New developments in cultured pearl production: use of organic and baroque shell nuclei

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Cultured pearls can be produced both with and without a nucleus. Marine pearl oysters that produce Akoya, South Sea and Tahitian cultured pearls typically use nuclei for their pearl products. The nucleus material used for these beaded cultured pearls is traditionally from freshwater Mississippi mussels. In recent years, there have been a number of attempts to use alternative pearl and shell materials as nuclei. This includes different types of shells, Bironite, laminated/powdered shell, freshwater cultured pearls and even natural pearls. The most recent development, detailed in this article, is the use of organic nuclei for the production of 2nd generation beaded baroque cultured pearls. Pearls cultured in this way first appeared on the market at the 2012 BaselWorld show. This paper examines how these pearls are linked to this new type of nucleus, how it is used in the pearl farming process, and details a gemmological study of the different generations of final pearl products.

Introduction

The process of culturing round pearls was discovered and refined at the beginning of the 20th century. The initial Mise-Nishikawa method was further developed by Kokichi Mikimoto and his company who brought round cultured pearls to the international market from 1919 onwards (Simkiss and Wada, 1980; Strack, 2006). Producing such cultured pearls required three things: a host oyster, a donor oyster's saibo (mantle tissue) and a nucleus (Taylor and Strack, 2008; Hänni, 2012). The grafted mantle cells slowly form a pearl sac around a spherical nucleus (pearl sac is complete after about 30 days, Cochennec-Laureau et al., 2010), which is responsible for secreting and depositing regular layers of nacre onto the nucleus and eventually leading to a cultured pearl. The basic method of forming such a beaded cultured pearl has not changed much since its beginnings.

The authors were presented with samples of a new type of pearl product from French Polynesia by a pearl trader during the 2012 BaselWorld show. These pearls had unusual shapes, came in large sizes (up to 23mm) and were characterised by a high visually appealing lustre (Figure 1). These pearls were called "Keshi baroque" cultured pearls. However after we carried out radiographic analysis, it was already clear that these were baroque-shaped beaded cultured pearls, making the use of the term "Keshi" wrong (Hänni, 2006; Segura and Fritsch, 2012). Similar baroque-shaped beaded cultured pearls were later encountered at the September Hong Kong Jewellery show, in French Polynesia and Switzerland. Samples were donated to the Swiss Gemmological Institute SSEF and we were able to carry out closer examination of these cultured pearls to understand their formation mechanisms.

Figure 1. Baroque-shaped beaded cultured pearls examined during the BaselWorld 2012 show. The sample on the left has a diameter of 23mm © L.E. Cartier

Figure 2. Different products from the Pinctada margaritifera *oyster. From left to right: baroque-shaped beaded cultured pearls, round beaded cultured pearls, beadless ("keshi") cultured pearls and "Tokki" cultured pearls. © L.E. Cartier*

Figure 3. Different types of nuclei material commonly used in South Sea / Tahitian pearl farming. Mississippi mussel shell (left), Pinctada maxima shell (middle) and 'US White' Mississippi shell material (right). The sample on the far left is 7.5mm in diameter. © L.E. Cartier

Figure 4. Organic nuclei that are inserted into the oyster. The sample on the left illustratively shows the absorbing capacity of these nuclei. The result of this expansion will be a larger pearl sac, compared to regular nuclei. The first generation pearl (harvested after 9-12 months- see Group A in Figure 6) is not sold. © L.E. Cartier

Recent developments in nucleus materials

The traditional source of nuclei for cultured pearls comes from the Mississippi and Tennessee watershed regions (Alagarswami, 1968; Gervis and Sims, 1992; Strack, 2006, Superchai et al., 2008). These areas had a long tradition of "musseling" because of the importance of different mussels to the US button manufacturing industry. However, the button industry experienced stiff competition from Japan button manufacturers and later from plastic buttons and by 1919 was struggling (Claassen,1994). "Musseling" activity recovered when demand for nuclei from the pearl industry grew: first from the Japanese Akoya industry, and from the 1960's onwards from Australia and French Polynesia.

Mississippi shells are especially sought after in pearling for their size, specific gravity, drilling properties, thermal properties and purity (Kanjanachatree et al., 2007). The colour and purity of a nucleus is important for Akoya cultured pearls as they are frequently characterised by smaller nacre thickness, and the nucleus must not become visible for a pearl to remain commercial (Ward, 1995). There is a general consensus in the industry that Mississippi shell material is the best option in the quest to produce high-quality cultured pearls (Figure 3). Research has shown that the type of nucleus material has a significant influence on the quality, shape and surface perfection of a resulting cultured pearl (Te Reko Parau, 2010: 37-38). For example, investigation shows the use of *Pinctada maxima* shell as nuclei material for Tahitian cultured pearls to be just as good as Mississippi shell material (Scoones, 1990; Bertaux, 2006).

