ORE MICROSCOPY AND CHEMICAL COMPOSITION OF SOME LAURITES[1]

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Abstract

Quantitative ore-microscopic properties of laurite are defined from a study of five laurites from Borneo, from Goodnews Bay, Alaska, and from the Stillwater Complex, Montana. Laurite is white, rather bright, isotropic, and hard, probably having {001} parting. It is negative to standard etch reagents. For Goodnews Bay laurite, $(Ru_{1.01}Ir_{0.01})S_{1.99}$, R_{air} at 470, 546, 589, and 650 nm is 47.8, 42.5, 40.3, and 37.2%, respectively; quantitative color designation derived from R is $Y=42.1$, $x=0.292$, $y=0.299$; mean $HV_{25}=3150$. For Borneo laurite, $\sim(Ru_{0.6}Ir_{0.2}Os_{0.3})S_{1.9}$, $R_{air}=45.8$, 41.8, 40.3, and 38.2% at standard wavelengths; $Y=41.6$, $x=0.296$, $y=0.303$; mean $HV_{25}=2870$; cell edge $a=5.6135\pm0.0025$Å. Microprobe analyses indicate that a series of laurites exists between the extreme members noted above. As Ru in the laurites decreases, both Ir and Os increase. Similar compositional variation is shown by an unidentified platinoid alloy that accompanies Goodnews Bay laurite. The rather large change in composition, in which Ir+Os proxies for 0.4 Ru atom, produces slight but measurable changes in the quantitative properties of these laurites. The high microindentation hardness of laurite seems to distinguish the species from other optically isotropic minerals whose R_{air} in the middle of the visible spectrum is about 40%.

Introduction

Laurite is the natural cubic ruthenium sulfide, RuS_2. It occurs with other minerals of the platinum-group metals in ultramafic complexes and in placer deposits. Laurite is a source of ruthenium metal, which because of its hardness is alloyed with other metals of the platinum group to produce long-wearing electrical contacts.

Laurite was originally described from platinum-bearing sands of Borneo by Wöhler (1866) and Sartorius von Waltershausen (1866). Stumpfl and Clark (1965a, p. 935) found laurite "in very insignificant amounts only" in their samples of gold-platinoid concentrates from southeast Borneo. They analyzed and described from their samples another natural form of RuS_2—noncubic, containing considerable Ir and Os—for which they did not propose a formal name. Knop (1966) suggested that this unnamed anisotropic mineral might be a mixture of laurite and iridosmine, irresolvable by microscope and microprobe. However, Knop's suggestion is not consistent with the facts originally reported by Stumpfl and Clark (1965a) for their anisotropic, twinned mineral having $R_{white} \sim 60$–65 percent and $HV_{100}=1270-1450$, mean 1380. Hulliger (1964) and Parthé, Hohnke, and Hulliger (1967) have

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found that various synthetic sulfides of platinum-group metals are non-cubic, though some of these substances also have cubic dimorphs. The metal:sulfur ratio of these substances is $1:\sim3$, $1:2$, and $2:3$. We think it plausible to suppose that Stumpfl and Clark's noncubic Ir-Os-bearing RuS_2 mineral may be related to one or another of these synthetic non-cubic platinoid sulfides.

Laurite in platinum concentrates from the Merensky Reef of the Bushveld Complex, at Potgietersrust, was identified by Bannister and Hey (Bannister, 1932) as the climax of a mineralogic detective story in which the principal clue was provided by L. J. Spencer's recognition that the supposedly orthorhombic crystal forms of Potgietersrust "cooper-ite" figured in a paper by Adam (1931) were those of a cubic substance (Spencer, 1932) that Bannister and Hey later showed was laurite. Laurite has since been found in the Merensky Reef at Rustenburg (Cousins, 1964; Kingston, 1966b, p. 818, "rare") and at the Union mine (Cousins, 1964; Kingston, 1966b, p. 818, "common"). Outside the Merensky Reef but within the Bushveld Complex, in platinum-bearing pipes, laurite occurs at Driekop (Stumpfl, 1961, p. 836, "rather rare") and at Onver-wacht (Ramdohr, 1950, p. 815).

Betekhtin (1961, p. 16) suggested that laurite might be present locally in some of the primary platinum ores of the Urals, presumably at Nizhnyi Tagil.

Razin (Rozhkov and others, 1962, p. 73–76) described laurite from the platinum-bearing Inaglinsk alkalic ultramafic massif and from asso-ciated alluvial deposits at Inagli Creek, Aldan upland, Yakutsk ASSR.

Whether Ottemann and Augustithis (1967) actually observed laurite in the platinum-bearing nuggets from Ethiopian laterite, their account does not clearly state.

