the context of their geological and tectonic settings. It is shown that assay data for these fall into two groups: those with either low or high Pt×100/Pt+Ir+Os. The latter are represented by the concentrically zoned intrusions of the Alaskan-type (Goodnews Bay District, Tulameen, Urals, Yubdo, and Colombia). On the other hand, deposits with a low ratio are related to less-fractionated source rocks emplaced as "cold" large sheets of the Alpine-type such as those in New Guinea, Atlin, and Tasmania. The much older Witwatersrand Os-Ir alloys also may have originated from similar rock units emplaced within an original "primitive ultramafic unit".

INTRODUCTION

Soon after publication of a paper on Os, Ir, and Ru alloys from world-wide occurrences (Harris & Cabri 1973) we received some "osmiridium" samples from Tasmania. We were interested in analyzing these quantitatively in order to determine whether these grains, from yet another occurrence, confirmed our earlier findings.

This paper reports the results of a study of the Tasmanian grains and a very detailed reanalysis of thirty grains from British Columbia whose compositions were previously published. These latter grains were checked for homogeneity in greater detail than is usual in order to ascertain the presence and nature of any zoning. In addition, the first occurrence of the mineral ruthenosmiridium is reported.

These mineralogical findings are discussed in relation to what is known of the mineralogy and geology of other sources of Os-Ir and platinum alloys.

MATERIALS, ORIGIN, AND METHODS OF INVESTIGATION

The samples of natural Os-Ir-Ru alloys, both labelled "osmiridium", came from two areas identified as "19 Mile Creek, Bald Hill", from the Heazlewood district of northwestern Tasmania and as "Adamsfield", presumably from the Adamsfield district of southwestern Tasmania. The exact localities of the British Columbia nuggets have been detailed previously (Harris & Cabri 1973).

The exact locations of the Tasmanian samples, *i.e.* claims or workings, is unknown. The original "Bald Hill" has recently been renamed Caudrys Hill and the general area which includes the "Bald Hill Osmiridium Field" is now referred to as the Heazlewood River Complex (M. Rubenach pers. comm. 1975). Rubenach (1974a, b) considers the Heazlewood River Complex to consist of rocks similar to the nearby ophiolite Serpentine Hill Complex which was emplaced as a thrust slice before the Middle Cambrian. Some of the Nineteen Mile Creek dunites have been interpreted as deformed cummulates but the possibility that some are residual upper mantle rocks cannot be excluded (Rubenach pers. comm. 1975). Rubenach (pers. comm. 1975) also believes that the distribution of old workings shows that the alluvial osmiridium was derived entirely from the Nineteen Mile Creek dunite and from the highly serpentinized "undifferentiated ultramafics" which occur 1 km northeast of the summit of Caudrys Hill. "These bedrock sources, however, were too low-grade for successful mining, except where they were so greatly weathered that they would be mined as detrital deposits" (Mertie 1969, p. 70). Most of the "osmiridium" was recovered from placers, including eluvial and stream placers buried by Tertiary lava flows, and from weathered serpentinite atop Bald Hill. "The osmiridium ranged in size from very fine grains up to nuggets that weighed several ounces, but little or no platinum was commonly found. The heavy minerals recovered with the osmiridium included gold, gold alloyed with platinum, chromite, picotite, magnetite, pyrrhotite, and pyrite" (Mertie 1969, p. 70).

The Adamsfield "osmiridium" deposits were discovered in 1925 and soon superseded in importance the Heazlewood district deposits. These deposits yielded 12,500 ounces of "osmiridium" during 1925-1934 (Mertie 1969). Brown (1972) studied the area and the following is abstracted from a summary he recently prepared for us. An Alpine-type ultramafic body, consisting of serpentinite sheaths around partly serpentinized and fresh peridotitic rocks (massive dunite and pyroxenite, and layered dunite, olivine pyroxenite, and pyroxenite), occupied the core of a meridional anticline which crops out along an arcuate belt 16 km by 2 km. Contact with the enclosing Cambrian and Ordovician sedimentary rocks is everywhere faulted and no metamorphic effects attributable to the ultramafic rocks have so far been observed. Disseminated primary "osmiridium", chromite and secondary magnetite are present in, and associated with, the Adamsfield ultramafic rocks. "Osmiridium" and chromite are found in Upper Cambrian sedimentary rocks unconformably overlying the ultramafic mass and in Holocene alluvial sand and gravel deposits. The "osmiridium" normally occurred as irregular grains less than 1 mm across but nuggets weighing nearly 2 ounces have been found (Nye 1929). Nye also reported occasional "osmiridium" grains in serpentinite but these were rare and no "osmiridium" has so far been found in any primary peridotite.

