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COMPOSITION OF THE PLATINUM-GROUP MINERALS IN THE SALMON RIVER PLACER DEPOSIT, GOODNEWS BAY, ALASKA

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ABSTRACT

The composition and the associations of platinum-group minerals from the Salmon River placers, Goodnews Bay, Alaska, are compared with those of assemblages in other Alaskan-type complexes. Pt–Fe alloy, with an average value 25 at.% Fe, corresponds to isoferroplatinum (Pt_3Fe). Ir concentrations in isoferroplatinum reach 15.4 wt.%, and Rh concentrations, as much as 2.27 wt.%. Tulameenite, which replaces the isoferroplatinum grains, appears as a rim with distinct boundaries. It forms a Pt_2CuFe–PtFe series and also contains up to 2.64 wt.% Ni. Iridium and osmium occur as inclusions in the isoferroplatinum matrix and are depleted in Ru. The Ir content of osmium reaches 26 at.%, and the proportion of Os in iridium varies from 12 to 20 at.%. The concentration of Pt in iridium reaches 21.79 wt.%, which exceeds the limit of solubility of Pt in Ir at the maximum temperature of equilibration (~850°C). The composition of PGE-sulfarsenides corresponds to irarsite, with accessory platarsite and osarsite components: (Ir,Pt,Os)AsS. As predominates over S where substantial Pt exists, and excess S is present in irarsite with a high Os content. Solid solution along the erlichmanite (OsS_2) – sperrylite ($PtAs_2$) series is restricted. A wide range of compositions and levels of minor elements (Ir, Pd, Rh) in Pt–Fe alloys from different Alaska-type occurrences reflects geochemical features of the ore-forming system at the source. Fractionations of the PGE in the ore-forming system, from Ir-rich nuggets to Rh-rich and to Pd-rich alloys, reflect the decrease in temperature of the ore-forming system. Compositional variation and temperature range of alloy genesis decrease in the order from Goodnews Bay and Inagli to Galmoenan, Fifield, Nishnii Tagil, then to Tulameen and Yubdo, and down to Pustaya and Itchayvayam occurrences.

Keywords: platinum-group minerals, Alaskan-type complex, placers, Goodnews Bay, Alaska.

SOMMAIRE

Nous décrivons la composition et les associations de minéraux du groupe du platine de concentrés prélevés dans les placers de la rivière Salmon, Goodnews Bay, en Alaska, et nous les comparons à celles des assemblages dans d'autres complexes de type Alaska. Les grains de l'alliage Pt–Fe, contenant en moyenne 25% Fe (base d'atomes), correspond à l'isoferroplatinum (Pt_3Fe). Les concentrations d'Ir dans l'isoferroplatinum atteignent 15.4% (par poids), et les concentrations de Rh, jusqu'à 2.27%. La tulameenite, qui remplace les grains d'isoferroplatinum, forment un liseré avec une bordure franche. Cette espèce fait partie d'une série Pt_2CuFe–PtFe et contient aussi jusqu'à 2.64% de Ni (en poids). L'iridium et l'osmium se trouvent en inclusions dans une matrice d'isoferroplatinum, et sont appauvris en Ru. La teneur en Ir de l'osmium atteint 26% (base d'atomes), et la proportion d'Os dans l'iridium varie entre 12 et 20% (base d'atomes). La concentration de Pt dans l'iridium atteint 21.79% (en poids), ce qui dépasse la limite prévue à la température maximum d'équilibrage (~850°C). La composition du sulfarséniure contenant les éléments du groupe du platine correspond à l'irarsite, avec composantes de platarsite et d'osarsite accessoires: (Ir,Pt,Os)AsS. L'arsenic prédomine sur le soufre là où une fraction importante de Pt existe, et un excédent de soufre est présent dans l'irarsite

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ayant une teneur élevée en Os. Il y a une solution solide restreinte entre erlichmanite (OsS_2) et sperrylite ($PtAs_2$). Une grande variabilité en compositions des alliages Pt–Fe et en teneurs en éléments traces (Ir, Pd, Rh) parmi les divers exemples connus de complexes de type Alaska témoigne des caractéristiques géochimiques du système minéralisateur à la source. Le degré de fractionnement des éléments du groupe du platine dans les systèmes minéralisés, à partir de pépites riches en Ir aux alliages riches en Rh et en Pd, illustre l'effet d'une diminution en température du système minéralisateur. La variation en composition et l'intervalle en température de formation des alliages diminuent dans la séquence de Goodnews Bay et Inagli à Galmoenan, Fifield, Nishnii Tagil, ensuite à Tulameen et Yubdo, et enfin à Pustaya et Itchayvayam.

(Traduit par la Rédaction)

Mots-clés: éléments du groupe du platine, complexe de type Alaska, placers, Goodnews Bay, Alaska.

