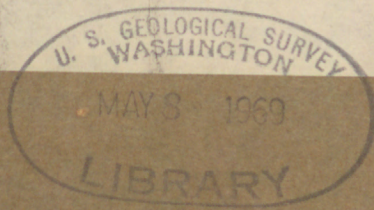


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PRELIMINARY REPORT ON SULFIDE AND PLATINUM-GROUP  
MINERALS IN THE CHROMITITES OF THE STILLWATER  
COMPLEX, MONTANA

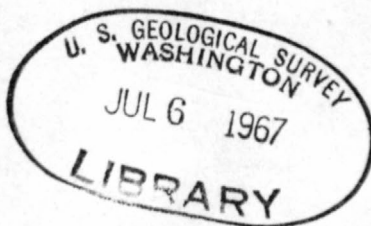
by

NORMAN J PAGE and EVERETT D. JACKSON

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Preliminary report on sulfide and platinum-group minerals

in the chromitites of the Stillwater Complex, Montana

By Norman J Page and Everett D. Jackson, Menlo Park, Calif.

5-     Abstract.--Platinum-group minerals, previously known to occur in  
the layered gabbros of the Banded and Upper zones of the Stillwater  
Complex, have been found in the Ultramafic zone as well. Laurite and  
other complex platinum-group sulfides and sulfarsenides are present in  
at least four of the chromitite zones of the Peridotite member. The  
10- economic potential of these occurrences cannot be evaluated at the  
present time, but the possibility of obtaining platinum-group metals as  
a byproduct of chrome mining operations should not be overlooked in the  
future.



The geochemical affinity of the platinum-group metals for layered intrusions of mafic and ultramafic igneous rocks is well documented (Wright and Fleischer, 1965). These metals occur predominantly as sulfide minerals or as alloys spatially associated with sulfide minerals. The presence of sulfide minerals along the base of the Stillwater Complex was known as early as 1883 (Roby, 1949). Although assay values for platinum-group metals have been obtained on samples from these basal rocks (Howland, 1933; Howland and others, 1936), no platinum-bearing minerals have as yet been identified. Sulfide minerals, including the platiniferous mineral sperrylite and the palladium-bearing mineral stibiopalladinite, have also been described in the layered gabbros of the Banded and Upper zones of the complex, and have been compared with similar occurrences in the Merensky Reef of the Bushveld Complex in South Africa (Howland and others, 1936). Sulfide minerals in the Ultramafic zone of the Stillwater Complex, which forms the stratigraphic unit separating the basal rocks from the Banded and Upper zones, have not previously been reported.

Acknowledgment.--The authors are grateful to Michael Fleischer, of the U.S. Geological Survey, for the translation from the Russian original of the paper by Genkin and others (1966).



## SULFIDE MINERALS IN THE ULTRAMAFIC ZONE

Jackson (1961) has divided the Ultramafic zone into two stratigraphic units--a lower, Peridotite member, and an upper, Bronzitite member (fig. 1). Scattered individual blebs and small

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Figure 1 near here

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grains of sulfide minerals have been observed in all the ultramafic rock types of both members, from the Benbow area in the east to the Gish area in the west. Field observations suggest, however, that these sulfide minerals are concentrated in the chromitite zones of the Peridotite member (fig. 2).

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Figure 2 near here

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Thus far, we have found sulfide minerals to be present in the A and B chromitite zones in the Benbow and West Fork areas, in the G zone in the Nye Lip, Mountain View, West Fork, and Gish areas, in the H zone in the Mountain View and Chrome Mountain areas, in the I and J zones in the Mountain View and West Fork areas, and in the K zone in the Nye Lip and Iron Mountain areas (fig. 2). In a few places the sulfide minerals form massive pods subparallel to the footwalls of the chromitite layers, replacing all the silicate minerals and surrounding the chromite grains with a mesostasis of poikilitic sulfide "cement." Most generally, however, they occur as isolated polymineralic aggregates replacing the silicate minerals in the chromitites or, more rarely, as inclusions in the chromite grains.