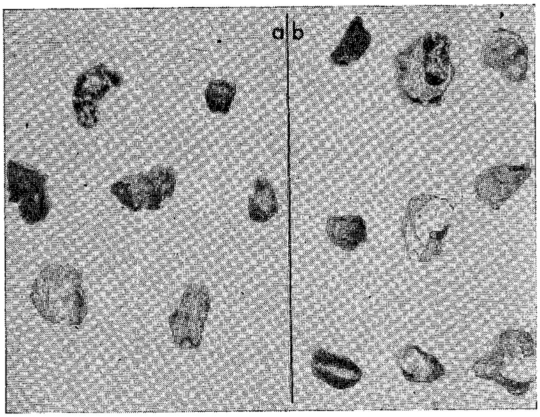
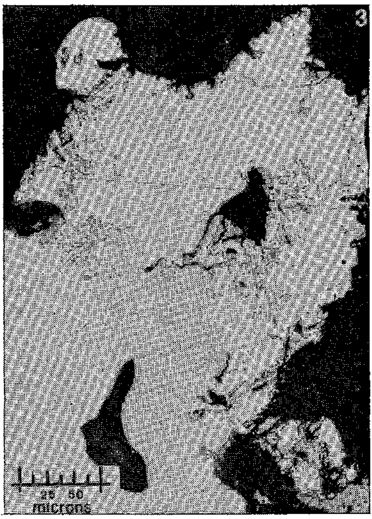


FIG. 1. (a) "Osmiridium" grains from Adamsfield. The first grain on the left in the middle row is Fe. (b) "Osmiridium" grains from 19 Mile Creek, Bald Hill, Heazlewood. Middle grain of first vertical row in (b) is 1 mm in diameter.



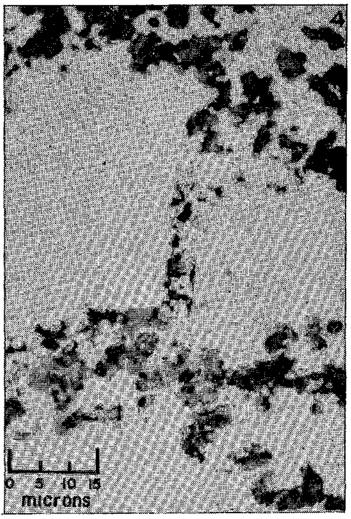


FIG. 2. Veins of irarsite (dark grey) in osmiridium. The top right hand corner is iridosmine with no inclusions of irarsite. Grain 4, Heazlewood.

FIG. 3. Eutectoid of irarsite (dark grey) in osmiridium (white) which is in contact with iridosmine (pale grey). Grain 9, Heazlewood.

FIG. 4. A complex intergrowth of irarsite (dark grey) with osmiridium (white) and iridosmine (pale grey). The larger iridosmine areas are parts of lath-like grains set in this intergrowth matrix. Black areas are pits. Grain 6, Heazlewood.

Seven grains from Adamsfield and nine from 19 Mile Creek were examined with a binocular microscope prior to mounting in araldite (Fig. 1a, b). The grains ranged in diameter from 0.5 to 1.5 mm and were mostly sub-angular; a few were sub-angular to rounded or were partly flattened. Most were silvery to greyish-white in colour and all but one were non-magnetic — the magnetic grain proved to be tramp iron.

The individual nuggets were mounted in cold-setting araldite and polished. In polished section the "osmiridium" grains varied in mineralogy from discrete single-phase minerals, such as iridosmine or rutheniridosmine, to alloys containing inclusions of an unspecified Mg-silicate and/or irarsite (IrAsS). The irarsite commonly occurred as a zone of complex intergrowths at the grain margin, sometimes as a vein traversing the alloy (Fig. 2), as a eutectoid (Fig. 3), and also as a complex intergrowth throughout the alloy matrix (Fig. 4). Several grains contained coexisting hexagonal and cubic alloys, but only three of these had both coexising minerals large enough for reliable analysis.

The alloys were quantitatively analyzed with the electron probe using the procedures described by Harris & Cabri (1973). In addition, step-scanning traverses at 20-micron intervals were done for grains determined to be non-homogeneous.

