NATURAL PEARLS FROM AUSTRALIAN *PINCTADA MAXIMA*

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The fascinating and colorful history of natural pearling in Australian waters is presented, from the early six-man luggers to the large ships in modern fleets where pearl culture has been the focus for the past several decades. For the scientific investigation of this paper, the authors retrieved natural pearls from wild *Pinctada maxima* in Australian waters and recorded the various properties that might help to differentiate between natural pearls from this mollusk and those that are accidental by-products of the culturing process. Three distinct categories of host *Pinctada maxima* shells and mantle pearls were collected and examined by the authors: (1) from wild shell prior to any pearl culturing operation, (2) from wild shell after pearl culturing and approximately two years on the farm, and (3) from hatchery-reared shell prior to pearl culturing. Data were collected from microscopy, X-rays of internal structures (using real-time microradiography and X-ray computed microtomography, various forms of spectroscopy, and LA-ICP-MS chemical analysis. The results showed that microradiographic structures previously considered indicative of an accidentally cultured *P. maxima* pearl may not be conclusive, and that such criteria should only be applied with the utmost caution by an experienced technician.

According to Cilento (1959), natural pearls have been found off the western and northern coasts of Australia since well before European settlement in the early 19th century. Coastal-dwelling Aborigines and fishermen from Sulawesi had collected and traded pearl shell for possibly hundreds of years.

> The pearling industry in Queensland dates from 1868, when Captain William Banner, of the Sydney brig Julia Percy fished the first cargo of pearl shell from Warrior Reef. Captain Banner noticed the natives preparing for a dance, and saw they had big mother-of-pearl pendants round their necks. He made a bargain with Kebisu, mamoose (chief) of the headhunters of Tutu, who, for generations, raided the islands of Torres Strait in their great war canoes.
>
> Perhaps the menace of Banner's shotted fore and aft guns, which could far outrange the eight-foot bows and barbed arrows of the black bowmen of Tutu, had something to do with the friendliness of the blood-thirsty and crafty Kebisu and his headhunters. In return for tomahawks and iron—the most valuable things in their eyes—they gave Capt. Banner as much as he wanted of what they considered the common and relatively valueless pearl shell and pearls.
>
> Capt. Banner and his crew won a rich harvest from the coral sea, for pearl shell was then worth £150 a ton in Sydney; and Banner collected many large pearls. (Cilento, 1959)

Pearling, particularly for the recovery of natural pearls from the most remarkable of all pearl oysters—*Pinctada maxima*—in the adventure-strewn waters off the Australian coast, has a diverse and fascinating history. This history may be eyed through the literary skills of authors such as E.W. Streeter and Louis Kornitzer, who hailed from a time when natural pearls were objects of great value and wrote about them with passion and wonder.

As one delves into the history of pearling in this region, it is difficult not to become wrapped up in a wondrous web of adventure and intrigue, danger from every conceivable corner, and the ecstasy of the ultimate find: a lustrous sphere, perhaps with that smoothly flattened side that gives it the shape of a button, or slightly elongated to form a teardrop, exposed within the mantle with the gills glinting behind it, the curtained backdrop to this pearl's debut on the world's stage (figure 1).

See end of article for About the Authors and Acknowledgments.

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Figure 1. A natural round 6.04 × 5.93 mm pearl sits within the mantle of a P. maxima *pearl oyster, whose gills provide a dramatic backdrop to one of nature's great miracles. Photo by K. Scarratt.*

Kornitzer takes us on a helter-skelter ride through his journeys from Singapore down through the island realms that encase the Java, Banda, Celebes, and Timor Seas and ultimately into those wild waters that run from Exmouth Gulf and up through Broome and on to Darwin. His stories are the very epitome of boyhood adventure dreams, leaping from the pages to convince the reader that "a pearling he must go":

> It was as a humble young dealer in Hatton Garden that the urge to adventure came to me, that strong, compelling urge like a kick in the pants, which is produced by the fact that one's family is hungry and growing. I had a chance to go pearl-hunting in the tough pearling grounds in North-Western Australia, and I took it. From Australia the chase for pearls led me in half a lifetime all around the world, but I was a stone that rolled slowly enough to gather a minute quantity of moss. At any rate, I have never regretted it. One looks back with a strange satisfaction on the lonely and risky periods of one's life.
>
> As I was the first white trader ever to penetrate into the pearl fisheries of the Sulu Seas, I still have a proprietary feeling about that part of the world. (Kornitzer, 1947a)

These stories are eloquently told and retold in books such as Hurley's *Pearls and Savages* (1924), Berge and Lanier's *Pearl Diver* (1930), Benham's *Diver's Luck* (1949), and Bartlett's *The Pearl Seekers* (1954). Each work adds yet another layer of intrigue to an incredible adventure.

Lately, other highly informative and passionate accounts of Australian pearling have emerged. Two of particular note are *The Last Pearling Lugger: A Pearl Diver's Story* (Dodd, 2011) and *The Pearls of Broome: The Story of TB Ellies* (Ellies, 2010). Dodd's book brings the reader up to the early 1980s, when the luggers (figure 2) left service in favor of the much larger vessels in use today. The latter work recounts the incredible story of the Sri Lankan immigrant T.B. Ellies, who was one of the world's finest "pearl doctors" of the late 19th century. Practitioners of this lost art enhanced the appearance of a pearl by carefully removing blemishes on the outer layers.

Like many others in the Australian pearling industry, Ellies made his home in the town of Broome (figure 3). Activity had initially centered around Nickol

Figure 2. The men on deck of this lugger, at anchor in Darwin harbor in 1897, give scale to the small size of the vessel, which had cramped quarters for a six-man crew at sea for weeks at a time. Courtesy of Paspaley Pearling Co.

Figure 3. An early 20th century dealer in Broome sorts his natural pearls. Courtesy of Paspaley Pearling Co.

Bay and Exmouth Gulf, but by 1910 Broome was the largest pearling center in the world. Indeed, pearling remains an important part of the Western Australian economy, albeit largely through the cultured market.

In the mid-1880s, the famed English jeweler, entrepreneur, and author E.W. Streeter moved to Broome with his son (G.S. Streeter, a prolific author in his own right) and became heavily involved in pearling. By 1890, the elder Streeter had acquired significant property on the outskirts of the town, establishing a general store and owning one-eighth of the pearling fleet. Renowned for his great work *Pearls and Pearling Life* (1886) among others, he is also credited with the introduction of hard-hat diving. Indeed, the Streeter name is indelibly linked with the chronicles of this great pearling town (figure 4; Smith and Devereux, 1999).

Lennon (1934) describes hard-hat diving as one of the "world's most dangerous occupations." He notes, "Divers may work up to 30 fathoms [180 ft], but 22 fathoms is the average depth to which they descend. After bottoming the diver is pulled up a couple of feet and permits himself to be towed along by the lugger. Sighting shell, he signals to his tender, who lets him drop." Wearing an extremely cumbersome helmet and boots, the diver "works kneeling on his right knee and gathering with his right hand, taking good care to keep his head erect. If his head gets down, the air in his dress may shift and he would shoot aloft, feet first." Not recommended, as the normal method of ascending is to haul up the diver very gradually before surfacing, thus avoiding potentially fatal divers' paralysis, commonly known as "the bends."

Beyond the romance of the written word, early pearling in the region may somewhat be likened to the American "Wild West," as witnessed by fisheries inspector Pemberton Walcott. In his report covering the period from April 15 to June 30, 1881, he writes

> I have on good private information the following, which will require immediate investigation. During last pearling season, the majority of the fleet being at anchor in or near LaGrange Bay, three bush natives were killed by some De Grey River pearling natives; some time, days after, the bush natives retaliated by killing some De Grey pearlers (two or three), when the latter mustered in force, and in fact seem to have organized an expedition and followed the natives up, slaying all they surprised. I have reason to believe twenty to thirty were killed.

His report concludes

> It frequently occurs that, in holding any communication with the shore, a vessel has to run up creeks and is left high and dry at low water, so at the mercy of the natives, and no white man should land without means of protecting himself, for it may and does frequently happen that however friendly natives be at one time they maybe [*sic*] found hostile and troublesome at another, in consequence perhaps of some act which they may consider themselves bound to avenge. (Walcott, 1881)

The data provided in a report on North Western

Figure 4. This photo shows Streeter's Jetty, where the pearling luggers would unload their haul and scrape the keels of barnacles at low tide. The jetty was restored and reopened in 2001 as a community project to preserve the heritage of Broome. Photo by K. Scarratt.

TABLE 1. Value of pearl shell recovered from Western Australia, 1889–1898 (from Gale, 1901).

Year	Weight of mother-of-pearl (*P. maxima* shell) gathered		Value
	Tons	CWT (Hundredweight)	Pounds (sterling)
1889	744	10	74,450
1890	702	10	70,250
1891	749	-	89,880
1892	781	9	78,471
1893	540	17	35,499
1894	422	15	57,997
1895	352	14	26,258
1896	362	8	30,160
1897	366	-	38,630
1898	538	6	76,586
Shell total	5,556		578,181
Pearl total			**300,000**
Shell + Pearl total value at 1910			**878,181**
Shell + Pearl adjusted total £ value at 2011			**£82,259,214**
Shell + Pearl adjusted total US$ value at 2011			**US$127,273,557**

Australia's pearling industry to the attorney general by the chief inspector of fisheries (Gale, 1901) explain why intrepid adventurers came to such remote and often inhospitable places. Between 1889 and 1898, some 5,556 tons of pearl shell with a value of £587,181 were "declared" (table 1). While the annual haul fell between the beginning and end dates, the actual monetary amount rose slightly.

Gale's report also provides some insight into the pearling industry of the time. He noted that during the year from June 30, 1900, 177 boats were officially licensed. This represented a total tonnage of 2,480 tons, with the 159 luggers averaging 10 tons each. The 18 schooners, employed mainly as supply vessels and as storage for shell haul, ranged from 30 to 100 tons. Gale noted that each lugger carried a crew of six, with the diver in command. He added that a large amount of capital had been invested in each lugger: an average of £550 (£51,500 or approximately US$80,000 in 2011, adjusted for inflation) for a fully outfitted vessel. The approximate value of the fleet was £8.19 million, or US$12.7 million today.

Gale also provides us with some interesting asides concerning the value of pearls recovered during this period. He notes (as did other authors of the period) the difficulty of estimating this value from the quantity of pearl collected, due to heavy illicit trading of *snide*.[1] But taking figures from the statistical register for the previous 10 years, he estimates the value to be £300,000, or £28,101,000 today. He comments that these large numbers were somewhat offset by the costly expenditures involved: The average amount paid to the crew of each lugger was about £220, not including a £20 bonus to the diver for every ton of shell collected.

Kornitzer (1937) brings to vivid life the world of snide pearl trading in Broome in recounting one of his experiences. While fishing off the "long Wooden Pier" (probably referring to what is now known as Streeter's Jetty; figure 4), he is approached by a smuggler named Da Silva, who tells him:

> *Master, you buy fifty-grain round pearl, oh such a beautiful thing – you got thousand pounds in your pockit? If not I trust you. Master, you can sell it for two thousand for sure. I've got her here, you like to see?*

To control the shady business of snide, one P. Percy designed a box (patented in 1910) to securely hold any pearls found by the shell openers onboard the luggers. Pearls were placed in the box (figure 5) through a round hole in the top. The pearls went into the box along a "bent tube." The bend in the tube ensured that even if the box were tipped upside-down, the pearls would remain inside. All pearls recovered would be placed in the locked box for delivery to the owner upon docking.

In reality, the skipper had little time for monitoring what went into the box and what did not. His primary concerns were the navigation of the vessel and the safety of the divers. It was therefore more of an

Figure 5. Percy's patented box is used to store recovered natural pearls on the deck of this pearling lugger. Note the red cap over the opening and the padlock on the door at the front of the box. Photo courtesy of Paspaley Pearling Co.

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[1] The term for pearls that were smuggled from the lugger, usually by shell openers, and then sold clandestinely.

Figure 6. The Japanese cemetery in Broome, as seen in 2011. Photo by K. Scarratt.

"honesty box" than a true deterrent. Judging from the many texts that have alluded to it, a brisk business in snide pearls was prevalent in Broome.

Broome was indeed the Wild West of Australia, and just like any frontier settlement it was full of intrigue and character. One cannot write about the history of Broome without mentioning its Japanese cemetery (figure 6), the largest in Australia. More than 900 Japanese pearl divers are buried here in over 700 graves. The site testifies to Broome's close ties with the people of Japan and the enormous importance of pearling in the region.

The first interment was recorded in 1896, and a plaque at the entrance to the cemetery acknowledges the great many men lost to drowning or divers' paralysis. A large stone obelisk bears testimony to those who perished in the 1908 cyclone. It records the 1887 and 1935 cyclones, each of which caused 140 deaths. In 1914 alone, decompression sickness claimed the lives of 33 men. Not mentioned are victims of scurvy, the disease caused by vitamin deficiency, which was brought on by subsisting on fish and rice for many weeks aboard the luggers.

HISTORIC PEARLS

Given the region's long history of natural pearling, there can be little doubt that the vaults of important dealers worldwide, including those in Europe and the Arabian Gulf, contain a large number of treasures gained from Australian waters. *Pinctada maxima* in these waters indeed produce some of the finest known natural pearls in all sizes and shapes (e.g., figure 7). But as production emphasis shifted to the highly successful "South Sea" cultured pearls, the casual observer began to overlook the natural pearl. And over the last few decades, the natural pearl even strayed from the minds of those most closely associated with the fishing of this incredible mollusk. Indeed, it had become economically unimportant to them.

