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THE OPTICAL PROPERTIES OF MONTBRAYITE, Au_2Te_3, FROM ROBB MONTBRAY, QUEBEC, COMPARED WITH THOSE OF THE OTHER GOLD TELLURIDES

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ABSTRACT

Qualitative optical properties are described, and reflectance spectra provided, for cotype montbrayite, from the Robb Montbray mine, Quebec, together with the results of electron-microprobe analyses. The optical data are compared with data for all of the known gold telluride minerals; microscope-spectrophotometry is found to be a useful technique to distinguish the different minerals. Attention is drawn to discrepancies between reflectance spectra measured with single- and double-beam microscope-spectrophotometers.

Keywords: montbrayite, gold tellurides, reflectance spectra, electron-microprobe analyses, Robb Montbray, Quebec.

SOMMAIRE

Nous décrivons ici qualitativement les propriétés optiques du cotype de la montbrayite, qui provient de la mine de Robb Montbray, en Abitibi (Québec), ainsi que les spectres de réflectance et les résultats des analyses à la microsonde. Les données optiques sont comparées à celles de toutes les espèces de tellurures d'or connues. Les mesures spectrophotométriques par microscope permettent de distinguer parmi ces minéraux. Nous signalons des décalages dans ces résultats, selon que les mesures ont été effectuées avec appareils à faisceau unique ou à deux faisceaux.

(Traduit par la Rédaction)

Mots-clés: montbrayite, tellurure d'or, spectres de réflectance, analyses à la microsonde électronique, mine de Robb Montbray, Québec.

INTRODUCTION

Montbrayite, nominally Au_2Te_3, or $(Au,Sb)_2Te_3$, was first reported by Peacock & Thompson (1946) from the Robb Montbray mine, Montbray Township, Abitibi County, Quebec. Since then, it has been reported from only two other localities: in Armenia (Scherbina & Zaryan 1964) and at Kalgoorlie (cited by Bachechi 1972). This rarity may be more apparent than real since, as Uytenbogaardt & Burke (1971) pointed out, in polished section it "...is very difficult to distinguish between calaverite, krennerite [the gold ditellurides] and montbrayite". As with so many ore minerals, the distinction between visually similar mineral phases can be made by microscope-spectrophotometry. When one of us (WP) obtained some cotype montbrayite, it was decided to complete the optical characterization of the mineral and to compare it with the other known tellurides of gold.

The sample used in this investigation was acquired from the Royal Ontario Museum (by exchange): it was labeled "Frohbergite, Robb Montbray, Canada", measured $27 \times 20 \times 20$ mm, weighed 21 g, and was registered as M37271 (originally M–15815–B); this was part of the material donated to the ROM by Hugh Park in 1928 and later studied by Peacock and Thompson. Most of the sample onsists of tellurobismuthite, though it also contains minor amounts of melonite, altaite, petzite, frohbergite, chalcopyrite, sphalerite and wires of native gold. In addition, included in the tellurobismuthite was a chunk ($6 \times 6 \times 5$ mm) of a mineral that closely resembles the published description of montbrayite. That this was, indeed, montbrayite, was confirmed when its X-ray powder pattern and cell parameters were found to match those for the mineral published by Peacock & Thompson (1946). The mineral association, paragenesis and intergrowth textures are identical to those mentioned in the detailed descriptions provided by them, and by Rucklidge (1969).

CHEMISTRY AND OPTICS

Fragments from the montbrayite-rich area of the sample were mounted in cold-setting epoxy resin and polished using the procedures described by Criddle *et al.* (1983). This polished mount (registered as E.1319) was analyzed by electron microprobe at the Natural History Museum, London; independently prepared material (from the same sample) was analyzed at the University of Hamburg. The operating conditions of the electron microprobes, and the results, are summarized in Table 1 and compared with results of earlier analyses by Peacock & Thompson (1946), Rucklidge (1969) and Bachechi (1972).