ANALYTICAL RESULTS

The electron probe analyses of the Os-Ir-Ru alloys for nine grains from 19 Mile Creek and five from Adamsfield are listed in Table 1; three of these grains consisted of coexisting Os-Ir-Ru alloy species. The following combinations occurred: rutheniridosmine + osmiridium, iridosmine + osmiridium, and rutheniridosmine + ruthenosmiridium. The mineral ruthenosmiridium is reported for the first time though the name and compositional range were proposed earlier by Harris & Cabri (1973) in order to cover all possible species and varieties for the Os-Ir-Ru alloys. The ruthenosmiridium, however, is very close in composition to the osmiridium field (Fig. 5), as well as to being called platinosmiridium (*cf.* Harris & Cabri 1973, p. 111). However, with at.% Ru > at.% Pt, the name ruthenosmiridium is correct. The analyses correspond well with the boundaries of the miscibility gap on the Os-Ir binary proposed by Harris & Cabri (1973), viz. 45 and 58* at.% Ir. Reiswig & Dickinson (1964) showed that for the pure Os-Ir system from 2660 to 1000°C, the solvi are nearly vertical, occurring at about 36.3 and 58.3 at.% Ir. The latter value is in excellent agreement with the natural samples, but the 36.3 at.% Ir boundary for hexagonal synthetic alloys does not agree well with the ~ 45 at.% Ir boundary determined from natural alloys. The solvus must either change slope at lower temperatures or the impurity elements in natural alloys affect this boundary.

It is interesting to note that, though the Tasmanian minerals had been known in the literature as "osmiridium", very few of them are, indeed, in the samples we examined, cubic osmiridium, the majority being hexagonal rutheniridosmine or iridosmine. Another interesting feature is that platinum seems to prefer the cubic osmiridium or ruthenosmiridium structure as evident from its greater abundance in these minerals in contrast to smaller amounts present in the hexagonal alloys. This may also be observed

TABLE 1. ELECTRON PROBE ANALYSES OF NATURAL Os-Ir-Ru ALLOYS FROM TASMANIA

Locality	Weight Per Cent									Atomic Proportions			Mineral
	Ir	Os	Ru	Pt	Pd	Rh	Fe	Ni	Totals	Ir	Os	Ru	
Heazlewood													
Gr.1*	44.7	48.9	5.8	1.1	n.d.	.59	.30	.03	101.42	42.6	46.9	10.5	Rutheniridosmine
Gr.2	44.5	49.7	5.5	1.0	n.d.	.72	.20	.03	101.65	42.3	47.7	10.0	Rutheniridosmine
Gr.3	41.9	48.8	7.0	2.4	.12	.89	.15	.02	101.28	40.1	47.2	12.7	Rutheniridosmine
Gr.4(white)	42.4	49.3	6.7	2.2	n.d.	.86	.10	.02	101.58	40.5	47.4	12.1	Rutheniridosmine
Gr.4(cream)*	59.8	25.4	5.3	9.2	.05	1.0	.40	.12	101.27	62.7	26.8	10.5	Ruthenosmiridium
Gr.5	45.0	49.2	5.7	1.1	n.d.	.66	.19	.02	101.87	42.7	47.1	10.2	Rutheniridosmine
Gr.6	44.2	49.2	6.0	1.2	n.d.	.73	.18	.02	101.53	42.0	47.2	10.8	Rutheniridosmine
Gr.7	43.7	49.4	5.9	1.5	.05	.70	.06	n.d.	101.31	41.7	47.5	10.8	Rutheniridosmine
Gr.8	42.8	48.4	7.1	2.2	.05	.84	.08	n.d.	101.47	40.7	46.3	13.0	Rutheniridosmine
Gr.9(white)	44.1	49.0	6.2	1.7	.05	.84	.11	.04	102.04	41.8	46.9	11.3	Rutheniridosmine
Gr.9(cream)	59.8	26.8	5.0	7.4	.05	.92	.18	.06	100.21	62.1	28.1	9.8	Osmiridium
Adamsfield													
Gr.2	44.7	48.4	5.6	0.67	.05	.61	1.4	.27	101.70	43.0	46.9	10.1	Rutheniridosmine
Gr.3 *	46.5	49.1	5.3	0.75	n.d.	.60	.07	.01	102.33	43.9	46.7	9.4	Iridosmine
Gr.4(white)	46.5	47.9	5.4	0.96	n.d.	.66	.29	.04	101.75	44.3	46.0	9.7	Iridosmine
Gr.4(cream)	65.3	26.5	3.7	5.0	n.d.	.53	.45	.10	101.58	66.0	27.0	7.0	Osmiridium
Gr.5	46.4	44.7	7.6	1.0	.05	.49	.56	.09	100.89	43.7	42.5	13.8	Rutheniridosmine
Gr.6	46.3	49.8	4.2	0.67	n.d.	.49	.28	.05	101.79	44.3	48.0	7.7	Iridosmine

n.b. Cu, not-detected. * non-homogeneous, re-analysed by step-scanning.