INTRODUCTION

Concentrically arranged associations of pyroxenite rimming a dunite–peridotite core are variously referred to in the scientific literature as Ural–Alaska-type, Alaska-type or zoned ultramafic complexes (Noble & Taylor 1960, Taylor & Noble 1960, Thayer 1960, Johan 1994, Johan *et al.* 1990, 1991, Nixon *et al.* 1990, Slansky *et al.* 1991). Such Alaska-type complexes, through erosion, have been source rocks for Pt-bearing placers in Colombia, Ecuador, western Canada, Alaska, and Russia (*e.g.*, Kemp 1902, Mertie 1919, 1940, 1969, 1976, Findlay 1963, St. Louis *et al.* 1986, Shashkin & Stolyarenko 1991, Tistl 1994). A zoned ultramafic complex south of Goodnews Bay, Alaska, has been identified as the source of more than 20 tonnes of platinum found in placers (Van der Poel & Hinderman 1997, 2000). However, the composition of the Pt–Fe and Os–Ir–Ru alloys in the Goodnews Bay placers has been established on the basis of results of only a few electron-microprobe analyses (Toma & Murphy 1977). Other platinum-group minerals (PGM) identified in placer concentrates from Goodnews Bay include mertieite (Desborough *et al.* 1973), rhodium alloys (Snetsinger 1973) and bowieite (Desborough & Criddle 1984). These minerals have since been reported from other Alaska-type complexes in the world that are similar to the Goodnews Bay complex. In this investigation, we document the general features of compositions of the platinum-group minerals and their paragenesis as a whole, and compare them with assemblages in other Alaskan-type complexes.

GENERAL GEOLOGY

Platinum placers were discovered in 1926 about 15 km south of Goodnews Bay in southwestern Alaska. The PGM examined by us were recovered from a heavy-mineral concentrate from alluvial placers in the Salmon River, which drains the ultramafic rocks of the elongate Red Mountain ridge (Fig. 1). The intrusive body at Red Mountain is predominately dunite and peridotite, with peripheral borders of olivine pyroxenite, magnetite pyroxenite and hornblende pyroxenite. These units intrude metasedimentary and metavolcanic rocks of Paleozoic to Mesozoic age (Foley *et al.* 1997, Van der Poel & Hinderman 1997, 2000). Pyroxenite has been revealed beneath the sedimentary cover on the flanks of the ultramafic body (Bird & Clark 1976). The dunite consists of olivine with minor amounts of monoclinic pyroxene, magnetite, ilmenite and chromite. Dunite is variably replaced on both a microscopic and macroscopic scale by serpentine. The geology and history of placer formation and production in the district are described in detail by Mertie (1976).

ANALYTICAL METHODS

The composition of the PGM was determined with a Camebax–Micro electron microprobe, using the RMA–92 program (L.N. Pospelova and V.M. Chubarov, analysts). The acceleration voltage was 20 kV, probe current 20–30 μA, and the counting time, 10 seconds for each analytical line. Standards used during analyses include: Pt, Ir, Os, Pd, Rh, and Ru metals, $CuFeS_2$ (for Cu, Fe, S), InAs (for As), and $CuSbS_2$ (for Sb). The following X-ray lines were used: $L\alpha$ for Pt, Ir, Pd, Rh, Ru, As, and Sb, $K\alpha$ for S, Fe, and Cu, and $M\alpha$ for Os. The interference of lines was corrected with the help of a file of experimentally calculated coefficients (Lavrent'ev & Usova 1994).

COMPOSITION AND TEXTURAL RELATIONSHIP OF THE PLATINUM-GROUP MINERALS

Pt–Fe alloy

Grains of Pt–Fe alloy are rounded and up to 0.5 mm in size. The concentration of Fe in the Pt–Fe alloy varies from 19 up 31 at.% (6.31–11.77 wt.%) with an average value 25 at.%. Such Pt–Fe alloy corresponds to isoferroplatinum (Pt_3Fe). In some cases, grains are covered by a thin brown or gray film containing secondary minerals: tetraferroplatinum (PtFe), tulameenite (Pt_2FeCu) and the platinum-group-element (PGE) sulfarsenide series (Figs. 2A–E). The levels of the minor PGE in isoferroplatinum are relatively high (Fig. 3A). For example, Ir concentrations are as high as 15.4 wt.% (Table 1). Isoferroplatinum–iridium micro-aggregates typically contain the Ir-rich platinum, which com-