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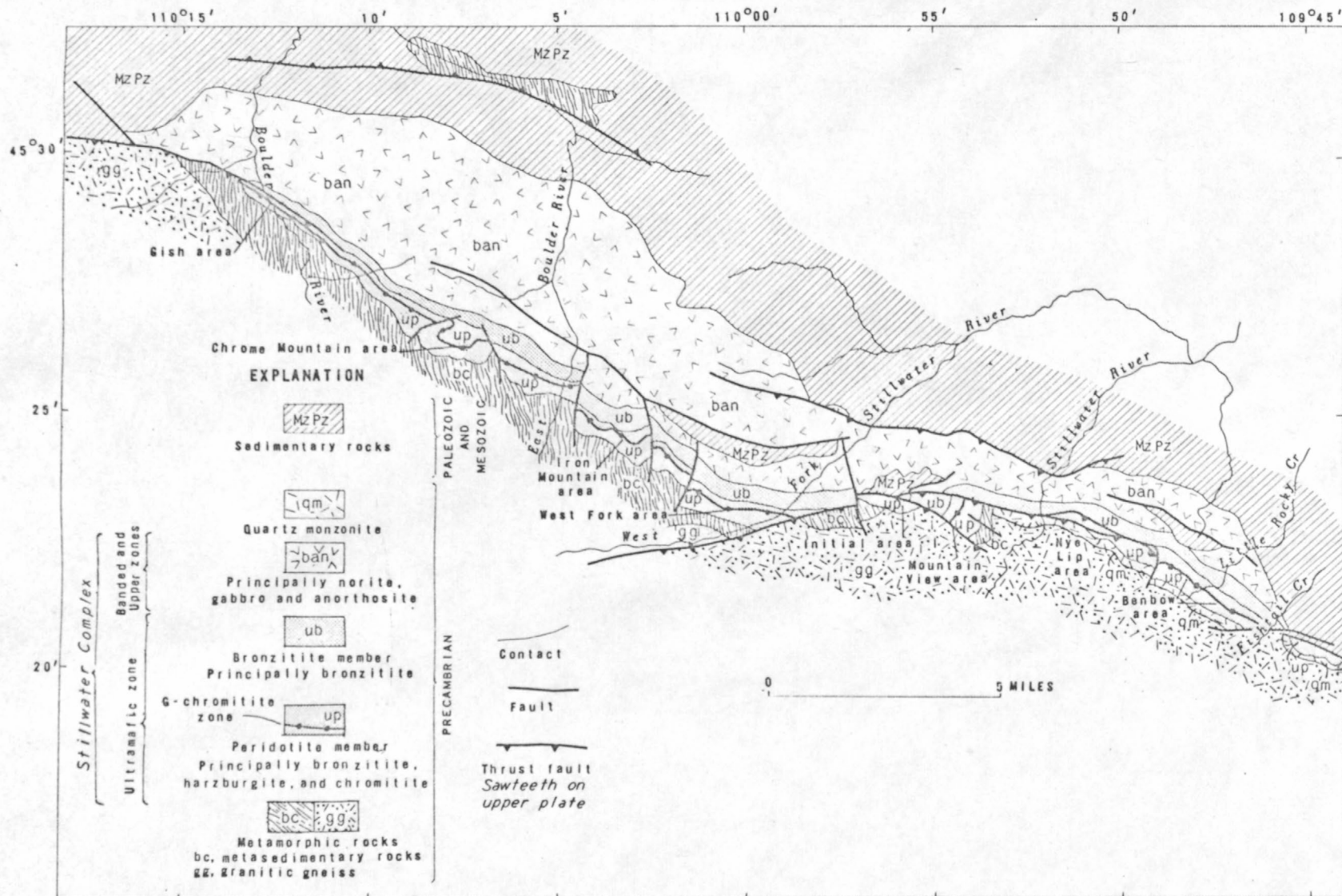
Figure 1.--Geologic index map of the Stillwater Complex.