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*Reported incorrectly as 62 at.% Ir in Harris & Cabri (1973, p. 107, 110).

in the analyses of alloys from the Atlin area in British Columbia (Harris & Cabri 1973) and of platiniridium from the Tulameen River, British Columbia (Cabri & Hey 1974).

The Tasmanian Os-Ir-Ru alloys, plus thirty alloys from British Columbia previously reported by Harris & Cabri (1973), were examined in great detail in order to determine the presence of non-homogeneity and, where present, to quantify this feature. The best method was found to be step-scanning at 20-micron intervals using three spectrometers set to quantitatively record Os, Ir, and Ru. Step-scanning traverses were made on the twelve non-homogeneous minerals (three from Tasmania and nine from Atlin) by starting the traverse at the grain centre and moving towards the grain edge. Several different profiles were obtained as are shown for four examples illustrated in Figures 6 and 7. Os and Ir correlate closely, with increases in Os being accompanied by decreases in Ir, and vice-versa. The largest variation across the radius of the grains studied was about 10 at.% Os or Ir, but, as is illustrated in Figure 7, such variations do not always follow a single trend but sometimes reverse themselves. The Ru content, on the other hand, appears to remain relatively constant.

Several traverses were made on three selected non-homogeneous osmiridium grains from the Atlin district, B.C. Contours were drawn at 1 wt.% Ir intervals and these are illustrated in Figures 8, 9 & 10. It is apparent that the non-homogeneity may result from a type of zonation within a single mineralogical species and that this zonation is not always regular and often reverses itself. Zoning illustrated by Koen (1964, Plate II) for Witwatersrand Os-Ir grains is similar, but the zonation is generally between hexagonal and cubic alloys, *i.e.* phase zoning vs. compositional zoning.

Discussion

Origin of the zonation

Zoning in Os-Ir alloys has been discussed by Koen (1964a, b), Hiemstra (1964). Cousins (1973a, b), and Stumpfl (1974). Koen concluded that, if the Witwatersrand Os-Ir grains are indeed detrital, the conformable relationships between their shapes and internal structures (zoning) must have developed at the time of their crystallization. Cousins (1973a) observed that, for zoned Os-Ir alloys, concentric zoning is most common and is present in the detrital grains of many alluvial deposits. He further suggested that the platinum-group elements (PGE), proposed to have been present orig-

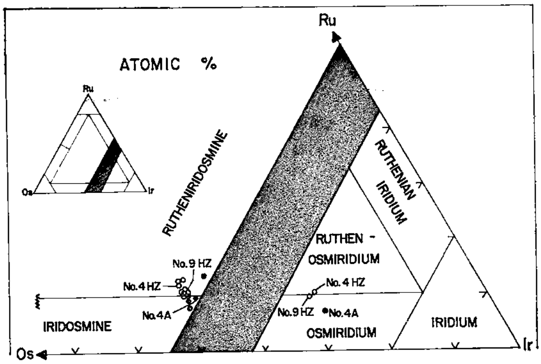

FIG. 5. Os-Ir-Ru alloys from Tasmania. Filled circles and A = Adamsfield area; open circles and HZ = Heazlewood district (Bald Hill). The miscibility gap (shaded) is that proposed by Harris & Cabri (1973).

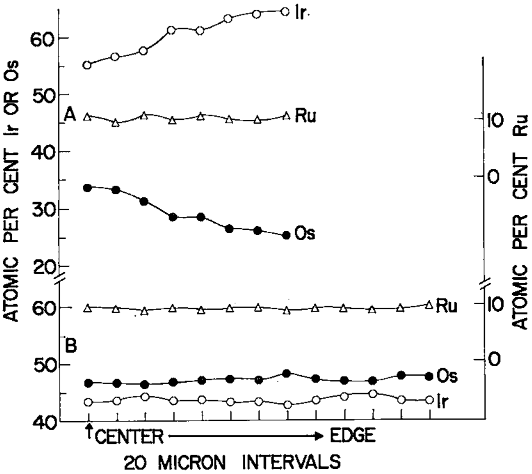

FIG. 6. Step-scanning traverses for two samples; (A) ruthenosmiridium, grain 4, Heazlewood; (B) iridosmine, grain 3, Adamsfield.