Thankfully, the focus is shifting again, and natural pearls from *Pinctada maxima* are now edging their way back into the minds of those who love all that is rare and beautiful (N. Paspaley, pers. comm., 2011). Perhaps due to the prevalence of snide, few records exist of notable natural specimens from Australian waters, even though it can be assumed that most, if not all, of the largest nacreous natural pearls have been the product of *Pinctada maxima* rather than a smaller pearl oyster[2].

In P.O. Lennon's interesting account of the Australian pearl industry, a plate illustrates several "empire" pearls and five "Indian" pearls (three drops and two rounds) weighing 9.32–48.92 grains. There are also six somewhat larger "Australian" pearls: one near-perfect round weighing 110 grains, two off-rounds (18 and 20.80 grains), and three drops (a pair totaling 62.80 grains and a single weighing 86.80 grains).

In August 1949, an account of a major pearl find was reported in the *Northern Standard*:

> More than five tones [*sic*] of pearl shell brought back to Darwin this week has been declared by local shell experts to be of the finest quality ever to be taken in Darwin waters, either before or since the war. The shell represents the catch of two luggers belonging to Mr. Nicholas Paspaley, who said it prom-

Figure 7. This historical photo shows an array of natural pearls on the desk of a dealer in Broome. Photo courtesy of Paspaley Pearling Co.

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[2] Pearl oysters include marine bivalves classified in the family Pteriidae and the genera *Pinctada* and *Pteria*, such as *Pinctada maxima*, *Pinctada margaritifera*, *Pinctada mazatlanica*, *Pinctada fucata* (*martensii*) and *Pinctada imbricata*, *Pinctada radiata*, *Pinctada maculata*, *Pteria penguin*, and *Pteria sterna*.

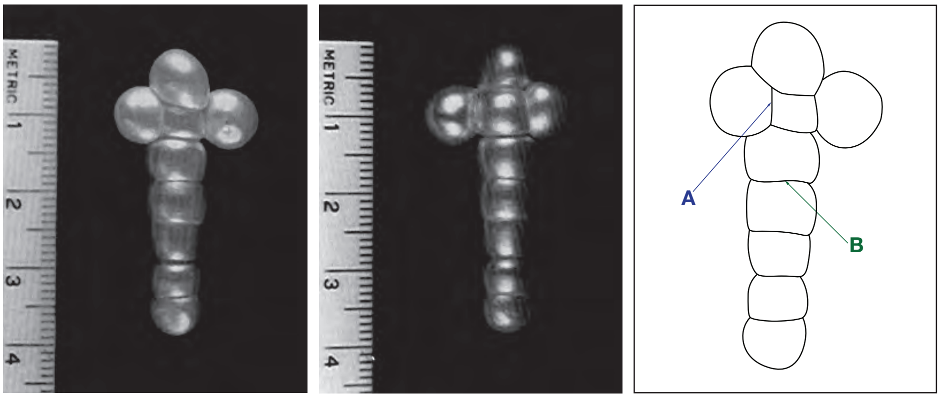


Figure 8. The back of the Southern Cross (left) reveals a very slightly flattened surface. The front of the cross is seen in the middle. The line drawing on the right shows the only two remaining joints (A and B) that were completely natural at the time of examination in 1981. Joint A is supported by some adhesive, while the other joints are now artificial (Scarratt, 1986b).

> ised well for future operations of his fleet.
>
> In addition to the shell, the luggers brought back a perfect drop shaped pearl estimated to weigh between 50 and 60 grains. Local authorities say it is the best pearl taken in Darwin since operations commenced after the war. Mr. Paspaley said that last year he had taken a pearl weighing 106 grains but its quality was much inferior to the one brought in this week. ("Pearl shell," 1949)

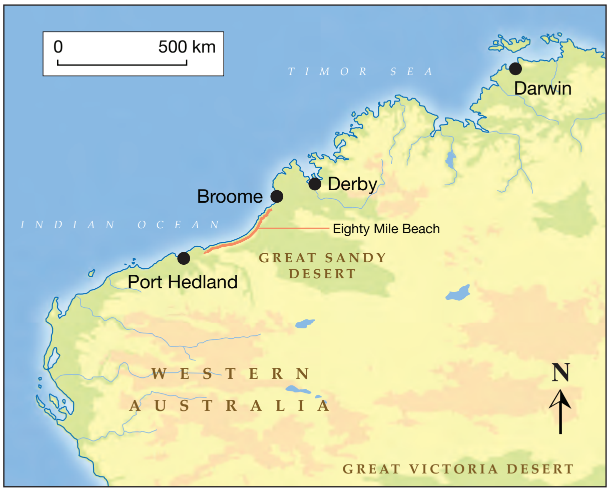
In 1917, a Japanese diver working for James Clark (the "Pearl King") discovered the Star of the West, a 100-grain beauty also known as the Broome pearl. This specimen was described in the July 1918 edition of *The Colonizer* as a "perfect drop with a skin of iridescent luster diffused with a pinkish glow." Other pearls of similar size are loosely recorded as the A. G. Russel, a 100-grain perfect round; the Eacott, a large drop; the Bardwell, a double button; the Rodriquez, a 92-grain perfect round; the 100-grain Hawke and Male; and the E. G. Archer, a 76-grain drop.

But the most storied Australian pearl is unquestionably the Southern Cross (figure 8). Kunz and Stevenson (1908) describe its history with both fascination and some disdain:

> The "Southern Cross" is an unusual pearl or rather cluster of pearls which attracted much attention twenty years ago. It consists of nine attached pearls forming a Roman cross about one and one half inches in length, seven pearls constituting the shaft or standard, while the arms are formed by one pearl on each side of the second one from the upper end. The luster is good, but the individual pearls are not perfect spheres, being mutually compressed at the point of juncture and considerably flattened at the back. If separated, the aggregate value of the individual pearls would be small, and the celebrity of the ornament is due almost exclusively to its form. This striking formation was exhibited at the Colonial and Indian Exhibition at London in 1886, and later at the Paris Exhibition in 1889, where it was the center of interest, and obtained a gold medal for the exhibitors. It is reported that an effort was made to bring about its sale at £10,000, the owners suggesting that it was especially appropriate for presentation to Leo XIII, on the occasion of his jubilee in 1896. The writers have been unable to obtain information as to its present location.

Henry Taunton (1903) offered further details on the Southern Cross in a very interesting account of his Australian wanderings. He presents apparently reliable statements showing that it was found on March 26, 1883, at Baldwin Creek, off the coast between Broome and Derby (figure 9). It was discovered by a boy named Clark, in the employ of master pearler James W. S. Kelly. It was delivered to Kelly in three distinct pieces, though the boy reported that he found it in one piece a few hours earlier. Kelly sold it in three pieces, receiving £10 from a fellow pearler named Roy. Roy sold it for £40 to a man named

Figure 9. Eighty Mile Beach runs from Broome down to Port Hedland and is bounded inland by the Great Sandy Desert. The famed Southern Cross was found off the coast between Broome and Derby.



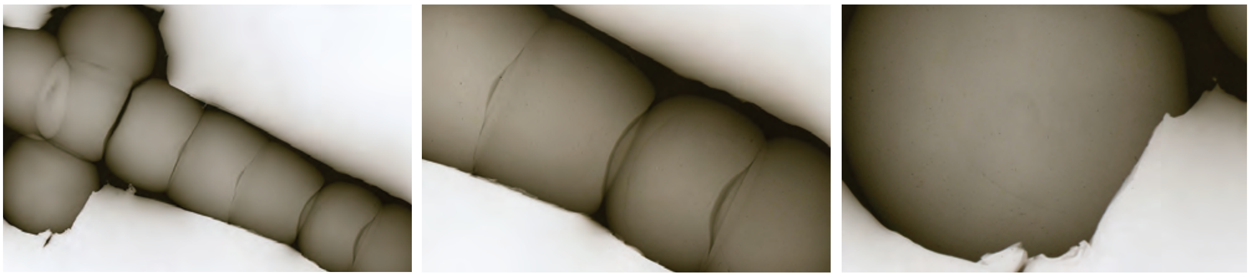


Figure 10. The microradiograph of the Southern Cross on the left was taken in 1981. The white surrounding area is a lead template used to absorb scattered X-rays. The image clearly shows the junctions between each of the pearls forming this unique cluster. A closer view of the microradiograph (center) shows the two lower pearls in the Southern Cross and the natural growth structures (black lines). An even closer view (right) shows the natural growth structures (black lines) in the lower arm of the cross.

Craig, who in turn dealt the pearl to an Australian syndicate.

According to Taunton, there were only eight pearls in the cluster when it was sold by Kelly in 1883. To make it resemble a well-proportioned cross—the right arm being absent—another pearl of suitable size and shape was subsequently secured in the town of Cossack and attached in the proper place. In the meantime, the other pearls had been refastened together by diamond cement, for a total of three artificial joints in the cluster:

> As if to assist in the deception, nature had fashioned a hollow in the side of the central pearl just where the added pearl would have to be fitted; and the whole pearling fleet with their pearls and shells coming into Cossack about this time, it was no difficult matter to select a pearl of the right size and with the convexity required. The holder paid some ten or twelve pounds for the option of selecting a pearl within given limits; and then once more, with the aid of diamond cement and that of a skillful "faker," this celebrated gem was transformed into a perfect cross. (Taunton, 1903)

When it was examined by one of the authors in 1981 (Scarratt, 1986b), the Southern Cross weighed 99.16 grains (24.79 ct), measuring 37.2 mm long and 18.3 mm wide. The length was similar to that reported by Kunz and Stevenson (1908), while the general shape matched the photo from a 1940s exhibit.

Scarratt examined the cluster for both its natural origin as well as the natural formation of the cross. He clearly determined that the pearls were natural, though by that time only two of the joints (A and B in figure 8, right) remained entirely natural.

The microradiograph of the cluster[3] (figure 10) clearly shows dark junction lines representing varying degrees of organic material or simply voids between each pearl, indicating the fragility of each junction and going some way toward validating Clark's statement that the cluster was discovered intact and broke shortly afterward. It may also be noted that the arms of the cross are created by pearls of unequal size and shape, which brings into question Taunton's "positive statement" that one of the arms was added by a "skillful faker," for surely that person would have chosen a closer match.

This examination of the Southern Cross also highlights just how fine the growth structures can be in pearls from *P. maxima*. Figure 10 (center and right) shows magnified microradiographic views of sections from the Southern Cross, which reveal only a very few organic (line) structures, demonstrating how "tight" the crystalline component is for each of the pearls in the cluster. This structural characteristic, while not universal for pearls from *P. maxima*, may certainly be regarded as common to them.

In Brief

- Historically, Australia has given the world an untold but significant volume of natural pearls, some of which have been quite notable.
- For several decades, the commercial importance of natural *Pinctada maxima* pearls has declined as the cultured pearl industry has matured.
- A newly rekindled market for natural pearls has generated interest in natural *P. maxima* pearls from Australian waters.
- Microradiographic structures previously used to distinguish between natural *P. maxima* pearls and accidentally cultured specimens are not necessarily conclusive.

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[3] This microradiograph was obtained using fine-grained X-ray film in conjunction with an X-ray unit, designed specifically for the London Laboratory, that used a Machlett tube with a water-cooled molybdenum target and beryllium windows.

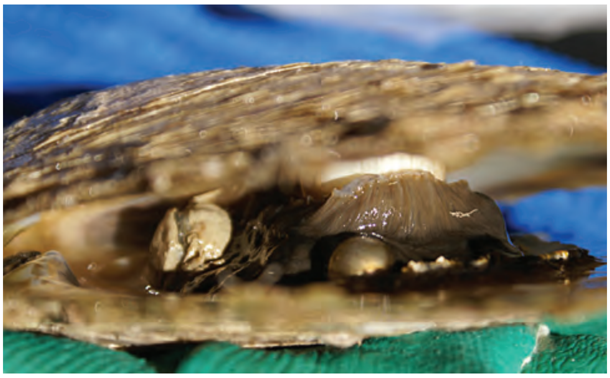


Figure 11. A pea crab (left) scurries around within a P. maxima*, while a natural pearl (center) sits in the mantle against the backdrop of the gills and adductor muscle. Photo by K. Scarratt.*

THE MOLLUSK

P. maxima (described in Jameson, 1901) is the largest species of the Pinctada genus and indeed the largest of the "pearl oysters," reaching sizes that may exceed 40 cm. The species has an extraordinary life span of up to 40 years or longer. It occupies a wide-ranging area of the Pacific, from Burma to the Solomon Islands, with Australian, Papua New Guinean, and Philippine waters the traditional habitats. Indeed, it may still have prolific shell beds in these areas. The range extends from Hainan, off the coast of China, down to the eastern and western coasts of Australia. The mollusk lives at depths of up to 90 meters, but growth rates are optimized if the depth is limited to 30–40 meters.

P. maxima have a light beige color externally, though variants do occur, and radial markings are absent. Internally, the nacre is thick and has a high luster, with the outer border having a gold or silver band, the reason why *P. maxima* is popularly known as the golden- or silver-lipped pearl oyster. The left valve is convex and the right valve only slightly so.

Pea crabs, *Pinnotheres villosulus*, live in symbiotic harmony with some 85% of *Pinctada maxima*, both wild and hatchery-grown (figure 11). Such close associations between various mollusks and pea crabs are common. Upon opening *P. maxima*, one is often treated to the extraordinary sight of a small crab scurrying around within the mantle cavity, as if the lower portion were a bed on which to lay its weary head while the upper portion holds the comforting blankets to its shell cradle.