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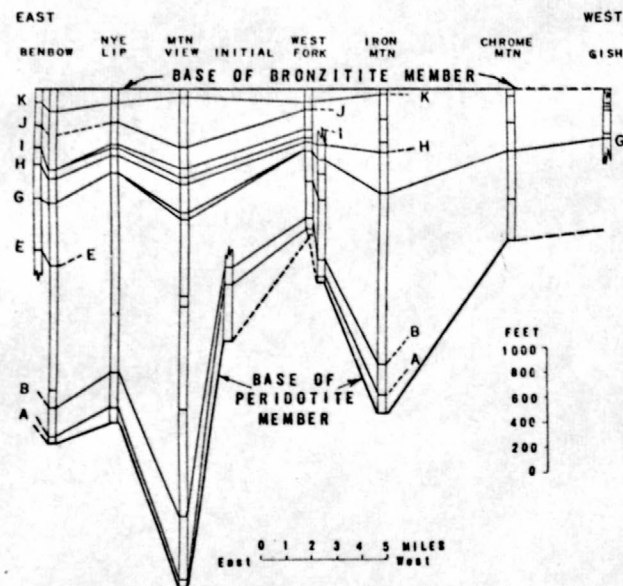




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Figure 2.--Correlation diagram showing the chromitite zones in the Peridotite member of the Ultramafic zone. Zones are lettered alphabetically from bottom to top of the section.





The most abundant sulfide minerals in the chromitites are pyrrhotite, chalcopyrite, and pentlandite, which are also abundant in the basal rocks and in the Banded and Upper zones (Howland and others, 1936). Electron-microprobe analyses indicate that the range in composition of pyrrhotite is at least from  $\text{Fe}_{0.96}\text{S}$  to  $\text{Fe}_{0.93}\text{S}$ . Several types of pyrrhotite are present in some single chromitite layers and can be distinguished from one another by their relative Fe content and textural appearance. The pentlandite contains only minor amounts of Co and has a Ni to Fe ratio of approximately one to one.

Other sulfides and arsenides are present, but appear to have a scattered and limited distribution. These include a member of the cobaltite group, niccolite, a tin arsenide, molybdenite, and pyrite. Complex arseno-sulfo-seleno-antimonide minerals have also been found, but their exact identification has not been completed.

The cobaltite-group mineral has heretofore never been described from the Stillwater Complex. Thus far we have observed this mineral in the A-zone and G-zone chromitites and among the sulfides at the base of the complex as well. Uncorrected electron microprobe analyses suggest the following range of composition, in weight percent:

20 - 22 percent Co, 9 - 11 percent Ni, 7 - 8 percent Fe, 16 - 18 percent S and 43 - 49 percent As. Compared with a similar gerdorsffite from Sudbury, Ontario (Hawley, 1962), the Stillwater cobaltite-group minerals contain a greater amount of Co and less Ni.



5- Niccolite, also previously unknown in the complex, has been found in the A-zone chromitites, but only in small (5 - 25 micron diameter) polyminerale inclusions in chromite. These inclusions are commonly composed of three phases, having pyrrhotite and chalcopyrite in addition to niccolite. They occur in groups of 5 to 15 per grain, tend to be located near centers of chromite grains, and usually have no visible connections with grain boundaries. Silicate inclusions in the chromites are commonly associated with these sulfide inclusions in the same samples.

10- A light-gray tin arsenide with moderately low reflectivity has been found in isolated grains 5 to 50 microns in diameter, apparently replacing silicates in the G- and H-zone chromitites. This mineral, from microprobe analyses, appears to have the composition  $\text{Sn}_3\text{As}_2$ , but further work is needed to characterize its composition and physical properties completely.

15- Molybdenite, also previously unknown in the complex, is present as small sparsely disseminated grains in the G, H, and K chromite zones.

## PLATINUM-GROUP MINERALS IN THE CHROMITITE ZONES

Platinum-group minerals have been observed in the B chromitite zone of the Benbow area, in the G and H zones of the Mountain View area, and in the K zone of the Iron Mountain area. Their presence is also indicated by unpublished assay data from a chromitite very low in the section in the Chrome Mountain area. Thus far, the platinum-group minerals have been recognized only in chromitites and not in peridotites or bronzitites in the Ultramafic zone, and, furthermore, they have been recognized only in those chromitites that contain the more common Fe-, Ni-, and Cu-bearing sulfide minerals.