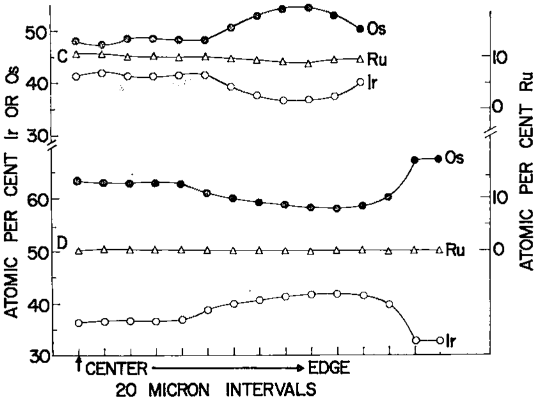

FIG. 7. Step-scanning traverses for two samples; (C) rutheniridosmine, grain 1, Heazlewood; (D) iridosmine, grain 5, Atlin (R.O.M. No. M 12340).

inally in solid solution in sulphide minerals in ultramafic rocks, were liberated from these sulphides by weathering processes in "molecular or colloidal dimensions" and became reduced to metals. "These very fine-grained metallic particles appear to accrete to form much larger particles, many of which, by the inclusion of other platinoid elements, form accretion alloys" (Cousins 1973a, p. 70). These "alluvial particles" were considered to have grown in transport, explaining why they are thought to be larger than the grains of platinum-group minerals (PGM) in primary deposits. Similar ideas had been presented by Ottemann & Augustithis (1967) for the platinum alloys in the laterites of the Yubdo area, Ethiopia. Cousins (1973b, p. 198) states "The zoning therefore may be due to a process of accretion — possibly resembling that involved in the growth of agates and similar concretionary bodies." Stumpfl (1974, p. 133) states "Zoning (often concentric) is widespread amongst Witwatersrand Os-Ir alloys. This can be attributed to chemical accretion during transport, diagenesis, and low-grade metamorphism, and testifies to a certain solubility of even the most inert PGE, *i.e.* osmium and iridium". It is difficult to understand how a grain can be considered to have formed during transport by "chemical accretion".

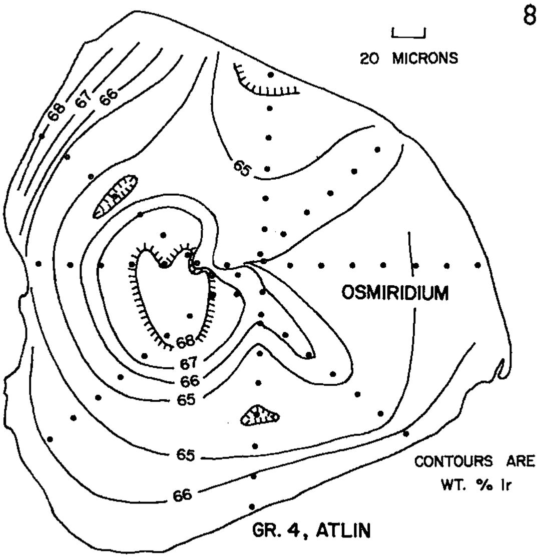

FIG. 8. Zoning in osmiridium grain No. 4, Atlin (R.O.M. No. M 10120).

As the proposals of Cousins and of Stumpfl regarding the accretion hypothesis are based on the papers by Augustithis (1967) and Ottemann & Augustithis (1967), close examination of the original papers is necessary to determine whether accretion, originally proposed for a lateritic and *eluvial* environment, is applicable to the Witwatersrand, Tasmanian, and other *alluvial* deposits.

The platinum nuggets in the lateritic cover of the zoned Yubdo ultramafic massif were described as "element agglutinations within early alteration stages of the ultrabasic rocks predating the actual laterization or perhaps also during laterization" (Ottemann & Augustithis 1967, p. 269). Their hypothesis was based on a microscopic and electron probe study of one platinum

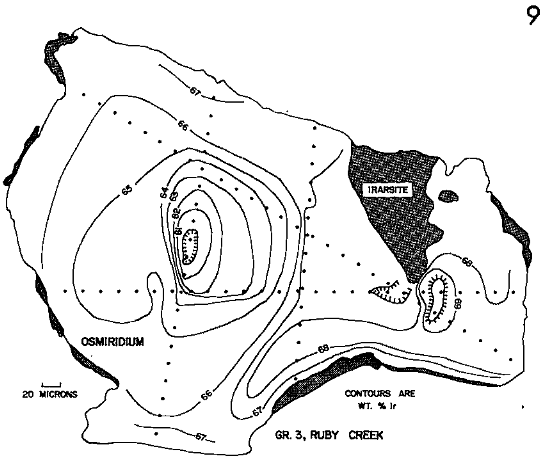

FIG. 9. Zoning in osmiridium grain No. 3, Ruby Creek, Atlin (R.O.M. No. M 11735). There is a band of iridosmine a few microns wide (not illustrated) between the irarsite and osmiridium.