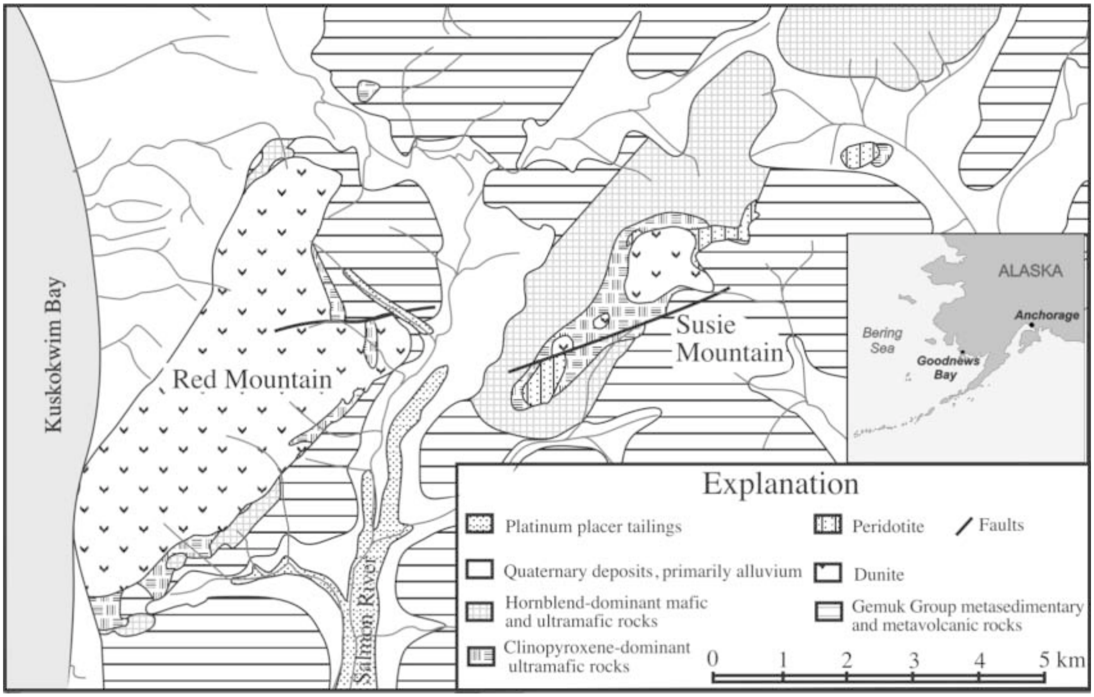

FIG. 1. Geological map of the Goodnews Bay platinum district, as interpreted by Mertie (1976) and Van der Poel & Hinderman (2000).

monly is the product of high-temperature decomposition of a Pt–Ir solid solution. Similar Ir concentrations (up to 16.6 wt.%) have been reported for isoferroplatinum with iridium intergrowths from the Inagli placer, Aldan Shield (Tolstykh & Krivenko 1997) and the Yubdo placer, Ethiopia (up to 26 wt.%) (Evstigneeva *et al.* 1992, Cabri *et al.* 1981). Isoferroplatinum in nuggets from Fifield, Australia, also contain significant quantities of Ir (up to 6.58%) (Slansky *et al.* 1991). The Rh content of Pt–Fe alloys in the Salmon River placer also is relatively high, as much as 2.27 wt.%, and correlates positively with Ir content. The concentration of other elements (Pd, Os, Ru, Cu) is more restricted (Table 1).

The tulameenite that replaces the isoferroplatinum grains forms a rim with a distinct boundary (Figs. 2A–C). Analytical results for tulameenite and tetraferroplatinum are gradational and show the isomorphous nature of the two compositional end-members (Fig. 3B). The alloy of the Pt_2CuFe–PtFe series also contains Ni, which increases to 2.64 wt.% as the tetraferroplatinum end-member in tulameenite is approached, *i.e.*, Ni and Cu display a negative correlation. The composition with the highest Ni content corresponds to 12 mol. % of the ferronickelplatinum component in tulameenite (Fig. 4). Ni-bearing tulameenite is also described at Tulameen (Nixon *et al.* 1990), Yubdo (Cabri *et al.* 1981, Evstigneeva *et al.* 1992) and in the Nizhne–Tagil'skiy dunite massif in the Ural Mountains (Genkin 1997). At Goodnews Bay, the tulameenite is most similar to that at Yubdo (Fig. 4), but it does not contain minor elements (Ir, Pd, Rh: Table 1). These elements were probably eliminated during replacement of the primary PGE alloys by tulameenite, and presumably reacted with S and As in a later stage.

Os–Ir alloy

Grains of Os–Ir alloy are represented by iridium and osmium, which occur as inclusions in the isoferroplatinum matrix (Fig. 2F). There are two two-phase associations: isoferroplatinum–iridium and isoferroplatinum–osmium (Fig. 5). The first one is related to destabilization of a high-temperature solid solution. The second one represents rare inclusions of osmium in Pt–Fe alloy (Fig. 2F). A three-phase equilibrium intergrowth was documented earlier at Goodnews Bay (Toma & Murphy 1977). A distinctive feature of osmium and iridium is that they are depleted in Ru (Table 1). The solubility of Os in iridium and Ir in osmium does not reach their maximum in comparison with Os–Ir alloys of the ophiolitic association (Weiser &