Mississippi mussels used in nucleus production are all from the Unionidae family. It is estimated that 80% of US shell production comes from Tennessee at present (TWRA, n.d.). There are currently 10 species of freshwater mussels that can be harvested commercially in Tennessee. These include: Pink heelsplitter (*Potamilus alatus*), Washboard (*Megalonaias nervosa*), River pigtoe (*Pleurobema cordatum*), Lake pigtoe (*Fusconaia flava*), Mapleleaf (*Quadrula quadrula*), Southern (Snoot nose), Mapleleaf (*Quadrula apiculata*), Three ridge (*Amblema plicata*), Elephant Ear (*Elliptio crassidens*), Ebony (*Fusconaia ebena*) and Monkeyface (*Quadrula metanevra*) (TWRA, 2012). The last available export statistics of US mussel shell production value was $821,000 in 2010 (Olson, 2012). There are concerns with the health of mussel populations in different areas of the Mississippi, due to overfishing, pollution and ecological change (Strayer et al., 2004). The long-term supply of Mississippi shell material is uncertain, which has led to an increase in the cost of Mississippi nuclei, especially for larger sizes. Manufacturers of nuclei material have been increasingly sourcing mussel shell material from other countries in recent years, especially China.

Due to the high cost of Mississippi nuclei and the dependence on the resource there have been numerous experiments to use alternative materials (Roberts and Rose, 1989; Ventouras, 1999; Superchi et al., 2008). These include Tridacna spp. (Gervis and Sims, 1992; Ju et al., 2011), Chinese freshwater cultured pearls (Hänni et al., 2010), nuclei composed of powdered and compressed shell material (MRM, 2012) and natural pearls of low quality (Hänni et al., 2010). Bironite, a processed form of natural dolomite, has also been tested but did not find wider acceptance in the market (Snow, 1999). This article reports on a new innovation in the choice of nucleus material - the use of organic rather than inorganic shell nuclei (Figure 4). The authors in 2010 had been informed of new types of organic nuclei before the appearance of the above described baroque-shaped beaded cultured pearls. It was clear to us that this new pearl product was linked to the new type of organic nucleus.

Organic nuclei: concept and applications in the pearl culturing process

The studied organic nuclei were produced by Imai Seikaku Co. Ltd. (Awaji Island, Japan). They have similar properties to super absorbent polymer (SAP) spheres: they absorb surrounding liquid and grow. Initially compact, the nuclei become soft and gelatinous (see Figure 4). The nuclei are coated with a thin film, which makes them compatible with the oyster's tissue. As with regular nuclei, they also include a bio-coating that consists of fibronectins (FNC- α, Patent No. 62309272). Fibronectins found in the bio-coating favour the healing process in the oyster after the surgical operation of saibo and nucleus insertion.

Figure 5. A pearl oyster operating technician inserting an organic nucleus into a Pinctada margaritifera *oyster. © L.E. Cartier*

