SPECTRAL CHARACTERISTICS OF NATURAL-COLOR SALTWATER CULTURED PEARLS FROM *PINCTADA MAXIMA*

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Natural-color saltwater cultured pearls (SWCPs) from *Pinctada maxima* were studied using UV-Vis-NIR and PL spectroscopy to better understand the mechanisms of their coloration and to separate them from other SWCPs with similar natural colors. Several spectral features were observed, suggesting that the samples' bodycolor is due to a mixture of pigments. Although similar spectral characteristics are observed in SWCPs from *Pteria sterna* and *Pinctada margaritifera*, subtle differences permit the identification of the host mollusk.

Saltwater cultured pearls from *Pinctada maxima* are farmed primarily in Australia, as well as in Indonesia, the Philippines, Myanmar, and other localities (see Shigley et al., 2010, and references therein). Marketed as "South Sea" cultured pearls, they are usually bead-nucleated and can reach large sizes (sometimes >20 mm). The colors commonly found in the market range from white to light gray ("silver") to "cream" to yellow and "golden" (Elen, 2001, 2002b; Mamangkey et al., 2010; Shigley et al., 2010, and references therein). Less commonly, they may show pinkish, purplish, reddish, or brown bodycolors with various overtones (see figure 1 and photos in table 1). The darker SWCPs from *P. maxima* sometimes appear similar to lighter-colored SWCPs from *Pinctada margaritifera* and *Pteria sterna*.

The spectral characteristics of yellow to "golden" natural-color SWCPs from *P. maxima* have been documented previously (Elen, 2001, 2002b; Mamangkey et al., 2010). This article presents a diffuse-reflectance and photoluminescence spectroscopic study of natural-color SWCPs from *P. maxima* in an effort to characterize their coloration mechanisms. A better understanding of these mechanisms will help to identify the *P. maxima* host mollusk of South Sea cultured pearls and to separate natural-color samples from their artificially colored counterparts.

MATERIALS AND METHODS

For this study, the author selected 21 undrilled SWCPs from *P. maxima* in a range of colors (again, see table 1). They were obtained from a reputable source (see Acknowledgments) and represented as natural-color. The samples varied from 9.1 to 16.8 mm in diameter; for details on their color and size, see table 1. Their fluorescence was observed with a six-watt long- and

Figure 1. Saltwater cultured pearls from the Pinctada maxima *mollusk (here, 9.1–16.8 mm in diameter) may occur in a variety of attractive natural colors. Composite photo by S. Karampelas.*

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TABLE 1. Characteristics of natural-color SWCPs from *P. maxima*.

Photo	Sample no.	Bodycolor	Dimensions (mm)
	GGL002	Yellowish brownish gray	9.3–9.9
	GGL003	Yellowish brown	11.1
	GGL004	Gray-purple	9.7
	GGL005	Gray	11.3
	GGL006	Light gray-purple	11.8–12.3
	GGL008	Gray (slightly brown)	10.6–11.4
	GGL009	Reddish gray	9.1–9.4
	GGL013	Grayish purple (light gray on the bottom)	10.3–11.8
	GGL014	Gray-yellow-green	10.1–10.8
	GGL020	Yellow-brown	11.7–13.7
	GGL021	Gray-brown (lighter on the side)	15.1–16.8
	GGL022	Gray	10.5–12.0
	GGL023	Light gray	10.6–12.2
	GGL024	Gray-yellow-purple (lighter on the bottom)	13.8–15.8
	GGL025	Gray	10.7–12.0
	GGL026	Gray-brown (lighter on the bottom)	10.0–11.2
	GGL030	Gray-brown-purple	10.3
	GGL033	Light purplish brown	9.7–10.1
	GGL037	Light gray-pink	10.0
	GGL043	Gray-pink	12.5
	GGL044	Light gray-pink	11.3

* Images not scaled to size.

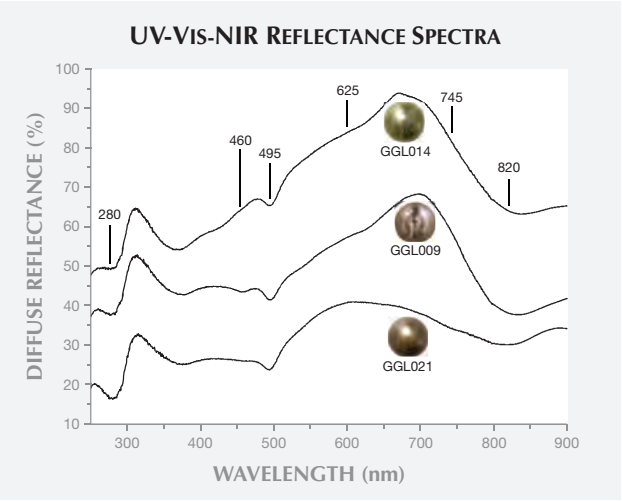


Figure 2. A gray-yellow-green SWCP (top line) shows absorptions at 280, 330–385, 385–460, 495, and a weak continuous absorption with a maximum at 820 nm, as well as less-intense features at 460, 625, and 745 nm. Bands at the same positions but with different intensities are observed in the spectra of reddish gray (middle) and gray-brown (bottom) samples. For clarity, the spectra for GGL009 and GGL014 are shifted upward by 5% and 25%, respectively.