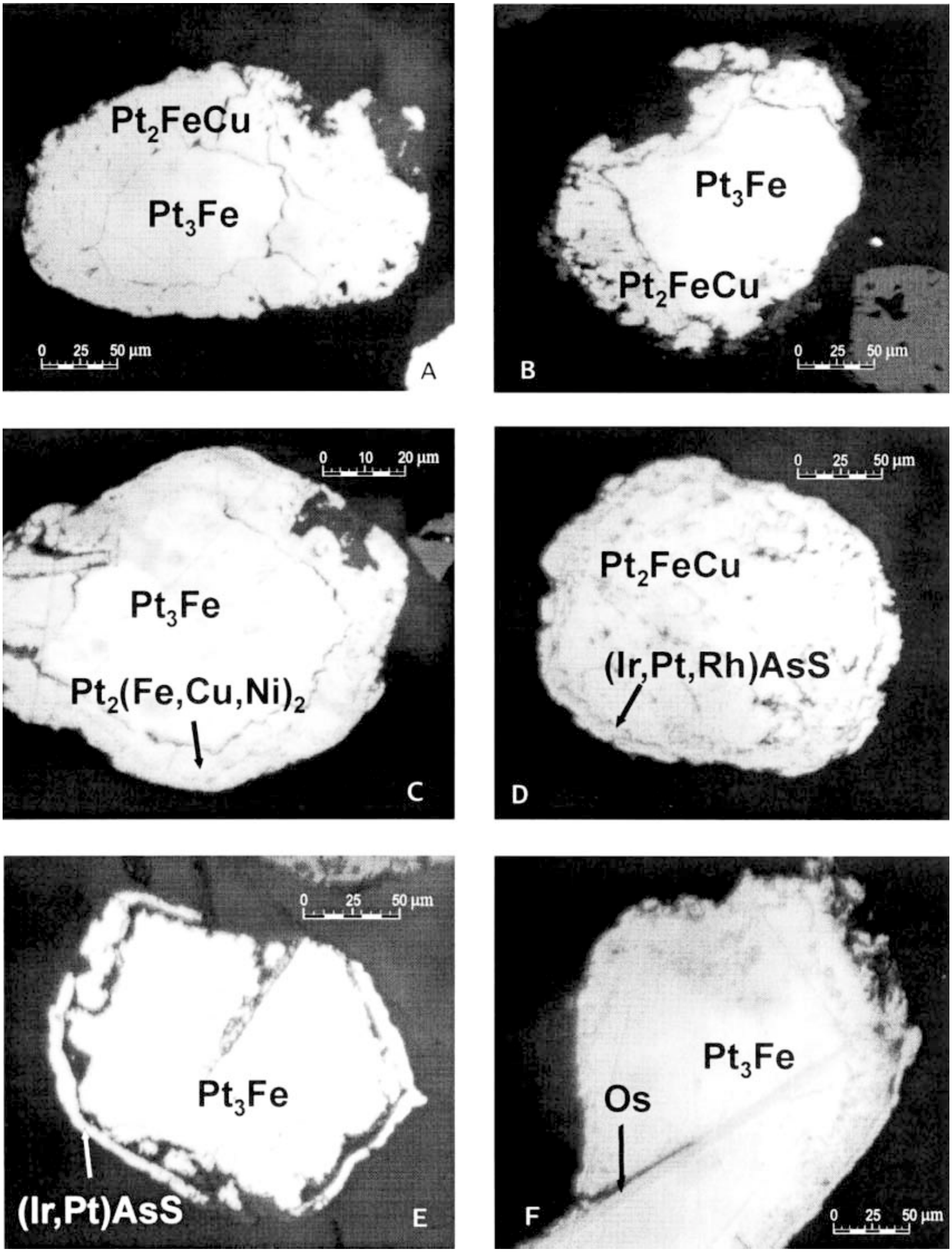

FIG. 2. Scanning-electron microscope images, showing relationships among PGM. A,B,C. Grains of isoferroplatinum surrounded by a tulameenite rim. D. Tulameenite with a rim of secondary irarsite. E. Isoferroplatinum grains surrounded by irarsite. F. Inclusion of osmium in isoferroplatinum, which is surrounded by irarsite.