In Rucklidge's re-examination of the type speci-

TABLE 1. CHEMICAL COMPOSITION OF MONTBRAYITE

		1	2	3	4	5
Au	wt.%	46.1 (46.0 - 46.3)	46.0	47.36 ± 0.19	47.7	44.32
Pb		1.1 (0.9 - 1.2)	1.1	1.02 ± 0.08	1.3	1.61
Bi		3.8 (3.6 - 3.9)	4.0	3.23 ± 0.14	2.9	2.81
Sb		1.1 (1.0 - 1.1)	1.0	1.12 ± 0.04	0.3	0.90
Te		47.1 (46.9 - 47.2)	47.4	46.66 ± 0.15	47.0	49.80
Total		99.2	99.5	99.76	99.8	99.99

1. This study: average and range of 5 analyses made at 20kV, 2.50×10^{-8} amps, with a Cambridge Instruments Microscan IX, using pure metal and PbS standards. Cu and Ag were sought, but not detected.
2. This study: (analysis by Prof. Dr. M. Tarkian at the University of Hamburg) an ARL-EMX microprobe was used at 20kV: standards and emmission lines = PdBiTe (BiMα, TeLα), PbS (PbMα), Sb_2S_3 (SbLα) and Au metal (AuMα).
3. Electron microprobe (Bachechi 1972); included Ag 0.37 ± 0.05.
4. Electron microprobe (Rucklidge 1969); included Ag 0.6.
5. Chemical analysis (Peacock & Thompson 1946); included Ag 0.55.

men, he had reported "...small but probably essential amounts of Bi and Pb" in montbrayite. This fact is given some support by the unsuccessful attempts of Peacock & Thompson (1946), Markham (1960) and Cabri (1965) to synthesize pure Au_2Te_3, and was confirmed by Bachechi (1972), who showed that Sb alone, or Bi, Pb and Sb, were required to stabilize the mineral.

Our analyses are in good accord with the results from earlier electron-microprobe work (Table 1), differing only in the absence of detectable Ag. It is clear from the analytical data that resolution of the uncertainty concerning the mode of substitution of Sb, or Sb, Pb and Bi, for Au or Te, or both elements, must await the findings from a structure determination of the mineral. Bachechi's (1971) partial structural determination of montbrayite failed to address this problem.

TABLE 2. THE QUALITATIVE OPTICAL PROPERTIES OF THE GOLD TELLURIDES

	PLANE-POLARS:			CROSSED POLARS:	
	COLOR	BIREFLECTANCE	PLEOCHROISM	EXTINCTION	ANISOTROPY
MONTBRAYITE					
air	pale creamy white	very weak	absent	incomplete	weak: greenish to brownish greys.
oil	pale creamy white	weak	absent	oblique	moderate: bright slate-blue to a dull, brownish, grey.
CALAVERITE					
air	pale creamy white	weak	absent	oblique	moderate: reddish brown, yellowish light grey, light grey, mid-grey, violet-grey, dark blue.
oil	slightly darker than in air	weak to moderate	absent	oblique	moderate to strong: dark brown, mid-grey, silver-grey, bluish grey, violet-grey, brown, slate-blue.
KRENNERITE					
air	white with a creamish tint	absent	absent	incomplete	weak: dull brownish greys.
oil	pale to darker pinkish white	weak	absent	oblique	moderate: mid-violet-grey to grey.
KRENNERITE (Ag-rich)					
air	pinkish to creamy white	weak	slight	oblique	weak to moderate: light to dark browns.
oil	pink-brownish white to pale cream-white	distinct	distinct	oblique	moderate: brown-grey to grey.
SYLVANITE					
air	creamy white to brownish white	distinct	distinct	oblique	strong: greys, dark browns and light greys.
oil	(as in air, but all the effects are intensified when immersed in oil)				
KOSTOVITE					
air	brownish white to white	distinct	distinct	straight	very strong: silver-grey to a a distinct violet-grey.
oil	(as in air, but all the effects are intensified when immersed in oil)				
PETZITE					
air & oil	grey	isotropic		isotropic	

Optical properties

The qualitative optical properties of montbrayite are summarized and compared with those of the other gold tellurides in Table 2. With the exception of those for montbrayite, all of the observations were made by a single observer (AJC) on minerals from which reflectance, compositional and confirmatory X-ray data were obtained and published by Criddle & Stanley (1986) in the Quantitative Data File for ore minerals (QDF2) of the Commission on Ore Minerals of the IMA.