The occurrence of laurite in chromitites of the B, G, H, and K zones of the Stillwater Complex, Montana, was recently reported by Page and Jackson (1967, p. D125), and Desborough has found laurite in concen-trates from the Goodnews Bay platinum placer deposits, Alaska. The geology and chemical composition of the Goodnews Bay deposits were earlier studied in detail by Mertie (1940).

The occurrence of Goodnews Bay and Stillwater laurite is briefly de-scribed in this report, and new data on the chemical composition and ore microscopy of the mineral are given, supplemented with new data for Borneo laurite and notes on platinoid minerals likely to be mistaken for laurite.

MICROSCOPIC OCCURRENCE AND PROPERTIES

Occurrence.—Laurite from Goodnews Bay (nos. 1–3 of Table 1) occurs

as roundish, equant subhedral, and irregular grains embedded in and attached to larger grains and nuggets of a bright yellowish-white native alloy of platinum-group metals. Subhedral chromite grains are similarly embedded in the alloy. Grains and nuggets of the alloy range in mean diameter from 0.2 mm to 1 cm; grains of laurite range from 25 to 175 μm. A new Pd-Sb-As mineral, to be described by Desborough, is part of this assemblage of placer minerals, which also includes native gold, native platinum, sperrylite, and other minerals still to be identified. The alloy contains mainly iridium, osmium, and ruthenium in varying proportions. (See section on microprobe analysis.) For lack of a suitable osmium standard for use in microprobe analysis and of a suitable standard of high reflectivity for use in quantitative optical studies, the alloy will not be further described here. Laurite is present in one out of 10 grains of the alloy, but the laurite content of alloy grains is much less than 1 percent by volume. The laurite content of bulk samples of placer concentrates is unknown.

Laurite from the Stillwater Complex (no. 4) occurs as very small, elongate, diamond-shaped inclusions in chromite (Page and Jackson, 1967). The laurite inclusion studied by us, measuring 8 by 14 microns, is interpreted as a partly developed pyritohedron {102} like the rhombohedral pyrite form figured in Dana's System (Palache, Berman, and Frondel, 1944, p. 283, Urals). Pyrrhotite and Ni-Fe sulfides interstitial to chromite are present as traces. Sulfide minerals make up only 0.01% of the H chromitite zone, the source of our sample. A few tenths of the sulfide fraction is laurite and other platinoid minerals.

Laurite from Borneo (no. 5) was provided by the U. S. National Museum as a blacksand sample, USNM 9659. A single laurite grain, a broken cube 0.2×0.3 mm across, was recovered in a fraction that contained abundant chromite and a few grains of unidentified minerals and metal.

Qualitative properties.—Goodnews Bay and Borneo laurite were polished by the chemical-mechanical method of Cameron and Van Rensburg (1965). Stillwater laurite was polished with alumina on a lead lap. All sections were given a final lapping with a water suspension of alumina on cloth. The quality of the polish was generally excellent.

In polished section, in daylight-filtered white light, our laurite by itself or against chromite looks white (gray to some observers) and rather bright. Its appearance in oil is unchanged. Isolatable grains viewed in air against galena under a comparison microscope are white with a perceptible bluish tint, and very slightly darker than galena. Laurite against the exceedingly bright yellowish-white alloy in Goodnews Bay concentrates looks bluish gray and much darker than the alloy; in oil the laurite is

considerably darker and bluer. There is no reflection-pleochroism in air or in oil. Anisotropism is not detectable orthoscopically or conoscopically in air or in oil, and the polarization figure shows no dispersion of the ellipticity. The polishing hardness of laurite is greater than that of chromite and the platinoid alloy. Many laurite grains from Goodnews Bay show the trace of a good parting; some show in addition a less well defined parting whose trace is approximately perpendicular to that of the good parting. Some laurite grains that were severely deformed during microhardness testing showed square plucked areas. We believe that Goodnews Bay laurite has {001} parting, rather than {111} cleavage reported by Sartorius von Waltershausen (1866) for Borneo laurite and questioned by Ramdohr (1960, p. 757). We also believe that laurite no. 5 (Borneo) fails along a {001} parting when severely deformed during indentation, but this parting is not visible in the unindented grain.

Laurite no. 5 (Borneo) differs slightly in color from the other laurites of the suite. Though it is white in air, the grain has a very faint yellow tint when isolated by a field diaphragm; some observers see white or gray only. The yellow tint is not detectable in oil. Seen under the comparison microscope in air, Borneo laurite looks slightly bluish against galena but white against Goodnews Bay laurite, which looks gray against Borneo laurite. The difference in color between Borneo laurite and Goodnews Bay laurite is confirmed by the quantitative determination of color discussed below. Other qualitative optical properties of Borneo laurite are the same as those of laurites 1–4.