TABLE 1. COMPOSITION OF PGE ALLOYS IN THE SALMON RIVER PLACER CONCENTRATES, GOODNEWS BAY, ALASKA

Sample	Pt	Ir	Os	Pd	Rh	Ru	Fe	Ni	Cu	Total
Isoferroplatinum, Pt_3Fe										
AL10 wt%	89.80	0.00	0.00	0.00	0.45	0.05	8.08	0.00	1.15	99.53
AL23	88.39	0.00	0.00	0.00	0.00	0.00	9.52	0.00	0.00	97.91
AL40	88.19	0.00	0.00	0.11	0.00	0.00	9.58	0.22	0.40	98.50
AL9	87.26	0.00	0.00	1.74	0.00	0.00	9.72	0.00	0.00	98.72
AL2	87.52	0.00	0.00	0.32	0.00	0.00	9.75	0.27	0.34	98.20
AL50	86.33	0.38	0.00	0.27	1.31	0.00	8.90	0.00	0.30	97.49
AL66	87.06	0.48	0.00	0.56	0.00	0.00	9.12	0.00	0.38	97.60
AL5	83.41	0.56	0.20	0.23	1.46	0.00	11.13	0.13	0.39	97.51
AL45	86.60	0.69	0.00	0.50	1.10	0.00	8.63	0.00	0.27	97.79
AL4	86.11	0.98	0.00	0.90	0.92	0.00	9.22	0.08	0.61	98.82
AL4	85.13	1.03	0.00	1.08	0.86	0.00	9.19	0.08	0.16	97.53
AL6	80.48	1.77	0.34	0.22	2.18	0.10	11.77	0.33	0.33	97.52
AL53	84.90	1.92	0.00	0.08	1.05	0.06	10.21	0.17	0.73	99.12
AL24	85.21	2.20	0.00	0.32	0.60	0.00	8.97	0.00	0.30	97.60
AL16	82.65	2.74	1.24	0.88	1.49	0.00	7.96	0.00	0.36	97.32
AL13	85.61	2.76	0.00	1.63	0.40	0.00	8.23	0.00	0.66	99.29
AL54	83.78	3.57	0.00	0.28	1.26	0.00	9.36	0.00	0.00	98.25
AL32	82.97	3.91	0.07	0.51	1.09	0.00	8.68	0.00	0.36	97.59
AL8	82.99	3.93	0.13	0.36	1.32	0.09	8.99	0.08	0.63	98.52
AL15	83.37	4.40	0.00	0.18	1.66	0.00	8.40	0.00	0.60	98.61
AL20	82.52	4.51	0.00	0.21	1.52	0.07	9.25	0.09	0.32	98.49
AL7	83.29	5.00	0.00	0.28	0.92	0.00	8.84	0.08	0.30	98.71
AL36	81.05	5.51	0.07	0.10	1.47	0.08	9.27	0.09	0.29	97.93
AL14v	77.50	8.35	0.11	0.22	1.94	0.08	9.07	0.00	0.61	97.88
Al30a	78.00	9.85	0.15	0.29	1.91	0.13	7.86	0.00	0.46	98.65
Al13/5	78.20	11.15	0.00	0.27	1.26	0.00	6.31	0.00	0.82	98.01
AL30	73.72	13.92	1.00	0.25	2.22	0.16	7.54	0.00	0.47	99.28
AL14	71.53	14.36	1.10	0.07	2.27	0.30	8.37	0.08	0.61	98.69
AL14a	72.09	15.40	1.21	0.09	2.14	0.30	8.24	0.00	0.35	99.82
Tulameenite–tetraferroplatinum series, Pt_2CuFe										
AL54a	75.90	0.00	0.00	0.00	0.00	0.00	11.41	1.40	9.24	97.95
AL38	75.30	0.00	0.00	0.00	0.00	0.00	11.94	0.64	9.31	97.19
AL27	74.93	0.00	0.00	0.13	0.00	0.00	12.38	0.82	9.06	97.32
AL15/2	75.70	0.00	0.00	0.00	0.00	0.00	12.93	1.01	8.18	97.82
AL4A	74.38	0.64	0.00	0.00	0.12	0.06	13.06	2.64	6.50	97.40
AL10A	76.19	0.00	0.00	0.00	0.00	0.00	13.06	1.40	7.11	97.76
AL17	76.33	0.00	0.00	0.00	0.00	0.00	13.43	2.53	5.46	97.75
AL17a	77.04	0.00	0.00	0.00	0.00	0.00	14.36	2.53	3.90	97.83
Ir–Os–Pt alloy										
AL18	20.29	59.64	11.89	0.00	2.74	1.17	2.78	0.00	0.47	98.98
Al13/5c	46.44	39.27	11.98	0.00	1.26	0.62	3.24	0.00	0.25	103.06
AL18b	17.40	62.53	12.22	0.00	2.71	1.16	2.71	0.08	0.49	99.30
AL18c	14.83	63.20	12.43	0.00	2.89	1.21	2.25	0.07	0.50	97.38
AL18a	8.55	71.47	13.69	0.00	3.16	1.39	1.53	0.00	0.50	100.29
Al13/5d	21.79	54.10	17.51	0.00	1.99	0.89	1.69	0.00	0.25	98.22
Al13/5a	20.65	57.05	17.57	0.00	2.00	0.95	0.80	0.00	0.12	99.14
AL14b	13.34	62.97	17.62	0.00	3.36	1.38	0.88	0.00	0.45	100.00
AL14c	10.66	63.00	19.39	0.00	3.62	1.27	0.91	0.00	0.43	99.28
Al13/5b	17.10	59.29	19.94	0.00	2.00	0.87	0.69	0.00	0.21	100.10
Os–Ir alloy										
Al13v	1.62	25.90	71.09	0.00	0.39	0.18	0.08	0.00	0.00	99.26
AL53v	1.52	19.42	77.35	0.00	0.34	0.76	0.00	0.00	0.00	99.39
AL45v	1.51	10.69	84.15	0.00	0.77	1.85	0.08	0.00	0.00	99.05