Inspection of this Table will show that, in circumstances where all of the minerals are available for comparison by the same observer, it is possible for them to be identified. However, the Table also shows that replacement of Au by small amounts of silver in krennerite will noticeably modify the appearance of this mineral. If such modification is considered, and if comparison is made with the descriptions of the same minerals by other observers, *e.g.,* Uytenbogaardt & Burke (1971) and Ramdohr (1980), it is clear that, with the exception of the characteristically twinned sylvanite and kostovite, and the low-reflecting and isotropic petzite, identification of the gold tellurides is not straightforward. Such uncertainties can, however, be resolved by microscope-spectrophotometry.

Spectral reflectance data

Two of the most bireflectant grains of montbrayite were measured using the equipment and procedures outlined in Criddle *et al.* (1983). Reference was made to a WTiC reflectance standard (Zeiss no. 314), and the ×16 air and oil objectives were adjusted to provide effective numerical apertures of 0.15. Zeiss oil, n_D = 1.515, DIN 58 884, was used for immersion measurements. Reflectance data were collected at an interval of 10 nm from 400 to 700 nm. These are summarized (at a 20 nm interval) in Table 3, and are plotted in Figure 1.

The dispersion of the reflectance spectra is fairly constant for R_1/R_2 and $^{im}R1/^{im}R_2$, but the pairs of spectra differ in absolute reflectance. Given the symmetry of the mineral, and the fact that it has oblique but incomplete extinction, it is evident that none of the measurements could be made at orientations corresponding to the directions of principal vibration. For these reasons, it should be recognized that, consistent and reproducible as the reflectance spectra are, they should be considered scalar values, to be used only for purposes of mineral identification.

The spectra, plotted in Figures 2 and 3, show, respectively, the minimum (R_1) and maximum (R_2) reflectance curves for montbrayite; they are compared with the appropriate spectra for all the other gold telluride minerals (taken from QDF2: Criddle & Stanley 1986). From these, it will be apparent that the individual minerals may be distinguished on the basis of absolute reflectance, dispersion of the reflectance, bireflectance, and dispersion of the bireflectance. It is worth noting that the only minerals where the potential exists for misidentification are montbrayite and krennerite but, even here, and regardless of variation in the reflectance of krennerite (due to the incorporation of silver), there are significant differences in the dispersion of the reflectance of both minerals.

TABLE 3. R AND ^{im}R DATA FOR MONTBRAYITE

	R_1	R_2	$^{im}R_1$	$^{im}R_2$	R_1	R_2	$^{im}R_1$	$^{im}R_2$
λnm	1:				2:			
400	46.1	49.9	34.0	38.0	47.2	50.9	35.1	39.4
420	47.55	51.3	35.4	39.6	48.5	52.5	36.5	40.9
440	49.0	52.8	36.9	41.1	50.0	54.1	37.9	42.5
460	50.5	54.5	38.4	42.5	51.5	55.8	39.3	43.9
480	52.1	55.9	39.9	43.8	52.95	57.1	40.9	45.2
500	53.6	57.1	41.4	45.0	54.4	58.45	42.2	46.3
520	54.9	58.15	42.7	46.1	55.8	59.5	43.4	47.2
540	56.1	59.0	43.9	47.0	56.8	60.3	44.6	48.1
560	57.1	59.7	44.9	47.6	57.7	60.9	45.5	48.7
580	57.9	60.3	45.8	48.2	58.4	61.4	46.3	49.2
600	58.7	60.8	46.55	48.7	59.1	61.85	46.9	49.6
620	59.3	61.15	47.2	49.1	59.6	62.2	47.6	50.0
640	59.8	61.5	47.7	49.4	60.1	62.5	48.0	50.3
660	60.2	61.9	48.1	49.7	60.4	62.7	48.3	50.5
680	60.6	62.1	48.45	50.0	60.7	62.9	48.55	50.65
700	61.0	62.4	48.7	50.2	61.0	63.2	48.9	50.8

These data are further summarized in Table 4, the computed color values relative to the two COM-recommended illuminants of the CIE. Those relative to illuminant A will correspond most closely to the subjective appearance of the minerals (Table 2) since the conditions of illumination used (an unfiltered quartz-halogen lamp run at ~3200 K) approximate to the color temperature of illuminant A.

