THE MICRORADIOGRAPHIC STRUCTURES OF NON-BEAD CULTURED PEARLS

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Figure 1: Four saltwater non-bead cultured pearls (NBCP) photographed with a part of a Pinctada maxima (silver-lipped pearl oyster) as a backdrop.

Introduction

The origin determination ('natural' or 'cultured' formation) of pearls submitted for examination to any laboratory with pearl testing facilities is based on a number of important factors. Critical to the outcome there are two that are specific; "equipment" and the "experience" of those performing the tests. Whilst these points can be applied to any area of gemology, it is especially critical in the identification of pearls, since microradiograph (x-ray) systems and the experience of staff can vary so much between countries and the laboratories within each country, and pearl testing itself is a limited and specialized field of gemology where relatively few individuals have wide experience. This report looks at the microradiographic structures of non-bead cultured pearls (NBCPs) in particular (Figure 1), since there is some concern in the industry about the criteria used to identity this type of pearl, which includes pearls often referred to as "Keshi".

Non-bead cultured pearls (NBCP)

Before moving on to the images showing the various structures encountered in NBCPs, it is probably best to explain what a non-bead cultured pearl is to those who may be unsure. Briefly, such a pearl is one that formed with the aid of human intervention, but without the insertion of a solid bead, and is therefore not able to be classified as a bead cultured pearl (BCP) or natural pearl[1]. This intervention may be *direct*, intentional via the placement of tissue from a sacrificed donor mollusk into a living host mollusk, or *indirect*, via unintentional formation caused by a number of possible factors directly related to the culturing operation as a whole (Hänni, 2006). Most of the freshwater non-bead cultured pearls currently in the market are likely formed by the former process, whereas most of the saltwater non-bead cultured pearls are likely due to the latter. The author is not aware of any farms that intentionally produce saltwater NBCPs today or even produced them in the past and no reference to such pearls exist in the major complete or partial pearl texts available (Strack, 2006), (Farn, 1986b), (Taburiaux, 1986), (O'Donoghue, 2006).

Equipment

B.W. Anderson presented a paper in 1931 that was published in the *British Journal of Radiology* in January 1932 (Anderson, 1931). In presenting this paper Anderson began by saying *"We find in no less an authority than the fourteenth (1929) edition of the Encyclopedia Britannica the statement that "The only method of ascertaining which variety (of pearls) is 'cultured' and which is 'natural' is to cut the pearl and examine the cross section". He went on then to state, "We hope to show that this statement is entirely untrue".* Similarly, it is hoped that the reader will come to appreciate the significant role that x-rays have played in the study of 'pearls' from before Anderson's statement until present day.

In 1901 Dubois (Dubois, 1901) suggested that the use of x-rays (radiography) might prove useful for the detection of pearls in oysters (Webster, 1966). This was not the first suggestion that the radiography could prove to be a useful technique if used in the identification of gem materials, Doelter (Doelter, 1896) suggested that this technique might prove useful in identifying a variety of gem materials; a direction later taken up in Max Bauer's, *Precious Stones*, (Bauer, 1904). However, the advent of simple gemological equipment such as Smith's jeweler's refractometer (Smith, 1905) made the use of x-rays in the identification of any gem material, other than pearl, superfluous.

It was not until the commercial introduction of the round cultured pearl in 1921 (Mikimoto, 1921) that the importance of x-rays as an identification tool within gemology was realized. Three techniques involving the use of x-rays were found to be of particular use and all remain today as the primary test methods used for the separation of cultured from natural, and in some cases treated

[1] Imitation 'pearls' or composites are not discussed in this article.

pearls. The three techniques are; microradiography[2] (Alexander, 1941); Laue diffraction (Webster, 1955, Unknown, 2004); and fluorescence (Farn, 1986a).

Microradiography was considered as it was felt that the nucleus of a bead nucleated cultured pearl should readily be revealed by this technique. Unfortunately, at the time this was put forward the techniques in use and the kind of films available, in addition to inexperience in interpreting the microradiographs, inevitably resulted in disappointing experimental results. The images apparently did not clearly define those bead nucleated cultured pearls with thick nacre coatings and in addition did not reveal some of the finer growth structures of natural pearls (Webster, 1966).

A microradiograph may be thought of as either an enlarged x-ray photograph (radiograph) or a radiograph that is examined with the aid of magnification. Radiographs taken of pearls always need to be magnified in order to view the fine detail, hence radiographs of pearls when examined are 'microradiographs'. In varying shades of gray to black, microradiographs of 'pearls" reveal, the differences in which crystalline and organic material as well as voids absorb or transmit x-rays. Voids and organic material within a "pearl" allow x-rays to pass (to expose the film below) with greater ease than does the crystalline material. Therefore, the darker grays to black areas on a "pearl" microradiograph reflect the presence of organic material or voids, whereas the lighter gray areas reflect a greater crystalline component. Given that the concentric growth structure of natural and non-bead cultured pearls as well as the outer layers of bead nucleated cultured pearls, consists of layers with each having a variable amount of organic and or crystalline material present, a pearl microradiograph reveals the growth history of a pearl, much in the same way as the cross section of a tree reveals its growth history.

Around 1930 Philips developed and manufactured a Metalix x-ray unit for the use of jewelers; this instrument which gave the appearance of some strange creature for outer-space, had four adjustable legs angled inward from their feet and holding an horizontally positioned x-ray tube, housed in a black metal housing, aloft by approximately 2 feet. The unit was air cooled and had no safety shielding and thus was operated in a similar manner to dentists instruments of today; with remote control cabling. However, it was possible to configure it for microradiography, lauegrams and x-ray fluorescence observations. The Metalix was still used regularly in the London Laboratory up to the early 1980's, but in the latter years mostly as a *standby unit*. In Mumbai the Metalix was in use in several home laboratories at least through the late 1980's and on into the 1990's and a dental-type unit was used as a primary testing instrument at the Pearl Association's Laboratory during the same period.

Pearl testing in London and Paris from the 1920's to the 1940's was carried out through a combination of the Laue diffraction technique (for undrilled or part-drilled 'pearls') and various

[2] Microradiography is usually used when specimens are thin and of low x-ray absorbance and the detail required is too fine to be seen with the unaided eye. Inspection of the image with the aid of a low-power microscope or the enlargement of the radiograph is required to visualize the available detail. Microradiography generally employs soft x-rays generated in the range of 5 to 50 kV. The photographic emulsion is usually single coated and finer grained than the emulsion of ordinary x-ray films. In addition to distinguishing between natural and cultured pearls microradiography has been used for a number of biological and horticultural applications (Unknown, (1980), *Radiography in Modern Industry*, 4th, C. C. S. Richard A. Quinn, 202, Eastman Kodak Company, Rochester, New York 14650.

optical techniques including the pearl endoscope for drilled pearls. While the later formed US laboratories concentrated on microradiography. The techniques which produced the disappointing results achieved from early pearl microradiography experiments where improved considerably in the intervening years and this, with the availability of film with a much finer grain, began an era in which microradiography rose as the primary pearl testing technique. This change in direction came about at a time of its greatest need; the introduction of the non-beaded cultured pearl.

Pearl x-ray units have gone through many design improvements over the last five decades but the one unchanged factor, until recently, was the use of film. The use and processing of film based microradiography has many limitations, not least of which are the use of chemicals in the processing, the need for a dark room, the longevity of the film and exceptionally the time it takes from exposure to the point where one can examine the film.

This changed within the last several years as high resolution real-time microradiography made its appearance. Depending upon the specification of the unit purchased real-time microradiography instruments, give the operator instant images where extremely fine detail can be recorded and zoomed into on a large format high resolution monitor. The immediacy of the imaging achieved in a small fraction of the time it would take using film based techniques also allows for multiple images to be taken in many different directions and at varying magnifications, contrast and color representations on almost any pearl being examined. It is also possible to produce high resolution 3-D imaging by utilizing a rotating holding device and a video recording facility built into the system. In this manner a full picture of the internal structure of every pearl can be achieved, non-destructively. The images may be viewed in a variety of contrasts and colors that may aid in viewing the internal structures, transmitted to other locations via e-mail, and stored for ever without deterioration.

GIA has three Real-Time units, one in each location; these are Faxitron CS-100's (Figure 2). The units were designed for the inspection of SMT assemblies, semiconductors and PCBs but are excellent for pearl microradiography and have all of the capabilities described above. It should be noted that while the capital cost of these units is approaching 10 times that required for film based microradiography this number becomes insignificant when one takes into account the time as well as consumable costs saved.

All of the images that follow were obtained using the Faxitron CS-100. By the very nature of this 2D communication not every aspect of what is possible in using this instrumentation may be effectively presented here.

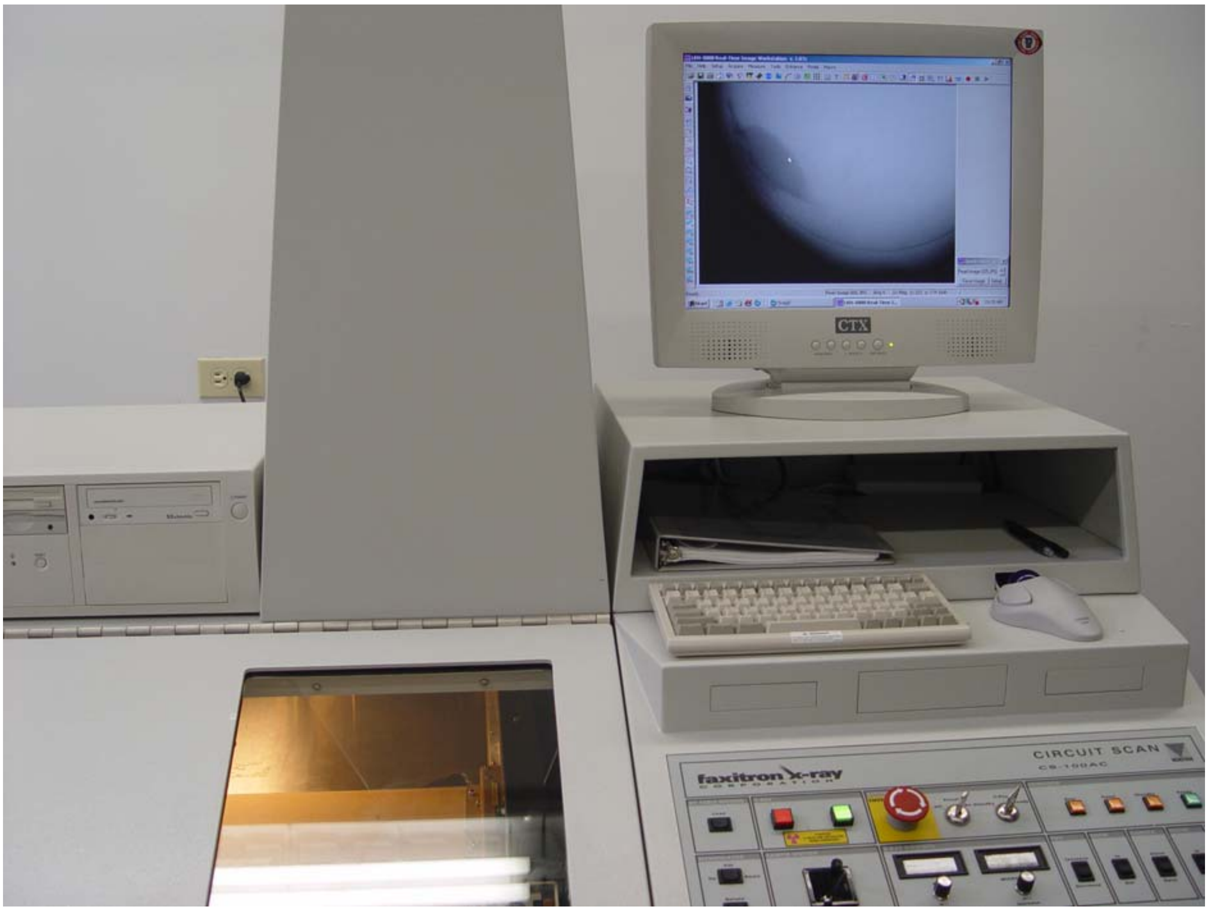

Figure 2: The Faxitron CS-100 includes a very large sample compartment (lower left) control panel (lower right) and Monitor (upper right). Both the detector and tube move toward and away from the specimen through the control panel allowing for a wide variety of potential analysis conditions.

