“The chaîne opératoire of Ancient Egyptian glass manufacture: raw materials, production and use” Dr Anna Hodgkinson

December Meeting Review by Margaret Patterson

At the beginning of December Dr Anna Hodgkinson gave a talk to the Essex Egyptology Group about her work on glassworking in Ancient Egypt (working with a team of Egyptian and international workers and archaeologists, under the auspices of the Amarna Project and Freie Universität Berlin). She began by setting the scene for use of glass in Egypt and nearby areas like Mesopotamia and the Levant in ancient history. The earliest occurrence of glass in this region is of natural glass, and there are two types of this. The first is natural glass, which is a result of natural events like meteoric impact in the desert. This was used throughout Pharaonic Egypt and was mainly sourced from the western (or Libyan) desert. The other type is obsidian, which is a volcanic glass and was rarely used in Egypt – mostly for tools.

The first regular occurrence of artificial glass in Egypt, Mesopotamia and the Levant is during the 16th Century BCE. There is some evidence from earlier than this, but it appears to’ve been accidental rather than deliberate making of glass. The first evidence of glass working or manufacture in Egypt is during the reign of Thutmose III, 1479-1425 BCE, and she showed us some finished objects from this time or slightly later (beads from Hatshepsut’s reign and a Taweret figurine with the cartouche of Amenhotep II). The first confirmed evidence of glass production is from the Amarna Period (with possible evidence also from Malqata during the reign of Amenhotep III). Hodgkinson stressed that glass production and glassworking are different things – glass production is creating glass from the raw materials, glassworking is turning this created glass into finished objects.

Glass in Ancient Egypt appears to’ve been used to imitate other precious materials, and was valued similarly to them. Dark blue glass (which is coloured with cobalt) is believed to’ve been produced to mimic lapis lazuli which is only found in Afghanistan. Lapis lazuli may have yellow pyrite veins in it, and this may be what the wavy yellow decoration on these pieces is intended to call to mind. Light blue or turquoise coloured glass is made using copper, and was probably intended to imitate the semiprecious stone turquoise. On one of the walls at Karnak is a text called the Annals of Thutmose III, which presents a list of products that were brought into Egypt. One collection of these consist of little drawings of irregularly shaped and perfectly spherical lumps of goods. The labels for these refer to some as turquoise and some as lapis lazuli – but the perfectly spherical ones are likely to be artificially produced glass ingots rather than the natural (irregular) stones they imitate.

Glass Fish from British Museum

Hodgkinson showed us a map of the eastern Mediterranean plus Mesopotamia, with several sites marked on it that have evidence of glass during the 14th-11th Centuries BCE. It's quite clear that there was a network of glass trade and exchange during this period. The Uluburun shipwreck has provided a lot of the evidence for this, and more comes from the Amarna letters. These include people like the Mayor of Tyre in Lebanon writing to the Egyptian Pharaoh saying that they are sending him glass as he requested. There are also letters that show that Egypt was also exporting glass at this time – until recently it was thought that Egypt only imported glass until later in history but these letters (and other evidence) demonstrate that this was not the case.

The next part of Hodgkinson's talk was about the actual process of making glass – the chaîne opératoire of her title. The glass that was being made by Ancient Egyptians (and others in the wider region) at this time is called soda lime glass. To make it you most importantly need what is called a "network former", which in this case is silicon oxide (Si_2O): quartz or sand. But to melt pure quartz requires temperatures of 1700°C which haven't been demonstrated to be achievable in Egypt at this time – the furnaces they built could reach 1100°C. And so they added what are known as "network modifiers" which alter the properties of the mixture. The three of these that were added were plant ash, magnesium (which is called a flux because it lowers the melting temperatures) and lime (which comes from limestone, CaO, and is a stabiliser). From the later New Kingdom there is evidence that the production of glass was a two step process – initially a reaction vessel was used to mix the raw materials at heat it to 900°C. Then the material was cooled and colourants were added, after which it was reheated and formed into a raw glass ingot. But experimental archaeology by Paul T. Nicholson and Caroline Jackson has demonstrated that a one step process would also work.

There were several different colourants that the Ancient Egyptians used in their glass, and Hodgkinson listed these for us. As she had already mentioned earlier dark blue glass was coloured with cobalt (+ copper) and light blue glass with copper. Red glass also involved copper, that had undergone a redox reaction. Green was produced with a mix of copper and iron, yellow with lead and antimonate, black (actually deep violet) with manganese and white with calcium and antimonate. Antimonate was also used to make the finished glass opaque.