Microhardness

Microhardness measurements were made on different samples of montbrayite at Salzburg and in London. Leitz Miniload 2 hardness testers were used in both cases. At Salzburg, a total of 22 indentations were made on 6 grains: the margins of the indentations were found to be generally straight, rarely slightly convex, and the indentations were slightly fractured (in a radial "star" pattern). VHN_{100} is 192–233, mean 213. In London, ten indentations, at the same load (by CJS) produced measurements, of the perfect to slightly fractured indentations, of 223–253, mean 238. Little should be made of these differences since, in London at least, the indentations were made on individual grains (components of larger polycrystalline grains) set in epoxy resin, the elasticity of which is unknown.

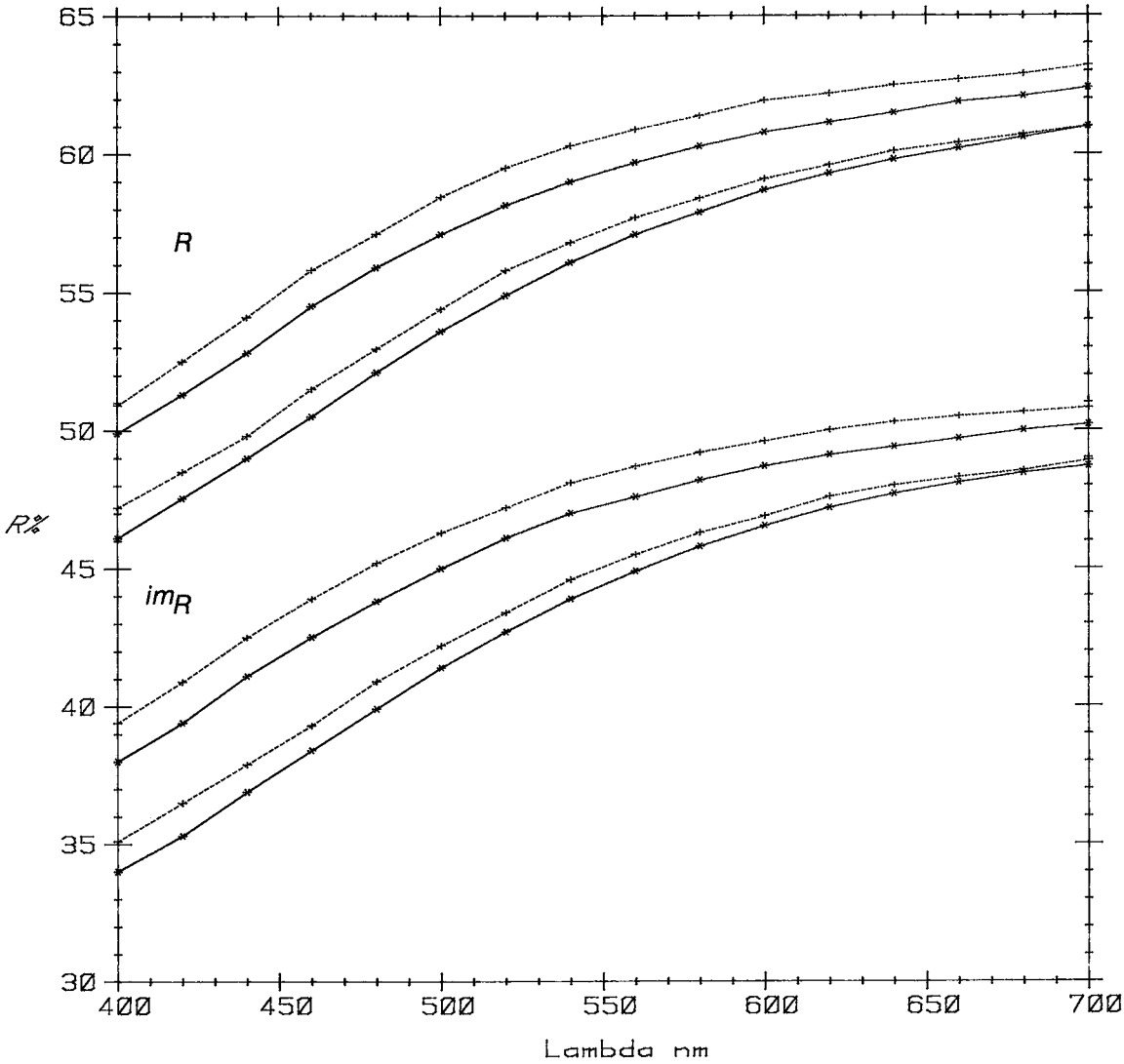

FIG. 1. R and ^{im}R spectra for montbrayite.

DISCUSSION

This brief investigation has shown the efficacy of microscope-spectrophotometry in the identification and optical characterization of the gold tellurides, and lends support to the suggestion of Simpson & Hurdley (1984) that "... colour values of gold-containing minerals offer significant potential as aids to mineral identification..". A cautionary note is, however, in order: the successful application of quantitative reflectance data to mineral identification is dependent on a sound understanding of methodology, including a knowledge of the constraints imposed by optical symmetry (Criddle 1990a, b), and the availability of reliable data-bases of R spectra. The reliability of the latter, *e.g.*, the QDF2 (Criddle & Stanley 1986) and the Atlas of Ore Minerals (Picot & Johan 1982) is, to some extent, proved by the consistency of the data for individual minerals (since the data-sets were produced independently by different operators using different equipment). In addition, it is undoubtedly true that modern, single-beam, microscope-spectrophotometers (with which the data were obtained for the above-mentioned data-bases) are capable of great precision in measurement. Problems may arise in the comparison of data collected with such instruments and with double-beam spectrophotometers. A case