Borneo laurite (no. 5) is negative to the standard etch reagents of Short (1940) and to aqua regia. Rozhkov and others (1962, table facing p. 114) likewise found that laurite is negative to standard etch reagents. Grains of Goodnews Bay and Stillwater laurite were inadequately isolatable or too small for etching.

Reflectivity.—The reflectivity of laurite is given in Table 1. Grains 1 and 2 presented perfectly polished areas greater than 25 microns in diameter. Measurements on these grains thus represent the best values we obtained. Grain 3 seemed equally suitable, but at a magnification X560 an almost irresolvable flaw—neither a pit nor a scratch—was visible. Evidently this flaw was bad enough to reduce the reflectivity measured here, for the composition of this grain (Table 2) is not significantly different from that of grain 1. The data are presented merely to illustrate the problem caused by an almost indetectable polishing defect. The seemingly unflawed area available in grain 4 was only 2 to 3 microns in diameter. The reflectivity of this grain is close to that of grain 3. We suspect that the values reported for grain 4 are low, but the reason for the discrepancy is unknown. Direct visual comparison with galena suggests

TABLE 1. REFLECTIVITY OF LAURITE

Wave-length, nm	R_{air}, %								
	1	2	3	4	5	6-L	7-L	8-L	9-L
	M 2-A pure	M-nugget	M 2-C	55MV50	USNM 9659				
470	47.8±0.8	47.0	47.7	48.0	45.8±0.7	—	—	—	—
546	42.5±0.6	42.1	38.5	39.0	41.8±0.8	42.3	41	—	—
589	40.3±0.3	40.0	36.4	38.3	40.3±0.3	40.7	37	41–42	43.6
650	37.2±0.5	37.2	35.4	36.3	38.2±0.4	37.8	32.5	—	—

1–3 Goodnews Bay, Alaska. 1–2, flawless areas. 3, very slightly flawed.

4 Stillwater Complex, Montana; H chromitite zone, Mountain View area.

5 Borneo. U. S. National Museum sample.

6-L Borneo. Data as originally reported by Frick (1930, p. 68) for green, orange, and red light.

7-L Borneo. Data as reported by Schneiderhöhn and Ramdohr (1931, p. 181) for green, orange, and red light; a revision of 6-L.

8-L Union mine, Merensky Reef, Transvaal, South Africa (Kingston, 1966a, p. B98).

9-L Inagli, Aldan upland, USSR (Razin *in* Rozhkov and others, 1962, p. 73); yellow light. Same value, locality not stated, attributed to Pudovkina (Pudovkina, Ryabeva, and Aksenova, 1966, p. 34); wavelength 589 nm.

Reflectivity of laurites nos. 1–5 measured by B.F.L. with a Reichert photoelectric microphotometer on microprobe-analyzed grains. For most grains, reproducibility of measurements is ±1 percent, relatively; for example, 38.5±0.4 percent. For all grains, the standard error ranges from 0 to 0.8 percent, absolutely, and averages 0.3 percent. U.S. germanium standard calibrated by National Physical Laboratory, Teddington, England; R at 470, 546, 589, and 650 nm taken as 47.0, 51.3, 52.0, and 47.1 percent, respectively. All mounts in cold-setting plastic, press-leveled on plasticine.

that the reflectivity of grain 4 might be 5 percent low, relatively, but not so much as 10 percent low.

Kingston (1966a) observed that the reflectivity of (Ir, Os, Pt)-rich zones of a Union mine laurite was fractionally higher than the reflectivity of zones poorer in those elements.

The best reflectivity values, measured on grains 1, 2, and 5, agree very closely with the original values (table 1, no. 6-L) obtained by visual photometry by Frick (1930, p. 68) on laurite from Borneo. Frick's data, measured with a Berek slit microphotometer against a polished steel standard, were later revised by Schneiderhöhn and Ramdohr (1931, p. 181); their revised values are reported here as no. 7-L. Subsequently, Ramdohr (1950, p. 592, and later editions) dropped the numerical values and stated that laurite, which generally polishes poorly, is at least as bright as pyrite, for which he reports $R_{green} = 54$ percent.

Quantitative definition of color.—The reflectivity data can be used to

specify the color of laurite in quantitative terms according to the method applied to ore minerals by Piller (1966). For laurite no. 1 (Goodnews Bay), table 1, the brightness value Y is 42.1, and the trichromatic coefficients are $x=0.292$, $y=0.299$, $z=0.410$. Y, which is also one of the International Commission of Illumination tristimulus values of the spectrum colors, is a measure of absolute visual brightness. Together with the trichromatic coefficients, it is independent of the optical and illuminating conditions, and independent of the color perception of the observer. The value of Y is close to the measured reflectivity at 546 nm but not necessarily identical to it. Since the sum of the trichromatic coefficients x, y, and z is unity by definition, only two of the three values are independent, z can be ignored, and the observer can visualize a three-dimensional figure in which x and y represent chromaticity and Y represents brightness (Piller, 1966, p. 181).

