

## THE JOHNS - MANVILLE PLATINUM - PALLADIUM PROSPECT, STILLWATER COMPLEX, MONTANA, U.S.A.

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### ABSTRACT

Exploration initiated in 1967 has resulted in the discovery of a significant deposit of platinum-group elements in the Stillwater complex, an early Precambrian igneous intrusion in south-central Montana. The mineralization occurs in a horizon of sulfide-rich anorthositic rocks (plagioclase and plagioclase-bronzite cumulates) within the Banded Zone of the complex. The favorable horizon is essentially continuous over a strike length of 39 km. In the West Fork exploration adit, the average grade is 14.7 g/t (= p.p.m.) Pt+Pd and 0.15% Cu+Ni across a width of 1.9 m and over a strike length of 657 m. In another location, an average grade of 22.3 g/t Pt+Pd is indicated across a width of 2.1 m and along a strike length of 5.5 km. The average Pt:Pd ratio is 3.5 in each instance. The presence of mineralization is reflected by coincident soil geochemical, induced polarization and magnetic anomalies in most cases.

### SOMMAIRE

Un programme d'exploration lancé en 1967 a abouti à la découverte d'un important gisement de métaux du groupe du platine dans le complexe de Stillwater, massif intrusif du Précambrien inférieur, situé dans la partie centrale méridionale du Montana. La minéralisation se présente dans un niveau d'anorthosites riches en sulfures (cumulats de plagioclase ou de plagioclase + bronzite) dans la zone rubanée du complexe. Ce niveau favorable persiste sur une distance de 39 km. Dans la galerie d'exploration West Fork, la teneur moyenne est de 14.7 g/t (= p.p.m.) Pt + Pd et 0.15% Cu + Ni sur une largeur de 1.9 m et une distance de 657 m. A un autre endroit, on trouve une teneur moyenne de 22.3 g/t Pt + Pd sur une largeur de 2.1 m et une distance de 5.5 km. Aux deux endroits, le rapport Pt:Pd moyen est de 3.5. Dans la plupart des cas, des anomalies simultanées de trois types: (1) géochimique (dans le sol), (2) magnétique, et (3) polarisation induite, signalent la présence de la minéralisation.

(Traduit par la Rédaction)

### INTRODUCTION

A field exploration program initiated in 1967 by the Johns-Manville Corporation has resulted in the discovery of significant occurrences of platinum-group elements (PGE) in the Stillwater complex, an early Precambrian stratiform igneous rocks which extend for a strike length of longitude 110°00' W in south-central Montana. This paper briefly describes the geological setting of the mineralization and the methods of exploration that led to its discovery.

The Stillwater complex comprises a differentiated sequence of layered mafic and ultramafic igneous rocks which extend for a strike length of 48 km and have a maximum exposed thickness of 7.4 km (Fig. 1). The igneous layering generally strikes west-northwest and dips moderately to steeply northward. The facing of the layers is also to the north. Along its lower (southern) margin the intrusion is in contact with older (> 3140 m. y.) hornfelsed metasedimentary rocks and younger intrusive quartz monzonite (2750 m. y.) which bracket the age of emplacement of the Stillwater magma (Nunes & Tilton 1971, Page 1977). The upper part of the complex is overlain unconformably by Phanerozoic sedimentary rocks so that the original vertical extent of the intrusion is not known. In addition to the aforementioned early Precambrian quartz monzonite, the complex is intruded by late Precambrian diabase and by Tertiary granitic rocks. The Stillwater complex is cut by numerous north- or northeast-trending transverse faults and west-northwest-trending thrust and ramp faults, most of which probably developed during the Laramide orogeny (Jones *et al.* 1960).

The nature of the igneous layered sequence as described by Jones *et al.* (1960) is outlined in Table 1. The subdivision summarized here differs somewhat from that of Hess (1960), particularly with regard to the Banded and Upper Zones; these have not been as thoroughly studied as the Basal and Ultramafic Zones.