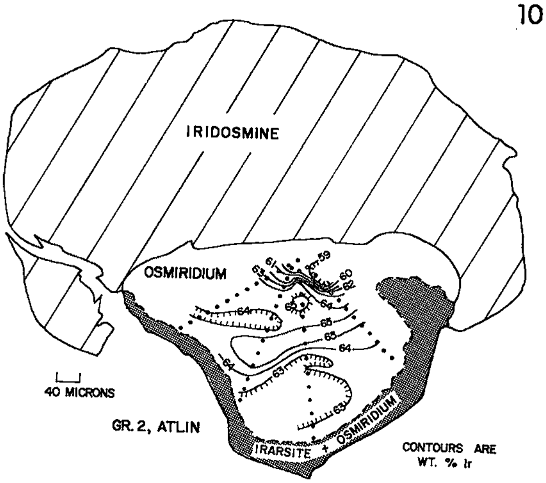

FIG. 10. Zoning in osmiridium in contact with unzoned homogeneous iridosmine — Grain 2, Atlin (R.O.M. No. 10120). A photomicrograph of this grain is given in Fig. 1 of Harris & Cabri (1973).

nugget and on the confirmation by *x*-ray analysis of one sperrylite grain found in the Yubdo dunite. Sperrylite was reported to be abundant and also to be the only PGM in the dunite (Augustithis 1965). It is also interesting to note that Augustithis (1965) comments on the resistance of sperrylite to chemical leaching in the birbirite. The electron probe studies of sperrylite reported to be in progress by Ottemann & Augustithis (1967) have not been carried out (Ottemann, pers. comm. 5/2/75). Ottemann & Augustithis gave the following reasons for suggesting the growth of the Pt-nuggets in the lateritic soil by "element agglutination":

a) No native platinum was found in the ultramafic rocks and the sperrylite grains are smaller than the Pt nuggets. Because only one sperrylite grain (identified microscopically) in the dunite has been confirmed, the identity of the remaining "abundant" sperrylite grains remains to be verified. It would have been fortuitous, indeed, to have found large PGM grains in the dunite as these minerals are expected to be dispersed far more in the primary rock than they are in the eluvial concentrates. Also, panning and other washing and gravity methods employed to obtain these concentrates may not have recovered the very smallest alloy particles.

b) The angular shape and protuberances of the Pt-nuggets were presented as evidence of the nuggets' growth in the lateritic soil. It appears to us that such features are more consistent with an *in situ* or eluvial origin from the dunite or birbirite by physical liberation during chemical weathering of the silicates. The latter view, expressed also by Duparc & Molly (1928), is consistent with the observation that the nuggets obtained from the *alluvials* in the Birbir River, some distance downstream from the mouth of the Yubdo River, were reported to be "quite different from that of the eluvium and occurred as much smaller grains, of rounded shape . . ." (Molly 1959, p. 477).

c) The fact that chromite inclusions, with altered and corroded margins, are enclosed in the Pt-nuggets was presented as evidence that the nuggets grew around the unaltered or altered chromite grains in "an environment of disintegration of the ultrabasics or of the birbirite . . .". We interpret the chromite inclusions, on the other hand, to be primary inclusions that formed during crystallization of the platinum in the dunite. In the platinum nuggets, numerous other PGM inclusions, such as euhedral osmiridium, erlichmanite (OsS_2), and some unknown PGM, all have the textural features suggestive of primary crystallization rather than "element agglutination".

d) It was also suggested that gold, the presence of which is poorly documented in the platinum-iron alloy, could have been freed from quartz veins that traverse the Yubdo Complex and was incorporated in the structure of the platinum alloy during the alteration process. It was further suggested that the gold separated from decomposing rock through colloidal dispersions, and was later incorporated in the platinum alloy through "autoaggregation". These proposals are based on incomplete data and for which the physical and chemical reactions involved are not known.

Thus the "element agglutination" hypothesis, proposed by Augustithis (1967) as a contrast to his ideas on differential leaching of Mg, is based upon minimal information of the processes involved with respect to platinum nuggets; the evidence presented may be reinterpreted in a diametrically opposite manner. The proposal by Cousins that this accretionary process resembles "the growth of agates and similar concretionary bodies" is also difficult to understand. Agates are known to be banded forms of silica, usually chalcedony, which usually formed in vugs in volcanic rocks. The term concretion, on the other hand, is a loose one used for more or less rounded bodies, chiefly or inorganic origin, in sedimentary rocks, which appear to have grown outward from a centre.