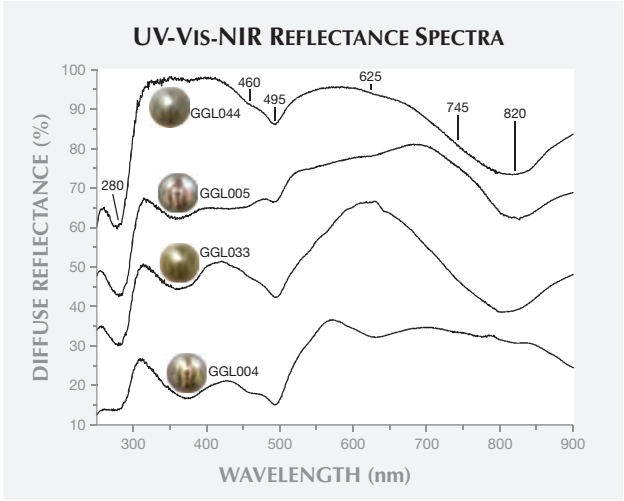


Figure 3. Absorption bands at identical positions as in figure 2, but with different relative intensities, are shown in the diffuse-reflectance spectra of these four SWCP samples. The samples' color variation is due to the different relative intensities of these bands. For clarity, spectra GGL004 and GGL033 are shifted downward by 15% and 5% respectively, and GGL044 upward by 5%.

short-wave (365 and 254 nm, respectively) UV lamp. UV-Vis-NIR spectra were obtained for all samples using a Cary 5000 spectrometer fitted with a Varian diffuse-reflectance accessory. The parameters used were identical to those presented by Karampelas et al. (2011a). Photoluminescence (PL) spectra of all the samples were acquired using a Renishaw Raman 1000 spectrometer coupled with a Leica DMLM optical microscope using 50× magnification, with an excitation wavelength of 514 nm emitted by an argon-ion laser (Ar^+), a power of 10 mW, a 10-second acquisition time, and a resolution of about 0.1 nm. The results were compared to previously published studies of natural-color SWCPs from *P. margaritifera* and *Pteria sterna*.

RESULTS AND DISCUSSION

Figures 2 and 3 show the diffuse-reflectance UV-Vis-NIR spectra from 250 to 900 nm for seven natural-color *P. maxima* SWCPs. Each features an absorption (i.e., a decrease in diffuse reflectance) at about 280 nm. In figure 2, each sample shows a region of continuous absorption centered at ~820 nm (in the near-infrared) that gradually absorbs through the visible region (i.e., 390–780 nm). An absorption from the UV to the blue region, consisting of two bands centered at about 330–385 and 385–460 nm, is observed in the spectrum of the gray-yellow-green sample (GGL014). An additional band at 495 nm and three shoulders at ~460, 625, and 745 nm are present. Bands at the same positions, but with different intensities, are seen in the spectra of samples GGL009 (reddish gray) and GGL021 (gray-brown).

Figure 3 presents diffuse-reflectance spectra of four differently colored SWCPs: light gray pink, gray, light purplish brown, and gray-purple. These have absorp-

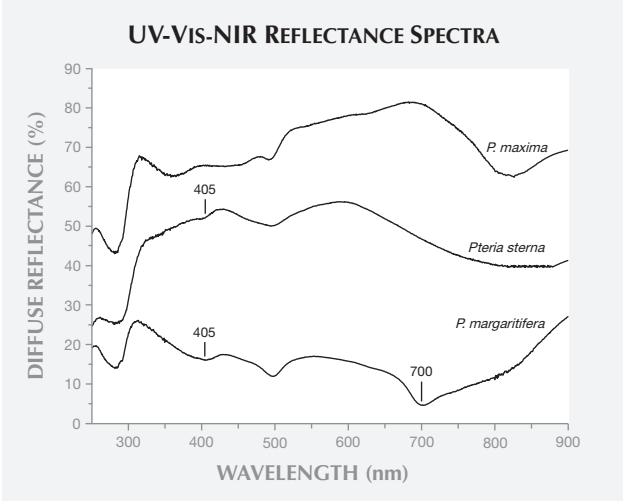
In Brief

- Saltwater cultured pearls (SWCPs) from *P. maxima* in a variety of natural colors were studied using UV-Vis-NIR and PL spectroscopy.
- Their bodycolors depend on the relative intensity of up to six absorptions, which are probably determined by various combinations of several pigments.
- Natural-color SWCPs from *P. margaritifera* and *Pteria sterna* show similar absorption and PL bands, but their UV-Vis-NIR spectra also show a 405 nm band that is not seen in those from *P. maxima*.
- An additional band at about 700 nm is known only from *P. margaritifera* SWCPs, while *Pteria sterna* SWCPs display more-intense PL bands and characteristic red fluorescence to long-wave UV radiation.

tions similar to those observed in figure 2. The same six absorptions in the visible region are observed in all the samples; only their relative intensity varies. Their specific colors are due to the different relative intensities of these bands. Absorptions at identical positions are observed in natural-color SWCPs from *P. margaritifera* and *Pteria sterna* (Karampelas et al., 2011a,b). An additional absorption at 405 nm often occurs in natural-color SWCPs from *P. margaritifera* and *Pteria sterna*, and another at 700 nm appears only in natural-color SWCPs from *P. margaritifera* (figure 4).