As natural pearls may form within *P. maxima* as the result of some trauma to the mantle, it is interesting to speculate on the possible role of intruding crustaceans in producing these magnificent wonders. The animal certainly does wander in the region of the gills (which filter water and exchange oxygen), and by all accounts this appears to be the area of the mollusk where most natural pearls form. Figure 12 shows this position to be typically within the mantle and in front of the gills, close to the widest point of the adductor muscle.

Natural blister pearls that encase dead pea crabs

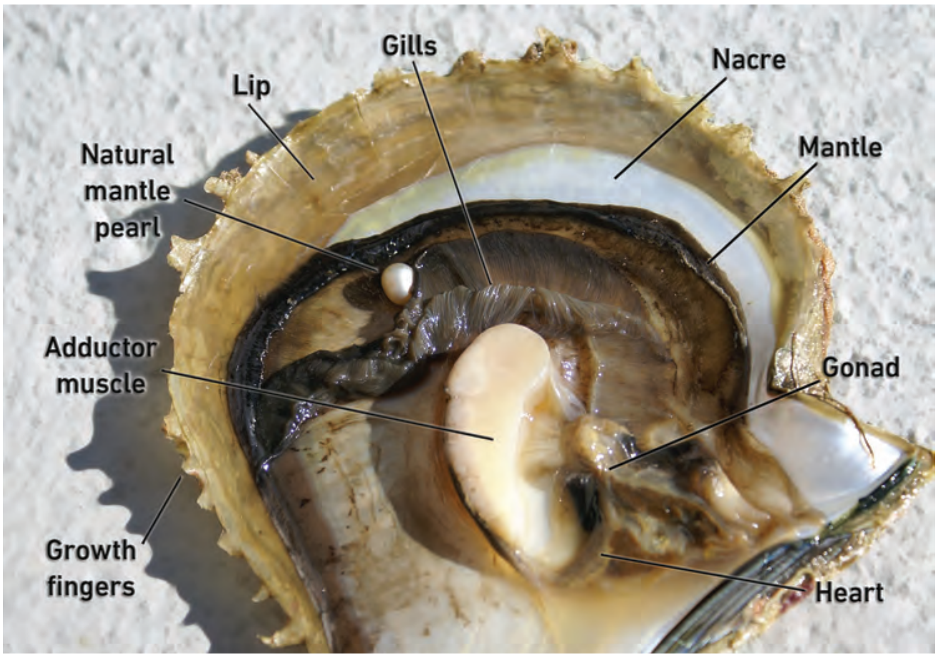


Figure 12. A partial anatomy of P. maxima *is shown here using an opened shell that also contains a natural mantle pearl. These pearls are typically positioned near the gills. Photo by K. Scarratt.*

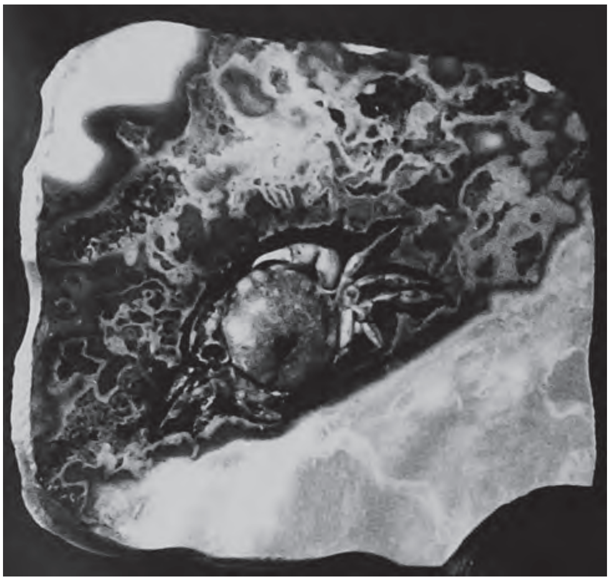


Figure 13. "Buried in a pearly mausoleum. The end of a small inquisitive crab in a pearl blister." This photo is from the archives of E. Hopkins.

inside the shell have been noted on several occasions, not only in *P. maxima* but also in other shells (Edwards, 1913; Hedegaard, 1996; PearlMan, 2011; figure 13). There have also been reports of "pearlfish" (slim, eel-shaped marine fishes of the Carapidae family) and other cohabiters of this wonderfully protective pearl shell dying inside *P. maxima* and providing the basis for the formation of other incredibly interesting blister pearls (Smith, 2003; Hochstrasser, 2011).

A supreme example examined by one of the authors (KS) in recent years is shown in figure 14. Here a blister pearl–encrusted pearlfish is attached to the shell, not far from where the heart and gonad would have been in the living mollusk. This attests to the symbiotic harmony of the fish living within the protective valves of the *P. maxima*.

As one ponders the lengthy life cycle of this mollusk and considers many decades of examining microradiographs of the natural pearls produced within its slender and near transparent mantle, it is surprising to find there is still debate over what initiates the growth of a natural pearl. It is clear that within the valves, life is not motionless. Apart from invading life forms, another potential trigger is the tremendous amount of ocean floor debris that likely finds its way over the mantle and onto the mollusk's gills.

There is no convenient single initiator but rather a wealth of possibilities that make the growth process even more intriguing. Of the hundreds of thousands of microradiographs examined by the authors, very few definitively show what caused a particular pearl's formation. Two spectacular examples that come to mind appear in figures 15–17.

In figures 16 and 17, the *Pectinidae* shell is extraordinarily clear. The owner understood the uniqueness of the pearl and stored it safely in his collection, which has allowed us to reexamine the specimen several times as imaging technology has improved. The images in figure 17 were obtained via X-ray computed micro-tomography and further manipulated to obtain the vividly detailed images presented here.

With these two pearls in particular, plus a few others we have documented that are not quite as spectacular, we were particularly lucky to have obtained them from reliable sources. In recent years, a variety of foreign bodies, including natural pearls and even shells, have been artificially inserted into cultured pearl sacs (produced from a graft of mantle tissue, or from mantle damage due to human handling) to further coat them with nacre. These practices, by deceiving gem laboratories and consequently the industry, have placed a question mark over all natural pearls.

Figure 14. A blister-encrusted fish can be observed toward the hinge of this 220 × 210 mm P. maxima shell (left). An enlarged view (center) more clearly shows the blister pearl–encrusted fish; the blister measures 63 × 13.91 mm. A partial microradiographic image (right) clearly displays the fish's skull and vertebrae.

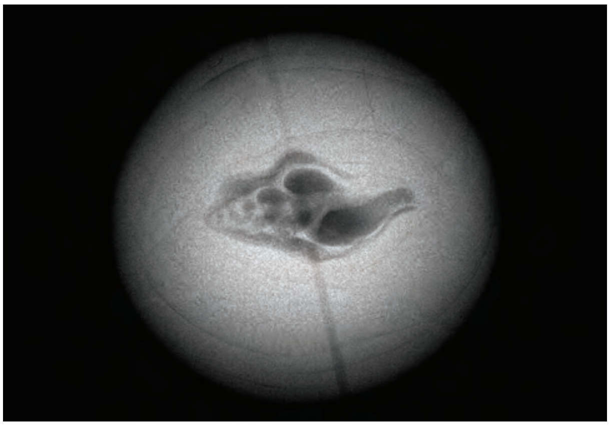


Figure 15. This microradiograph shows a shell, with chambers that appear to indicate a Strombidae, situated at the center of a natural pearl. Examined in GIA's Carlsbad laboratory circa 2002, the specimen was identified as natural. The pearl's current whereabouts are unknown. Note that the pearl has been drilled, as indicated by the dark broad line running slightly off vertical. The microradiograph was taken using X-ray film rather than real-time computerized imaging. The producing mollusk is unknown.

OTHER *P. MAXIMA* PRODUCTS

There is little if anything wasted by those who farm *P. maxima*. The mollusk provides us with not only pearls, both natural and cultured, but also very high quality mother-of-pearl and an edible delicacy.

Pearl shell (figures 18 and 19) is used today, as it has been for the last two centuries, in the manufacture of luxury utensils, as inlays in jewelry and furniture, and in various art forms. In fact, the value of the shell fished in toward the end of the 19th century often exceeded that of the natural pearls (table 1). Today, with the main use of the oyster (both wild and hatchery) being the production of large South Sea cultured pearls, the shell has a lower proportional value. Nevertheless, it remains an important element in the value stream of pearling companies.

It may be appropriate to quote Kornitzer again, for never have the writer's words been bettered in any works concerning this great bivalve:

> A shell it was, as large as a soup-plate, no more. A brilliantly nacreous thing with a natural polish, smooth as a mirror and reflecting not only my still youthful features, but also, it seemed, some of the things the future promised to hold for me.
>
> How interesting, and how foolish, to believe that one can see into the future at the magic touch of some alien thing and vaguely guess one's destiny in a waking dream!
>
> It happened in the prosaic London Docks, that staid businesslike place with its background of romance. As the man lifted the pearl shell out of the open case for me to admire its unusual size and weight, I did what probably nine women out of ten would have done in similar circumstances. I eyed myself carefully in the smooth and shining surface. Presently the reflection of my own face seemed gradually to fade, and even as I looked there took shape in my mind the vision of a life oddly governed by the moon-fired stones of my future love.

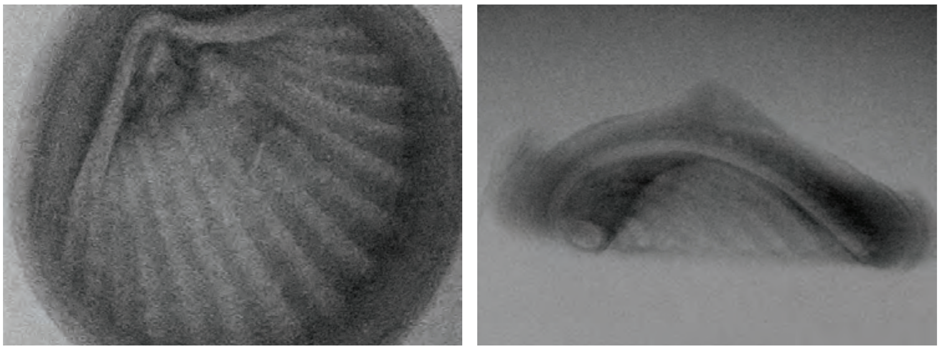


Figure 16. These top and side view microradiograph are of a 19.06-grain, 9.66 × 9.62 × 7.60 mm button-shaped natural pearl from a P. maxima *discovered in Australian waters in 2007. At its heart lies one of the most incredible sights: a perfectly preserved shell of the Pectinidae family, just 3.5 mm across.*

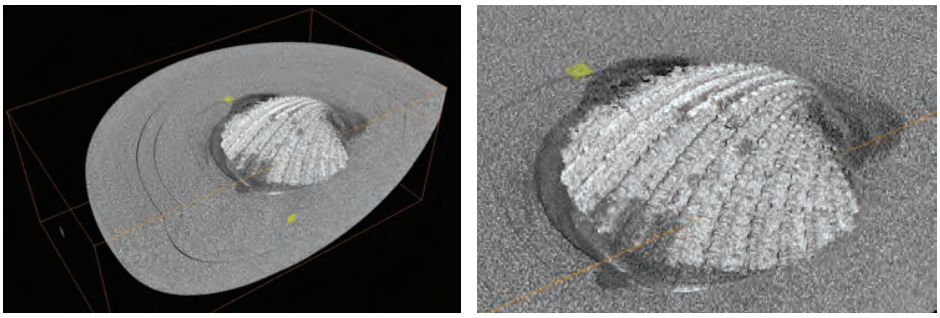


Figure 17. Images constructed using X-ray microtomography show the pearl-encrusted shell from figure 16. The computerized image on the left shows the shell and concentric growth structure. The enlarged image is on the right. Courtesy of Nick Hadland, Hadland Technologies.

Figure 18. These large P. maxima *shells display high-quality nacre (mother-of-pearl). Courtesy of Paspaley Pearling Co.*

Figure 20. Fresh pearl meat from the P. maxima *adductor muscles is regarded as a delicacy, particularly in China. Photo by K. Scarratt.*

> The vision faded. I stood like a ninny with the shell in my hand. The man nudged me and said, "Trying to drill holes into this shell with your eyes?"
>
> "No," I said apologetically. "I've been dreaming. These outlandish things seem to awaken in me the desire to travel, that's all." (Kornitzer, 1937)

Pearl meat from the *P. maxima* adductor muscle is a delicacy, particularly in China but also to anyone fortunate enough to experience this gastronomic delight (figure 20). Eaten raw or quickly flash-seared in a hot pan for just a few seconds or slowly braised, it will excite the taste buds of any dissenter.

It is estimated that 60% of all pearl meat harvested in Western Australia makes its way to Asian markets after drying and packing. It sells for Aus$100–$150 per kg. The rest is monopolized by top chefs in Sydney and Perth, as well as Broome, which is why very little pearl meat can be found in the shops (Broadfield, 2010).

Figure 19. Searching P. maxima *for natural pearls aboard a lugger. Courtesy of Paspaley Pearling Co.*

Chef Matt Stone of Perth says, "What I love about it most is the texture: It's halfway between a scallop and an abalone. It's got a bit of chew to it, but not so much as abalone" (Broadfield, 2010). All of the authors who have tasted the meat of *P. maxima* are in full agreement.