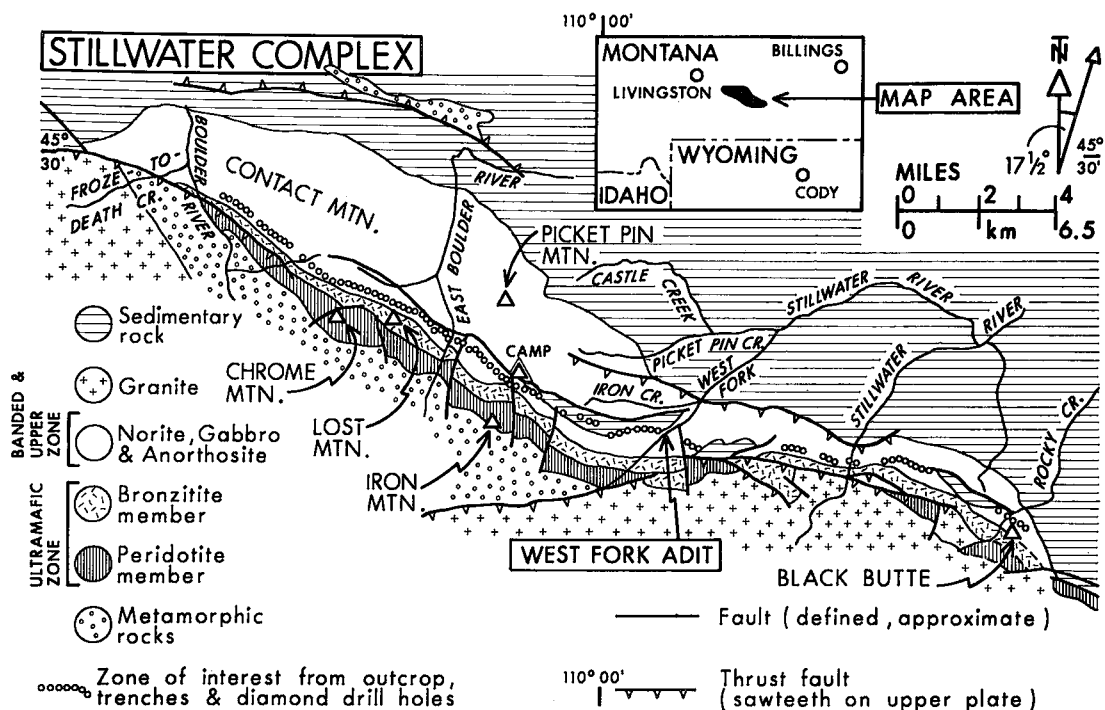


FIG. 1. Geological map of the Stillwater complex indicating position of ZOI mineralized horizon.

Concentrations of chromite in the peridotite member of the Ultramafic Zone have been exploited to a limited extent in the past. Magmatic nickel-copper sulfide deposits occur in the Basal Zone of the intrusion (Page & Simon 1978). The platinum-group-element mineralization outlined by the Johns-Manville Corporation is localized for the most part in the Banded Zone, with less important quantities occurring in the upper part of the bronzitite member of the Ultramafic Zone.

#### PLATINUM-GROUP-ELEMENT MINERALIZATION

PGE mineralization has been recognized in four settings within the Stillwater complex: (1) The first interesting PGE occurrence discovered as part of the Johns-Manville program is associated with the contact between the rocks of the complex and a younger intrusive granite stock south of Picket Pin Mountain (Fig. 1). A bulk sample of this material assayed 5.1 g/t (= p.p.m.) Pt, 3.4 g/t Pd, 0.4 g/t Rh, 0.24% Ni,

TABLE 1. SEQUENCE OF LAYERED IGNEOUS ROCKS IN THE STILLWATER COMPLEX\*

Zone	Member	Thickness	Characteristics
Upper Zone		2040 m	Anorthosite, gabbro, troctolite; lower boundary marked by appearance of olivine as cumulus mineral
Banded Zone		2255	Anorthosite, norite, gabbro; lower boundary marked by appearance of plagioclase as cumulus mineral; rhythmic layering
	Bronzitite	305	Bronzitite, essentially a single layer
Ultramafic Zone	Peridotite	915	Harzburgite, dunite, bronzitite, chromitite; rhythmic layering
Basal Zone		60	Noritic rocks, medium-grained, variable textural relations

\*Jones et al. (1960)