Zonation in minerals is common and may be formed by a variety of processes, other than in an aqueous medium at low-temperatures, such as by reactions with a melt during crystallization (zoned plagioclases), by reactions during metamorphism (zoned garnets), or by sluggish reactions in the solid state (arsenopyrite or sphalerite). Because the experimental work, to date, on the Os-Ir system suggests that these alloys are difficult to react and equilibrate at temperatures below 1000°C, it seems more likely that non-homogeneous or zoned Os-Ir alloys are the result of non-equilibration during primary crystallization rather than "element agglutination". This is also consistent with the textures and variety of other minerals included in such alloys, and with the complicated zonation illustrated in Figures 8, 9 and 10, especially with the non-homogeneity exhibited only by osmiridium coexisting with iridosmine as shown in Figure 10.

Origin of the Os-Ir alloys

Cousins (1973 a, b) has suggested that alluvials containing high (Os+Ir) with respectively low Pt are formed by differential leaching of the "agglutinized" platinum-group elements during transportation. This concept has been expanded into what may be called the "maturity hypothesis", *i.e.* "A mature placer will contain osmium and iridium as its major platinoids, while an immature one will contain mainly platinum" (Cousins 1973b, p. 192). Cousins qualitatively described the degree of rounding of single samples of alluvial PGM nuggets from Colombia, Goodnews Bay, Alaska, and Gold Beach, Oregon and came to the conclusion that "These samples suggest clearly, that the more mature the platinoid alluvial has become, (deduced from its chemistry) the better rounded the grains have become" (Cousins 1973b, p. 192). It is important to point out that the Tasmanian alloys, for example, in some cases occurred in detrital material on the serpentinite source rock of Bald Hill; the detritus must represent a very immature stage of erosion, but the alloys have a $Pt\times100/Pt+Ir+Os$ ratio less than or equal to the reportedly very mature Witwatersrand alloys. Also relevant is that both Cousins and Stumpfl not only suggest that salinity affects the dissolution of the PGE alloys, but refer to the "marine" placers of Goodnews Bay. However, Mertie (1969) describes the Goodnews Bay placers as being of fresh-water origin and clearly precludes sea-water effects. The maturity hypothesis, though interesting, needs more detailed supporting data before it can be accepted.

Another approach to understanding the origin of placers rich in (Ir+Os) and poor in Pt is to study the influence of their original source rocks, as was suggested by Cabri (1974). The first step is the data compilation presented in Table 2. Published information for nine areas of alluvial PG alloys was studied in an attempt to correlate the geology of the source rocks with the bulk $Pt\times100/Pt+Ir+Os$ ratio in the alluvials. Two contrasting ratios are apparent, with one ranging between 86 and 97 and the other between less than 2 and 36. This grouping is in contrast to that given by Cousins (Fig. 3, 1973b) for mostly unidentified samples. It should also be noted that there are reports that some areas may contain both high Pt and high Ir+Os, such as for the Goenoeng-Lawack area, Borneo (Mertie 1969), but there is not enough known of the geology or details of the samples assayed. As far as is known, the source rocks for the first group are all concentrically zoned ultramafic-mafic intrusions with ultramafic cores. Naldrett (1973) describes these rocks as having "intruded along orogenic belts either after or during the late stages of the main folding and metamorphism, but before the emplacement of granite batholiths". Naldrett labels these "Alaskan-type zoned intrusions" where "the zoning characteristic of this class is largely due to multiple intrusions of successive magmas, each successively more ultramafic than the preceding intrusion and tending to intrude through the core of the preceding intrusion". The examples listed in Table 2 range from late Precambrian to late Mesozoic or Tertiary.

As far as is known the source rocks for three of four deposits in the second group are repre-