Evidence from the Uluburun shipwreck (and other sources such as fragments from Ancient Egypt now in the Petrie Museum) shows that the final vessels in the process were cylindrical in shape which made the glass ingots a portable and usable shape. When it came time to make something from the glass pieces would be chipped off the ingot. In order to melt glass for turning into finished objects you need a much lower temperature than for the initial production – between 750°C and 900°C. The chips used would be selected to be the right size for the piece of work, and then melted down and turned into rods or plates (or a finished vessel).

Hodgkinson now showed us a few examples of small Ancient Egyptian objects made from glass – beads, earrings and rings. These were made using a technique called lampworking, which is still used today. In this technique a small focused flame is used to melt a glass rod which is then wrapped around a metal rod (called a mandrel) to form a small circular loop. There's archaeological evidence from Ancient Egypt of glass beads still stuck on the mandrel they were formed on.

Glass vessels are rarer than beads and they come with a wide range of types of decoration (like the chevrons on Amarna glass vessels). These vessels are made using a core-forming technique. The core is made of sand, dung and clay (as Hodgkinson pointed out it wouldn't be that nice to work with!), and it is attached to a rod to allow one to handle it safely while making the vessel. One way of then making the vessel is to melt a glass rod and wrap this around the core to create the vessel walls. Another way is to dip the core in crushed glass until it is coated, then heat it up to melt and fuse together into the vessel. Or the core can be dipped into molten glass. After the vessel walls are formed the decoration is added using other coloured glass rods which are melted onto the vessel to form lines. Hodgkinson gave a link to a website that describes this technique in more detail and also to a youtube video of someone using the dip in molten glass technique.

Another use for glass in Ancient Egypt was as inlays, such as those on the coffin from KV55. These were cut into shape – the individual chevrons and hieroglyphs – then placed into the pre-cut gaps in the gold structure and glued there. The inlays were then carved and decorated to finish off the piece. Unsurprisingly the really exquisite ones don't often show up in the archaeological record.

Coffin from KV55

Next Hodgkinson talked about the glass workshops known in the archaeological record of Egypt. Although she focused on Amarna during this part of the talk she started with a brief discussion of the evidence from Malqata (a city that was inhabited during the reign of Amenhotep III). Glass working was definitely carried out at the site, and there is a lot of evidence for this. There is also possible evidence of glass production – this would be quite early for glass production in Egypt, but as yet there hasn't been enough analysis done to be sure so Hodgkinson stressed it is speculative for now. The evidence of glassworking and potential production comes from four parts of the site: the south village, the refuse heaps, the north palace and the pavilion. Current work is being carried out near the pavilion (and the north village) and this area is referred to as an "industrial

area". The nearby housing in the north village is not an elite area, it seems to be occupied by artisans which ties in with identification of this part of the site as an industrial area and as a place where glass working and possibly production might take place.

As I said, Amarna was the focus of this part of Hodgkinson's talk. She began by giving us some context for the evidence of glassworking and production from earlier excavations before moving on to current work at the site, including her own work. Petrie worked at Amarna in the late 19th Century CE, and in the volume that he published in 1894 he discussed the evidence for glass production that he had found in his 1891-1892 season. This evidence came from an area just to the south of the central city, and also the waste heaps to the south east of the central city. Sadly none of the evidence was properly provenanced by modern standards, and it's impossible to link an individual find back to a specific location within Amarna. Within Petrie's finds were some that show evidence of glass production at Amarna – these were pieces of bubbly white glass waste fragments. Work by Smirniou and Rehren (published in 2011) looked at the fragments under a scanning electron microscope and showed some parts of the material had unmelted or unfused grains of quartz – so this is waste from glass that was in the process of being made. Glass workshops are dispersed throughout the area to the south of the central city, and Petrie found moulds for faience and glass pieces in this area as well (and also in the palace waste heaps). Later work by Thomas Eric Peet in 1921 also identified an industrial cluster next to the house of Ranefer (a chariotry official) – that had the remains of inlays and glass rods.