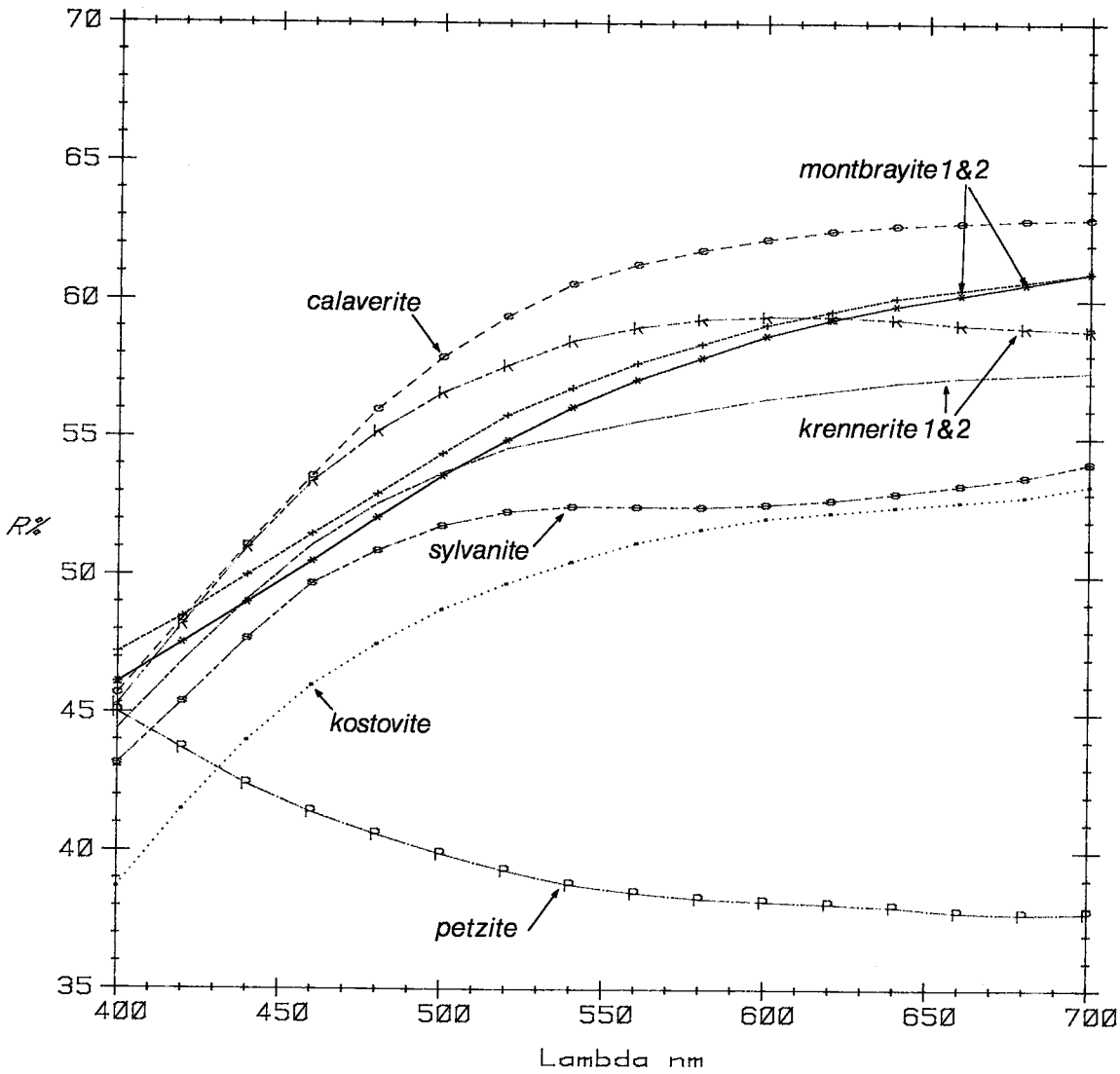

FIG. 2. R_1 spectra for the Au tellurides.

in point is to be found in the discrepancies between our data and those of Vyal'sov (1973) for the gold tellurides. Not only are there substantial differences in reflectance minima and maxima, but equally large differences in bireflectance. Further, Vyal'sov claimed to have determined the signs of the bireflectance for all of the gold tellurides (which we describe here). This represents a misunderstanding of what is physically possible with minerals that do not extinguish completely between crossed polars, and that do not have straight extinction. In these circumstances, even a statistical approach to the assignment of signs is invalid. Once these provisos are recognized, reflectance spectra, and the values derived from them, may be confidently recommended as both characteristic and diagnostic for most opaque minerals, as they certainly are for montbrayite.