The significance of the trichromatic coefficients, which are measures of hue and saturation, is best seen on Piller's figures 3 and 6. The trichromatic coefficients of laurite are those of a nearly white mineral—*how* white is indicated by the approximation of x and y to the position of C, the I.C.I. standard illuminant, for which $x=0.3101$, $y=0.3163$, being defined as the ideal achromatic point approximating the quality of daylight (Piller, 1966, p. 183). Because x and y of laurite are nearly identical to x and y for the E vibration direction of hematite, the quantitative information on color of laurite can be translated into ordinary perceptual terms by referring to this familiar mineral. Many observers see the color of E of hematite (the darker position, since hematite is optically negative) as pale gray; some observers, such as Ramdohr (1960, p. 885), see it as pale gray with a bluish tint. Therefore, an isolatable laurite grain will presumably look gray—neutral—to those who see E of hematite as gray, but will look slightly bluish to those who see a faint blue tint in E of hematite. The brightness value Y of laurite, 42.1, is much higher than Y for E of hematite, which is given by Piller (1966, p. 185) as 25.89. Thus, if the observer translates the trichromatic coefficients of laurite to visual perception in terms of hematite, he must at the same time nearly double his impression of the brightness of laurite relative to hematite.

For laurite no. 5 (Borneo), table 1, the brightness value Y is 41.6, and the trichromatic coefficients are $x=0.296$, $y=0.303$, $z=0.401$. Accordingly, this laurite is almost as bright as no. 1 but is somewhat yellower—*how much* yellower we can visualize in terms of hematite. The trichromatic coefficients of laurite no. 5 plot halfway between those of the E and O vibration directions of hematite (compare Piller's fig. 6); consequently many observers would presumably see isolatable grains of this laurite as almost perfectly white.

Two additional quantities, the Helmholtz units of dominant wave-

length (λ_f) and excitation purity (p_e), may be used to supplement the specification of color based on brightness value and trichromatic coefficients. The Helmholtz units, derived graphically or mathematically from the trichromatic coefficients (Piller, 1966, p. 182–183; diagrams and equation in Hardy, 1936), correspond to the attributes of hue and saturation.

For laurite no. 1 (Goodnews Bay), $\lambda_f = 477$ *nm* and $p_e = 0.084$; for laurite no. 5 (Borneo), the corresponding values are 479 nm and 0.066. These Helmholtz units represent additional formal statements of quantitative color properties, useful so long as the formal context and the chromaticity diagram (such as Piller's figure 3) are kept in mind. The excitation purity of standard daylight illuminant C is zero by definition; that of a pure spectral color or of a pure purple is unity. Because p_e of the laurites closely approaches zero, they look very nearly white, and no. 5 is formally stated to be whiter than no. 1, in agreement with the qualitative observation of color difference. If the excitation purity of the laurites were considerably closer to unity, they would look blue because their dominant wavelength is 477 to 479 nm. However, Piller's data for neutral and tinted ore minerals suggest to us that p_e must exceed ∼0.1 in order that the microscopist see a readily definable hue. The difference of 2 nm in the dominant wavelength of the laurites is slight, but the sense of the difference is consistent with the observed difference in the color of the laurites and with the interpretation of their Helmholtz units relative to those of hematite.

Those familiar with quantitative expressions of color may not require translation of the data by way of some familiar mineral example, and others will doubtless prefer not to define color in a quantitative way. Quantitative definition of color at least places this important property of ore minerals beyond fruitless argument, though one should bear in mind that the quantitative definition is only so good as the reflectivity measurements on which it is based.

Microindentation hardness.—The microindentation hardness of laurite was determined at loads of 15, 25, and 100 grams by means of a Leitz Durimet hardness tester fitted with a Vickers diamond indenter. At 25-gram load, Goodnews Bay laurite yielded nine measurable indentations on four grains, three of which had been analyzed by microprobe. The usable indentations, all having mean diagonal lengths of less than 4 microns, ranged from perfect to slightly fractured. On these, the range of HV_{25} according to convention 1 (explained by Leonard, 1969) is ∼1250 to 4824, mean 3150. Variation in HV_{25} is not statistically significant among the grains. Two grains previously tested at 25-gram load yielded usable indentations at 100-gram load; HV_{100} for these indentations is

1650 and 2012. The minute Stillwater laurite crystal shattered when indented at 15-gram load; for this defective indentation, HV_{15} is roughly 2900.