A total of six absorptions in the visible region are observed in SWCPs from *P. maxima*. Each sample's bodycolor depends on the relative intensity of these absorptions, which are probably determined by various combinations of several pigments (as many as six). To date, none of these six absorption features has been attributed to a specific pigment. The absorption from the UV to the blue portion of the electromagnetic spectrum (330–460 nm) has been documented in natural-color yellow to "golden" cultured pearls from *P. maxima* (Elen, 2001, 2002b; Mamangkey et al., 2010). Light gray, "cream," and "golden" natural colors of SWCPs from *P. maxima* have been associated with different thicknesses of the edge band structures, the organic matrix between the aragonite platelets that constitute the nacre (Snow et al., 2004).

Figure 4. UV-Vis-NIR diffuse-reflectance spectra are shown for gray natural-color SWCPs from three different mollusks. Similar absorptions are observed in all three spectra. An additional absorption at 405 nm is observed in the spectra of P. margaritifera *and* Pteria sterna *SWCPs, and another at 700 nm appears in those from* P. margaritifera*. For clarity, spectra from* P. margaritifera *and* Pteria sterna *are shifted downward by 30% and 15%, respectively.*



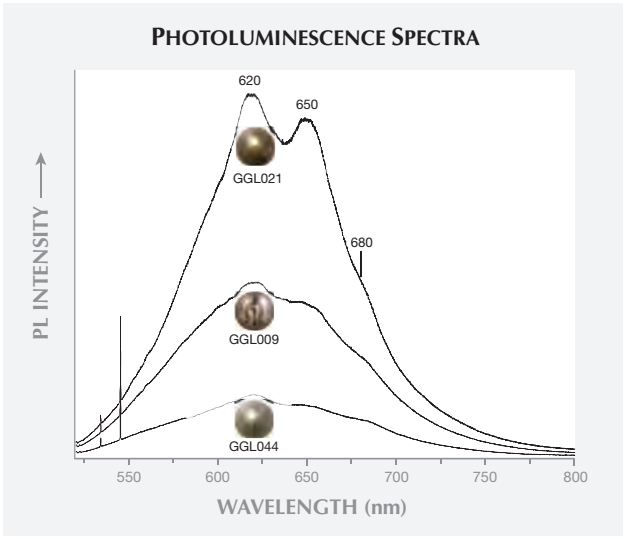


Figure 5. The photoluminescence spectra of three differently colored SWCPs from P. maxima *show bands at 620, 650, and 680 nm. The sharp features at 520 and 550 nm are due to the Raman effect.*

Figure 5 presents PL spectra of three different-colored *P. maxima* SWCPs (GGL009, GGL021, and GGL044). PL bands in the orange-to-red region at ~620, 650, and 680 nm are present in each of the spectra. Similar PL bands have been observed in natural-color SWCPs from *P. margaritifera* and *Pteria sterna* (Miyoshi et al., 1987; Kiefert et al., 2004; Karampelas et al., 2011b). None of these bands could be attributed to a known pigment. Under short- and long-wave UV radiation, the light-colored samples in the present study were inert, while the others showed a weak greenish yellow and weak yellow reaction, respectively. Similar luminescence has been observed in some natural-color cultured pearls from *P. margaritifera* (Elen 2002a; Wang et al., 2006). However, the vast majority of SWCPs from *Pteria sterna* exhibit red fluorescence to long-wave UV radiation; some dark natural-color SWCPs from *P. margaritifera* exhibit weak red luminescence as well (Kiefert et al., 2004).

CONCLUSION

SWCPs from *P. maxima* have a variety of natural bodycolors (e.g., figure 6) due to the relative intensity of several absorptions in the visible range. They also display three PL bands in the orange-to-red portion of the electromagnetic spectrum. Natural-color SWCPs from *P. margaritifera* and *Pteria sterna* show absorp-

Figure 6. This bracelet features a round grayish pink 12 mm saltwater cultured pearl, represented as having natural color, from P. maxima. *Photo © Autore.*

tion and PL bands similar to these. However, SWCPs from *P. margaritifera* and *Pteria sterna* exhibit a 405 nm band that has not been observed in specimens from *P. maxima*. Moreover, an additional band at about 700 nm is known only from *P. margaritifera* SWCPs. Samples from *Pteria sterna* display more-intense PL bands and a red fluorescence to long-wave UV radiation that is not observed in SWCPs from *P. maxima* and seen only rarely in those from *P. margaritifera*. None of these PL and absorption bands have been attributed to a known pigment. Further research using destructive means on isolated natural pigments found in SWCPs from *P. maxima* is needed to identify their exact nature.

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