Microradiographic structures and their interpretation

When a gemologist examines any material submitted for identification to a laboratory, or being offered in a transaction in the market place, the first thing they can use to make a preliminary judgment on the item is its external appearance. With enough experience a pearl tester can make fairly confident calls on the identification of many pearls and the only step remaining is to *prove* this initial judgment. Through microradiography methods the preliminary *tentative* observation is either confirmed or disproved. Even with a lot of experience though there are cases where surprises can and do occur, and for example a natural 'looking' pearl turns out in reality to be a NBCP when the microradiographs are examined. Hence, it is important to use first impressions as part of the testing process but not to get carried away with them and let them influence the final result more than they should. Over confidence can sometimes be just as dangerous as having too little experience.

Therefore the identification of natural, BCPs and NBCPs is frequently straightforward when the relevant microradiographic structures are examined. Yet like any science there are some exceptions to the rule and from time to time pearl testers are faced with samples that take longer and require more thought to reach a conclusion upon. These types of pearls are the ones that can create circumstances where one laboratory will issue one result and another will offer an opposing opinion.

Whilst they are virtually always natural v NBCP in nature, it is the author's personal experience that even some bead nuclei do get misidentified or go undetected on very rare occasions, and these instances tend to occur when BCP are mixed with other pearls in items. Whilst the differences in NBCP identification can be linked to the equipment and experience available in a laboratory, with even staff in the same laboratory not agreeing with each other on a result in all cases, the situations involving BCP are more likely down to the equipment available to a specific testing facility. On a related note, but one that I have been asked over the years, it may be of interest to know that dentist's x-ray units are not suitable for pearl testing, unless there is an obvious bead nucleus within the pearl. Even when obvious bead nuclei are present, some care has to be taken too, since some natural pearls do possess internal structures that can look remarkably similar to a bead, yet when examined carefully with right type of x-ray unit can reveal very fine concentric lines within the "bead" that prove beyond doubt that it cannot be a bead cultured pearl.

When focusing on NBCPs the resulting internal structures produced by the two, direct and indirect, formation circumstances referred to earlier can also vary. As a consequence the variation can create pearls where identification is straightforward and also examples where identification is far from straightforward and is prone to a matter of interpretation that could well lead to differing conclusions. Therefore the resulting internal images can in essence be grouped into three sub-groups based on this author's experience spanning a period of over twenty years in three different gemological laboratories. The first would be the straightforward cases where any pearl with similar structures would/should get the same result from any gemological laboratory, the second would be cases where the result is less certain although should be repeatable in different laboratories, and finally there are examples where the structures could quite easily be interpreted either way and results could therefore vary quite considerably. Whilst the latter are encountered less frequently, such pearls do exist and are sent to laboratories from time to time. At this point, it is also worth mentioning that the identification of some NBCP is complicated even further by any drill-holes present and in fact this very process has even been known to be used on saltwater and freshwater NBCPs to try and remove the evidence laboratories use to determine their origin (Crowningshield, 1986b), (Crowningshield, 1986a).

The microradiographic evidence

In order to show the levels of difficulty in interpreting structures the following microradiographs[3] will be split into the sub-groups already mentioned, starting from the easiest. However, in order to understand the results more, it should be mentioned that the pearls can be further grouped into those produced in saltwater environments (oceans) or freshwater environments (i.e. lakes) and that these two different environments also create differences in the resulting structures seen within pearls. As a general, but not definite, guide, the void or cavity-like evidence used by gemologists as a means of identifying NBCPs from natural and BCPs when examining the resulting microradiographs, are finer and more 'twisted' in freshwater cultured pearls (Figure 3), whilst being larger and more often more pronounced in saltwater pearls (Figure 4). This as stated before is not a consistent identification feature, but from experience it can be very useful.

[3] Some definition to the microradiographs included in this article may be lost when converting to pdf format. They are best observed using the software provided with the Faxitron CS-100AC System used to obtain them.

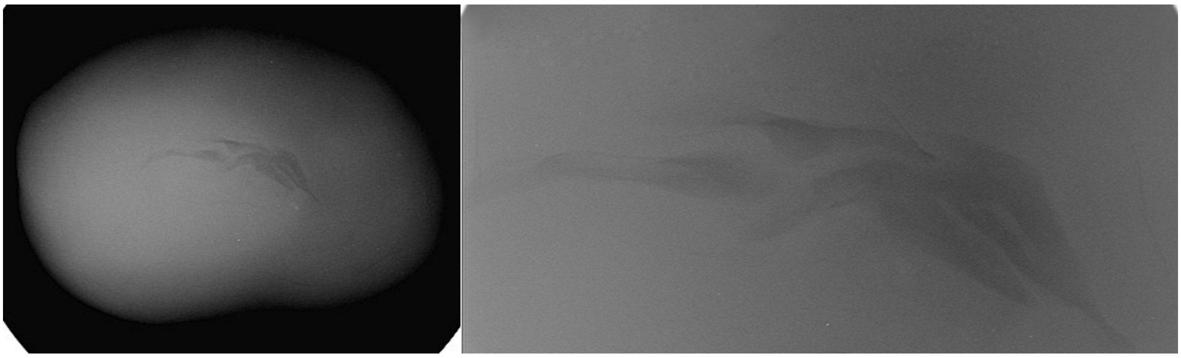

Figure 3: Typical internal 'twisted' structure seen in freshwater non-bead cultured pearls. The image on the right shows the void-like area magnified. This format will be repeated for all the remaining microradiographs.

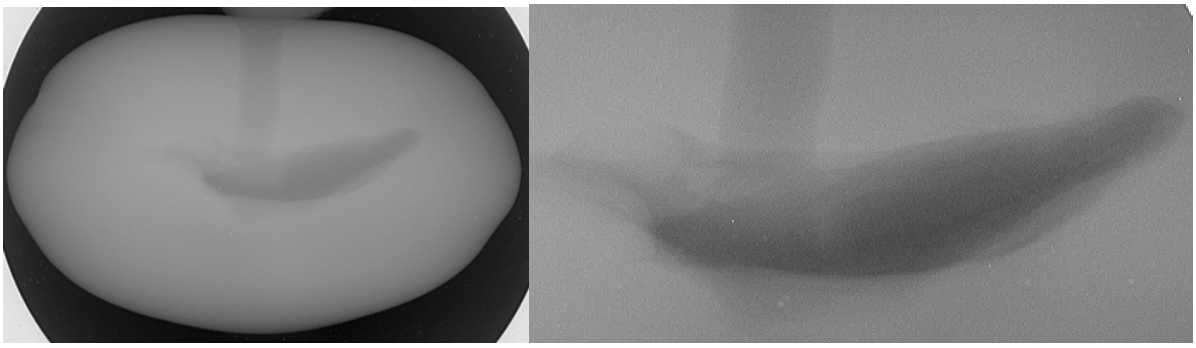

Figure 4: The typical appearance of voids in saltwater non-bead cultured pearls. When present, the voids tend to be much larger and more pronounced.

Whilst the microradiographs already shown in Figure 3 and Figure 4 provide obvious examples of the differences in the void structure/form observed in a freshwater and a saltwater NBCP, it is very important to understand that pearls must be rotated through at least two, preferably three, different orientations to reach any conclusions, so these images are just one example of a single direction for each pearl out of many that were taken to reach the final conclusion. It would make this report very long to include all the relevant images for each pearl referenced herein and for this reason only the most useful direction for each example is included.

Obvious examples

Since one example of each NBCP from the two different environments is not really a good representative sample of the structures, the images below will provide more of an idea about the differences between the two environments and the similarities of those within each of the specific environments. As stated before, some more microradiographs of what the author believes would be considered ‘obvious’ examples are shown first. The images beyond these initial ones will then be headed ‘less obvious’ and finally ‘questionable’.

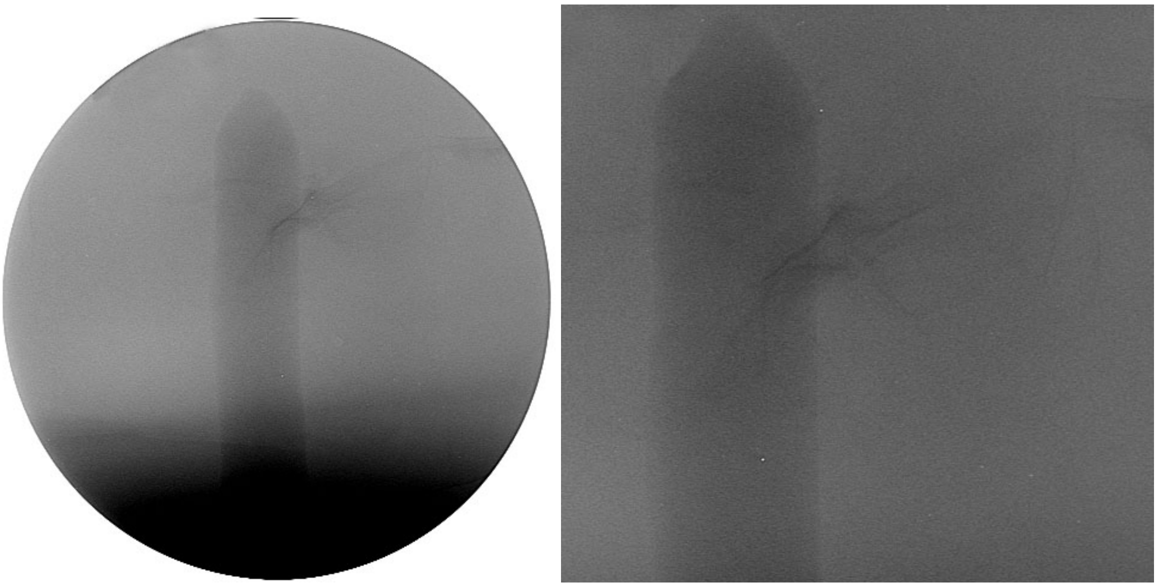

Figure 5: A freshwater NBCP in which the typical fine twisted structural evidence of its origin is clearly obvious. This structure was evident in all three directions examined; however this is the most telling direction.