WILD SHELL COLLECTION TODAY

The pearl culturing industry is one of Australia's most valuable aquaculture industries, with a value estimated at Aus$120–160 million (Hart and Friedman, 2004). Considering the natural as well as manmade challenges, this is truly a significant statistic. Clearly, one important factor behind the industry's success is the reliance on hatchery-grown mollusks that offer more control over production processes. Interestingly, the Paspaley Pearling Company, whose operations are focused on the waters of the Northern Territory and Western Australia, still fish for wild shell and use them for much of their culturing operations[4].

To protect the species, the harvesting of mother–of-pearl (MOP) in Western Australia was virtually phased out by the late 1980s, and strict quota controls were placed on sizes suitable for pearl culturing. Hart and Friedman (2004) point out that the fishing for *P. maxima* targets smaller shell (120–165 mm dorso-ventral measurement, or DVM; see figure 21) that are more suitable for pearl culture, leaving larger (175 mm+) MOP on the pearling grounds. They add that in 2004, the shell were protected by the "gauntlet" strat-

---

[4] Australia still has a predominantly wild oyster industry. The current Australian quotas are set at 1,342 units, made up of 992 units of wild shell and 350 units of hatchery shell; wild shell thus accounts for 74% of the quota. The number of shell permitted per quota unit is set each year by the Fisheries Department, depending upon the availability of shell.

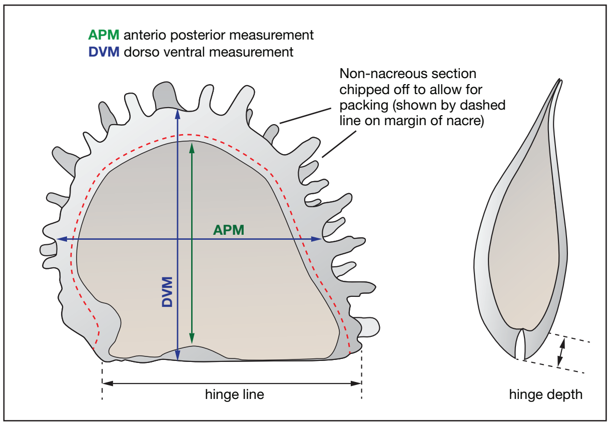


Figure 21. Common measurements applied to the morphology of P. maxima. *After Hart and Friedman (2004).*

egy adopted by the Fisheries Department, and that "with almost 20 years of protection from fishing mortality, there has been a buildup of MOP on some pearling grounds, leading to proposals to commercialize (again) this component of the fishery." The quota system has been so effective that the fisheries sector is now the "only remaining significant natural source of large *P. maxima* MOP left worldwide." As wild stocks fluctuate, however, historic norms are the most likely outcome.

The wild shell collected by Paspaley are kept separate from their hatchery shell via a strict stock control system that begins the moment a specimen is brought aboard the vessel. Collection of the wild shell occurs mostly off Western Australia's Eighty Mile Beach (between Broome and Port Hedland in figure 9), but the company also has a quota in Northern Territory waters. Although divers now operate from modern, specially designed vessels (figure 22), the principles are similar to those used in the days of the lugger. With today's larger ships, up to six divers are pulled along the seabed as the ship plows a slow-moving grid at the surface. Divers are still connected to the vessels by safety lines and air hoses, but they wear modern wetsuits and are not constrained by the hard-hat environment once used aboard the luggers.

As they move along the seabed, the divers trail below them a rope basket for the shells (figure 23). Once the basket is full, the diver ascends to a shallower depth where a large storage container awaits. He transfers the shells from his basket and returns down to the seabed to continue collecting. He may repeat this process several times before the dive ends. There is great rivalry between divers, with "scores" being eagerly awaited once back onboard the vessel.

While the practice is unquestionably safer now than it was in the days of the luggers, the everyday dangers of such a remote environment remain just as real today.

It takes a very special type of person to be a diver on a pearling vessel. Spending up to eight hours a day in the deep and unforgiving waters off Western Australia, the diver needs to be adventurous, but calm and to some extent fearless, while maintaining a focused approach to the task. Decompression sickness, sharks, saltwater crocodiles, jellyfish, sea snakes, tangled air

Figure 22. A Paspaley diving vessel operates off Eighty Mile Beach. The lines running from the stern of the vessel are the divers' air hoses and safety lines. Photo by K. Scarratt.

Figure 23. A Paspaley diver collects wild shell off Eighty Mile Beach. The diver's air hose and safety lines are connected to the vessel on the surface, which slowly pulls him along the ocean floor. Photo courtesy of Paspaley Pearling Co.

TABLE 2. Shell and pearls obtained off the Western Australian coast aboard Paspaley Pearling Co. vessels, July 26–29, 2011.

Specimen no.	Type	Wild/hatchery Operated/unoperated	Relationships	DVM x APM x Thickness (mm)	Length x Width x Depth (mm)	Weight	Shape
1WU	Pearl	Wild unoperated	Found in shell 1WU		6.04 x 5.93	6.128 grains	Round
2WU	Pearl	Wild unoperated	Found in shell 2WU		8.34 x 8.20 x 6.62	13.596 grains	Button
3WU	Pearl	Wild unoperated	Found in shell 3WU		7.87 x 6.46	9.984 grains	Oval
1WU	Shell	Wild unoperated	Pearl 1WU	138.64 x 126.13 x 31.54		242.8 grams	
2WU	Shell	Wild unoperated	Pearl 2WU	132.96 x 118.78 x 31.86		250.2 grams	
3WU	Shell	Wild unoperated	Pearl 3WU	138.57 x 129.19 x 31.37		258.8 grams	
1WO	Pearl	Wild operated	Found in shell 1WO		11.74 x 11.24 x 9.18	35.04 grains	Button
1WO	Shell	Wild operated	Pearl 1WO	200 x 170 x 45.93		775.6 grams	
1HU	Pearl	Hatchery unoperated	2HU and 3HU found in same shell		6.55 x 6.40 x 5.58	6.784 grains	Round
2HU	Pearl	Hatchery unoperated	1HU and 3HU found in same shell		6.06 x 5.90 x 5.11	6.04 grains	High button
3HU	Pearl	Hatchery unoperated	1HU and 2HU found in same shell		4.96 x 4.61	2.904 grains	Round—slight drop
4HU	Pearl	Hatchery unoperated	None		3.10 x 2.43	0.74 grains	Round

lines, and low visibility are just a few of the very real dangers. These dangers are difficult to convey unless the reader is a seafarer with knowledge of Australia's rugged western coast. Needless to say, few people who lead the pearling life do not know of someone who has been taken by a shark or nearly died following a sting from the thumbnail-size Irukandji jellyfish.

COLLECTION AND EXAMINATION OF PEARLS FROM WILD AND HATCHERY SHELL

Whenever natural nacreous pearls are spoken of, the tendency is to think of pearls from the Gulf region, which are produced mainly by *Pinctada radiata*. Indeed, one young European dealer was overheard saying that the only natural pearls are "Basra" pearls. Many are surprised to discover that high-quality natural pearls are also being produced by *Pinctada maxima*—or at all. Hopefully this paper will serve to address trade misconceptions.

Recently, questions have been raised in some gem laboratories concerning nacreous pearls from *Pinctada maxima*. These questions are related to the difficulty in some instances of determining whether a pearl from this mollusk is natural, non-bead cultured, or even bead-cultured using a natural or non-bead cultured (atypical) bead. Indeed, some laboratories may have taken, for a time, the extreme measure of not issuing identification reports on any nacreous pearls from *Pinctada maxima*.

An understanding of the *Pinctada maxima* has therefore become vital to the health of the natural pearl trade; the alternative is for the pearl business to become relevant only to the antiques market, with questions hanging even over these. Further, as the

Pinctada radiata mollusk begins to be used in the Gulf for pearl culture, so too will the same questions need to be addressed with regard to this mollusk

MATERIALS AND METHODS

Assuring sample integrity has always been a challenge within the gemological community. For the most part, gemologists have proceeded with research based on samples that have been donated or loaned rather than attempting to secure a higher degree of reliability concerning their origin. With gemstones, the highest degree of integrity is assured when a member of the research team collects samples *in situ* at the mine site, records the find/extraction in precise detail, and secures these samples in such a manner as to avoid any contamination.

With pearling, the challenges are often at least equal. We addressed sample integrity by first observing the thoroughness of Paspaley's stock control systems for both wild and hatchery shell and then working with them in a spirit of complete openness. Over several years, as wild shell were fished and "relaxed" aboard the vessel, the mantle in the area of the opening was inspected for likely natural pearls prior to putting them on the production line. The authors asked that video be taken of any pearls found still in the mantle of these wild shells. As more were eventually discovered, we were invited onboard to record them ourselves and retrieve the pearls and shell for examination in the laboratory.

Between July 26 and 29, 2011, the authors achieved their goal and left Western Australia with a clear understanding of how natural pearls are discovered within *P. maxima* shell, along with a small but suitable group of samples for laboratory examination (table 2).

From the tens of thousands of wild shell fished just prior to the team's arrival aboard the Paspaley vessel, three were discovered to have natural pearls still present within their sacs in the mantle, positioned in front of the gills and closest to the widest part of the adductor muscle (again, see figure 12). Upon inspection, we found that these shell had not been opened beyond the normal "natural relaxed" position. All three shells, and indeed all other wild shell aboard the vessel, were in the size range allowed for fishing wild shell for pearl culture (120–165 mm DVM; again, see figure 21). The three containing natural pearls ranged from 132.96 to 138.64 mm DVM and weighed (after cleaning) between 242.8 and 258.8 grams. The opening of the shell and the extraction of the pearls were witnessed by all members of the team. Both video and still images were recorded, and neither the shell nor the pearls have left the full control of the team since that time.

Figure 24. Three natural pearls (6.128–13.596 grains) extracted from three separate wild shells are shown together in one of the shells. Photo by K. Scarratt.

The three natural pearls extracted (figure 24) weighed between 6.128 and 13.596 grains, with minimum to maximum dimensions of 5.93 and 8.20 mm. Their shapes were near round, button, and near oval. The control numbers for each of these three shell and pearls are 1WU, 2WU, and 3WU. None of these three shells had been operated on for pearl culture or any other purpose prior to the discovery of the pearls.

A pearl weighing 35.04 grains was found in another wild shell, but in this instance the shell had previously been operated on and had been on the farm for more than a year (figures 25 and 26). As with the three previous discoveries, the pearl was found within the mantle, positioned in front of the gills and near the

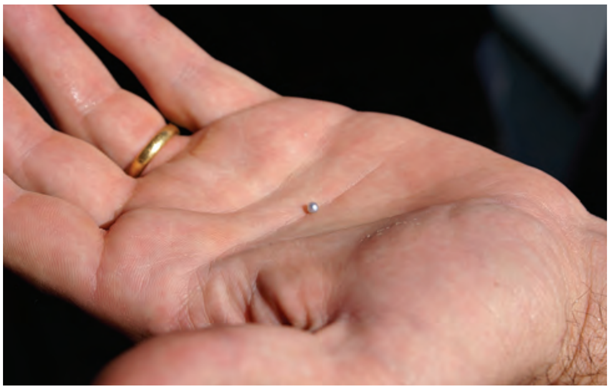
Figure 25. A 35.04-grain button-shaped pearl is discovered within a wild P. maxima *shell that had previously been operated on for culturing. Photo by K. Scarratt.*

Figure 26. The 35.04 grain button-shaped pearl is removed from the wild P. maxima *shell. The upper mantle has been folded back to reveal the pearl more clearly. Photo by K. Scarratt.*

widest part of the adductor muscle. The shell was considerably larger than the three unoperated shells, with a DVM of 200 mm and a cleaned weight of 775.6 grams, nearly three times the weight of the largest wild unoperated shell. The pearl was almost 2.6 times the size of the largest specimen found in the wild unoperated shells. The control number for this pearl and shell is 1WO.

Four other pearls were discovered during this investigation. The technicians aboard the vessels were aware of our interest and were on the lookout for anything unusual. In the first instance, one of the staff emerged from the operating room with a small dark pearl that had just been extracted from a hatchery shell that had yet to be operated upon. This pearl (4HU; figure 27) was rather small, measuring 3.10 × 2.43 mm and weighing only 0.74 grains.

Figure 27. Pearl 4HU was from a hatchery shell that had not been operated on. Photo by K. Scarratt.



In the second occurrence a hatchery shell, also yet to be operated upon, was brought out with three pearls in the mantle. This time the pearls were located close to the heel of the shell rather than in front of the gills, as with the wild shell. The three pearls—one round, another round but with a slight drop shape, and the other a high button—weighed 6.784, 6.04, and 2.904 grains, respectively (figure 28). The control numbers for these pearls were 1HU, 2HU, and 3HU.

All microradiographic images from the examination of the pearls and shells were obtained with the Faxitron CS-100, a high-resolution real-time 2D X-ray unit installed in GIA's Bangkok laboratory. The samples were also examined using X-ray computed microtomography with a Procon X-rays CT-Mini model, also in the Bangkok laboratory.

The pearls and shell were examined using Gemolite microscopes at 10×–60× magnification. Photomicrographs were recorded digitally using a Nikon system SMZ1500 with a Nikon Digital Sight Capture System and at various magnifications up to 176×.

The chemical composition of the pearls and shell were determined with a Thermo X Series II laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) system equipped with an attached New Wave Research UP-213 laser. UV-visible reflectance spectra for all samples were obtained with a Perkin-Elmer Lambda 950 UV-Vis-NIR spectrometer using a reflectance accessory bench fitted with an integrating sphere to capture data. Both Raman and PL data were recorded using a Renishaw inVia Raman microscope system incorporating a 512 nm argon ion laser. All instruments are installed in GIA's Bangkok laboratory.