0.03% Cu and 5% Cr<sub>2</sub>O<sub>3</sub>. (2) PGE mineralization occurs in coarse-grained bronzitite at the upper contact of the bronzitite member of the Ultramafic Zone. The 'Janet 50' zone, an example of such mineralization, occurs about 1 km NE of Iron Mountain (Fig. 1). The surface area of the showing is approximately 30 x 150 m and the average grade is 0.24% Ni+Cu and 2.7 g/t Pt+Pd with Pt:Pd from 1 to 2. Dr. L.J. Cabri (pers. comm. 1974) found that the principal opaque minerals in a bulk sample from this zone are pyrrhotite, pentlandite and pyrite with lesser chalcopyrite and minor galena, sphalerite, violarite, arsenopyrite, magnetite, gold, merenskyite/kotulskite, moncheite, sperrylite, graphite and Ag-Sb. A significant proportion of the platinum-group minerals (PGM) occurs as inclusions in pyrrhotite. Palladium is also found in solid solution in pentlandite. (3) A large lens of bronzitite, possibly a cognate xenolith, occurs within the Banded Zone and contains mineralization similar to that at the upper contact of the bronzitite member, with the addition of Pt-Rh and Pt-Fe alloys (Cabri & Laflamme 1974), braggite and Pd arsenides including stillwaterite. This has been designated the 'Janet 55W' zone; grades of 7.2 g/t Pt+Pd were obtained across widths of 1.5 to 3 m. The mineralized zones are discontinuous. (4) The most important PGE mineralization found to date occurs in a sulfide-rich horizon in the Banded Zone some 335 to 425 m above the upper contact of the bronzitite member. The horizon is essentially continuous, with an indicated strike length of 38.6 km and a true width typically on the order of 1.8 m. The mineralization in the zone of interest (ZOI) occurs mainly in dark-colored anorthositic rocks characterized by grey cumulus plagioclase and oikocrysts of ortho- and clinopyroxene. Sulfide and associated minerals occur principally as finely disseminated grains but also as globules up to several cm in diameter and as minute interstitial veins. The most abundant sulfide minerals are pentlandite, chalcopyrite and pyrrhotite. Sphalerite, galena, millerite and marcasite occur in minor amounts whereas covellite, native copper, stibnite, argentian tetrahedrite, magnetite, graphite, gold and palladian gold are observed even less commonly. The principal PGM are, in order of decreasing abundance, braggite, vysotskite, moncheite and Pt-Fe alloy, with minor or rare amounts of cooperite, stillwaterite, arsenopalladinite, palladobismutharsenide, palladoarsenide, kotulskite, zvyagintsevite, Pd-tellurides, merenskyite and sperrylite (L.J. Cabri, pers. comm. 1974, 1976). A significant

proportion of the palladium is also present in solid solution in pentlandite (E.W. Nuffield, pers. comm. 1974, 1975; L.J. Cabri, pers. comm. 1974). Estimated grade in the ZOI exposed in the exploration adit is 14.7 g/t Pt+Pd with Pt:Pd = 3.5 and 0.15% Cu+Ni over a strike length of 657 m and a true width of 1.9 m. In another part of the ZOI explored by shallow diamond drilling, a grade of 22.3 g/t Pt+Pd with Pt:Pd = 3.5 is indicated over a strike length of 5.5 km and a true width of 2.1 m.

A layer of 'troctolite' with up to 70% cumulus olivine, 20% intercumulus pyroxene and the balance intercumulus plagioclase, normally occurs below the anorthositic rocks that contain the mineralization. As the olivine in the troctolite is generally serpentinized, the rock is highly magnetic and serves as a useful marker horizon in magnetometer surveys.

#### EXPLORATION METHODS

The decision was taken in 1962 to investigate the feasibility of an exploration program aimed at discovering deposits of the platinum-group elements. The Stillwater complex was selected as a favorable area for exploration on the basis of (a) its similarity to the well-known Bushveld complex in South Africa, (b) reference by Howland *et al.* (1936) to an occurrence of PGE in what is known now as the Banded Zone, and (c) the reported occurrence of sulfide horizons, also in the Banded Zone (Hess 1960). The field program was initiated in 1967 and has involved an expenditure, exclusive of salaries, of about 7 million dollars through 1977. The chronology of exploration activities is summarized in Table 2. A variety of exploration methods has been employed, including traditional prospecting, geological mapping, soil and silt geochemistry surveys, magnetometer surveys, induced polarization (I.P.) surveys, very low-frequency electromagnetic survey (VLF EM), trenching, diamond drilling and underground exploration.