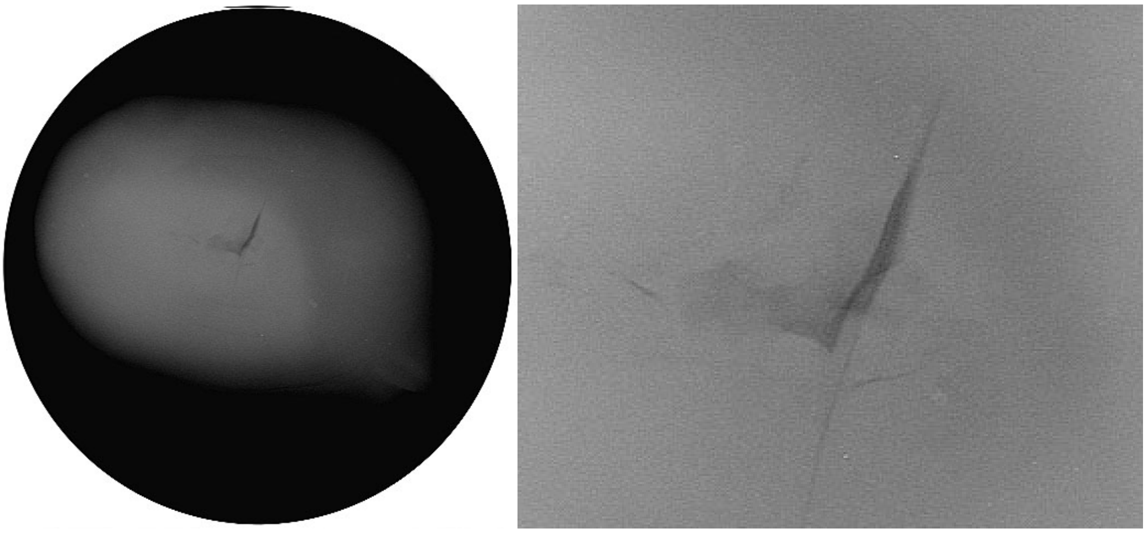

Figure 6: A freshwater NBCP in which the typical fine twisted structural evidence of its origin is clearly obvious, although this example is rather more obvious. This structure was evident in all three directions examined; however this is the most telling direction.

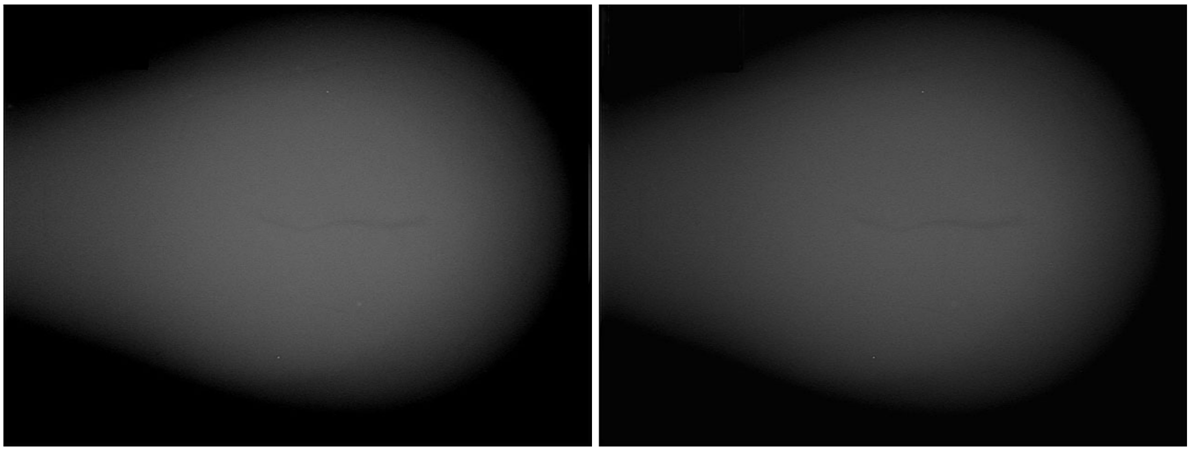

Figure 7: A freshwater NBCP in which the structural evidence of its origin is clearly obvious but is finer than in the previous examples. In this example the microradiographs are the same in all aspects apart from the contrast. This structure was evident in two directions but not in the third; however this is the most telling direction.

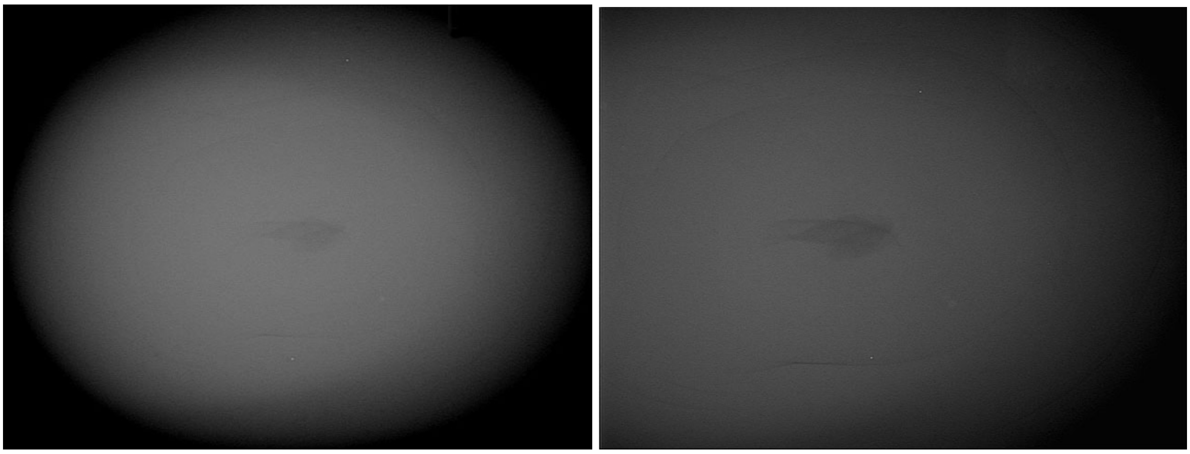

Figure 8: A freshwater NBCP in which the typical fine twisted structural evidence of its origin and surrounding concentric structure is clearly obvious. This structure was evident in all three directions examined; however this is the most telling direction.

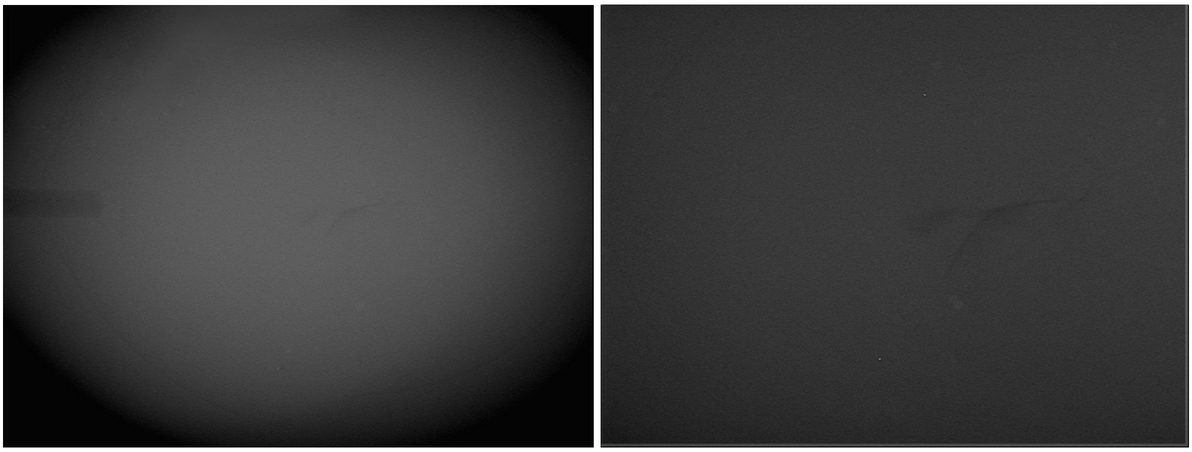

Figure 9: A freshwater NBCP in which the typical fine twisted structural evidence of its origin is clearly obvious, although not quite as obvious as in some of the previous examples. This structure was evident in two of the directions examined; however this is the most telling direction.

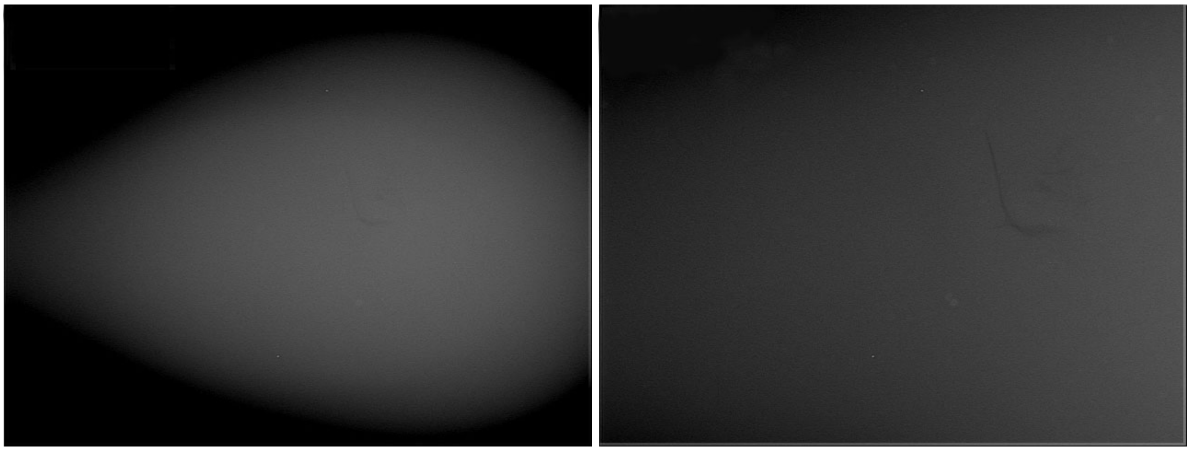

Figure 10: A freshwater NBCP in which the typical fine twisted structural evidence of its origin is clearly obvious, although not quite as obvious as in some of the previous examples. This structure was evident in two of the directions examined; however this is the most telling direction. This pearl was very similar to the one shown in figure 9.