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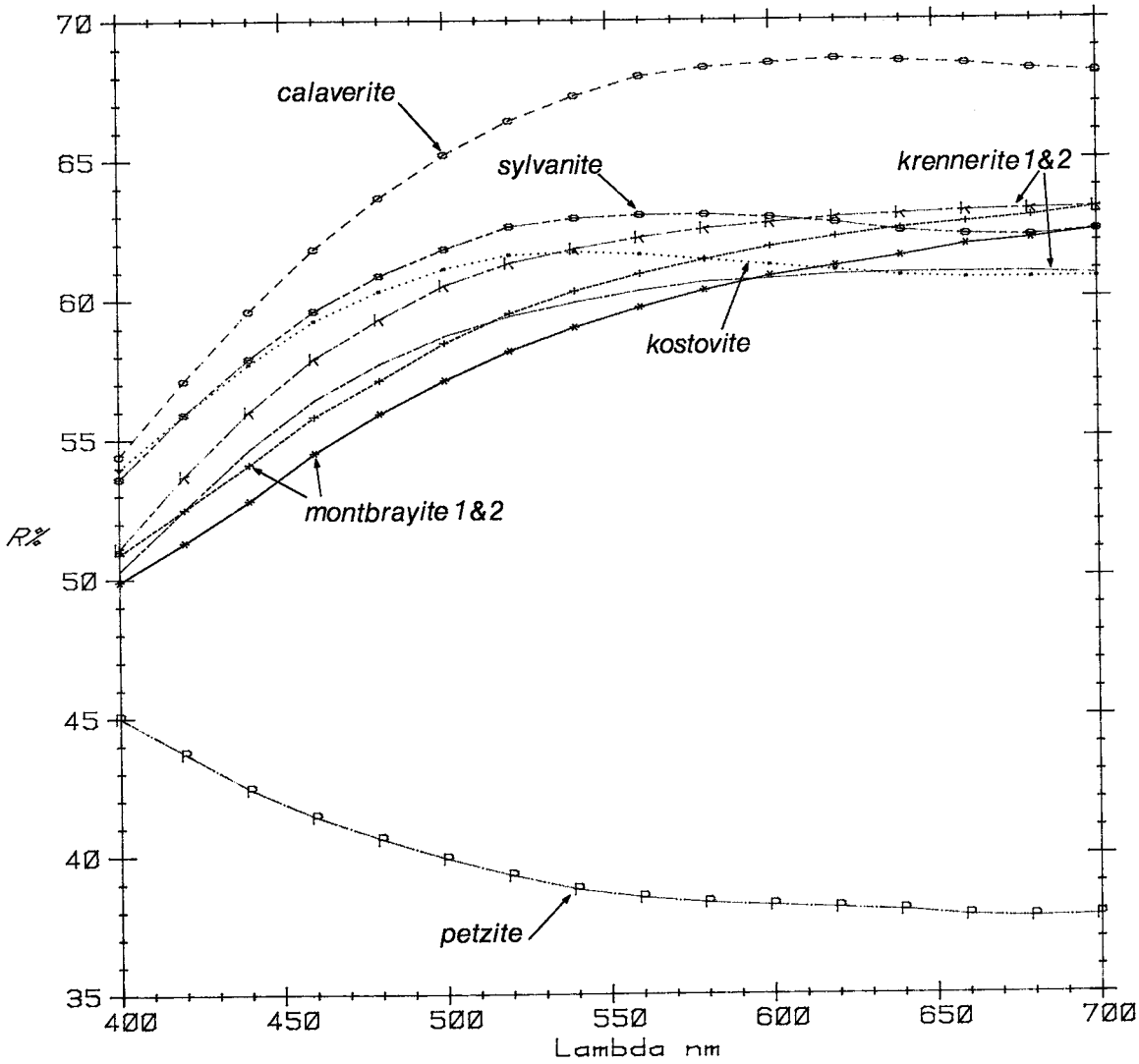

FIG. 3. R_2 spectra for the Au tellurides.

TABLE 4. COLOR VALUES RELATIVE TO ILLUMINANT C (6774 K)

	Montbrayite 1		Montbrayite 2		Calaverite		Krennerite 1		Krennerite 2		Sylvanite		Petzite	Kostovite	
	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R	R_1	R_2
x	.324	.320	.323	.320	.323	.319	.320	.318	.319	.317	.316	.315	.303	.322	.313
y	.331	.328	.330	.328	.334	.329	.330	.326	.328	.326	.326	.325	.307	.331	.323
Y%	56.6	59.3	57.3	60.5	60.7	67.4	58.4	61.9	55.3	60.0	52.4	62.7	38.8	50.8	61.4
λ_d	577	576	577	575	574	573	573	573	574	573	571	570	473	575	567
P_e%	7.5	5.8	7.0	5.6	8.2	6.8	6.3	4.7	5.7	4.4	4.0	3.5	3.8	7.0	2.5
	RELATIVE TO ILLUMINANT A (2856 K)														
x	.459	.455	.457	.455	.457	.454	.454	.453	.454	.452	.451	.450	.441	.456	.448
y	.412	.412	.412	.412	.414	.413	.413	.412	.412	.411	.412	.412	.404	.413	.411
Y%	57.3	59.8	57.9	61.0	61.2	67.8	58.8	62.2	55.7	60.3	52.5	62.8	38.5	51.2	61.4
λ_d	586	585	585	584	583	582	582	582	584	582	581	578	486	584	574
P_e%	10.7	8.2	9.9	7.8	11.1	7.9	8.3	6.4	7.8	5.9	5.2	4.5	1.7	9.6	3.0

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