One of the principal reasons for the success of the exploration program was the development in 1968 of sensitive techniques for the analysis of Pt and Pd in soils by Bondar-Clegg Company of Ottawa. Reconnaissance silt and soil geochemical surveys resulted in the identification of numerous anomalies related to sources in the Banded Zone. For example, in the area west of the East Boulder River, background concentrations in the soils were less than 30 ppb Pt and 10 ppb Pd whereas ano-

malous stations gave maximum values of 265 ppb Pt and 193 ppb Pd. These regional anomalies were in general followed up with more detailed soil sampling, time-domain I.P. and magnetometer surveys. In one case, the regional anomaly was found to result from mineralized boulders (*i.e.*, glacial 'float') which in turn were traced 800 m up-ice to their source in what became designated as the 'Janet 50' zone. The results of a detailed soil geochemistry traverse over the 7.6 m wide C-602 mineralized zone, which

assayed 15.4 g/t Pt+Pd with Pt:Pd = 2.5, are summarized in Table 3.

The results of the geochemical and I.P. surveys over the 'Janet 96W' zone, part of the zone of interest (ZOI), are illustrated in Figure 2. The superimposed soil chemistry and I.P. chargeability anomalies clearly outline the mineralized zone in the bedrock. In general, background I.P. chargeabilities are on the order of 1 to 3 milliseconds whereas anomalies are 3.5 to 8 milliseconds.

TABLE 2. SUMMARY OF THE EXPLORATION HISTORY OF THE JOHNS-MANVILLE Pt-Pd PROSPECT

<u>Year</u>	<u>Expenditure</u>	<u>Activity</u>	<u>Results</u>
1962-66	-	Literature search	Selection of Stillwater complex as favorable target area on basis of similarity to Bushveld complex and reported presence of PGE
1967	\$ 2,500	Preliminary sampling of known disseminated sulfide mineralization, soil sampling	Low to negligible assays, no significant anomalies
1968	19,000	Reconnaissance mapping, prospecting & soil sampling south of Picket Pin Mountain Regional stream geochemistry	Discovery of mineralization at contact of gabbroic rocks with younger granite Anomalies related to a source in the banded zone in the Iron Creek area
1969	77,000	Reconnaissance soil geochemistry, mapping, magnetic surveys, prospecting	Numerous small, erratic soil anomalies in the Iron Creek area
1970	81,000	Overburden trenching of soil geochemical anomalies Regional soil geochemical surveys	Discovery of sulfide-rich c.-g. bronzitite boulders in till Numerous anomalies, especially west of East Boulder River
1971	80,000	Boulder tracing to locate source of sulfide-rich boulders found in 1970  Mapping, trenching, sampling of Janet 50 zone Regional soil geochemical survey of western part of complex	Source area of boulders near upper contact of upper bronzitite, mineralized outcrop found during line cutting in preparation for I.P. survey of Janet 50 zone  Numerous anomalies
1972	237,000	Mapping, trenching, sampling & drilling of Janet 50 discovery area I.P. survey of Janet 50 area  Detailed magnetic, geochemical & I.P. surveys of area found to be anomalous during reconnaissance surveys (Janet 55W zone)	Numerous sulfide-rich zones located in c.-g. bronzitite Anomaly (70 ms) related to graphite-rich bronzitite Numerous geochemical/geophysical anomalies
1973	568,000	Drilling and trenching of composite geochemical/geophysical anomalies in Janet 55W zone Trenching of superimposed magnetic/soil geochemical/I.P. anomalies in Janet 96W zone Drilling of magnetic/soil geochemical/I.P. anomalies near Janet 96W zone	Zone of discontinuous sulfide mineralization in c.-g. bronzitite outlined Exposure of 2-3% disseminated sulfide in pegmatoidal bronzite troctolite Discovery of main mineralized band ZOI (zone of interest) in lower norite unit
1974	1,004,000	Reconnaissance & detailed geochemical surveys, mapping & prospecting to evaluate extent of ZOI along strike Bulk sampling of ZOI for metallurgical testing Commencement of exploration adit	Strike length of ZOI estimated to be 41.8 km Satisfactory recoveries of Cu, Ni, Pt and Pd indicated
1975	2,527,000	Continuation of underground exploration  Surface exploration, deep drilling	Adit driven 855 m, 365 m of raises & crosscuts completed. Underground diamond drilling totaled 745 m. ZOI delineated further
1976	1,530,000	Underground exploration terminated Metallurgical bench tests	Recovery of 85% Pt+Pd, 68% Ni, 75% Cu
1977	855,000	Drilling and surface exploration of ZOI	Confirmation of the presence of a high-grade zone 5.5 km long x 2.1 m wide, averaging 22.3 g/t Pt+Pd