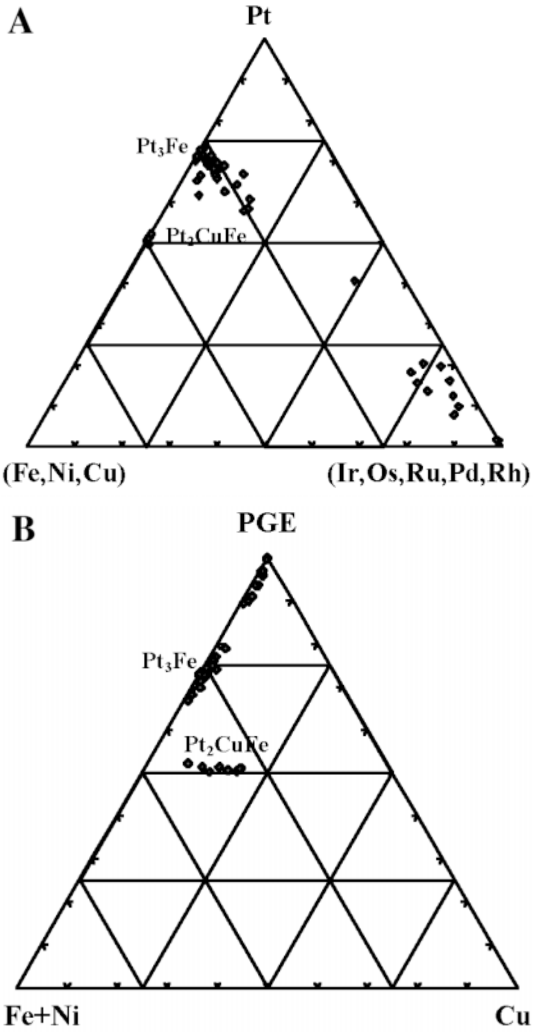

FIG. 3. Composition of Pt–Fe, Pt–Fe–Cu and Os–Ir alloys from the Goodnews Bay placer. A. Plots of alloy compositions on a (Fe,NiCu) – Pt – (Ir,Os,Ru,Pd,Rh) diagram, showing trend of differentiation between isoferroplatinum and iridium. B. Plots of composition of primary minerals without Cu and a series of secondary tulameenite compositions in terms of (Fe+Ni) – PGE – Cu.

TABLE 2. COMPOSITION OF IRARSITE FROM GOODNEWS BAY, ALASKA

Sample	Pt	Os	Ir	Rh	Ru	S	As	Total
1 wt%	16.26	7.4	39.91	0.48	0.39	6.90	27.82	99.16
2	15.09	0.00	38.74	3.84	0.89	8.84	29.22	96.62
3	2.54	9.14	48.09	2.30	1.02	15.82	17.68	96.59
4	3.11	14.34	46.64	1.18	0.14	16.32	16.55	98.28

1. $(Ir_{0.67}Pt_{0.27}Os_{0.13}Rh_{0.02}Ru_{0.01})_{\Sigma 1.10}As_{1.20}S_{0.70}$. 2. $(Ir_{0.61}Pt_{0.23}Rh_{0.11}Ru_{0.02})_{\Sigma 0.97}As_{1.18}S_{0.83}$. 3. $(Ir_{0.70}Os_{0.13}Rh_{0.06}Pt_{0.04}Ru_{0.03})_{\Sigma 0.96}As_{0.66}S_{1.38}$. 4. $(Ir_{0.68}Os_{0.21}Pt_{0.04}Rh_{0.03})_{\Sigma 0.97}As_{0.62}S_{1.41}$.

Bachmann 1999, Augé & Maurizot 1995). The Ir content of osmium ranges from 10 to 26 at.%, and the content of Os in iridium varies from 12 to 20 at.%. The levels of Pt concentration in osmium and iridium are quite different. Whereas the Pt content in osmium is 1.48–1.62 wt.%, the concentration of Pt in iridium reaches and even exceeds the limit of the solubility (21.79 wt.%, Table 1) at the maximum temperature of equilibration (~ 850°C) (Slansky *et al.* 1991). There are also compositions that plot within the imiscibility gap in the (Os + Ru) – (Pt + Fe) – (Ir + Rh) diagram (Fig. 5).

PGE sulfarsenides

Sulfarsenides of the PGE were detected in platinum nuggets from Goodnews Bay. Sulfarsenides replace

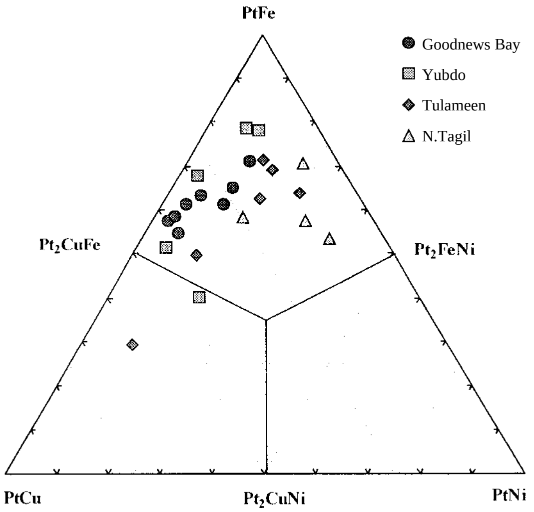

FIG. 4. Composition of the tulameenite–tetraferroplatinum series from the Goodnews Bay placer in terms of PtCu – PtFe – PtNi, in comparison with some occurrences in Alaskan-type complexes; Yubdo (Cabri *et al.* 1981, Evstigneeva *et al.* 1992), Tulameen (Nixon *et al.* 1990), Nizhne Tagil'skiy (Genkin 1997). Ideal compositions: tulameenite: Pt_2CuFe, tetraferroplatinum: PtFe, ferronickelplatinum: Pt_2FeNi.