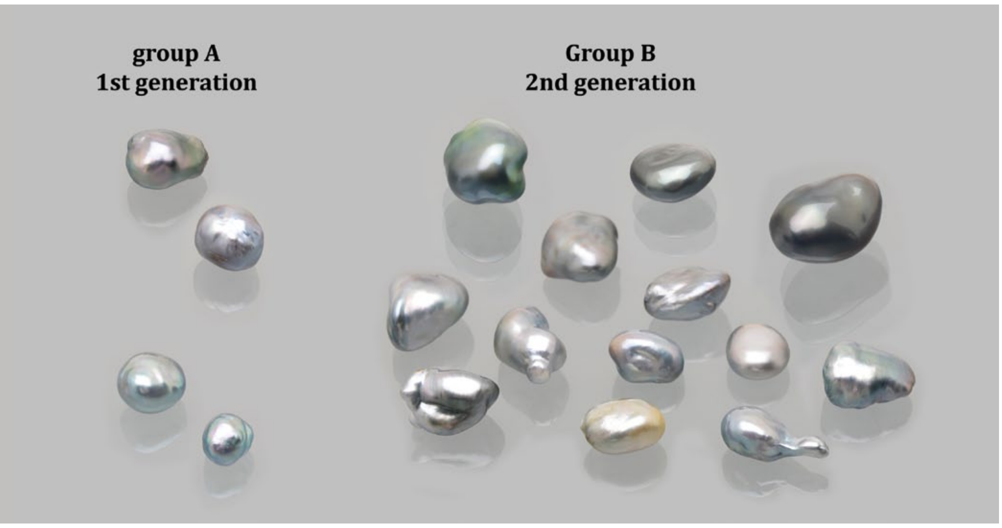

Figure 6. The cultured pearl samples investigated in this study. The pearls from group A were formed as a 1st generation product with an organic gelatinous nucleus. These cultured pearls are not introduced into the pearl trade but are only created to produce an inflated pearl sac. The upper two pearls are from Pinctada margaritifera *(Micronesia), the lower two from* Pinctada fucata *(Japan). The cultured pearls of group B are the 2nd generation product and all come from French Polynesian* Pinctada margaritifera *production. The 2nd generation pearls contain a baroque shaped bead made from a freshwater shell. © M.S. Krzemnicki*

Once a pearl oyster is deemed of sufficient size, it can be grafted/seeded. However, the age an oyster is grafted varies ranging from 1.5-2.5 years to 3-4 years for *Pinctada margaritifera* (Cartier et al., 2012; pers. comm, John Rere, 2012). The organic nucleus can be inserted into the gonad with a piece of donor mantle tissue very similar to the normal production of beaded cultured pearls. In salt-water and in the enclosed environment of the oyster's gonad the growth of the nucleus is distinctly slower than seen in Figure 4 but still considerable. The saibo will remain close to the nucleus because the organic nucleus is expanding. The majority of nucleus growth occurs before the pearl sac is completely formed (i.e. in first hours/days after operation). This nucleus is covered with nacre and a first generation pearl can be harvested several months later (generally 9-12 months). These pearls are, to our knowledge, not marketed because of their small nacre thickness and light weight; the aim is to sacrifice these in order to have a large and still young pearl sac with a good potential to produce nacre of high quality (lustre, overtones).

The pearl sac is baroque (due to the nature of the nucleus - see shape of bloated nucleus in Figure 4), and much more flexible than a pearl sac that had hosted a regular nucleus because of the continuous pressure and irregular expansion of the organic nucleus. A large baroque shell nucleus can now be inserted and is left in the oyster for the regular 12 months required for a cultured pearl to deposit good nacre thickness. The end product is a large baroque beaded cultured pearl as seen in Figure 1. It has to be added that this is a niche product and that all the cultured pearls produced in this manner come in baroque shapes. To our knowledge so far, no round cultured pearls have been cultured using this specific type of organic nucleus.

Gemmology

Materials and methods

For the gemmological investigation, we analysed in total 17 cultured pearl products, which were loaned or donated to the SSEF (see acknowledgements). All pearls show a more or less baroque shape, combined with a light grey to dark grey colour, partially with high lustre and distinct overtones (Figure 6). The size and weight of these pearls range from 2.2 ct to 41.2 ct.

Based on information from the suppliers and radiographies, the studied pearls can be divided into two groups. Cultured pearls of group A are 1st generation products containing an organic gelatinous nucleus (as seen in Figures 4 and 5). They are produced solely to create a large pearl sac in a short time of about 9-12 months. The samples of group B are large 2nd generation cultured pearls with a baroque-shaped shell piece as nucleus. They are the result of grafting a large bead in a young but large pearl sac produced by the 1st generation pearl product. In our study, the cultured pearls are from *Pinctada margaritifera* from French Polynesia and Micronesia (two samples of Group A); and two samples from *Pinctada fucata* (group A, samples 65913-O and -P) from Japan.

Apart from a visual examination and a close microscopic inspection, all samples have been analysed by radiography (on Agfa X-ray films) and X-ray luminescence (Hänni et al. 2005) using a Faxitron instrument (90 kV and 4 mA excitation). On two samples (65913-P, and 65913-B) we additionally collected UV-Vis reflectance spectra (Varian Cary 500 with a diffuse reflectance accessory) and specific gravity (Mettler Toledo hydrostatic balance). For a better understanding of internal structures and nuclei, eight samples (62860-B, 65913-A, -F, -H, -L, -M, -N, -O) were selected based on radiographies and further analysed by X-ray microtomography (CT-scan), using a Scanco μ-CT 40 scanner (70kv). Subsequently, these specimens together with samples 65913-C, -J (in total 10 samples) were cut and polished to better study their internal structures by microscopy. On one cut sample (65913-A) we did a ED-XRF chemical analysis (Thermofisher Quant'X) to identify its freshwater nature.