Figure 28. Pearls 1HU, 2HU, and 3HU were found in the mantle but close to the heel of this hatchery shell, which had not been operated on. Photo by K. Scarratt.

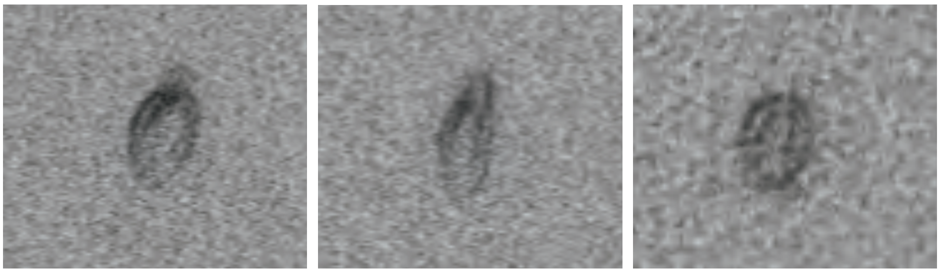


Figure 29. These micro-CT images show (left to right) X-, Y-, and Z-direction slices of pearl 1WU, zoomed center.

OBSERVATIONS AND RESULTS

Microscopy. Selected microscopic images are shown in tables 3–7. As expected, the horny exterior of the shells hosted many foreign life forms taking the shapes of calcified undulating tubes (table 5F) coral exoskeletons (tables 3F, 4F, and 5E), or other unknown forms. We noted that the hinge of one shell also acted as the sarcophagus of a shrimp-like encrustation (table 6F), while a worm-like blister was apparent in shell 2WU (see table 4E).

In each case, the shell had three major components: the non-nacreous edge, the nacreous inner core, and the hinge (tables 3A-3B, 4A-4B, 5A-5B and 6A-6B), all of which were characteristic in their appearance. The non-nacreous edge under magnification revealed a clear prismatic growth in cross-section when viewed directly from above; the appearance differed slightly between reflected and transmitted light (tables 3D, 4D, 5D, and 6D). The nacreous central region, which was solid and had a naturally high luster, revealed the expected structure of overlapping platelets (tables 3C, 4C, 5C and 6C) when viewed at high magnification and in the ideal reflective lighting.

Magnification of each pearl, regardless of the source (wild or hatchery), revealed the expected overlapping platelet structures typical of nacreous pearls, both natural and cultured (tables 3I-3J, 4I–4J, 5I–5J, 6I–6J, 7B–7C, 7H–7I, 7J–7K, and 7P–7Q). In these instances, though, the structures observed in the pearls from hatchery shell (table 7) appeared somewhat coarser than those produced in wild shell.

Microradiography and Micro-CT. Dubois (1901) suggested the use of X-rays (radiography) for detecting pearls in oysters and ably demonstrated the technique a decade later (Dubois, 1913). But it was not until the introduction of the round cultured pearl (Mikimoto, 1922) that the importance of X-rays as a gem identification tool was realized. Three X-ray techniques were applied to pearl identification. One in particular, microradiography, proved the most versatile (Alexander, 1941).

Since the advent of X-rays in pearl testing, there have been many technical advances, particularly in the areas of imaging and computerization. While film photography is still used as a backup, many gem laboratories today employ the more convenient high-resolution 2-D real-time options, along with 3-D X-ray computed microtomography (micro-CT).

Both real-time microradiographs and micro-CT images were recorded for pearls 1WU, 2WU, and 3WU (from wild unoperated shell). For the first sample, microradiographs recorded only the vague appearance of an organic area toward the center of the pearl in one direction but a clearer image of this small centralized structure revealing micro "growth rings" was produced from another direction (table 3L). This sample was otherwise free of growth structures when microradiographs were taken in any direction. 3-D micro-CT scans revealed structures similar to those seen in the 2-D microradiographs. Zoomed-in areas of selected slices from the X, Y, and Z directions are shown in figure 29.

For pearl 2WU, the microradiographic detail was

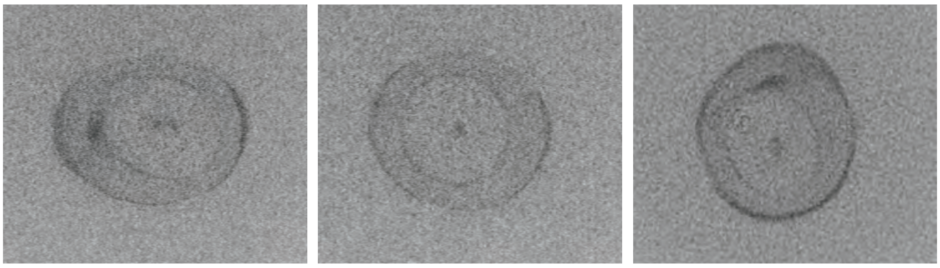
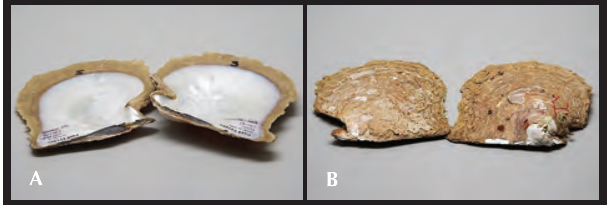
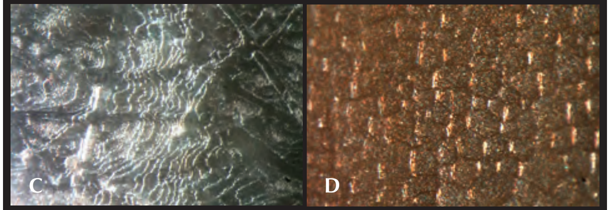


Figure 30. These micro-CT images show (left to right) X-, Y-, and Z-direction slices of pearl 2WU, zoomed center.

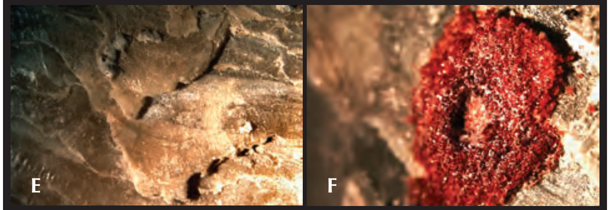
TABLE 3. Detail of shell and pearl 1WU (wild unoperated *P. maxima*).



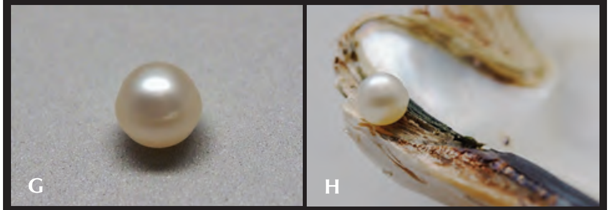
Interior and exterior views of the shell.



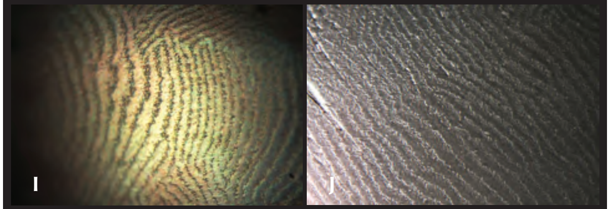
The shell's nacreous areas (left) reveal overlapping platelets. Non-nacreous areas (right) show cross sections of prismatic columns.



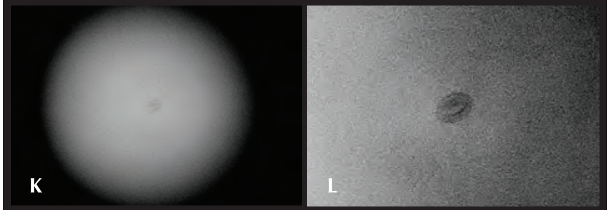
The exterior of the shell, seen at 10x magnification, also had a red material attached to it.



Pearl 1WU (left) is set against the shell in which it was discovered.

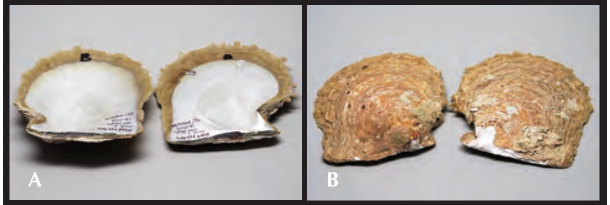


The overlapping platelet structure on the pearl's surface is shown in different lighting conditions. Magnified 176x.

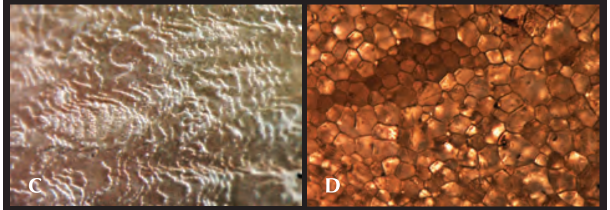


A microradiograph (enlarged on the right) reveals an organic growth structure toward the center of the pearl, which was otherwise relatively free of growth structures.

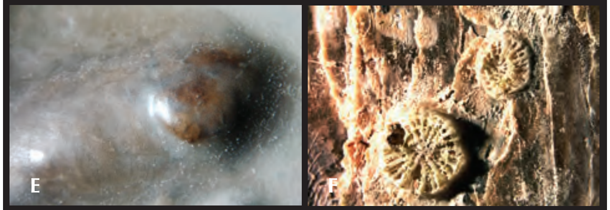
TABLE 4. Detail of shell and pearl 2WU (wild unoperated *P. maxima*).



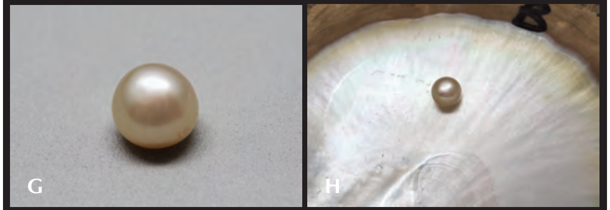
Interior and exterior views of the shell.



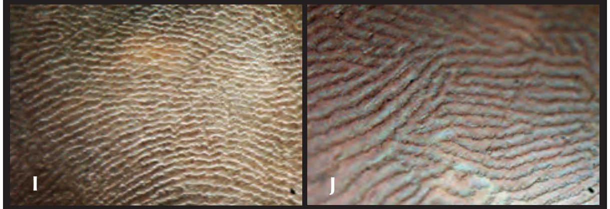
The shell's nacreous areas (left) reveal overlapping platelets. Non-nacreous areas (right) show cross sections of prismatic columns.



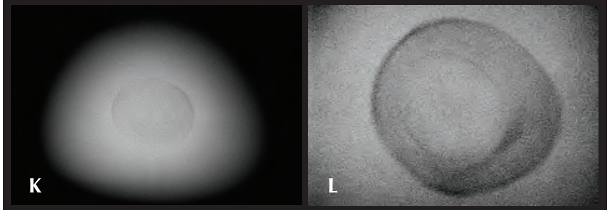
The head of a worm-like blister is seen on the nacreous surface (left). Small coral-like structures were attached to the outer surface (right).



Pearl 2WU (left) is set against the shell in which it was discovered.

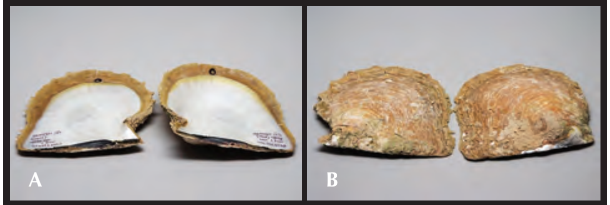


The overlapping platelet structure on the pearl's surface is shown in different lighting conditions. Magnified 176x.

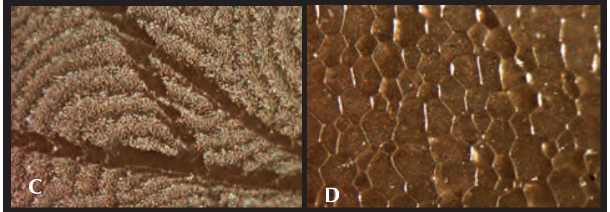


A microradiograph (enlarged on the right) reveals a near-symmetric organic area toward the center of the pearl, which was otherwise relatively free of growth structures.

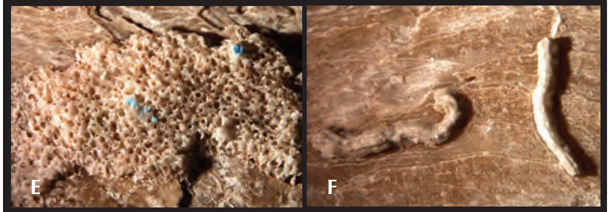
TABLE 5. Detail of shell and pearl 3WU (wild unoperated *P. maxima*).



Interior and exterior views of the shell.

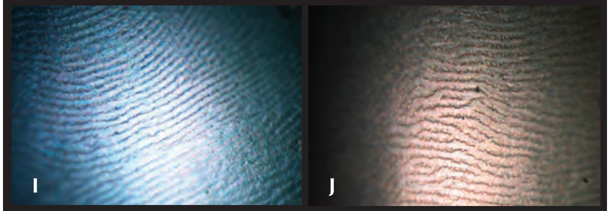


The shell's nacreous areas (left) reveal overlapping platelets. Non-nacreous areas (right) show cross sections of prismatic columns.

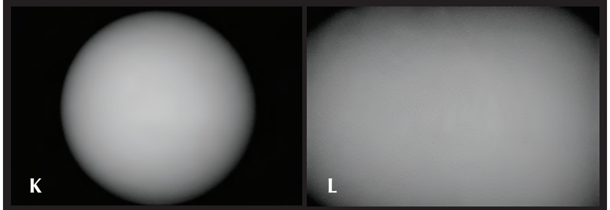


The shell's outer surface displayed coral-like structures (left) and tubeworm-like calcareous structures (right).