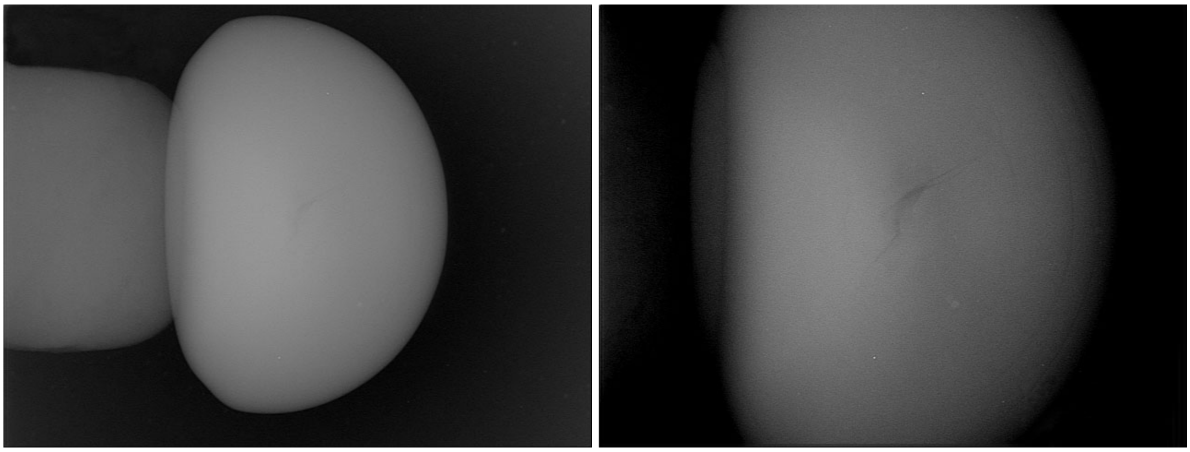

Figure 11: A freshwater NBCP in which the typical fine twisted structural evidence of its origin is clearly obvious. This structure was evident in all three directions examined; however this is the most telling direction.

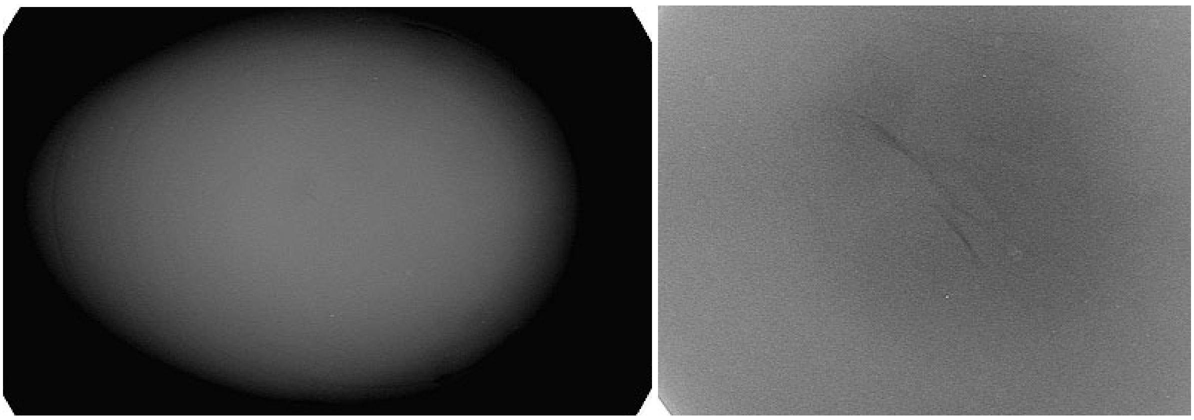

Figure 12: A freshwater NBCP in which the typical fine twisted structural evidence of its origin is clearly obvious, although more so at higher magnification. This structure was evident in two of the directions examined; however this is the most telling direction.

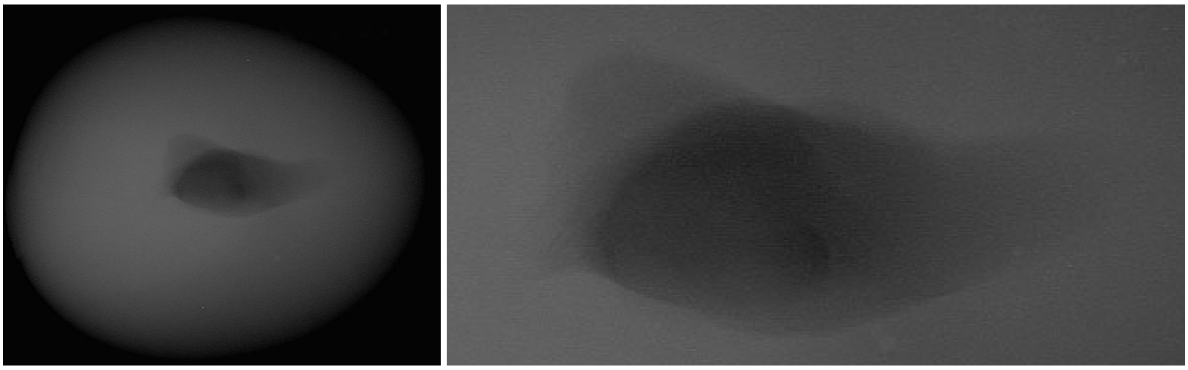

Figure 13: A saltwater NBCP in which a typical irregular structural void clearly proves its origin. This void was evident in all three directions examined.

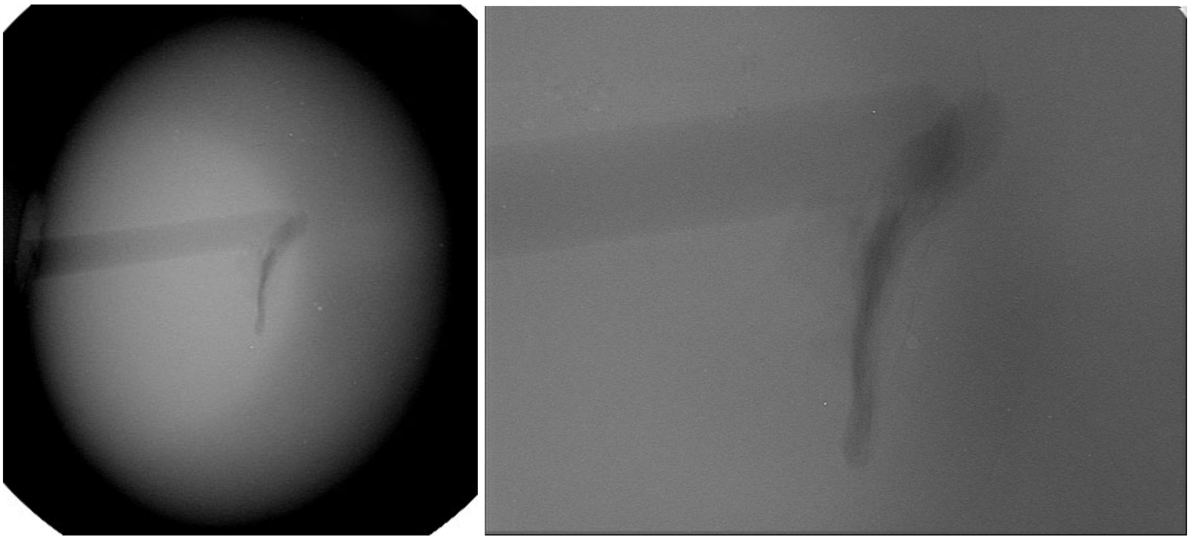

Figure 14: A saltwater NBCP in which a typical irregular structural void clearly proves its origin. This structure, which is slightly different in form from the other examples in this section, was evident in all three directions examined.

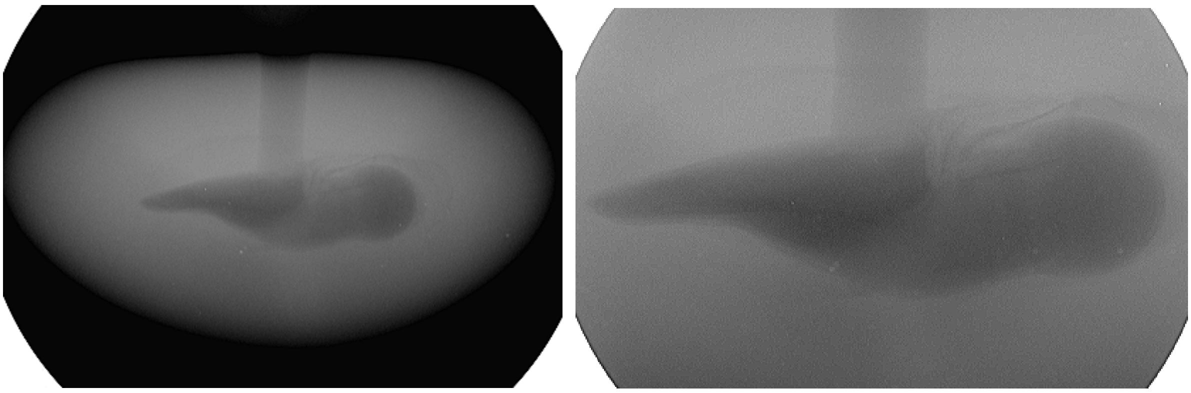

Figure 15: A saltwater NBCP in which a typical irregular structural void clearly proves its origin. This void was evident in all three directions examined, although the outline changed quite a lot depending on the orientation.

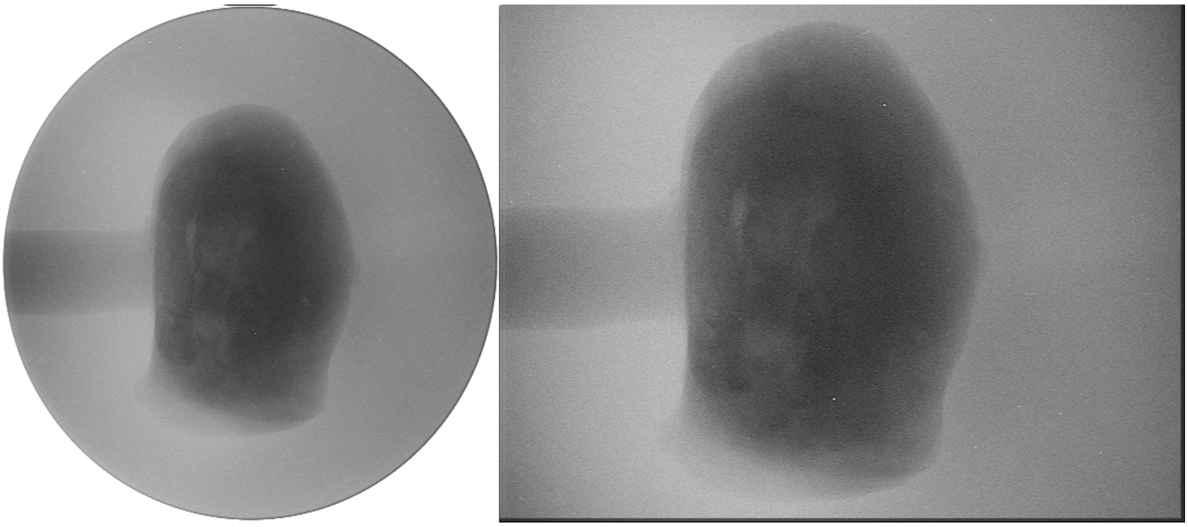

Figure 16: A saltwater NBCP in which a typical irregular, albeit more 'rounded', structural void clearly proves its origin. This void was evident in all three directions examined. Note that the drill-hole reaches the void and that there is some structure within the void.