The single grain of Borneo laurite (no. 5) yielded five very slightly fractured to perfect indentations at 25-gram load; $HV_{25} = 2760-2898$, mean 2870. Two indentations at 100-gram load caused pronounced fracturing, mainly by developing a single long crack whose trace is parallel to the cube edge. HV_{100} for these two indentations is 1097 and 1505—values that, owing to fracturing, we interpret as being closer to a minimum than to the mean or maximum.

Mean HV_{25} for Borneo laurite is less than that of Goodnews Bay laurite. However, a statistical comparison of the standard error of the difference of the two means shows that the actual difference between the means is considerably less than the standard error of the difference; therefore the difference, while it might be true, is not statistically significant. Nevertheless, the sense of the difference is consistent with Kingston's (1966a) suggestion that the polishing hardness of a compositionally zoned Union mine laurite varies inversely with osmium content. (See discussion of chemical composition, below.)

The results of the hardness tests amply confirm the qualitative observations of other workers that laurite is very hard. Like most minerals, laurite has indentation hardness increasing with decreasing load. The two successful trials on Goodnews Bay laurite at 100-gram load give values within the range reported by Young and Millman (1964, p. 450), 1605 to 2167, but two indentations are too few to establish a mean value of HV_{100} for this laurite. For diagnostic purposes, our mean $HV_{25} = 3150$ for Goodnews Bay, mean $HV_{25} = 2870$ for Borneo, and Young and Millman's midrange $HV_{100} = 1886$ seem reliable.

The microindentation hardness of Inagli laurite, reported by Razin (Rozhkov and others, 1962, p. 73) as 1393–1670, was determined at unspecified load. Nearly identical values—1396–1670, mean 1532—are reported by Pudovkina, Ryabeva, and Aksenova (1966, p. 34); locality and load are not specified.

MICROPROBE ANALYSIS OF LAURITES AND COEXISTING PLATINUM-GROUP ALLOYS

The composition of five laurite grains was partially determined by electron microprobe analysis utilizing two ADP (ammonium dihydrogen phosphate) analyzing crystals simultaneously and measuring the intensity of the following spectral peaks: $Ru_{L\alpha}$, $S_{K\alpha}$ and $Ru_{L\alpha}$, $Ir_{M\alpha}$, respectively. Other microprobe conditions were: fixed beam current, sample

current of about 1.5×10^{-8} A, 20 kV. Standards[2] used for determination of sulfur content were MoS_2, CdS, PdS, and Sb_2S_3. Standards used for determination of ruthenium and iridium were synthetic alloys: Ir_{100}, $Rh_{60}Ir_{40}$, $Rh_{50}Ir_{50}$, $Pt_{80}Ir_{20}$, $Pt_{95}Ru_5$. The purest laurite (grain M2-A pure) served as a standard for ruthenium. Results of composition determination for five grains are tabulated (Table 2). The large uncertainty (± 1 to 2 percent) is due to the atomic number differences in the samples and standards. The grains analyzed were checked for osmium, which was detected in all grains except M2-A pure (table 2). Osmium could not be determined quantitatively, owing to the lack of suitable standards. Elements other than Ru, Ir, Os, and S were not found in spectral scanning of the analyzed grains. The microprobe analysis of grain M2-A pure agrees closely with the ideal composition of RuS_2 and, we believe, gives some indication of the reliability of the analyses of the other laurite grains.

The alloy adjacent to or surrounding laurite was analyzed quantitatively for ruthenium and iridium. The low totals for the alloy, as for four of the laurites, are assumed to be due to undetermined osmium, the only additional element known to be present in the laurite and the chief undetermined element in the alloy. Where the alloy is present, it is much more abundant than laurite, and the Ru: Ir+Os ratio of the alloy varies directly with that of the coexisting laurite.

The presence of minor amounts of iridium and osmium in laurite seems to be common but not universal. Wöhler (1866) stated that osmium, detected but not directly determinable, was most likely present as osmium sulfide isomorphous with ruthenium sulfide in the original laurite from Borneo. Kingston (1966a) said that minor amounts of iridium and osmium were generally present in laurite from the Union mine, Merensky Reef, and showed that one laurite inclusion in pentlandite had an outer zone containing approximately 9 percent Ir, 10 percent Os, and 5 percent Pt, and an inner zone containing approximately 5 percent Ir, 3 percent Os, and 2 percent Pt. Page (Page and Jackson, 1967) found iridium and osmium in Stillwater laurite. Osmium is more abundant than iridium in the samples he checked. The Stillwater laurite grain available for the present study was too small for quantitative microprobe analysis. Bannister and Hey (Bannister, 1932, p. 197, 204) did not detect iridium, osmium, palladium, or platinum in Potgietersrust laurite, and Razin