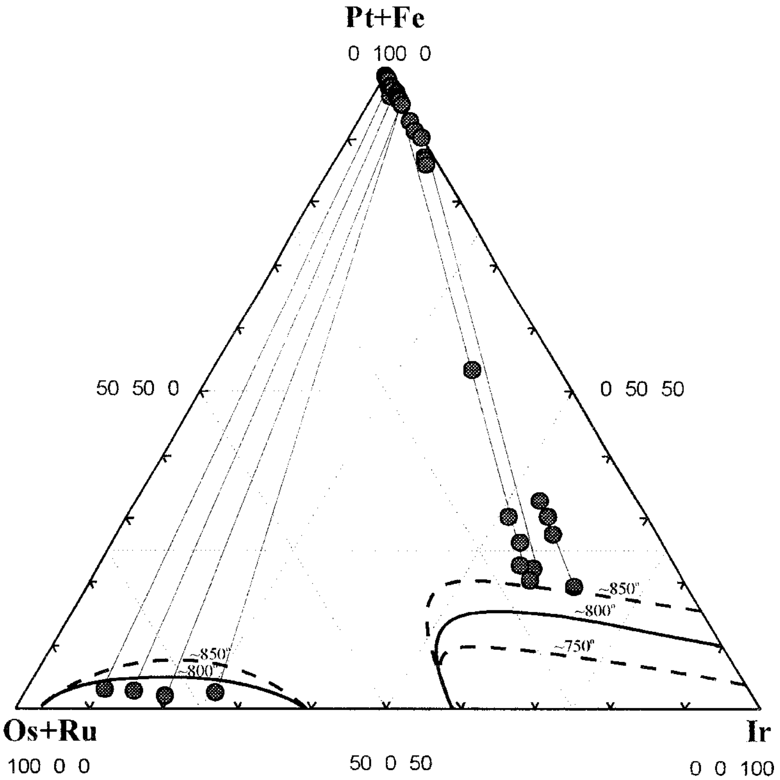

FIG. 5. Phase diagram for the system Os(+Ru) – Pt(+Fe) – Ir(+Rh) proposed by Slansky *et al.* (1991), showing two two-phase assemblages, compositions of which are connected by tie-lines. Isotherms delineate the solvus. Data points in the field iridium + isoferroplatinum imply a temperature of equilibration above 850°C.

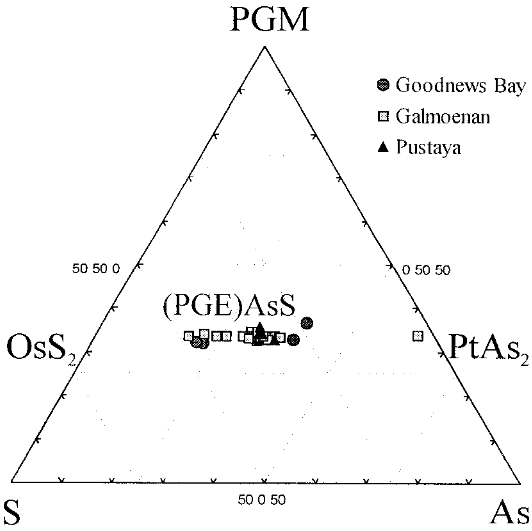

FIG. 6. Composition of the PGE sulfarsenide from the Goodnews Bay placer in comparison with those from the Pustaya (Tolstykh *et al.* 2000) and Galmoenan (Tolstykh *et al.*, in press) placers, plotted in terms of S – PGE – As proportions.