Less obvious examples

As can been seen from the previous images, the voids and void-like features present can clearly be seen. This 'clarity' is also apparent in the other directions on most of them and the features present can be seen in two or three orientations without too much effort. Now we move on to pearls where the evidence is less defined overall, only visible in a specific orientation as opposed to various orientations, or where differences in interpretation between testers might start to appear.

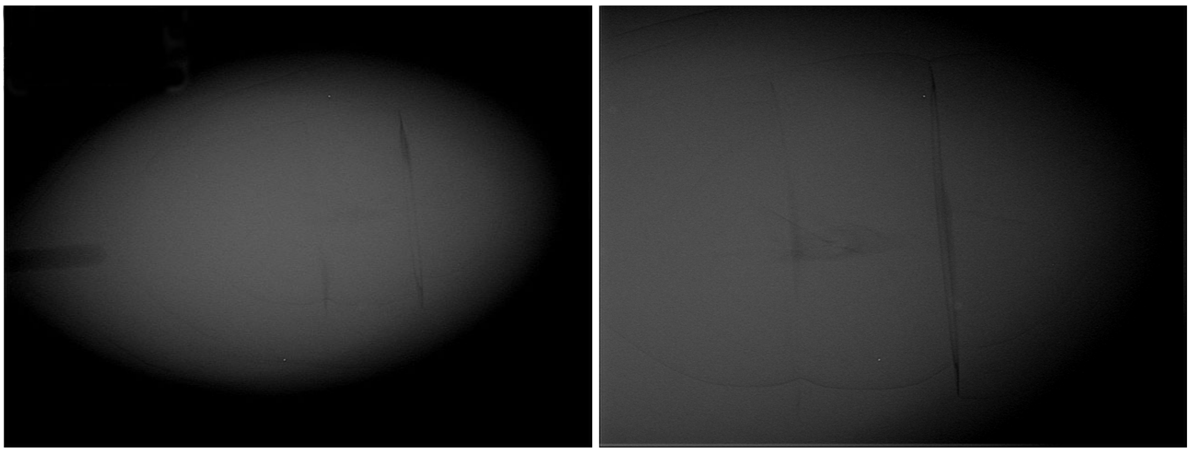

Figure 17: A freshwater NBCP in which the structural evidence is less obvious and which consists of various features which could begin to cause some confusion. The structure in this direction is the most telling as can be seen by the central oblique line and surrounding formation, yet the two near-vertical linear structures are also quite characteristic of freshwater NBCP (Scarratt, 2000).

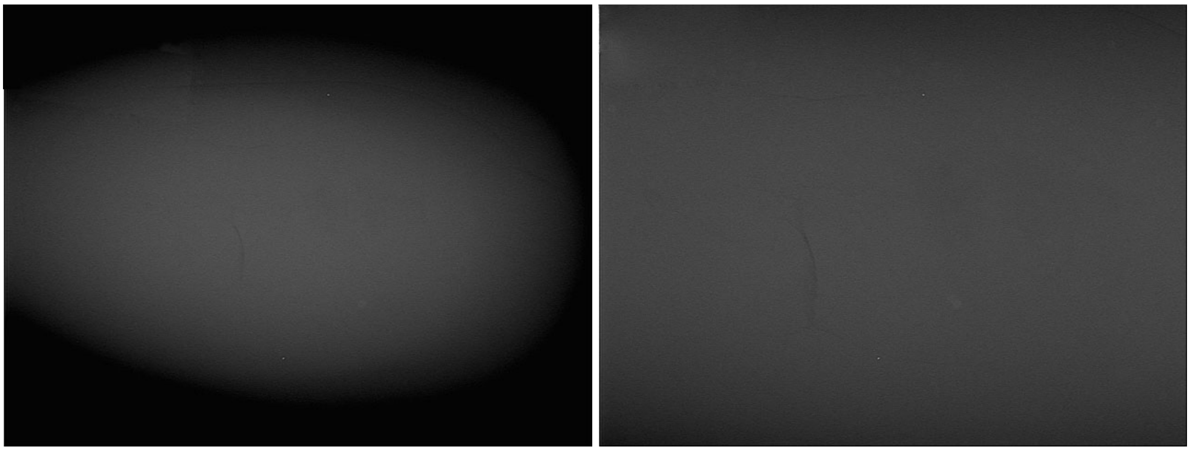

Figure 18: A freshwater NBCP in which the structure is fairly fine and not quite as clear as in previous examples. Closer examination in the magnified image to the right shows that it appears to be similar to a curving demarcation line between two sections of the pearl. This structure was also visible in a second direction, but not as clearly as shown in this direction.

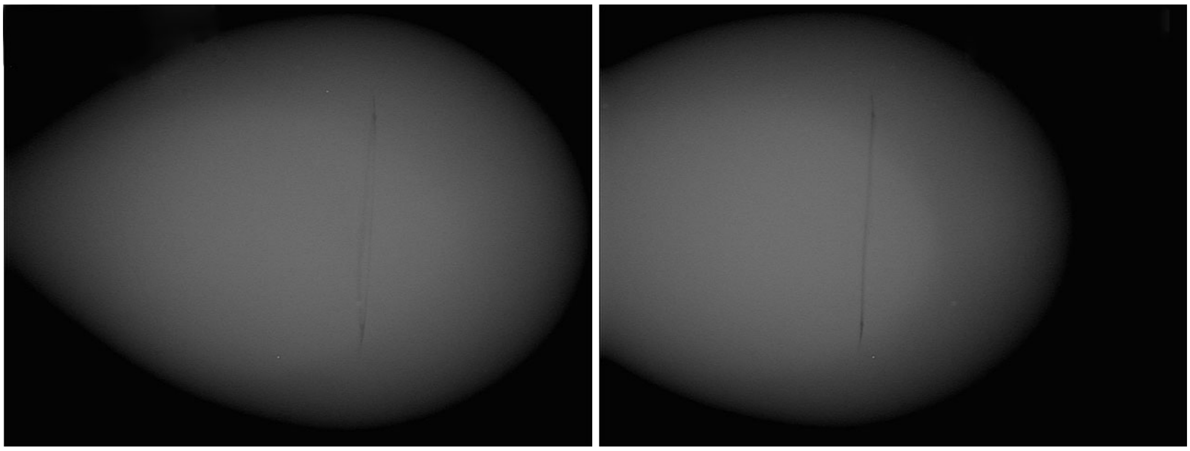

Figure 19: A freshwater NBCP in which a vertical linear structure can be seen in all side-n directions such as this one, but not down the length of the pearl. As stated in the caption for figure 17, which has similarities in structure, this type of structure is also quite characteristic of some freshwater NBCPs.

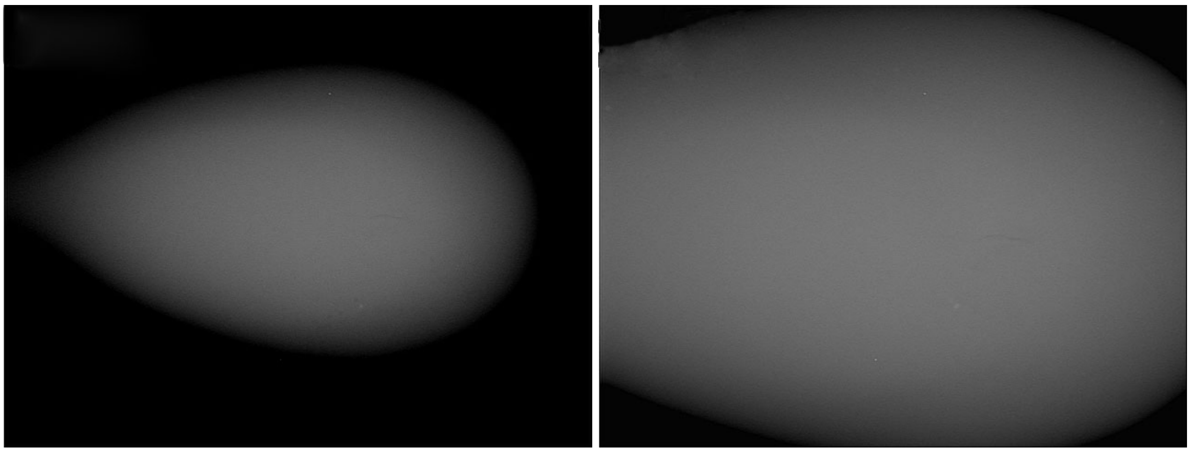

Figure 20: A freshwater NBCP in which the structure is very fine, but nether-the-less is clearly present. This structure was noted in two orientations. Note the lack of any other clear structure in these images, a feature that was also reflected in the other directions examined.

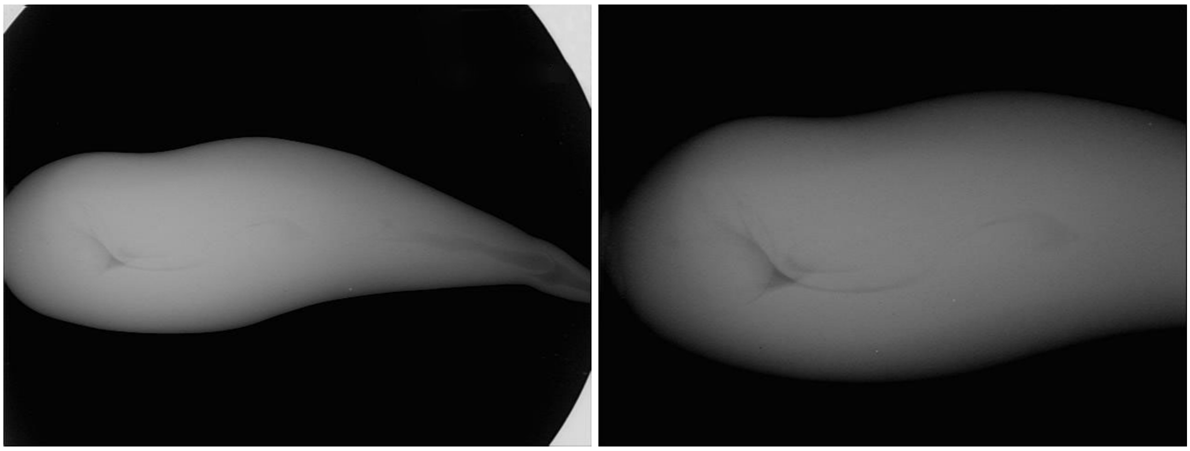

Figure 21: A saltwater NBCP showing linear structures that follow the shape of the pearl. Although there are no obvious voids as shown in previous examples of saltwater NBCPs, this type of linear structure is also quite typical of many "Keshi" type NBCP recovered from Pinctada margaritifera (this example) or Pinctada maxima mollusks.