TABLE 2. COMPOSITION OF SELECTED LAURITES AND ASSOCIATED ALLOYS
(All values weight percent, uncertainty indicated by ±)

Element and phase	Goodnews Bay, Alaska				Borneo USNM 9659	Ideal RuS$_2$
	M2-A pure	M2-C	M2-A impure	M-nugget		
Ru in laurite	61.0±1	59.5±1	53.5±2	40.5±2	30.0±3	61.18
Ru in alloy	—	33.5±2	19.5±2	1.0±1	—	—
Ir in laurite	1.0±1	2.0±1	7.0±2	13.0±2	20.0±2	—
Ir in alloy	—	43.0±1	48.0±1	67.0±2	—	—
S in laurite	38.0±1	36.0±1	34.4±1	31.1±1.5	27.0±1.5	38.82
Laurite totals	100.0	97.5	94.9	84.6	77.0	100.00

Analyst, G. A. Desborough.

(Rozhkov and others, 1962, p. 73) did not detect iridium or osmium microspectrographically in Inagli laurite.

X-RAY POWDER DATA AND CELL EDGE

Indexed powder data for Borneo laurite (no. 5) are given in Table 3. The interplanar spacings and cell edge $a = 5.6135 \pm 0.0025$ Å are close to those reported for Rustenburg laurite by Berry and Thompson (1962, no. 117; $a = 5.618$ Å). The approximate value of $a = 5.57 \pm 0.01$ Å for Inagli laurite, reported by Razin (Rozhkov and others, 1962, p. 73), seems exceptionally low. If one assumes the most probable indices for his five unindexed reflections, a for Inagli laurite becomes 5.56 ± 0.05 Å. This result suggests that the reported variation, rather than the cell edge, is too low. For a compilation of cell edges of other laurites and synthetic cubic RuS$_2$, see Sutarno, Knop, and Reid (1967, p. 1394).

The isostructural nature of synthetic cubic RuS$_2$ and OsS$_2$ suggests to us that an intermediate member near $(Ru_{0.5}Os_{0.5})S_2$ would have $a \approx$ 5.615 Å, about halfway between the values 5.6095 ± 0.0005 and 5.6196 ± 0.0003 Å precisely determined for a of the pure substances by Sutarno, Knop, and Reid (1967). The cell edge interpolated for this 50–50 compound agrees closely with measured $a \approx 5.614$ of Borneo laurite. We believe that this coincidence affords an approximate but independent confirmation of the analysis of Borneo laurite reported in table 2, provided the possible effect of the subordinate content of Ir in this laurite can be ignored. Whether it is safe to ignore it, we cannot tell. Synthetic cubic IrS$_{1.9}$, which also has the pyrite structure, has $a = 5.68$ Å (Munson,

TABLE 3. X-RAY POWDER DATA FOR BORNEO LAURITE (NO. 5)
$a = 5.6135 \pm 0.0025$ Å

hkl	$d_{obs.}$, Å	$d_{calc.}$, Å	I	hkl	$d_{obs.}$, Å	$d_{calc.}$, Å	I
111	3.24	3.24	s	520, 432	1.043	1.042	vvw
200	2.81	2.81	vs	521	1.025	1.025	vvw
210	2.52	2.51	mw	440	.9922	.9923	m
211	2.29	2.29	w	531	$.9480\alpha_1$	.9488	m
220	1.982	1.984	s	600, 442	$.9350\alpha_1$	.9356	m
221	1.867	1.871	vw	611, 532	.9102	.9106	vw
311	1.691	1.692	vs	620	$.8872\alpha_1$	.8876	mw
222	1.621	1.620	m	533	$.8560\alpha_1$	.8560	m
320	1.562	1.557	w	622	$.8461\alpha_1$	.8463	m
321	1.502	1.500	w	630, 542	.8369	.8368	vvw
400	1.402	1.403	vw	631	.8280	.8276	vvw
331	1.287	1.288	ms	444	.8105	.8102	vvw
420	1.256	1.255	ms	711, 551	$.7860\alpha_1$	.7861	ms
421	1.228	1.225	vvw		$.7860\alpha_2$	.7861	w
332	1.198	1.197	vvw	640	$.7785\alpha_1$	.7785	ms
422	1.144	1.146	m		$.7785\alpha_2$	.7785	w
511, 333	1.082	1.080	s				

Film no. D-7530. Camera diameter 57.3 mm; CuKα=1.54178, α_1=1.54051, α_2= 1.54433 Å; Ni filter; Straumanis film arrangement; cut-off $2\theta \sim 10°$; gelatine tip mount; film corrected for shrinkage; relative intensities estimated visually—s, strong; v, very; m, medium; w, weak. For cell edge, number following $\pm$ sign is standard deviation calculated from back reflections 440 through 640 excluding 631, which was too weak for satisfactory measurement.