Analytical results

The visual examination revealed that most of the pearls are characterised by a high lustre and well developed colour overtones. Especially for the large baroque-shaped pearls of the 2nd generation (group B), this surface quality is in some cases obvious and outstanding (Figure 1). Apart from irregular streaks, there are practically no dots and blemishes, and neither so-called circling features which are so common in cultured pearls especially from *Pinctada margaritifera* (Ito, 2011). This indicates a rather juvenile pearl sac from which the nacre for these large pearls precipitated; and especially that an expanding organic nucleus may avoid rotation and certain blemish formation on the pearl.

Some of the pearls from group B however show small roundish surface bumps due to small grown-on additional cultured pearls. This feature is quite commonly observed in beaded cultured pearls and is well known in the trade by the Japanese term "Tokki" (Krzemnicki et al. 2010, Krzemnicki et al. 2011).

The specific gravity was determined on a sample containing an organic gelatinous nucleus (group A: 65913-P) and a cultured pearl with a shell bead as nucleus (group B: 65913-B). The low SG of 1.36 for the group A specimen is strongly indicative of the pearl's quasi-hollow nature. Most of its weight is actually due to water incorporated in the gelatine. As a consequence, these pearls (65913-L to -P) were nearly floating on the immersion liquid (methylene-iodide) used for the radiographies. The SG of 2.74 for the beaded sample (group B) is characteristic for most pearls and actually reflects the density of calcium carbonate.

To identify the mollusc species and to detect a possible colour treatment, we chose from each group a sample of light grey colour (group A: 65913-P; group B: 65913-B) to analyse them with UV-Vis reflectometry. The resulting spectra (Figure 7) are characteristic for the natural colour pigments in *Pinctada fucata* (65913-P) and *Pinctada margaritifera* (65913-B) (Komatsu & Akamatsu 1978; Miyoshi et al., 1987; Iwahashi & Akamatsu 1994; Karampelas et al., 2011; Cartier et al., 2012), thus confirming the provided information about their origin.

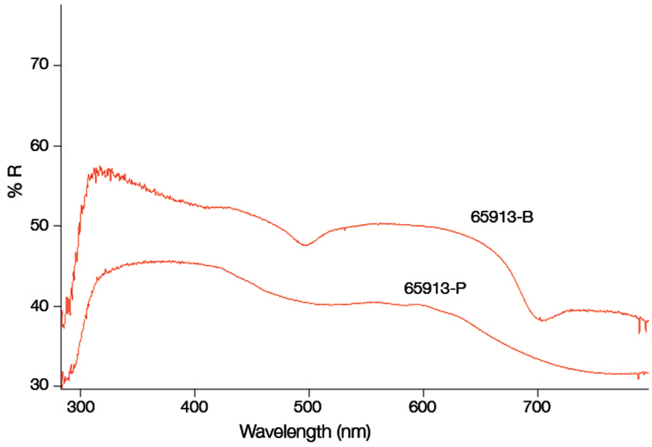

Figure 7. UV-Vis reflectance (R%) spectra of a light grey cultured pearl from Pinctada fucata *(sample 65913-P, group A, 1st generation) and* Pinctada margaritifera *(sample 65913-B, group B, 2nd generation). The dip at 700nm is a characteristic feature for* Pinctada margaritifera *and separates these pearls easily from other grey pearl species. © W. Zhou, SSEF*

Radiography

Comparing the radiographies of the pearls from group A (organic nucleus) and group B (shell piece) reveals very characteristic features, which makes a separation into these two groups straight-forward (Figure 8). All samples from group A show a large dark and featureless internal cavity (low X-ray absorbance) covered by a thin nacreous overgrowth (0.3 – 0.5 mm thick), which is the result of a short growth period (6-12 months) in both the *Pinctada fucata* and *Pinctada margaritifera* recipient oysters (pers. comm., Takuya Imai, 2012). All samples from group B except pearl No. 65913-H show a more or less baroque-shaped nucleus (shell piece), covered by a rather thick nacreous layer (0.5 – 4.0 mm). The baroque-shaped nuclei partially show weak linear to slightly curved lines, that are a result of layering in the shell material. The shell piece for this production was cut from freshwater shells (e.g. from Mississippi or Chinese freshwater mussels). This was confirmed by the distinct X-ray luminescence reaction of the cut samples of group B and by the high trace amount of manganese found in one of these cut pearls (sample 65913-A) when analysed by EDXRF. Thus, we can state that this new cultured pearl product is very similar to normal cultured pearls using spherical nacre beads cut from freshwater shells (e.g. Akoya-, Tahiti- and South Sea cultured pearls). As a consequence, the studied beaded cultured pearls (group B) show on radiographies a slightly brighter bead surrounded by a darker grey nacre layer. This observation is well known from any saltwater cultured pearl using a freshwater bead as the freshwater bead is absorbing X-rays slightly more than the saltwater nacre (Hänni et al., 2005). Due to the rather baroque shape of the freshwater bead this difference in grey between nucleus and nacre layer is however much less marked on the radiographies than when using a round bead. Thus, the identification of our studied beaded cultured pearls (group B) may sometimes be more challenging.