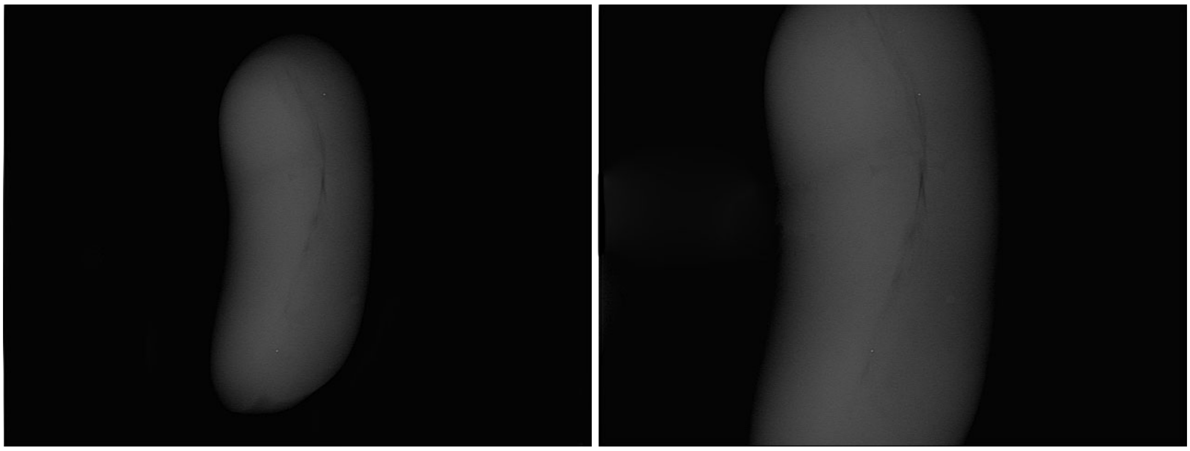

Figure 22: A saltwater NBCP, this time produced by a Pinctada maxima mollusk, showing similar but slightly more pronounced linear structure down the length of the pearl. In saltwater pearls not containing a prominent void, this is the next most likely encountered type of structural formation and the lines can either be long (as in this example) or short. Experience has shown that the shape of the pearl often relates to the length of this type of structure.

Questionable examples

The final group of pearls are those in which structures could be considered to be representative of natural pearls or non-bead cultured pearls and therefore in which the structures could be considered 'borderline'. Whilst these are generally not encountered so often, advances in culturing techniques over the years have meant that the chances of encountering them are greater than they were in the past and if culturing techniques continue to develop, could mean that more cases might appear in the future. Some very baroque natural pearls, for instance the freshwater '*Rose-bud*' pearls from the Mississippi river in the United States of America can also exhibit similar structures to freshwater non-bead cultured pearls, so care has to be taken in such cases. Additionally, as mentioned previously, the presence or absence of drill-holes can also influence the results on some pearls and hence pearls might drop into this category based on the drill-holes present. In extreme cases very large drill-holes might lead to an "undetermined" origin on some pearls, since the removal of too much structure will mean that any gemologist examining the pearls cannot safely offer any reasonable opinion on the likely origin of such pearls.

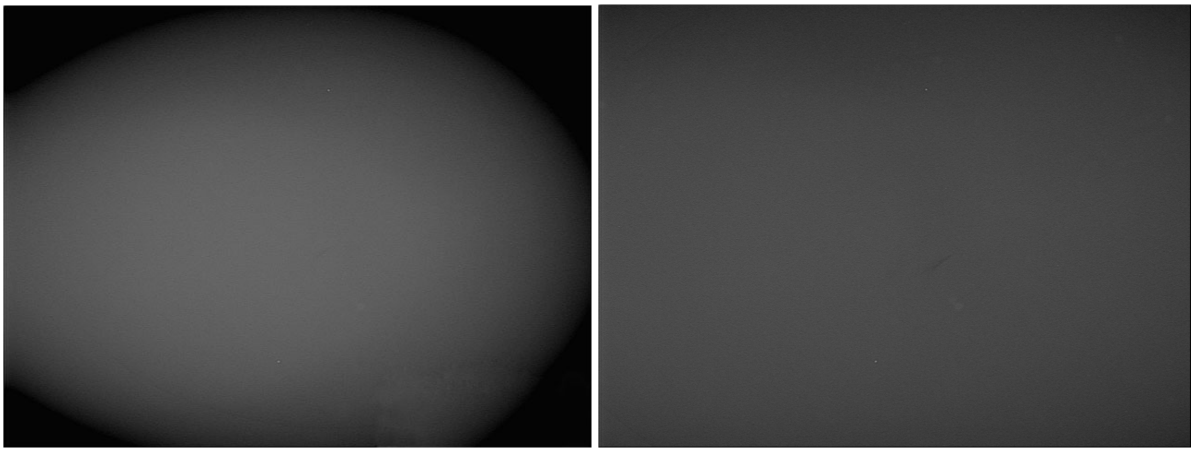

Figure 23: A freshwater NBCP in which only a small feature proving is non-bead cultured origin is visible. This feature was only seen 'clearly' in one orientation and did not show well in the others examined.

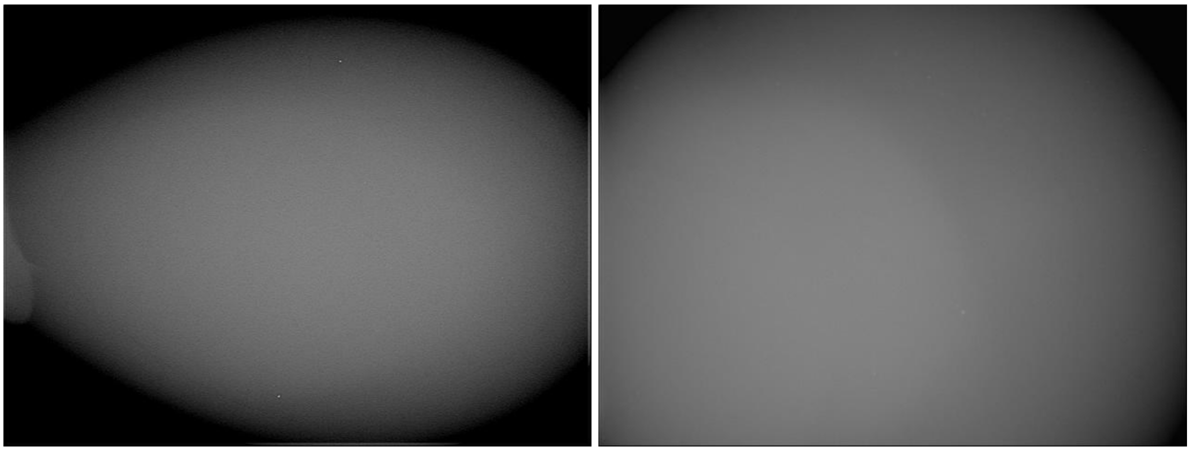

Figure 24: A freshwater NBCP exhibiting very little structure in any orientation. This in itself is very suspect but does not prove whether it is natural or NBC. The final opinion was based on the overall similarity to other pearls submitted in the lot (all proved to be NBC when tested).

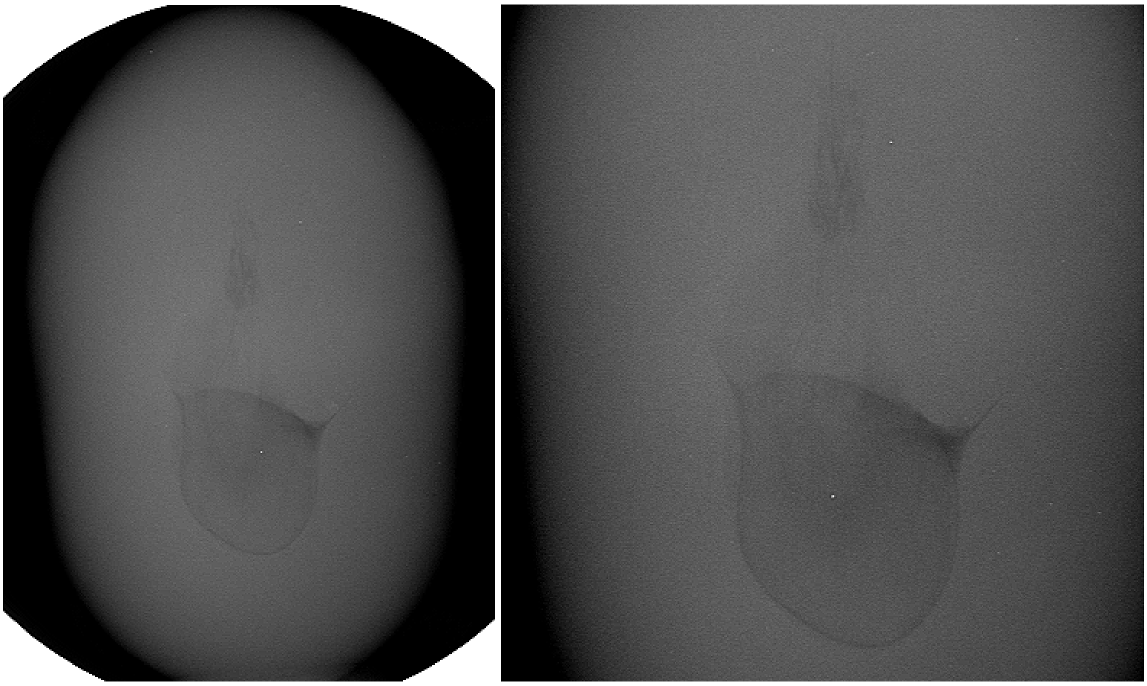

Figure 25: A saltwater pearl that exhibited a 'meaty' (conchiolin rich) area typically seen in natural pearls with a tail leading from it vertically. Overall this structure appeared too unusual to be considered natural when examined through different orientations and so it was classified as NBC.