Pearl 3WU (left) is set against the shell in which it was discovered.



The overlapping platelet structure on the surface of the pearl is shown in different lighting conditions. Magnified 176x.



A microradiograph (enlarged on the right) reveals little in terms of organic growth.

pronounced. A relatively large area of organic growth extended from the center of this 8.34 mm button-shaped pearl to encompass about one third of the sample's apparent volume. Within the dominant organic core, additional ringed growth structures could be observed toward the center of the pearl. Overall, the microradiographic structures revealed a great deal of organic material toward the center, while the outer portions appeared tightly crystalline with negligible organic material (table 4K–4L). 3-D micro-CT scans revealed structures similar to those seen in the 2-D microradiographs, but in slightly more detail. Zoomed areas of selected slices from the X, Y, and Z directions are seen in figure 30.

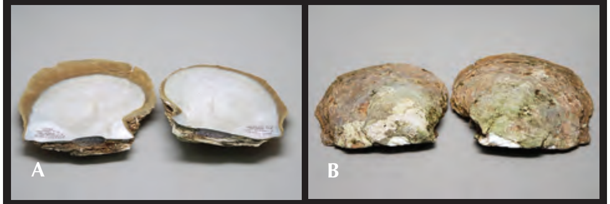
Pearl 3WU revealed little in terms of internal organic growth using 2-D microradiography (table 5K–5L). Under normal circumstances, therefore, one would regard this natural *P. maxima* pearl as "solid" throughout. Yet 3-D micro-CT scans revealed two tiny points of organic accumulation not seen in the 2-D microradiographs. Figure 31 represents three slices, from the X, Y, and Z directions, that show these two dark spots quite clearly.

Pearl 1WO, which weighs 35.04 grains and measures 11.74 × 11.24 × 9.18 mm, was recovered from an older and larger wild shell than shells 1WU, 2WU, and 3WU described above. This shell had already been (gonad-) operated on for pearl cultivation and had been on the farm for about two years. The pearl was recovered from the mantle in a similar area to that of the other three.

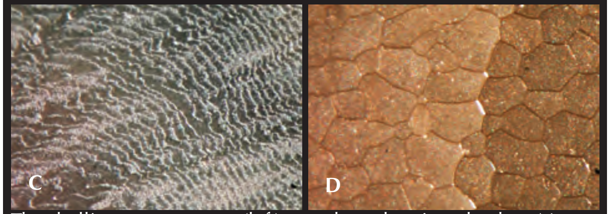
2-D microradiography (table 6K–6L) revealed a slightly off-center area of patchy organic material in a *P. maxima* pearl that otherwise seems to be "solid" throughout. 3-D micro-CT scans revealed images similar to those obtained in 2-D, but in greater detail. While it is impossible to adequately reproduce the 3-D aspect of the micro-CT scans in the two-dimensional medium of this article, figure 32 presents three slices each from the X, Y, and Z directions. Viewing these, one may surmise that the off-center area of patchy organic material is composed of many very small organic areas, both connected and unconnected with each other.

In table 7A, pearls 1HU, 2HU, 3HU, and 4HU present an interesting nomenclature dilemma: While they were found in mollusks that had not been operated on, these were hatchery-reared *P. maxima*. One school of thought suggests that as the host is "cultured" (i.e., hatchery-reared), anything that host produces should also be considered a product of culturing—i.e., a cultured pearl. As shown by the se-

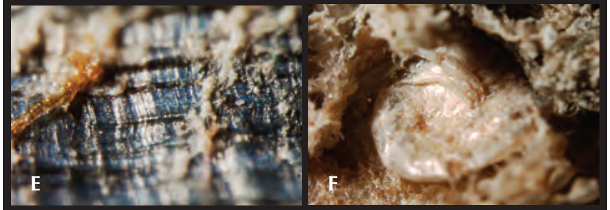
TABLE 6. Detail of shell and pearl 1WO (wild operated *P. maxima*).



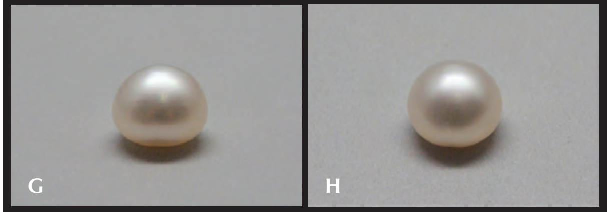
Interior and exterior views of the shell.



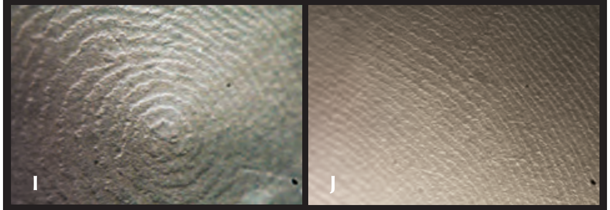
The shell's nacreous areas (left) reveal overlapping platelets. Non-nacreous areas (right) show cross sections of prismatic columns.



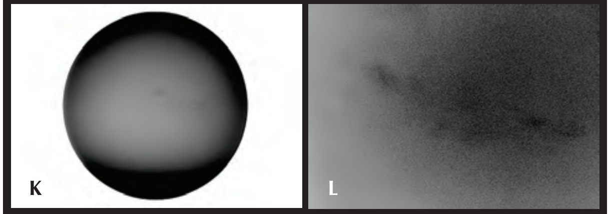
Discovered within the hinge ligament (left) was a small crustacean (right).



Pearl 1WO is shown in side and top views.



These images show the pearl's overlapping platelet structure. Magnified 176x.



A side-view 2-D microradiograph (enlarged on the right) reveals a slightly off-center area of patchy organic material.

ries of microradiographic images in table 7, however, nothing in their growth structures indicates a cultured origin. Indeed, all microradiographic indications point toward these pearls as being natural.

Not surprisingly, the microradiograph for pearl 4HU (which has a distinctly gray color) reveals the greatest amount of organic growth (table 7D–7E), and the pearl appears to have entirely natural growth structures.

The microradiographs for pearls 1HU and 3HU (table 7L–7M and 7N–7O) reveal virtually nothing in terms of growth structures, which is expected for natural *P. maxima* pearls. Yet there were no indications that they were a product of culturing, either.

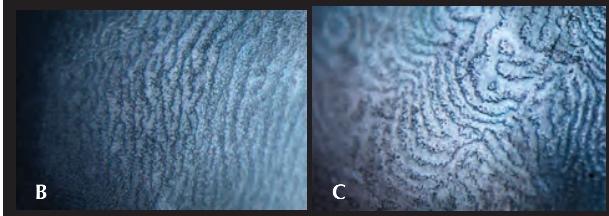
Some of the microradiographs for pearl 2HU (table 7E–7G) did indicate a slight "shadowing." As with pearls 1HU and 3HU, however, the growth appears to be tight and crystalline. There is insufficient organic growth to appear on a microradiograph as diagnostic data. The same was also true for the micro-CT scans performed on each of these pearls.

Fluorescence. Viewed under long-wave ultraviolet light, the pearls listed in table 2 showed a strong, fairly even chalky green fluorescence, and a much weaker chalky green under short-wave UV. The pearls were also examined using the DiamondView imaging system, which can produce a fluorescence image of the pearl in real time. The system uses a very short wavelength (below 230 nm) light source to excite fluorescence close to the surface of the pearl. These images have proved very useful in the detection of treatments, particularly coatings that are not visible under the microscope. The DiamondView images shown here (figure 33) will provide valuable reference data in future cases of treatment uncertainty. All three pearl types showed a distinctly blue fluorescence, sometimes slightly mottled, with no phosphorescence.

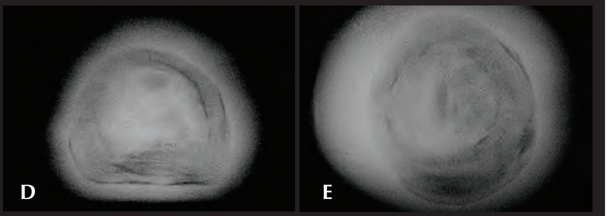
Raman and PL Spectra. Raman spectroscopy is a technique in which photons of light from a laser interact with a material and produce scattered light of slightly different wavelengths. Every material produces a characteristic series of scattered light wavelengths, and measuring these can identify a material. The light of a particular wavelength from a laser beam (or other light source) is used to illuminate the gem. Because this laser light is aligned along the optical path of a microscope, the operator can focus it onto a gem to obtain a Raman spectrum (Kiefert et al., 2001). Light emitted by the sample is collected and analyzed by the spectrophotometer to produce a spectrum, which is compared to an extensive mineral database assembled by GIA over the past two decades.

TABLE 7. Detail of pearls from hatchery unoperated *P. maxima*.

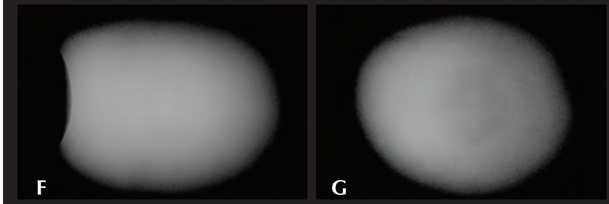
Left to right: 4HU, 1HU, 3HU, and 2HU were discovered in hatchery-reared shells prior to surgery.



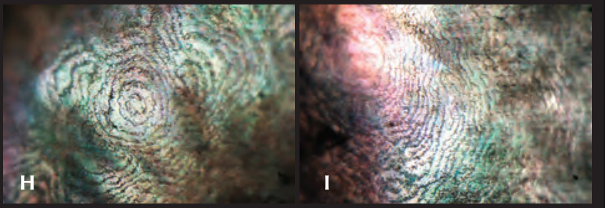
These images show the overlapping platelet structure on pearl 1HU. Magnified 176x.



Microradiographs of pearl 4HU.

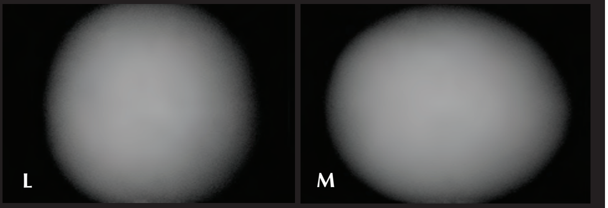


Microradiographs of pearl 2HU.

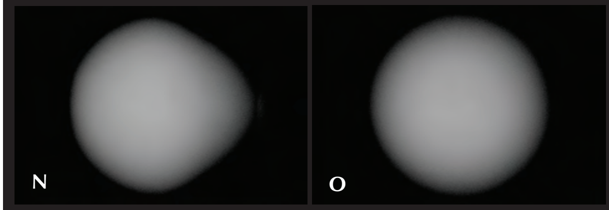


These images show the overlapping platelet structure on pearl 4HU. Magnified 176x.

These images show the overlapping platelet structure on pearl 2HU. Magnified 176x.



Microradiographs of pearl 1HU.



Microradiographs of pearl 3HU.

These images show the overlapping platelet structure on pearl 3HU. Magnified 176x.

Raman spectra recorded for the pearls listed in table 2 revealed two weak peaks located at 702 and 706 cm^{-1} (a doublet) and a strong peak at 1085 cm^{-1} (figure 34). These peaks are typical for aragonite, the crystalline material normally associated with pearls from *P. maxima*. No peaks associated with carotenoids or polyenes were recorded. No differences in the Raman spectra were noted between the three "types" of *P. maxima* pearls examined: from wild shell (unoperated), wild shell (operated), and hatchery-reared shell.

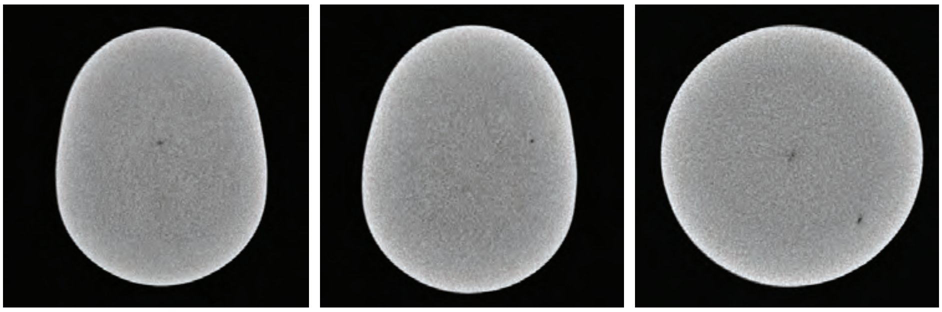


Figure 31. These micro-CT images show (left to right) X-, Y-, and Z-direction slices of pearl 3WU, zoomed center.

PL (photoluminescence) spectroscopy is a noncontact and nondestructive method used to probe the electronic structure of materials. In this process, a substance absorbs and re-radiates photons. It can be described as an excitation (in this study by a 514 nm argon ion laser) to a higher energy state, followed by a return to a lower energy state with the simultaneous emission of a photon (figure 35). The PL spectra can be collected and analyzed to provide information about the excited states, in this case by using the same system used to collect Raman spectra. No differences in the PL spectra were noted between *P. maxima* pearls from wild shell (operated or unoperated) and hatchery-reared shell.