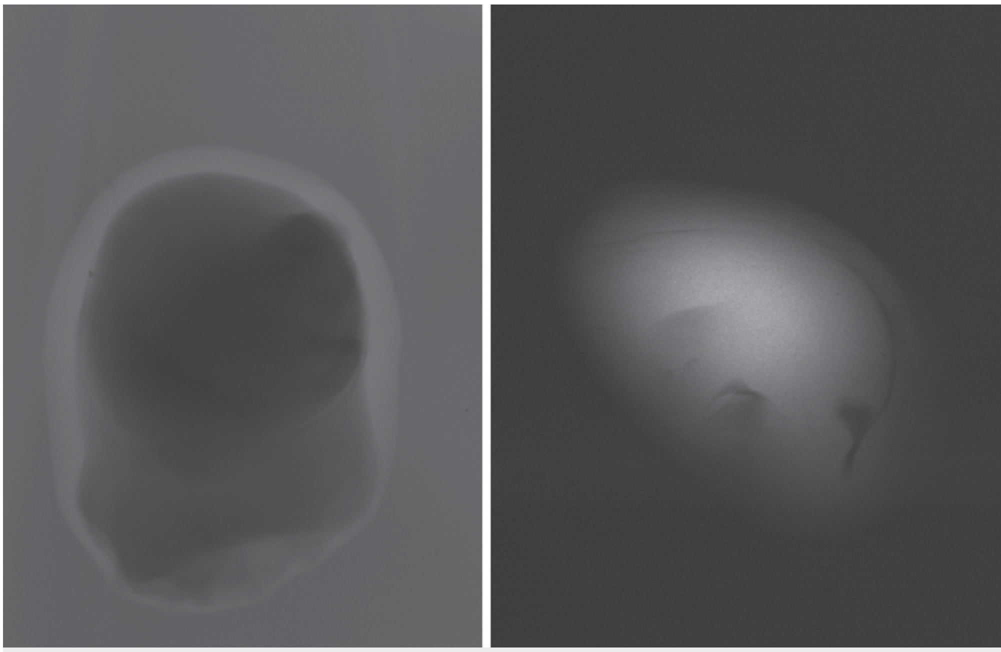

Figure 8. Radiography showing a specimen of 1st generation (group A) on the left containing an organic gelatinous bead (sample 65913-L) and a sample from the 2nd generation (group B) with a freshwater shell piece (sample 65913-A). The organic nucleus is nearly transparent to X-rays, therefore resulting in a dark centre, whereas the freshwater shell piece is slightly more absorbing (more bright) than the surrounding nacreous layer. A fine curved layering is visible in the shell piece together with some organic matter (dark) at the bead/nacre interface. © M.S. Krzemnicki