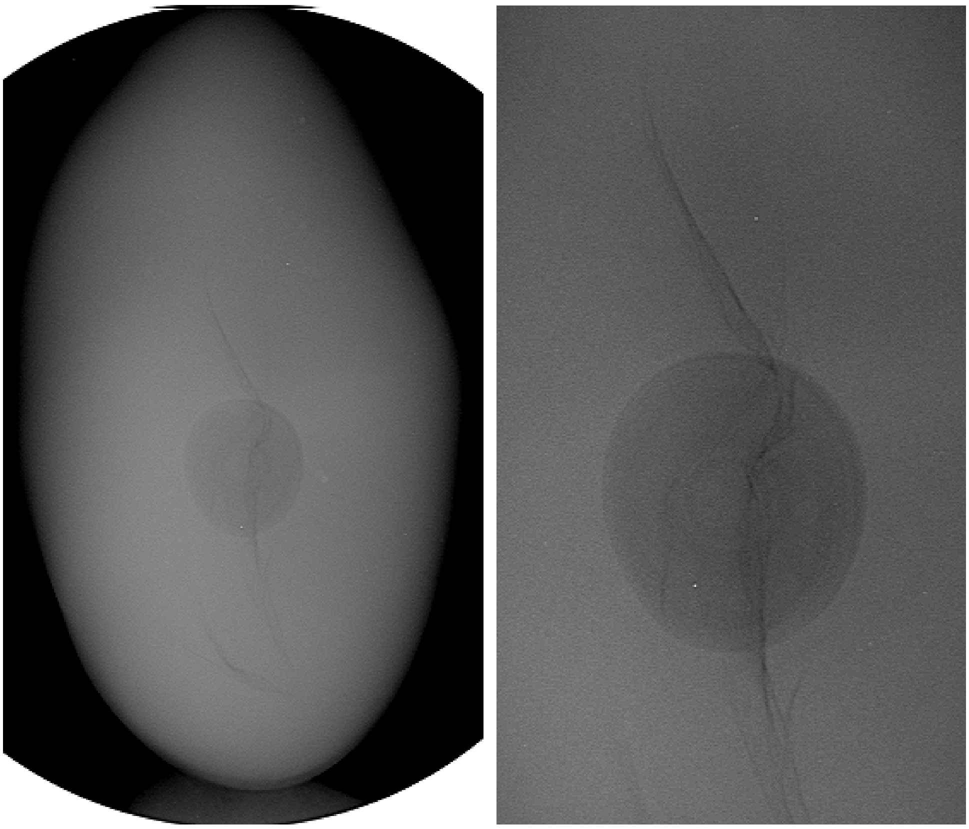

Figure 26: Another unusual pearl exhibiting a clear concentric natural nucleus as typically seen in some natural pearls, as well as some suspicious linear features cutting through the nucleus. The latter could be explained as concentric lines that combine into a plane in this orientation. The best direction to see that the nucleus is completely separate from the other structure is in the 'flat' orientation where the

pearl is thinnest. Overall this pearl was considered more natural and if submitted as a single pearl with no other association to go by would be classified more as natural.

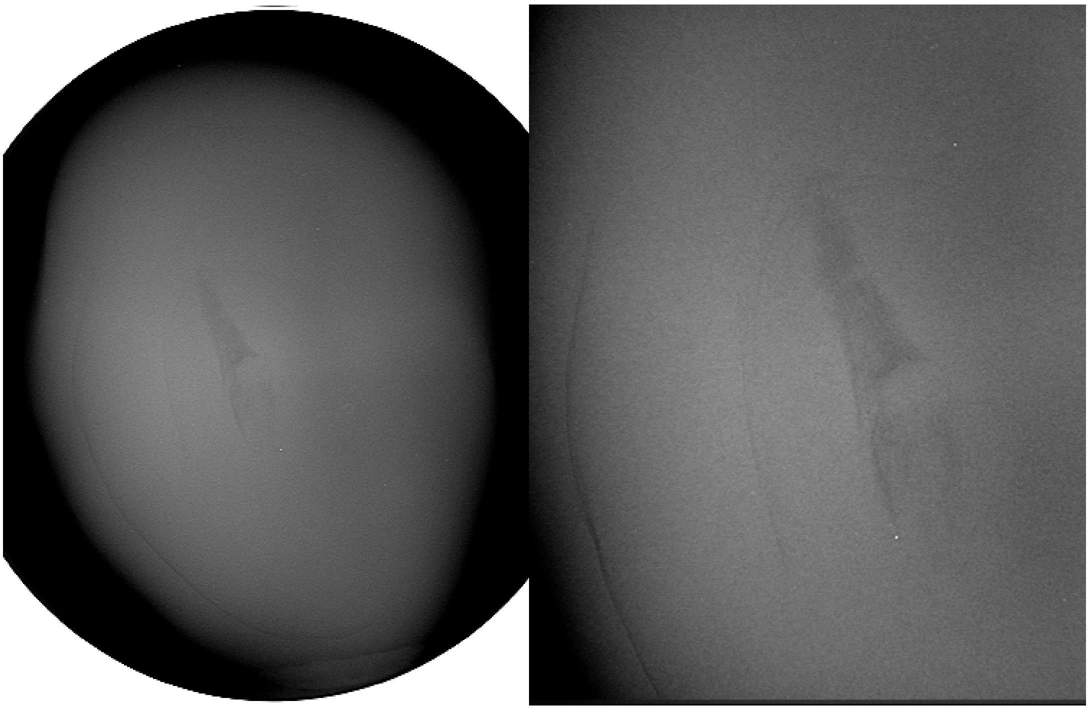

Figure 27: A tricky saltwater pearl to determine since the structure could well be associated with either a natural or a NBC pearl. The void-like feature has structure to it and some of the concentric growth arcs seen in natural and NBC pearls are evidently associated with the feature. Overall the pearl looked more like a NBCP than natural though, but it is certainly is a good example of the type discussed in the latter 'subjective' group.

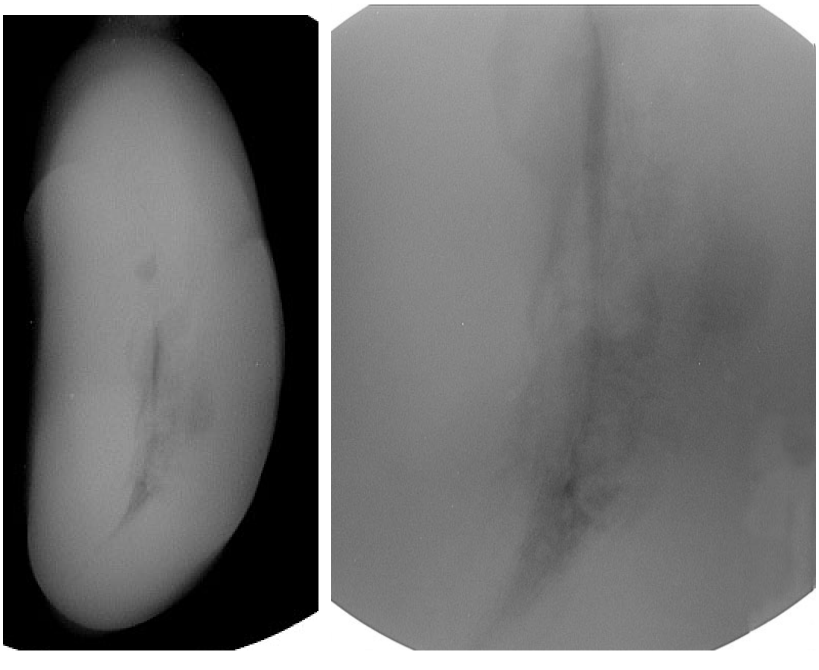

Figure 28: Another odd internally structured saltwater pearl. The void-like structure in this pearl is not quite the same as that seen in most of the NBCP examined so in conjunction with the exterior appearance this pearl was classified as a natural pearl.

Conclusion

This article shows a sample of the microradiographic structures visible in non-bead cultured pearls and some bead cultured and some natural pearls[4] so that those unfamiliar with pearl identification in laboratory conditions might gain a better understanding of some of the challenges faced. As is the case with all laboratories, the samples received for identification are completely unknown and hence the results of all the steps performed during the analysis have to be weighed and considered before reaching a final conclusion. These results may well be 100% certain and repeatable in most cases, however cases do exist where the results are not 100% certain and thus the 'best unbiased' opinion may have to be presented. In cases such as these only the mollusk itself can be certain of the origin. Given the doubt that can exist on the exact origin of some pearls and the few experts that the world has in this discipline it is sometimes possible that the interpretation of results may differ and hence different opinions expressed.

[4] Refer to Appendix A for additional structures of typical natural pearls and Appendix B for some examples of bead cultured pearls.

Appendix A

Natural Pearl Structures

The following microradiographic images are included to provide the reader with an idea of how ‘good’ or ‘classic’ natural pearl structures would appear. Natural pearls may show a diverse range of structures starting from where an obvious nucleus is visible (Figure 29 and Figure 30), to examples where no clear internal structure is evident. Whilst it is a matter of ‘luck’ as to what structure will appear when examining a single pearl, it should be fair to say that during the examination of a natural pearl item set with numerous natural pearls, i.e. a multi-row necklace, a wide range of internal structures will show on the resulting microradiographic images.

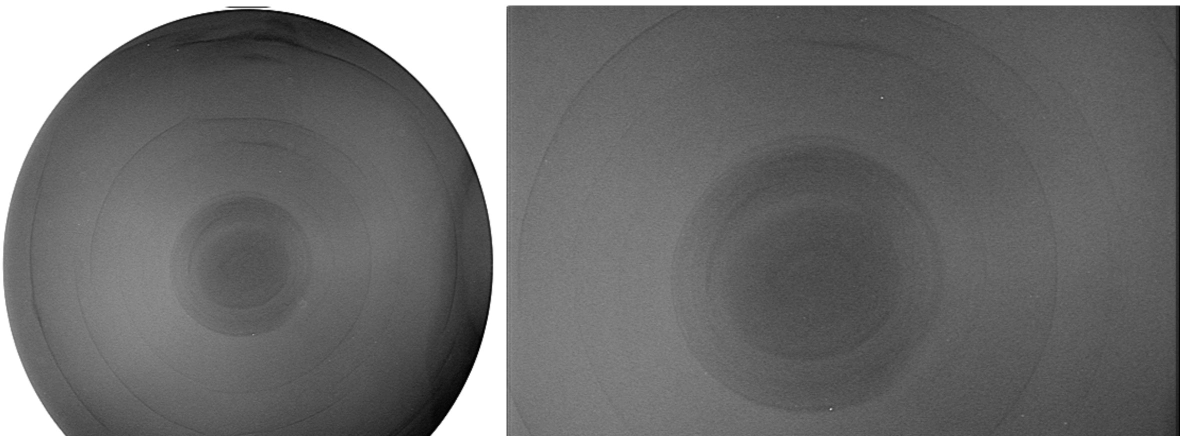

Figure 29: 'Classic' natural pearl structure. A dark concentric nucleus surrounded by a series of concentric arcs that resemble the cross-section of an onion or tree.

Sturman, N. (2009) The Microradiographic Structures of Non-Bead Cultured Pearls, August 20th 2009. *Lab Notes,* http://www.giathai.net/lab.php

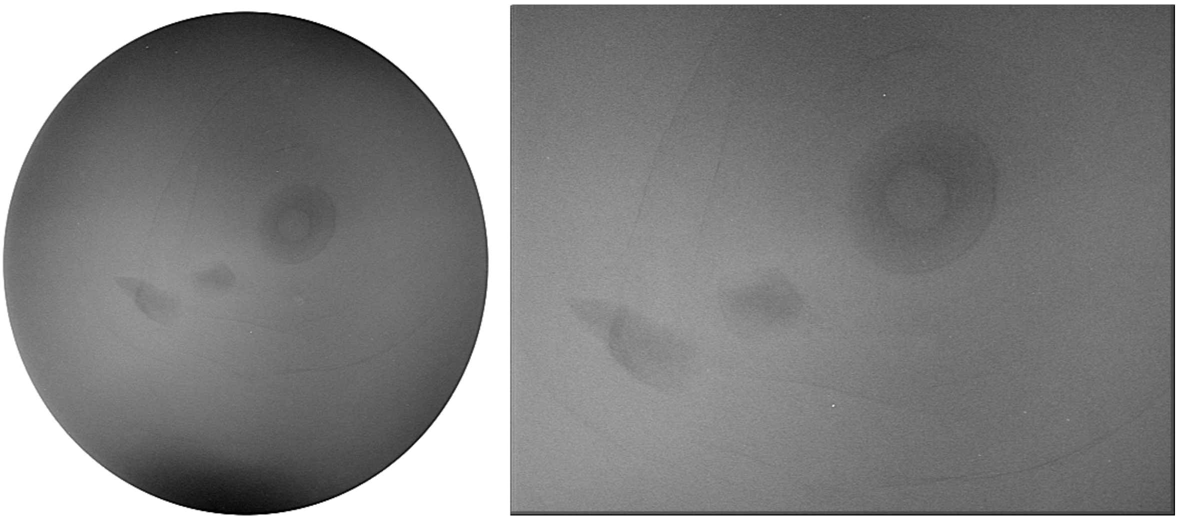

Figure 30: Another 'typical' natural pearl with its nucleus off-center and whiter than in the previous example. There are also some conchiolin rich shadowy areas associated with the concentric rings to the left of the nucleus.