Texturally, all the platinum-group minerals thus far examined occur as isolated grains, either in the interstitial silicate minerals of the chromitites, or in the chromite grains themselves. They have not been seen in contact with other sulfide minerals, so that their paragenesis cannot be established at this time.

Laurite ( $\text{RuS}_2$ ), also containing Os and Ir, occurs as diamond-shaped inclusions (20-50 microns in diameter) in chromite from the B, G, H, and K chromitite zones. Its identification was confirmed by qualitative electron-microprobe analyses, and it appears to be quite similar to the osmium-rich variety described by Stumpfl and Clark (1964/65) in gold-platinoid concentrates from southeast Borneo.



Other complex platinum-group sulfides and sulfarsenides have been recognized with the microprobe in samples from the G and H chromitite zones. One of these minerals is an Os-Ir-Pt-Ni sulfide in which the metals are listed in order of decreasing abundance based on relative X-ray peak heights from microprobe wavelength scans. Another platinum-group mineral is a complex sulfosalt containing Sn, Os, Ir, Cu, and traces of Pt and Pd. Both minerals are present as 5 - 20 micron grains. Not enough work has been done to characterize these minerals completely, but they seem similar to platinum-group minerals described by Stumpfl (1961) from the Bushveld Complex and by Stumpfl and Clark (1965) from the Driekop mine, by Kingston (1966) from the Rustenberg and Union mines in the Merensky Reef, and by Genkin and others (1966) from the Onverwacht deposits.

We have not as yet identified platinum-group alloys in the Stillwater Complex, but in view of their common occurrence in the Bushveld Complex (Cousins, 1964), we plan to look for them.

## ORIGIN OF SULFIDE MINERALS IN THE ULTRAMAFIC ZONE

The close association of the sulfide minerals in the Ultramafic zone with the chromitite zones is similar to the distribution of the gabbro pegmatites (Jackson, 1961). It may be that they were localized  
5- in much the same way, by the relative impermeability of the fine-grained chromitites to the passage of liquid phases upward through the crystal pile. On the other hand, the chromitites do lie near the bases of the cyclic units of the Ultramafic zone (Jackson, 1961), and it is conceivable that they represent mattes precipitated by the individual  
10- batches of magma that formed the cyclic units.



## ECONOMIC CONSIDERATIONS

These sulfide minerals, other than those containing platinum-group metals, have no economic potential at this time. The possibility of economic recovery of the platinum-group minerals is more difficult to evaluate. Similar occurrences have been reported in chromitites in the Bushveld Complex, and platinum assays as high as 0.6 ounces per ton have been reported there. However, the values have been spotty and difficult to reproduce, and Wagner (1929, p. 96) said of them "it appears doubtful whether they will ever be worked for their platinum contents." Nevertheless, the Stillwater chromitites have been mined for chrome ore in the past, and about a million tons of concentrates have been produced (Jackson, 1963). In the future, the possibility of obtaining byproduct platinum-group metals during chrome mining operations should not be overlooked.

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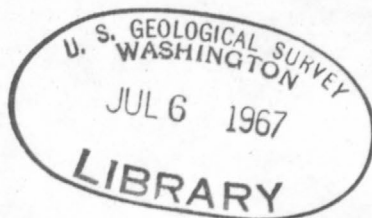
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1. A preliminary report on sulfides and platinum-group minerals in the chromitites of the Stillwater Complex, Montana, by Norman J Page and Everett D. Jackson. 10 p., 2 figs. On file at 15426 Federal Bldg., Denver, Colo. 80202; 8102 Federal Office Bldg., Salt Lake City, Utah 84111; South 157 Howard St., Spokane, Wash. 99204. Copy from which reproduction can be made at private expense is available in the Spokane office.

2. Geology of the Upper St. John and Allagash River Basins, Maine, by Eugene L. Boudette, Norman L. Hatch, Jr., and David S. Harwood. 77 p., 2 pl., 2 figs., 2 tables, and 14 sheets of appendix (13 maps plus 1 expl.). Scale, 2 at 1:250,000 and 13 at 1:62,500. On file in Room 1, 270 Dartmouth St., Boston, Mass., 02116; Office of the State Geologist, Dept. of Economic Development, Div. of Geology, State House, Augusta, Me. 04330.

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