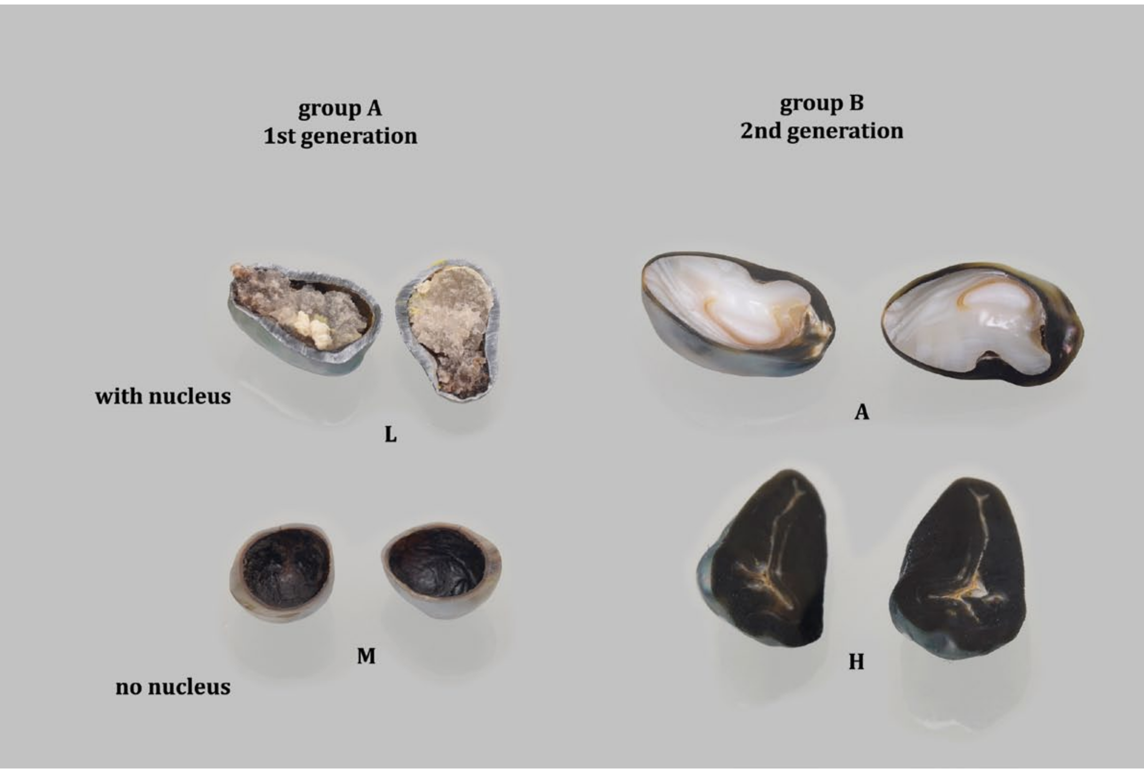

Figure 9. Four samples cut in half, showing different structures. Left are the two pearls from group A (1st generation): The upper left still contains a decomposed version of the gelatinous organic nucleus (sample 65913-L), whereas the lower left is without the organic nucleus (sample 65913-M). On the right side are two samples from group B (2nd generation): One containing a characteristic baroque-shaped shell piece as a bead (sample 65913-A), the lower sample only with an irregular cavity structure due to the rejection of the shell piece (65913-H). The upper row thus shows the normal products of the 1st and 2nd growth generation - both still with nucleus - whereas the lower row shows beadless cultured pearl products from both generations. © M.S. Krzemnicki

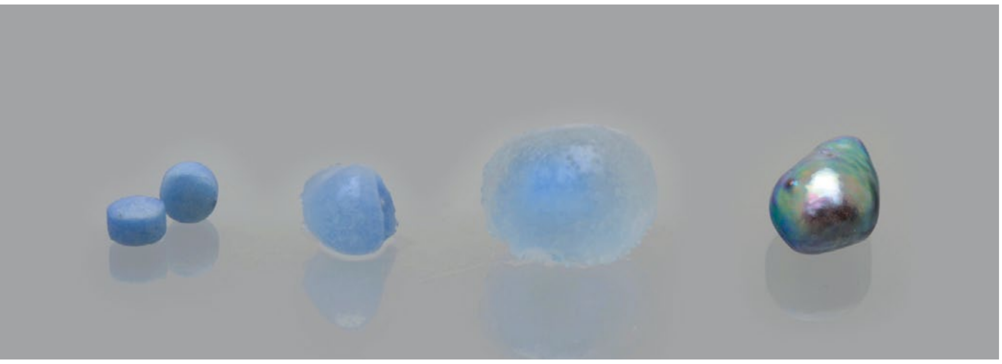

Figure 10. Organic nuclei used for the 1st generation cultured pearls such as sample 65913-O. The three stages of swelling show how these organic nuclei would inflate when soaked in water for five hours. When inserted into the gonads of an oyster, they expand less rapidly. © L.E. Cartier