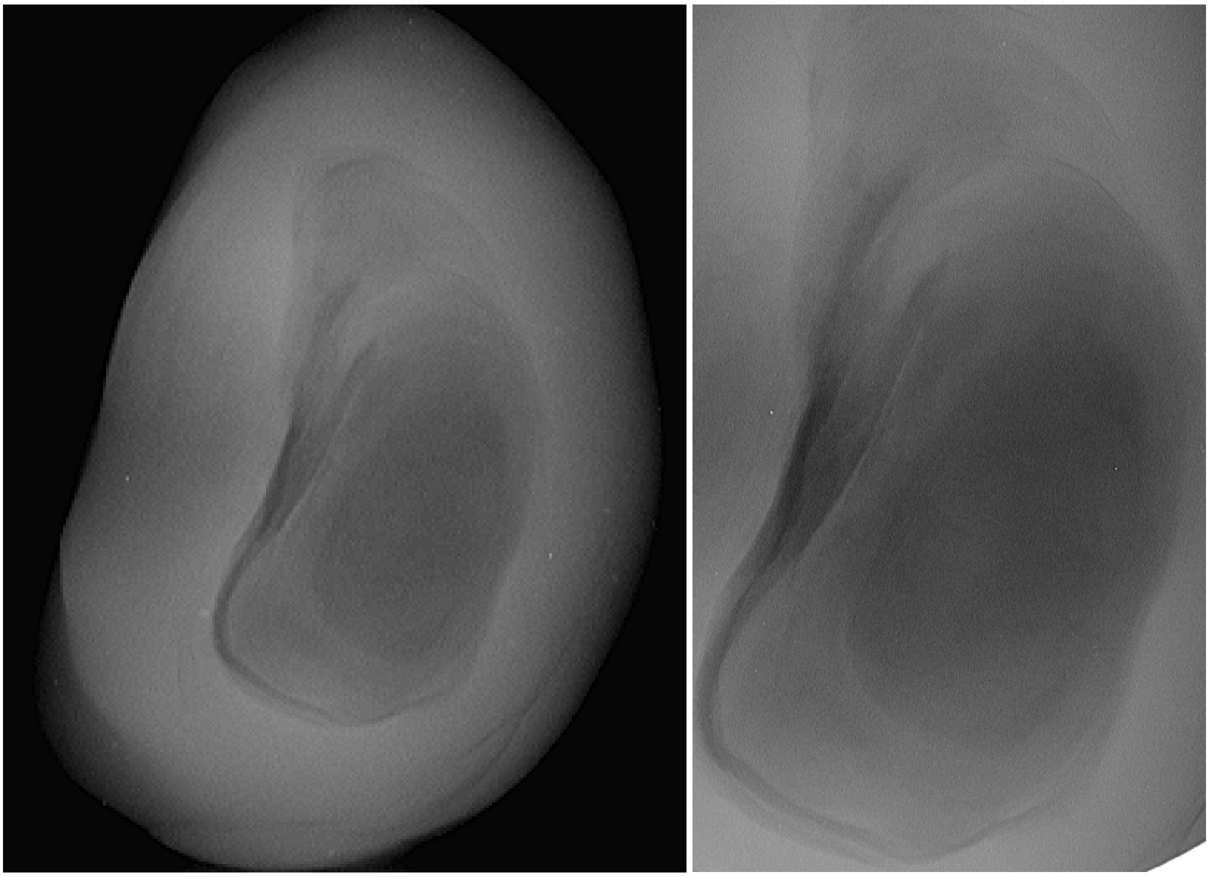

Figure 31: A 'meaty' (conchiolin rich) center in a natural pearl showing some concentric structure within the meaty center. Quite often cracks can be seen within this meaty center and this might create identification issues.

Appendix B

Bead Cultured Structures

Whilst most BCP structures are straightforward to identify, some can present challenges. This is especially so when the bead is small in relation to the size of the pearl and the demarcation line between the bead nucleus and nacre (pearl) overgrowth is vague. These cases can require even more care when the pearls are undrilled, since there is no way to visually inspect the interior with a loupe for more evidence either. The following microradiographs provide some idea of the range of structures seen in BC pearls:

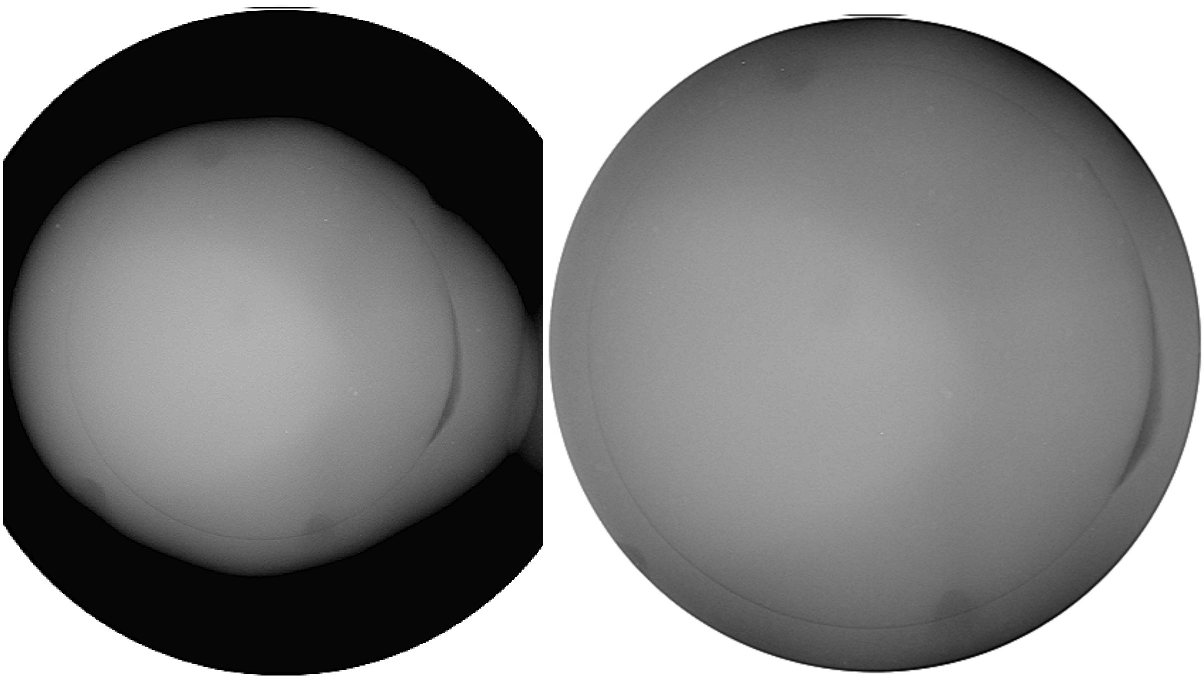

Figure 32: The typical microradiographic structure of a bead nucleated cultured pearl showing the mostly shell bead nucleus and much smaller overgrowth of nacre. Note the variation in thickness of the nacre and slight void between the bead and nacre in one position.

Sturman, N. (2009) The Microradiographic Structures of Non-Bead Cultured Pearls, August 20th 2009. *Lab Notes,* http://www.giathai.net/lab.php

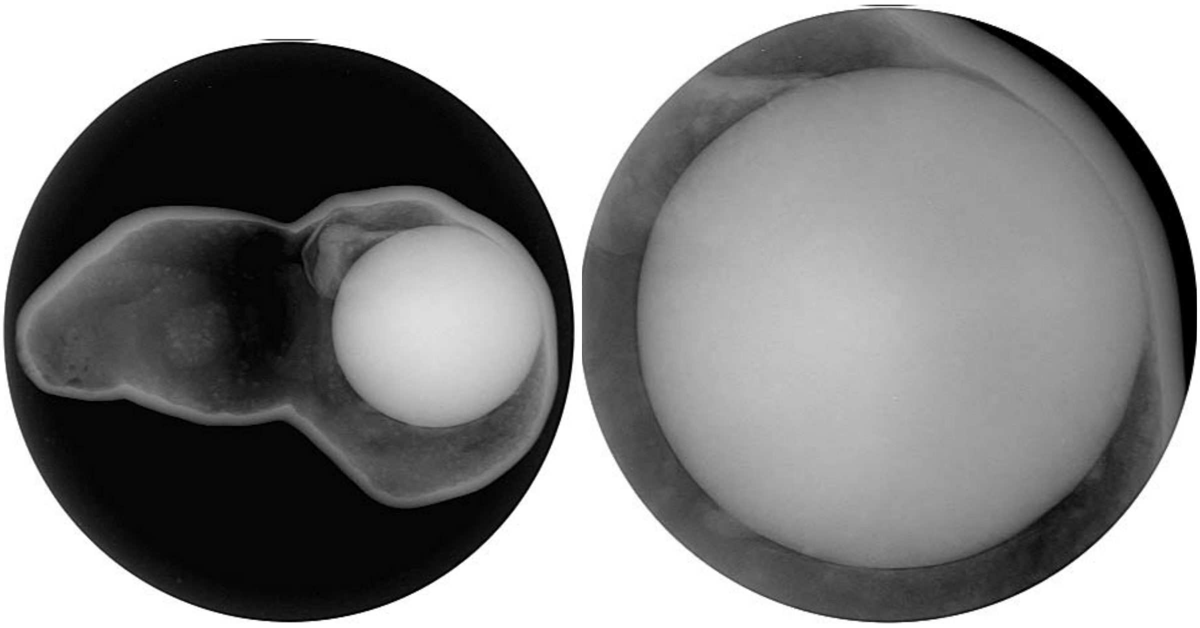

Figure 33: Another bead cultured pearl showing the variation that can be found in such pearls. In this case the baroque form of the pearl is produced by an essentially hollow structure around most of the bead. The bead can only be seen making contact in one area (viewed in this orientation) and fine inner structure within the void is also evident. In some cases the bead can move freely within such voids, however in this example no movement was detected.

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