UV-Visible Spectroscopy. UV-Vis-NIR spectroscopy is a complementary technique to EDXRF for examining the trace-element composition of gems, particularly when detailed in absorption coefficient. UV-Vis-NIR spectroscopy may provide information about the portions of the visible spectrum that are absorbed by these trace elements to create the gem's color. Given

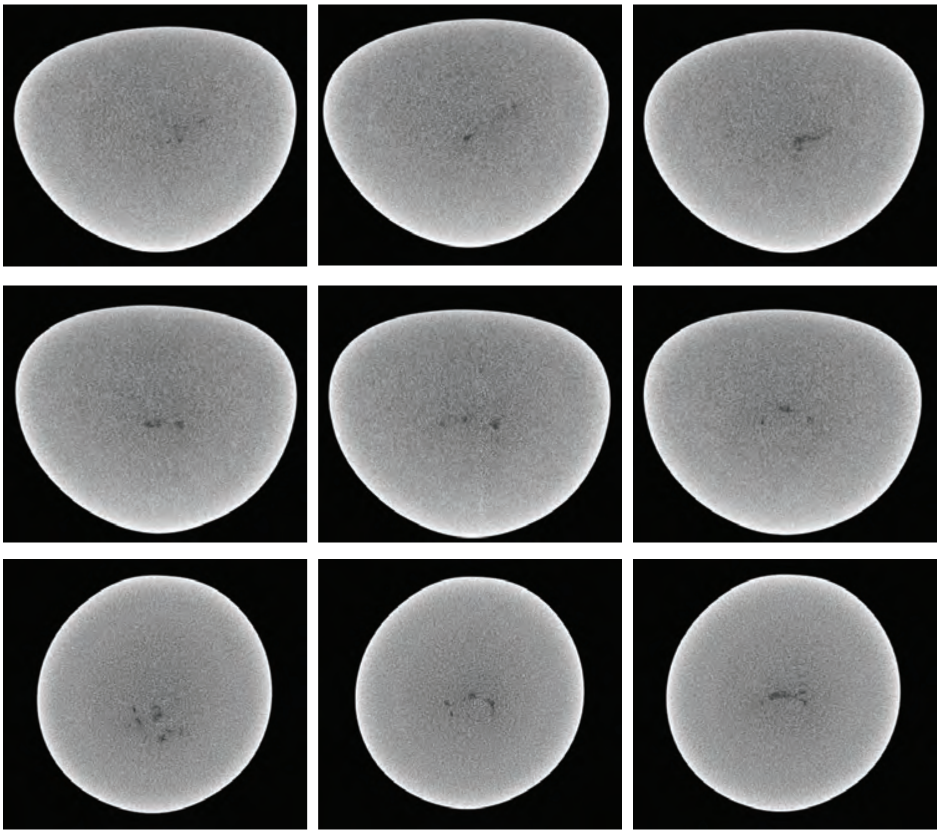


Figure 32. Each row (left to right) shows X-, Y-, and Z-direction slices from micro-CT scans of pearl 1WO.

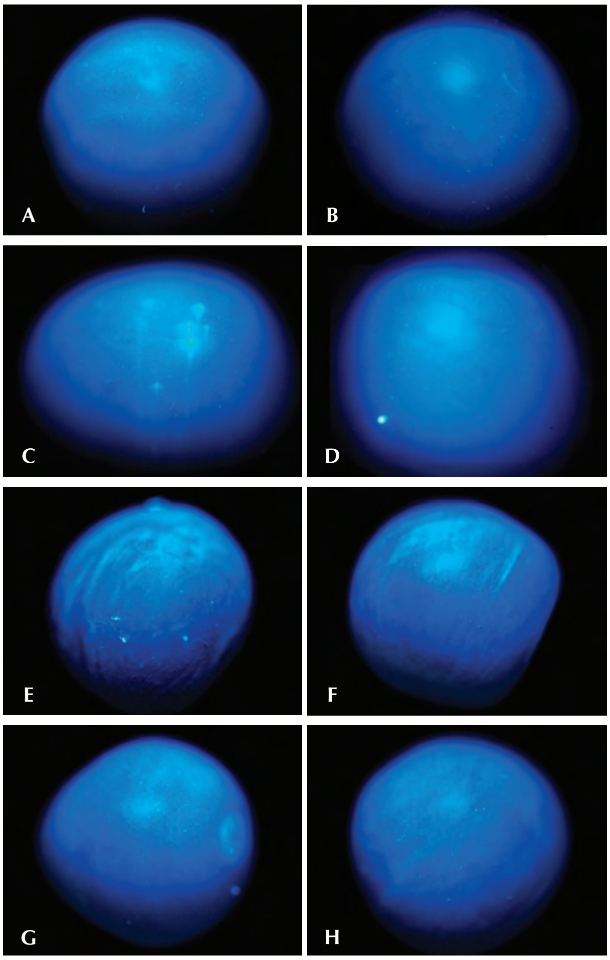


Figure 33. DiamondView images of pearls (A) 1WU, (B) 2WU, (C) 3WU, (D) 1WO, (E) 4HU, (F) 2HU, (G) 3HU, and (H) 1HU reveal blue fluorescence, occasionally mottled, and no phosphorescence.

the opaque nature of pearls, such spectra must be recorded in a percentage reflectance. These spectra are important in defining some species and in some cases whether or not a treatment has been applied.

The white pearls in this group for which spectra were recorded (table 2) revealed curves that differed only in the reflectance at given wavelengths (figure 36). The only exception was 2WU, where there appears to be a slight difference in shape throughout the visible range (nominally 400–700 nm). The percentage reflectance throughout the visible region for each of the other samples decreases slightly toward the longer wavelengths. For sample 2HU, this translates to a percentage reflectance of 77.2 at 400 nm to 72.7 at 700 nm. For 1WO, this translates to a percentage reflectance of 84.65 at 400 nm and 78.41 at 700 nm.

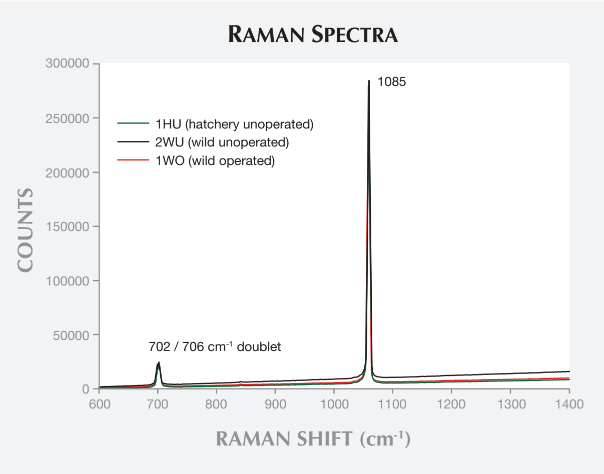


Figure 34. Three representative Raman spectra were gained from pearls produced by a P. maxima *hatchery-reared shell, a wild unoperated* P. maxima *shell, and a wild operated* P. maxima *shell. Each showed virtually identical spectral features that were consistent with aragonite. The representative samples are the same as those used for the PL spectra (figure 35).*

A reflectance trough at 278 nm is common to all the spectra for these pearls, as is a peak at 253 nm and a percentage reflectance drop to between 32 and 34 at 200 nm.

Chemical Composition. LA-ICP-MS provides qualitative and quantitative data of chemical elements. The laser sampling area (5 μm) can be focused on very small color and other surface zones. The ablation mark is less than the width of a human hair, visible only under magnification. The ablated particles are carried by helium gas to the plasma torch and mass spectrometer for analysis. The plasma unit atomizes and ionizes the atoms. The mass spectrometer measures the mass of each element for identification according to mass-to-charge ratio. LA-ICP-MS is a powerful method in the separation between saltwater and freshwater pearls and the detection of some treatments.

All of the pearls listed in table 2 were analyzed by LA-ICP-MS, and the results are presented in table 8. The pearls show great similarity in trace-element levels, with only 1WO trending toward the high end for Mn, Sr, Ba, La, Ce, and Pb. Many more examples of each type will need to be analyzed to determine if any significant trends exist.

TABLE 8. Trace-element composition recorded by LA-ICP-MS (figures are in ppmw).[a]

	Specimen	^{7}Li	^{11}B	^{23}Na	^{24}Mg	^{31}P	^{39}K	^{45}Sc	^{55}Mn	^{57}Fe	^{66}Zn	^{69}Ga	^{88}Sr	^{137}Ba	^{139}La	^{140}Ce	^{208}Pb	^{209}Bi
Wild unoperated	1WU	bdl	22.1	7177.0	136.2	bdl	123.9	bdl	2.3	179.4	1.1	bdl	1327	0.52	0.02	0.00	0.10	0.00
	2WU	bdl	19.6	9017.0	98.9	bdl	194.2	bdl	2.3	168.3	0.3	bdl	1440	0.76	0.03	0.09	0.30	0.04
	3WU	bdl	21.6	7708.0	139.8	28.3	162.2	bdl	3.5	158.0	1.0	bdl	1093	0.36	0.00	0.00	0.06	0.01
Wild operated	1WO	bdl	18.3	7749.0	166.1	bdl	133.9	bdl	17.9	158.2	3.4	bdl	1719	1.43	0.20	0.26	0.44	0.04
Hatchery	1HU	bdl	25.7	8329.0	183.2	23.0	147.2	bdl	7.2	164.9	0.7	bdl	1461	0.95	0.03	0.06	0.18	0.02
	2HU	bdl	26.9	7486.0	176.3	bdl	115.2	bdl	2.8	161.6	2.6	bdl	1414	1.15	0.06	0.07	0.13	0.02
	3HU	bdl	20.7	6918.0	146.0	29.0	81.3	bdl	1.5	165.3	1.0	bdl	1321	0.67	0.07	0.07	0.08	0.02
	4HU	bdl	19.6	6492.0	124.2	28.6	78.8	bdl	2.5	153.1	2.5	bdl	1318	0.71	0.01	0.01	0.02	0.03
Detection Limit		1.36	1.50	22.87	0.89	22	9.12	1.46	0.75	43.88	0.65	0.17	0.36	0.32	0.012	0.02	0.04	0.01

[a] *Abbreviations: bdl= below detection limit*

CONCLUSIONS

The foregoing text and images clearly establish the ongoing recovery of natural pearls from *P. maxima* in Australian waters, a region with a significant pearling tradition stretching back to the 19th century and earlier (figure 37). The historical evidence is contained within official records as well as personal experiences related by respected authors of the time, such as Kornitzer (1937) and Kunz and Stevenson (1908).

Many gemologists have written excellent papers on the separation of cultured from natural pearls using various techniques (see Recommended Reading list), but few have been wholly educational or all-encompassing in terms of the microradiographic structures one might expect from natural pearls. This may be because of the exceedingly wide variation of possibilities, the difficulty of gaining sufficiently high-resolution images, or the research time to devote to a project that produces a large volume of data. Moreover, the journals would have to be willing to publish the extraordinary numbers of images necessary to convey the scope of the data. Web publishing is beginning to provide a greater volume of microradiographic structural images, which were and are beyond the scope of printed jour-

Figure 35. Three representative PL spectra obtained from pearls produced by a hatchery-reared shell, a wild unoperated shell, and a wild operated shell. Each showed virtually identical spectral features that were consistent with pearls produced by P. maxima. *The representative samples are the same as those used for the Raman spectra (figure 34).*

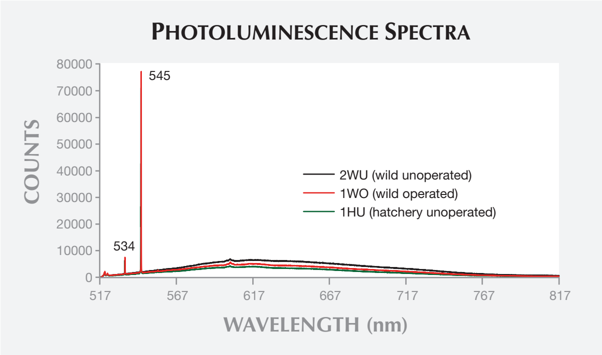


Figure 36. The reflectance spectra for the pearl samples. Note that the lamp switch point at 319 nm and a filter change at 373 nm create slight anomalous shifts in the recorded spectra.

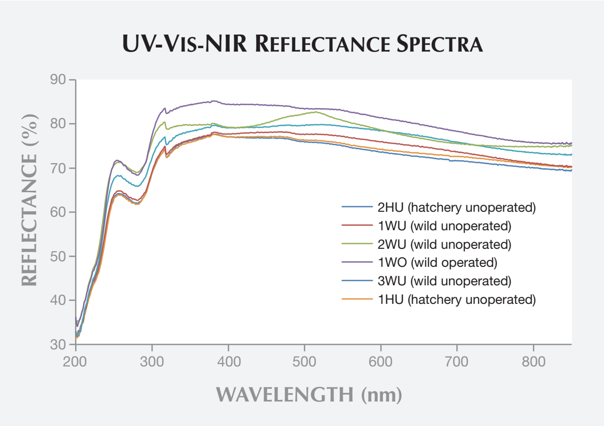


Figure 37. Australia's natural pearling tradition continues today, exemplified by this 11.74 × 11.24 × 9.18 mm pearl (weighs 35.04 grains) atop the shell of a P. maxima *oyster, discovered in July 2011. Photo by K. Scarratt.*

nals or books. An example of this is the document authored by N. Sturman (2009).

Sturman (2009) shows through a series of microradiographs both obvious and subtle examples of internal structures recorded for non-bead (intentional or unintentional) cultured pearls. The paper also presents a few historical microradiographs for both natural and bead cultured pearls.