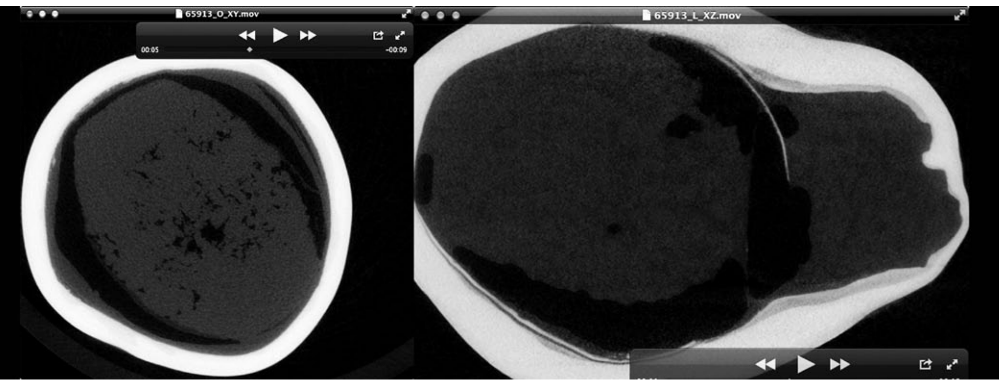

Figure 11. X-ray tomographic sections of two pearls with organic nucleus: Left a pearl (sample 65913-O) where the button-shaped organic nucleus has just slightly expanded revealing a somewhat granular appearance (grey). Right a pearl (sample 65913-L) where the organic nucleus burst outwards after a first expansion (already covered with a thin lining of nacre), thus resulting in a distinct baroque shaped pearl. The black parts in the tomographic slices are cavities, whereas the white and light grey inner lining of the sections represent the nacreous layer and the inner layers of organic matter deposited first by the young pearl sac. © M.S. Krzemnicki

After cutting of the samples

The close visual observation of the cut samples shows again very different features in the pearls of group A (1st generation with organic gelatinous nucleus) and group B (2nd generation with baroque shaped shell beads). Interestingly, we encounter in both groups/generations "normal" products containing a nucleus - organic (in specimen 65913-L, -O, -P of group A) or inorganic (in all samples of group B except 65913-H) - but also "bead-less" products, which might be the result of bead rejection (Figure 9). When cutting sample 65913-M (group A), we found that it contained water with a distinct foul odour. We assume that its organic nucleus was either rejected at some point or consumed/transformed. When cutting the other samples of group A, the organic gelatinous nuclei fast began to swell due to the cooling of the cutting wheel with water.

The extent of the swelling of the organic nucleus is rather reduced within the oyster's gonad over the growth period of several months, compared with the swelling ability when the organic nucleus is soaked in water for a few hours (Figure 10). The organic nucleus may either just swell rather uniformly (see sample 65913-O in Figure 10) or may expand after grafting into the gonads by bursting open the original shape as can be seen in sample 65913-L using three-dimensional analysis by X-ray microtomography (Figure 11). Hence the 1st generation pearl will be of distinctly baroque shape if the organic nucleus bursts.

Figure 12. The cut pearls of group B (2nd generation) with baroque shaped shell pieces cut from freshwater shells. The pearls (65913-A, -C, -F, and -J) all show curved layers in the shell bead, as can be expected in the thick hinge of the shell. © L.E. Cartier

Typically for this product, the beaded samples (group B, 2nd generation) contain baroque-shaped shell pieces, often with layered structures. Due to these structures, we assume that the beads were cut from the hinge of freshwater shells, where nacre thickness is at a maximum (Figure 12). One sample (65913-H), although collected as part of the 2nd generation beaded cultured pearls (group B) does not contain any bead, but actually reveals a long and irregular-shaped cavity-structure (Figure 9: lower right pearl), typical and characteristic for beadless cultured pearls. This pearl formed in an already existing pearl sac which collapsed after rejection of the baroque shaped shell bead. Similar beadless cultured pearls are well known in the trade and often sold as "Keshi" cultured pearls, although this term is not well defined (Hänni, 2006). In fact, this pearl is the only pearl of this study, which could be given that trade name, whereas all others (of group B) contain a bead and thus have to be named as beaded cultured pearls. See also the next section which discusses these two new cultured pearl products.

Discussion

For this investigation, we studied and analysed two new pearl products: a first generation product using an organic nucleus, so far not described in the gemmological literature (group A pearls in this study) and a second generation product using freshwater shell pieces as beads for large baroque-shaped cultured pearls.

The innovation (by Imai Seikaku Co. Ltd., Japan) to use organic nuclei in the first generation has two main reasons. First, to increase the growth rate and size of a pearl sac in a 1st generation and thus to be able to produce large sized cultured pearls faster than by the traditional method of grafting beads of increasing size from one generation to the next. Inserting a small nucleus also means that a smaller incision into the gonad is necessary, thereby reducing the risk of rejection and oyster mortality. A second reason for using this type of inflating bead is that a relatively young pearl sac has a better capacity to secrete nacre and produce a pearl with good colour and lustre (Figure 13), as statistical studies of pearl harvests have shown (Caseiro, 1995). When comparing a third generation pearl harvest to that of a first generation harvest, it is obvious that the average lustre of pearls is higher in first generation pearls (pers. comm., John Rere, 2012). The rationale behind this innovation in nucleus technology is simple: reduced pearl growth time lowers costs, and a potentially larger high quality pearl brings more income to a pearl farmer.