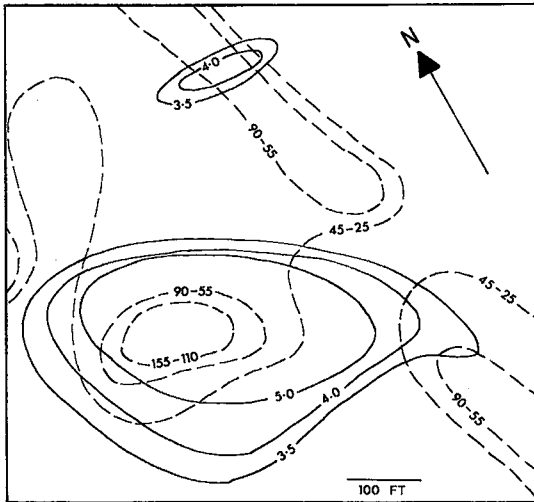


FIG. 2. Geochemical and induced polarization anomalies associated with Janet 96W mineralized zone. Dashed contours indicate ppb Pt — ppb Pd in soil. Solid contours indicate induced polarization chargeabilities in milliseconds.

The results of surface exploration activities were sufficiently encouraging to warrant initiation of underground exploration in 1974. An adit was driven into the north wall of the West Fork canyon (Fig. 1), the most accessible and geographically favorable location known at the time. This was undertaken in order to (a) establish the width, grade and continuity of the ZOI, (b) test mining and stoping methods, and (c) mine a large bulk sample (110 tons) for metallurgical testing. These results were favorable.

Metallurgical bench tests demonstrated that an acceptable sulfide concentrate averaging 2 to 3% of the milled 'ore' could be produced by flotation. Recoveries were in excess of 85% for Pt and Pd, 68% for Ni and 75% for Cu. Gold, silver and PGE other than platinum or palladium amount to approximately 2.3% of the total PGE content of the sulfide concentrate. Electric furnace melting produced a low-grade matte with only minor loss of economic metals to the slag. Similarly, hydrometallurgical refining of the matte yielded saleable copper and nickel precipitates, and acceptable products for PGE refinery feed with only minor losses.

#### CONCLUSION

The ZOI horizon in the Banded Zone of the Stillwater complex constitutes an important deposit of platinum-group metals. The ZOI appears

TABLE 3. GEOCHEMICAL TRAVERSE ACROSS C-602 MINERALIZED ZONE

Station	Distance	ppm Cu	ppm Ni	ppb Pt	ppm Pd
C-600	0 m	25	123	20	40
C-601	30	80	250	110	375
C-602	60	168	480	1670	2575
C-603	90	119	375	220	425
C-604	120	43	160	30	9
Local background		48	123	45	25

to be essentially continuous along 39 km of strike length and is typically 1.8 to 2.1 m thick. The grade of mineralization exposed in the exploration adit averages 14.7 g/t Pt+Pd and 0.15% Cu+Ni across 1.9 m and over a strike length of 657 m. In another locality, an average grade of 22.3 g/t Pt+Pd is indicated by diamond drilling across a width of 2.1 m and along a strike length of 5.5 km. The average Pt:Pd ratio is 3.5. These grades are 2 to 4 times those typical of the Merensky Reef in the Bushveld complex of South Africa.

#### ACKNOWLEDGEMENTS

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