TABLE 2. RELATION OF SOURCE ROCKS TO BULK Pt:Pt+Ir+Os RATIO FOR PLACERS FROM WIDESPREAD OCCURRENCES

Approximate Age	Event	Source Rock Class	Placer Area	$\frac{Pt\times100}{Pt+Ir+Os}$	Material	Reference(s)
pre-late Tertiary	weathering of source rocks	concentrically zoned	Colombia	95	weighted mean analysis of "platinum metals"	Mertie (1969, Table 27)
late Mesozoic or Tertiary	intrusion of source rocks	concentrically zoned	Goodnews Bay District	86	1936 - 67 production	Mertie (1969, Table 37)
late Triassic	intrusion of source rocks	concentrically zoned	Tulameen	87	1930 production record	O'Neill & Gunning (1934, p.98) Findlay (1969)
late Paleozoic or post late Paleozoic	intrusion of source rocks	concentrically zoned	Urals	94	weighted mean of 168 analyses of "platinum metals"	Mertie (1969, Table 24)
late Precambrian	intrusion of source rocks	concentrically zoned	Yubdo, Ethiopia	97	pan concentrate, eluvial platinum	Duparc & Molly (1928), Molly (1959)
Cretaceous	thrusting of source rocks	alpine-type, large obducted sheets	New Guinea	36	"osmiridium" concentrate	Sen Gupta (1972) procedure 1 Davies (1968)
pre-Jurassic?	emplacement of source rocks	alpine-type	Atlin	very low	black sand concentrate	Aitken (1959), Gledhill (1921)
Cambrian?	emplacement of source rocks	alpine-type	Tasmania	2	mean of ? number of anal. of "osmiridium & platinum"	Mertie (1969, Table 29, anal. D)
				5	"iridosmine" concentrate - sample 1	Sen Gupta & Beamish (1962)
				11	"iridosmine" concentrate - sample 2	Sen Gupta & Beamish (1962)
Precambrian	intrusion ? & weathering of source rocks, deposition & lithification of sediments	?	Witwatersrand	6	"platinoid" concentrate - Springs mine	Cousins (1973b, Table I)
				14	"platinoid" concentrate - av. for Witwatersrand	Cousins (1973b, Table V)
				29	"platinoid" concentrate - Wit Nigel mine	Cousins (1973b, Table I)

sentatives of Alpine-type intrusions (Tasmania, New Guinea and Atlin). Naldrett (1973) classifies these rocks as the first sub-type of the Alpine-type bodies and names them "large obducted sheets".

It is generally accepted that, with some exceptions, contact metamorphism is absent or inconspicious for such ultramafics, and that the peridotite bodies have serpentinized and talcose margins bounded by or associated with major faults, so that they appear to have been emplaced "cold" through the action of faulting. Alpine-type peridotites are generally spinel peridotites in the harzburgite-dunite range, grading in places to lherzolite. Irvine & Findlay (1972) considered the ultramafic portions of ophiolites to consist of two parts: (a) an upper cumulate portion representing the olivine-rich differentiate crystallizing from the magmatic products of partial melting of the mantle, generated at mid-oceanic ridges, and (b) a lower, residual portion representing mantle-material, partly depleted by the partial melting. It is obvious that such complexities, some of which may be impossible to unravel for specific ultramafic complexes, will make correlations between PGE ratios and detailed rock types subject to constant review and re-interpretation.

The fourth alluvial area whose PG-alloys have a low Pt×100/Pt+Ir+Os ratio is the Witwatersrand; these are also the oldest alluvials containing sufficient PGE to be recovered commercially as by-products. Viljoen *et al.* (1970) show that the main source of the Witwatersrand PGE was on the northeastern side of the Witwatersrand basin. They suggest that an "ultramafic unit" of "primitive" mafic and ultramafic lavas was the main source of the gold and PGE in the Kimberley-Elsberg conglomerates. They also note that chromite and "osmiridium" significantly increase upwards in the Witwatersrand sequence, the association in itself being significant for a mechanically alluvial origin of the PGM. It is an intriguing question to ponder whether rocks described as Alpine-type bodies may not have been emplaced among the mafic and ultramafic lavas thought to have been the source of the gold in the Kimberley-Elsberg Series. There is no doubt that the Os-Ir alloys in these very old placers have also been subjected to the effects of diagenesis and metamorphism.

The concept that the Pt×100/Pt+Ir+Os ratio in alluvials is directly related to two principal types of source rocks may further be extended as a measure of the degree of magmatic fractionation of these rocks. Greenland *et al.* (1974) have reviewed recent studies of Au/Ir relative to magmatic fractionation. They concluded that lower Au/Ir in the Alpine peridotite studied by Crocket & Chyi (1972) is consistent with an origin by mobilization and crustal intrusion of mantle peridotite, whereas the higher ratio in basalt implies that such rocks have undergone some degree of fractionation during their ascent from the source area. It is tempting to relate a low Au/Ir ratio with a high Ir abundance, and higher Au/Ir ratio with a lower Ir abundance. We may then further relate a higher Ir abundance (=low Au/Ir ratio), with a low Pt×100/Pt+Ir+Os ratio, to large obducted sheets (Alpine-type) of relatively unfractionated mantle-type material and a lower Ir abundance (= high Au/Ir ratio), with a high Pt×100/Pt+Ir+Os ratio, to concentrically zoned intrusions (Alaskan-type) which have undergone a greater degree of fractionation. Such projections must be considered as no more than very tentative at present because much more data are needed on Os+Ir in rocks of different environments.

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