The freshwater pearl industry, which traditionally produces cultured pearls without a nucleus, has also experimented with different materials (Scarratt et al., 2000). A recent product is so-called "soufflé" freshwater cultured pearls (Sturman and Strack, 2010; Wiesauer, 2012). These are pearls that were filled with mud that is later removed after drilling. The aim is also to produce large cultured pearls in a relatively short time, using the mud to expand the pearl sac and promote larger pearl size. This is similar to the process described in this article, with the difference that the organic nucleus leads to greater expansion and the first generation pearls of this study are not commercialised.

Figure 13. Pinctada margaritifera *oysters selected and sacrificed for mantle tissue ('saibo'). The beautiful orient and lustre of the shell is the primary criterion in selecting suitable donor oysters. This is more likely to be found in a young healthy oyster © L.E. Cartier*

All the pearls examined during this study were of more or less baroque shape. Bead rejection is far less than average both with the 1st generation organic nuclei and 2nd generation baroque shell nuclei. For the organic nuclei the reasons are: 1) the organic nuclei is relatively small (average 6.5mm), 2) this requires a relatively small incision in the gonad, and 3) the expanding nucleus strongly reduces the risk of the saibo becoming detached from the nucleus (pers. comm., John Rere, 2013). However, due to the nature of the nucleus' and pearl sac's expansion (see Figure 10), it is difficult to produce round cultured pearls using this technique. Furthermore, there have been no reports of circled pearl formation; we assume that this is because the pearl sac is constantly under pressure from an expanding nucleus.

As the average price of cultured pearls, for example in French Polynesia, has decreased in recent years, cost issues have become increasingly important for pearl farmers (ISPF, 2011). Nuclei are a huge cost point for farmers (Fong et al., 2005). The price of a large nuclei suitable for a third-generation pearl (e.g. 16 mm) is proportionally much higher than a regular first generation nucleus (e.g. 7 mm). A pearl farmer must thus make a careful calculation of costs and risks, and this explains why many farmers in French Polynesia produce far less third-generation cultured pearls (Cartier, 2012).

Although the pearls seen in Figure 1 were first described as "Keshi" baroque cultured pearls, the use of this term is wrong. These pearls contain a baroque-shaped shell nucleus and are therefore beaded cultured pearls. This innovation in nucleus material and the resulting pearls are also interesting samples to study in order to better understand formation of the pearl sac and of pearls. The lack of circled pearls when using the approach described in this article may also shed more light on the formation mechanism of circled pearls and how to avoid these in order for a pearl farmer to have a higher average quality of pearl production.

Although the cultured pearl samples (of 2nd generation) studied in this article come from *Pinctada margartifera*, these nuclei are also reportedly being used in *Pinctada maxima* production in Indonesia (pers. comm., Takuya Imai, 2012). The baroque-shaped beaded cultured pearls described in this article are a niche product on the market at present. They have been produced to also meet demand for large baroque cultured pearls. It will be interesting to follow what developments new types of nuclei, such as the organic nuclei described in this article, will lead to in the production of cultured pearls. Both generations of these new types of pearl product can be clearly identified as beaded cultured pearls using the techniques available in a gemmological laboratory.

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Acknowledgements

Takuya and Michiyo Imai (Imai Seikaku Co. Ltd., Japan) are thanked for donating organic nucleus and pearl samples. The authors are grateful to Prof. Henry A. Hänni for many fruitful discussions on nucleus materials and pearl culture. Judith Braun and Wei Zhou of SSEF are thanked for assistance with analytical examination of the samples. A number of pearl farmers are thanked for their insights on different types of nucleus materials and operating procedures, especially John Rere and Josh Humbert. Dr. Masahiro Ito (College of Micronesia) is also thanked for ongoing discussions on nucleus materials and pearl farming. We are grateful to Andy Müller (Hinata Trading, Japan) for thought-provoking discussions on pearls. René Lauper (Frieden AG, Switzerland) is thanked for supplying us with some of the studied pearl samples. Finally, Laurent Cartier is grateful to the Tiffany & Co. Foundation for travel funding.

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