1968); this phase was synthesized at 1500° C and the very high pressure of 60 kb.

Because the reported intensity of several indexed reflections of synthetic cubic RuS_2 and OsS_2 is markedly different, we sought to use the intensity data of Sutarno, Knop, and Reid (1967) as an additional check on the composition of Borneo laurite. However, our attempt to measure the intensity of critical reflections of Borneo laurite was unsuccessful, owing to slight spottiness of the film pattern obtained from the few inadequately sizable mineral particles that could be X-rayed.

QUANTITATIVE PROPERTIES RELATED TO COMPOSITION

Our analyses indicate that the composition of laurite varies substantially and serially. Iridium and Os together may proxy for almost half the Ru atoms in the lattice. We think this substitution produces rather slight but measurable changes in color, reflectivity, and microindentation hardness, and presumably in the cell edge as well. Owing to gaps in the data, we cannot demonstrate this variation in properties step by step; we can

only show that members having the extremes of composition possess slightly different properties (Table 4). The degree of difference is, for mineralogists, conveniently small and at present easily accommodated within the definition of the species laurite.

The confidence level for statistical comparison of reflectivity at the specified wavelengths is not high—80 percent at 470 nm, 70 percent at 546 nm, and 70 percent at 650 nm. However, the close agreement between careful qualitative comparison of color and quantitative determination of color based on reflectivity strongly suggests that the differences in reflectivity at these wavelengths are of the right sense and approximately of the right size. The lack of statistical significance in the different values of mean HV_{25} has already been pointed out; we would only repeat that the sense of the difference is consistent with Kingston's (1966a) direct observation of lower polishing hardness correlating with higher osmium content in zoned laurite from the Union mine.

Substitution of Ir and Os for Ru in the lattice of laurite might not be the sole cause of variation in the physical properties of the analyzed members. Variation in the ratio of metals to sulfur might, if real and not due to analytical error, have an appreciable effect on some physical properties of the laurites (P. M. Bethke, 1969, pers. comm.). To test this pos-

TABLE 4. QUANTITATIVE PHYSICAL PROPERTIES OF LAURITE CORRELATED
WITH CHEMICAL COMPOSITION

	1 M2-A pure $(Ru_{1.01}Ir_{0.01})S_{1.98}$	5 Borneo USNM 9659 $\sim(Ru_{0.6}Ir_{0.2}Os_{0.3})S_{1.9}$
Color parameters		
x	0.292	0.296
y	0.299	0.303
Y	42.1	41.6
R		
470 nm	47.8	45.8
546	42.5	41.8
589	40.3	40.3
650	37.2	38.2
HV_{25}, mean	3150	2870
a	[1][5.6095]	5.6135

[1] Cell edge of pure synthetic RuS_2 determined by Sutarno, Knop, and Reid (1967).

sibility, a suite of laurites showing virtually no substitution—or no varying substitution—of Ir and Os for Ru would be required. Such material is not at hand. For the suite we studied, slight change in physical properties in spite of large change in chemical composition is demonstrated by the data. Refinements of this relation we cheerfully leave to the crystal chemist.

<center>MINERALS RESEMBLING LAURITE</center>

Several other gray to white, optically isotropic or weakly anisotropic platinoid minerals of moderate brightness and considerable hardness might be mistaken for laurite. This group of minerals includes hollingworthite, irarsite, "roseite" of Ottemann and Augustithis, rhodium-bearing sperrylite, and the unnamed ruthenium mineral of Ottemann and Augustithis. Additional platinoid minerals of perhaps comparable brightness but seemingly lower hardness are braggite, cooperite, michenerite, and vysotskite. The main ore-microscopic properties of these nine minerals are abstracted below.

Braggite, (Pt, Pd, Ni)S, in oil is in part rather blue gray, in part somewhat brownish gray, is distinctly anisotropic in air, shows almost vivid polarization colors in oil, in air has $R >$ niccolite and $<$ a metal, in oil has $R \geqq$ stibiopalladinite [thus~55–60 percent in air and only slightly less in oil?—B.F.L.], and has a polishing hardness $>$ native platinum, $<$ sperrylite (Ramdohr, 1960, p. 388, 639). Razin (Rozhkov and others, 1962, p. 77–78) reports that in air braggite is white with a weak bluish-gray tint, showing reflection-pleochroism in bluish tones; in oil braggite shows reflection-pleochroism from bluish gray to pale brownish gray; anisotropism is marked; $R_{yellow} = 34.5$–35.5 percent; $HV = 742$–1030 at unspecified load. Pudovkina, Ryabeva, and Aksenova (1966, p. 28) report identical numerical data.