Of the eight natural pearls collected during this project, samples 4HU (found in a hatchery unoperated shell), 1WU (taken from the mantle of a wild unoperated shell), and 2WU (from the mantle of a wild unoperated shell) may have sufficient internal growth structures to be identified as natural in a "blind" test.

Pearl 1WO (from the mantle of a wild operated shell) may not have a classic microradiographic structure for a natural or nonbead-cultured pearl, which might result in some debate concerning its nature given that the mollusk had been on a farm. Nevertheless, a blind test would conclude that the pearl was of natural origin, a result that would be consistent with the data collected.

Returning to 3WU, the microradiographic structure recorded may easily misinterpreted as that of a nonbead-cultured pearl, and herein lies the first dilemma for those involved in both the pearling industry and pearl testing.

Over the past decade or so, the type of structure observed in pearl 3WU has been assumed to be an indicator of non-bead cultured growth. This assumption probably resulted from the structure's resemblance to the "classic" nonbead-cultured pearl structure (see Sturman, 2009). This pearl challenges that assumption.

The second dilemma concerns more the pearling industry. In industry discussions, it has often been suggested that anything produced by a mollusk on a pearl farm is cultured—and that a pearl produced by a hatchery-raised mollusk should also be considered cultured. Yet the very basis of a pearl culturing operation lies in the ability of technicians to create a "sac" for the cultured pearl. It is not the host mollusk but the creation of this sac that defines the process. Pearls produced within a sac that is a product of human intervention are clearly cultured. But if a sac is a creation of nature, without human intervention, then logic dictates that anything it produces is "of nature." Even if one opposes this logic, the fact remains that pearls 1HU, 2HU, 3HU, and 4HU, the products of pearl sacs formed by nature within hatchery-reared shell, are virtually indistinguishable from natural pearls and could not be identified as cultured.

This examination of a small number of definitive samples has therefore produced what may appear to be unexpected results that may add further to the challenges faced with pearl identification. Clearly, many more samples from each of the types discussed will need to be collected and examined before a clearer picture emerges. In the meantime, the authors will conduct ongoing expeditions and research. In late November 2012, some of the authors were able to extract another 30 natural pearls from Australian *Pinctada maxima*, and the technical data from these will be the subject of another report.

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REFERENCES

Alexander A.E. (1941) Natural and cultured pearl differentiation (parts 1 and 2). *G&G*, Vol. 3, No. 11/12, pp. 169–172, 184–188.

Bartlett N. (1954) *The Pearl Seekers*. Andrew Melrose Limited, London, 309 pp.

Bauer M. (1904) *Precious Stones*. Charles Griffin and Co., London, 647 pp.

Benham C. (1949) *Diver's Luck: A Story of Pearling Days.* Angus and Robertson, Sydney, 258 pp.

Berge V., Lanier H.W. (1930) *Pearl Diver: Adventuring Over and Under Southern Seas*. Doubleday, Doran & Company Inc., New York, 368 pp.

Broadfield R. (2010) Pearl meat the new gem on menus. *The West Australian*, http://au.news.yahoo.com/thewest/lifestyle/a/-/lifestyle/7110030/pearl-meat-the-new-gem-on-menus/.

Cilento R. (1959) *Triumph in the Tropics: An Historical Sketch of Queensland*. Smith & Paterson Pty. Ltd., Brisbane.

Dodd M. (2011) *The Last Pearling Lugger: A Pearl Diver's Story*. Macmillan, Sydney, 240 pp.

Doelter C.A. (1896) Verhalten der Mineralien zu den "Röntgen'schen" X-Strahlen. *Neues Jahrbuch für Mineralogie*, Vol. 2, pp. 87–106.

Dubois R. (1901) Sur la mode de formationdes perles dans Myt.ed, *Compte Rendu des Séances de L'Académie des Sciences*.

Dubois R. (1913) La Perle et L'huitre Perliere. *La Science et la Vie*, Vol. 11, No. 8. p. 15.

Edwards C.L. (1913) The abalones of California. *Popular Science*, Vol. 83, No. 36, pp. 533–550.

Ellies A. (2010) *The Pearls of Broome*. CopyRight Publishing, Brisbane, 978 pp.

Gale C.F. (1901) Report on Pearling and Turtle Industry in the Nor-West. Oct. 1, 3 pp.

Hart A.M., Friedman K.J. (2004) Mother-of-pearl shell (*Pinctada maxima*): Stock evaluation for management and future harvesting in Western Australia. FRDC Project No. 1998/153, Fisheries, P., Western Australia. November 2004, www.fish.wa.gov.au/res.

Hedegaard C. (1996) Formation and composition of gems from the sea: Pearls from American waters. *In Proceedings of Gemmologia Europa VI: Gemmologists of the World on Gems from the Sea,* CISGEM, Milan, pp. 106–129.

Hainschwang T., Hochstrasser T. (2011) Gem News International: A most unusual blister pearl. *G&G*, Vol. 45, No. 4, pp. 300–301.

Hurley F. (1924) *Pearls and Savages: Adventures in the Air, on Land and Sea—in New Guinea*. G.P. Putnam's Sons, London, 414 pp.

Jameson H.L. (1901) On the identity and distribution of the mother of pearl oysters; with a revision of the subgenus *Margaritifera*. *Proceedings of the Zoological Society of London*, Vol. 70, No. 2, pp. 372–394.

Kiefert L., Hänni H.A., Ostertag T. (2001) Raman spectroscopic applications to gemmology. In I.R. Lewis and H.G.M. Edwards, Eds., *Handbook of Raman Spectroscopy: From the Research Laboratory to the Process Line.* Marcel Dekker, New York, pp. 469–489.

Kornitzer L. (1937) *The Pearl Trader*. Sheridan House, New York, 359 pp.

——— (1947a) Pearls and men: First steps in a difficult art. *The Gemmologist*, Vol. 16, No. 195, pp. 285–290.

Kunz G.F., Stevenson C.H. (1908) *The Book of the Pearl*. The Century Co., New York, 548 pp.

Lennon, P. O. (1934) Knapping Flints, the Oldest Industry. *Sands, Clays and Minerals,* Vol. 2, No. 1, pp. 67–71.

Mikimoto K. (1922) *Processes for Causing Oysters to Produce Pearls*. United Kingdom Patent GB157788, issued April 10.

Pearl shell (1949) *Northern Standard*, Darwin, August 26.

PearlMan (2011) Speaking of natural pearls, Part 2, Sea Cortez Pearl Blog, http://www.perlas.com.mx/blog/tag/pea-crab/.

Scarratt K. (1986b) Notes from the Laboratory: The Southern Cross. *Journal of Gemmology*, Vol. 20, No. 3, pp. 145–146.

Smith G.F.H. (1905) An improved form of refractometer. *Mineralogical Magazine*, Vol. 14, No. 64, pp. 83–86.

Smith M.M., Heemstra P.C., Eds. (2003) *Smiths' Sea Fishes*. Struik Publishers, Cape Town, 1047 pp.

Smith P.A., Devereux L. (1999) Streeter's Jetty, Broome, Western Australia: An example of a heritage icon moving from private ownership to community control. *Australasian Historical Archaeology*, Vol. 17, pp. 116–120.

Streeter E.W. (1886) *Pearls and Pearling Life*. George Bell & Sons, London.

Sturman N. (2009) The microradiographic structures of non-bead cultured pearls, http://www.giathai.net/pdf/The_Microradiographic_structures_in_NBCP.pdf.

Taunton H. (1903) *Australind: Wanderings in Western Australia and the Malay East*. Edward Arnold, London.

Walcott P. (1881) Western Australia Report by the Inspector of Pearl Shell fisheries of his proceedings on the North-West Coast.

ADDITIONAL READING

Akamatsu S., Li T.Z., Moses T.M., Scarratt K. (2001) The current status of Chinese freshwater cultured pearls. *G&G*, Vol. 37, No. 2, pp. 96–113, http://dx.doi.org/10.5741/GEMS.37.2.96.

Anderson B.W. (1961) Cultured pearls with split nuclei. *The Gemmologist*, Vol. 30, No. 358, p. 86.

Anderson B.W., Payne C.J. (1953) The density of pearls and cultured pearls. *The Gemmologist*, Vol. 22, No. 262, pp. 81–86.

Gutmannsbauer W., Hänni H.A. (1994) Structural and chemical investigations on shells and pearls of nacre forming salt- and fresh-water bivalve molluscs. *Journal of Gemmology*, Vol. 24, No. 4, pp. 241–252.

Hänni H.A. (1983) The influence of the internal structure of pearls on Lauegrams. *Journal of Gemmology*, Vol. 18, No. 5, pp. 386–400.

Hänni H.A. (1996) A short synopsis of pearls: Natural, cultured, imitation. *Journal of the Gemmological Association of Hong Kong*, Vol. 18, pp. 43–46.

Hänni H.A. (1999) Sur la formation de nacre et de perles. *Revue de Gemmologie a.f.g.*, No. 137, pp. 30–35.

Hänni H.A., Kiefert L., Giese P. (2004) Ein notwendiger Test in der Perlenuntersuchung. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 53, No. 1. pp. 39–42.

Kornitzer L. (1947b) Pearls and men: On the valuation of pearls. *The Gemmologist*, Vol. 16, No. 197, pp. 339–344.

——— (1947c) Pearls and men: Pearls are expensive. *The Gemmologist*, Vol. 16. No. 193, pp. 231–235.

——— (1947d) Pearls and men: Seed pearls. *The Gemmologist*, Vol. 16, No. 188, pp. 91–95.

——— (1947e) Pearls and men: The advent of the cultured pearl. *The Gemmologist*, Vol. 16, No. 196, pp. 312–316.

——— (1947f) Pearls and men: The gentle art of being a rogue. *The Gemmologist*, Vol. 16, No. 191, pp. 207–211.

——— (1947g) Pearls and men: The lore of the pearl. *The Gemmologist*, Vol. 16, No. 189, pp. 120–124.

——— (1947h) Pearls and men: The pearls birth certificate. *The Gemmologist*, Vol. 16, No. 192, pp. 207–211.

Scarratt K. (1984a) Natural pearls. *Journal of Gemmology*, Vol. 19, No. 2, pp. 107–108.

——— (1984b) Notes from the Laboratory: A filled pearl. *Journal of Gemmology*, Vol. 19, No. 2, pp. 113–114.

——— (1984c) Notes from the Laboratory: Large non-nucleated cultured pearls. *Journal of Gemmology*, Vol. 19, No. 2, pp. 114–115.

——— (1984d) Notes from the Laboratory: Mauve freshwater natural pearls. *Journal of Gemmology*, Vol. 19, No. 2, pp. 119–121.

——— (1984e) Notes from the Laboratory: Stained mottled brown cultured pearls. *Journal of Gemmology*, Vol. 19, No. 2, pp. 107–108.

——— (1986a) Notes from the Laboratory: Natural pearl necklace with a bead-like centre. *Journal of Gemmology*, Vol. 20, No. 2, p. 95.

——— (1989a) Notes from the Laboratory: Double nucleated cultured pearls. *Journal of Gemmology*, Vol. 21, No. 5, pp. 294–295.

——— (1989b) Notes from the Laboratory: Repaired and filled pearls. *Journal of Gemmology*, Vol. 21, No. 5, pp. 294–296.

Scarratt K., Moses T., Akamatsu S. (2000) Characteristics of nuclei In Chinese freshwater cultured pearls. *G&G*, Vol. 36, No. 2, pp. 98–109, http://dx.doi.org/10.5741/GEMS.36.2.98.

Streeter E.W. (1882) *The Great Diamonds of the World*. George Bell & Sons, London, 321 pp.

——— (1892) *Precious Stones and Gems*. Bell, London, 355 pp.

——— (1895) *The Koh-i-Nûr Diamond: Its Romance & History*. George Bell & Sons, London.

Wang W., Scarratt K., Hyatt A., Shen A.H.-T., Hall M. (2006) Identification of "Chocolate Pearls" treated by Ballerina Pearl Co. *G&G*, Vol. 42, No. 4, pp. 222–235, http://dx.doi.org/10.5741/GEMS.42.4.222.

Webster R. (1949) Stained pearls and x-rays. *Journal of Gemmology*, Vol. 2, No. 2, pp. 51–54.

——— (1950) London laboratory's new x-ray equipment. *G&G*, Vol. 6, No. 9, pp. 279–281.

——— (1954) Some unusual structures in pearls and cultured pearls. *Journal of Gemmology*, Vol. 4, No. 8, pp. 325–334.

——— (1955a) X-rays and their use in gemmology: Part II: Friedrich and Knipping experiment. *The Gemmologist*, Vol. 24, No. 286, pp. 87–91.

——— (1955b) X-rays and their use in gemmology: Part IV: Skiagram method for pearl testing. *The Gemmologist*, Vol. 24, No. 288, pp. 131–135.

——— (1955c) X-rays and their use in gemmology: Part V: Laue patterns. *The Gemmologist*, Vol. 24, No. 289, pp. 148–151.

——— (1957a) Cultured pearls: Part III: Cultivating the oyster. *The Gemmologist*, Vol. 26, No. 314, pp. 158–163.

——— (1957b) The detection of cultured pearls: Part 1: How it started. *The Gemmologist*, Vol. 26, No. 315, pp. 178–184.

——— (1957c) The detection of cultured pearls: Part 2: Further identification methods. *The Gemmologist*, Vol. 26, No. 316, pp. 200–207.

——— (1966) X-rays in the testing of gems. *X-Ray Focus*, Vol. 7, No. 1, pp. 2–5.

Webster R., Anderson B.W. (1983) *Gems: Their Sources, Description and Identification*, 4th ed. Butterworths, London, 1006 pp.