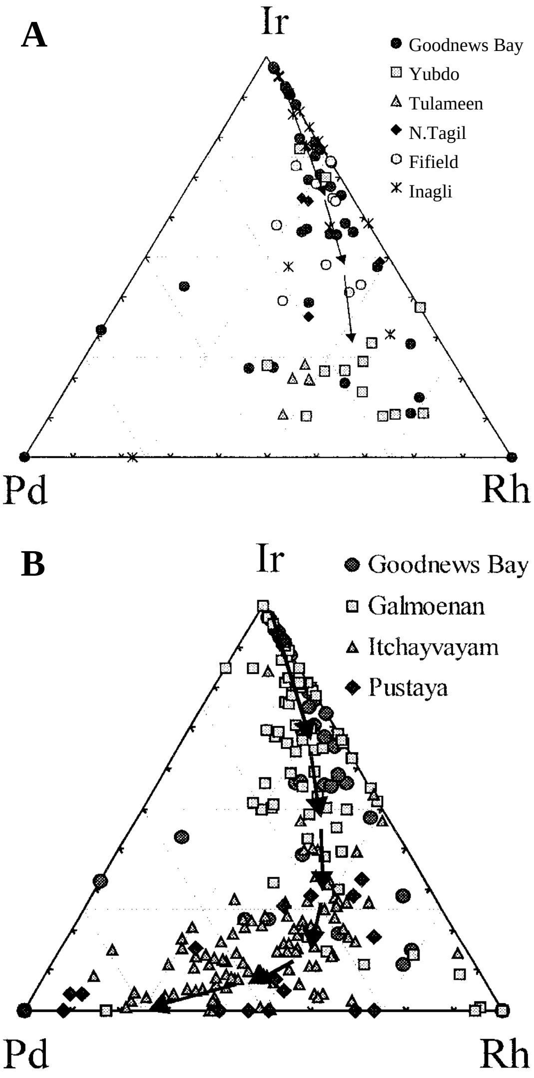

FIG. 7. Ratio of minor elements contents in isoferroplatinum from the Goodnews Bay placer in comparison with some other Alaskan-type occurrences (A), and the Kamchatka district (B). Arrows indicate the trend of the change of Pt–Fe alloy composition with decreasing temperature of ore formation.

tulameenite (Fig. 2D) and form a rim around isoferroplatinum (Fig. 2E). The PGE sulfarsenides correspond in composition to irarsite with platarsite and osarsite components (Table 2). There is a departure from stoichiometry involving S and As. Data points showing compositions of minerals from Goodnews Bay placer, Pustaya placer (Tolstykh *et al.* 2000) and Galmoenan (Tolstykh *et al.*, in press) define an incomplete solid-solution series $(PGE)S_2$–$(PGE)As_2$ (Fig. 6). It is interesting that As predominates over S in those cases where substantial Pt exists, and excess S is present in irarsite with high Os content. The trend can be explained by the introduction of Os as erlichmanite, OsS_2, and Pt as sperrylite, $PtAs_2$.

DISCUSSION

The isoferroplatinum–iridium association of the source rock of the Salmon River placer was formed by exsolution of the primary high-temperature Pt–Ir solid solution near a maximum temperature of equilibration of ~ 850°C. However, in some cases the exsolution process was incomplete, as some compositions approximate $Pt_{0.41}Ir_{0.35}Os_{0.11}Fe_{0.10}Rh_{0.02}Ru_{0.01}$, which is represented by the point in the center of the (Os + Ru) – (Pt + Fe) – (Ir + Rh) diagram (the miscibility gap) (Fig. 5). The levels of minor elements in Pt–Fe alloys reflect geochemical features of the ore-forming system at the source. They indicate a strong fractionation of PGE in the ore-forming system (Johan *et al.* 2000) and a difference in temperature of ore deposition, which decreases in the direction (Ir+Rh)-rich to Pd-rich PGE alloy (Slansky *et al.* 1991). The differences in content of minor elements in Pt–Fe alloy from several occurrences can be seen from Figure 7. Minor-element concentrations and their relationships in the Pt–Fe alloys vary from one occurrence to another, but in general a path can be seen from the Ir corner toward the Rh corner and then a bend to the Pd corner on the Pd–Ir–Rh diagram. Ir predominates in the Pt–Fe alloys in Goodnews Bay (this study), Inagli (Tolstykh & Krivenko 1997) and Galmoenan (Tolstykh *et al.*, in press) placers. However, the Goodnews Bay data show a wide range of compositions among Pt–Fe alloys, like in other occurrences of Alaskan-type complexes: Fifield (Slansky *et al.* 1991), Nizhne–Tagil'skiy massif (Genkin 1997), Tulameen (Nixon *et al.* 1990) and Yubdo (Evstigneeva *et al.* 1992, Cabri *et al.* 1981) (Fig. 7A). This range indicates a long thermal history for the Goodnews Bay mineral grains. The Pt–Fe alloys of the Itchayvayam placer, Koryakia region, Russian (unpubl. data) and Pustaya placer in Kamchatka (Tolstykh *et al.* 2000) are saturated with Rh and Pd and have a wide range in Rh–Pd in the lower part of the Ir–Rh–Pd diagram (Fig. 7B). Ir-rich platinum is a high-temperature alloy that formed together with Pt-rich iridium at (above) critical solvus temperatures (~850°C). If the temperature decreases from (Ir+Rh)-rich to Pd-rich nuggets, we can conclude that the Alaska-type alloys indicate diverse temperature conditions during the generation of the PGE alloys. Compositional variation and temperature range of alloy genesis decrease from Goodnews Bay and Inagli to Galmoenan, Fifield, Nizhne Tagil, next to Tulameen and Yubdo, and down to Pustaya and Itchayvayam. Alloy compositions of all Alaska-type occurrences compose a trend that reflects the evolution of the geochemistry of the Ir ⟶ Rh ⟶ Pd ore-forming system.

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