Cooperite, PtS, in oil is coffee brown to olive-leather brown, shows very weak anistropism in air but moderately strong anistropism in oil, has $R_{green} = 41$ percent ("which may be a good deal too low"), and has a polishing hardness $<$ native platinum (Ramdohr, 1960, p. 641). $R_{green} = 41$ percent is the value given by Schneiderhöhn and Ramdohr (1931, p. 216) and credited by Ramdohr to Frick; Frick (1930, p. 67) originally reported $R_{green} = 37.1$ percent. Razin (Rozhkov and others, 1962, p. 76–77) reports that in air cooperite is gray with a creamy-brown tint, in oil a richer brown; anisotropism is distinct; $R_{yellow} = 40$–42.4 percent, HV = 505–588 at unspecified load. Pudovkina, Ryabeva, and Aksenova (1966, p. 34) report nearly identical numerical data: $R_{589} = 40.0$–42.4 percent, $HV = 505$–588, mean 544, at unspecified load. Timofeeva (1968, p. 462) reports the color as coffee brown, anisotropism weak in air but distinctly

increased in oil, $R <$ pyrrhotite, $HV = 203–276$, mean 239, at unspecified load. Zhuravlev, Genkin, and Stepanova (1968) report that cooperite is gray white, is distinctly anisotropic, and has $R_{600} = 37$ percent. To that description, Genkin (1968, p. 63–69) adds that the bireflectance of cooperite in air is negligible and that $R_{550} = 39.0\%$. Clearly the data for braggite and cooperite are both conflicting and overlapping.

Hollingworthite, (Rh, Pt, Pd) (As, S)$_2$, described by Stumpfl and Clark (1965b), is medium gray, optically isotropic, and has R_{white} slightly less than 40–45 percent; its polishing hardness is greater than that of sperrylite. In oil hollingworthite shows a bluish tint, slightly more pronounced than that of the rhodium-bearing sperrylite described below. An iridian hollingworthite from Noril'sk, described by Genkin (1968, p. 55–61), is gray white with a bluish tint, isotropic, with $R_{540} = 52.5$ percent, $HV = 657$ at unspecified load. Ruthenian hollingworthite from Noril'sk, described by Genkin and others (1966), is gray white, isotropic, with $R_{560} = 49.2$ percent, $HV_{50} = 848$.

Irarsite, (Ir, Rh, Ru, Pt)AsS, described by Genkin and others (1966), is gray white, optically isotropic, with $R_{520} = 47.8$ percent, $R_{560} = 47.0$ percent, and $HV_{50} = 976$. It resembles ruthenian hollingworthite but looks bluish gray and somewhat darker.

Michenerite, probably PdBi$_2$ according to Hawley and Berry (1958), is light gray; its scratching hardness is B and it reacts positively to HNO$_3$, FeCl$_3$, and aqua regia. However, the michenerite later described by Genkin, Zhuravlev, and Smirnova (1963) and found to be (Pd, Pt) BiTe, has R_{white} [?] = 56 percent; its polishing hardness is less than that of chalcopyrite.

"Roseite" of Ottemann and Augustithis (1967), (Os, Ir)S, is light gray and has a polishing hardness about equal to that of osmiridium. The reflectivity of "roseite," not reported by Ottemann and Augustithis, seems from their photomicrograph to be distinctly less than that of ferroplatinum.

Rhodium-bearing sperrylite of Stumpfl and Clark (1965b), (Pt, Ir, Rh) (As, S)$_2$, is medium gray, optically isotropic [?], showing a bluish tint in oil; $R_{white} = 40–45$ percent; hardness is greater than that of sperrylite. Rucklidge (1969, p. 619) thinks it reasonable to regard this mineral as a platinum-rich irarsite.

The unnamed ruthenium mineral of Ottemann and Augustithis (1967) was not described or analyzed; they thought it was most probably a derivative of laurite.

Vysotskite, (Pd, Ni)S, is grayish white with a bluish tint; reflection-pleochroism, detectable only in oil, is grayish bluish to grayish lilac; anisotropism is indicated by bluish to brownish tints seen with nicols

crossed; R_{white} [?] is~44–45 percent; hardness is rather high but < steel; polishing hardness > chalcopyrite and millerite (Genkin and Zvyagintsev, 1962, p. 718–719). Vysotskite was earlier described by Genkin (1959) as his unnamed mineral 8.

Adequate quantitative data are lacking for many of the minerals noted above. At present the high microindentation hardness of laurite seems to distinguish it from all the isotropic gray-white minerals having a reflectivity near 40 percent, but cautious application of this distinction is advisable.

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