One of the places where modern re-excavation has taken place is referred to as O45.1, by a team led by Paul T. Nicholson. There is clear evidence here for raw glass production – in particular they found fragments of ingots, some of which had unfused quartz in them (the same as the waste glass Hodgkinson discussed earlier). They have also excavated furnaces that were probably used for melting glass. Nicholson and Jackson have built replicas of these furnaces and demonstrated that you can achieve a temperature as high as 1150°C, which is more than high enough to make raw glass.

Hodgkinson herself led excavations at a site within Amarna called M50.14-16 in 2014 and 2017. This is an area about 80-100m to the south of Ranefer's house that she had mentioned earlier. M50.14-16 consists of two typical Amarna period tripartite houses, between which there is a food preparation court with an oven. The houses are surrounded by a large-ish area of open court, with separation walls and firepits in this court. And in this court there is a lot of evidence of glass work and possible glass production. She's working on the analysis of this material now (~2500 small finds, plus a lot of bulk finds!) and is hoping to write it up in a book about the site and its use for glass work and production.

Leonard Woolley had previously excavated this part of Amarna when he was working at the city in 1922, and it's published by him and Peet in their first volume. They didn't publish it very thoroughly, as they weren't so interested in industry, but they do discuss a

firepit or kiln which he found in the court and say that this is a place where glass was worked. Hodgkinson said it's a particular shame that they didn't write it up properly because in the 100 years since he excavated the site has deteriorated and much information has been lost.

When her team re-excavated the place where Woolley had said the firepit was, there was no sign of it and I think at first it wasn't clear if it had been destroyed or if the position was inaccurate. They did however find a lot of evidence in that area of industry taking place. This included glass beads and piece of glass, evidence of faience manufacture and evidence for bronze working (including thick walled clay vessels used to melt copper). As well as this were several pieces of agate, a semi-precious stone which is often confused with carnelian and jasper which were also used by the Ancient Egyptians. She said they also found a lot of fragments of glass ingots, some with impressions of the vessels they were formed in. They also found glass rods, some of which have impressions of tweezers and other tool marks which give evidence of how they were manipulated by the ancient craftsmen. There were also some fragments of glass vessels – these may've been discarded due to breaking during production, tho Hodgkinson stressed that they have no evidence to disambiguate whether they were made at this site or just broke at this site. A lot of the beads they have found (including some quite large groups) have little trails and threads of glass – so it's quite possible that these are unfinished and haven't yet had their final polishing which would suggest they were made on site. But Hodgkinson did note that it's possible that they were meant to be like that – she does think that's implausible, however, as they would be quite uncomfortable to wear as they are.

Hodgkinson said they have also found fragments of cylindrical vessels, which may have been crucibles for making glass – but sadly they are hampered in proving this because the necessary analysis can't currently be done in Egypt (and they can't take the finds out of the country to undertake the analysis elsewhere). They do look like they have traces of the production process – for instance some of them have the remains of a "parting layer" (which lets you get the glass ingot out more easily after it been made). Hodgkinson also pointed out that the fragments of ingots that they have fit perfectly into the fragments of vessels. So this is all quite suggestive that glass production was taking place here, however it's also still possible that these were the vessels used to remelt ingots in order to make glass rods and worked items. Another interesting find of this type is a glass ingot that has a sloped top surface – as if the vessel it was in had been left to cool at an angle rather than sat flat on a surface.

When they excavated the part of this court area called M50.14 they discovered what had happened to Woolley's firepit – he hadn't recorded it in quite the right place, as they found what he had described in this area to the side of where he said it was! The firepit itself is a pit with vitrified material in it, and they also found material that had been added to insulate the glass so that it would cool slower and anneal. She's been able to fit

together some pieces of this material and so has an idea of what the pit oven would look like. Hodgkinson did stress that this is a workin progress, and as she continues to analyse the finds she may alter her reconstruction.

To summarise this part of the talk Hodgkinson said that based on the evidence from both early and modern excavations they can see that there's a large industrial cluster in the main city south. In this area there was a network sharing skills and staff, perhaps even under the oversight of Ranefer whose house is so close by – and these workshops would've share resources such as the materials used to colour their glass etc.

Hodgkinson now moved on to her own experimental work, which she did in collaboration with Miriam Bertram. A group of unfinished beads found in M50.14 were their inspiration – they were found near a group of small superficial firepits (rather than the more substantial pit oven she was just discussing). So they began to think about how the ancient Egyptians actually worked with the glass – could they reach temperatures of between 750°C and 900°C with these tiny fireplaces? Her first step was to learn modern glassworking techniques, so that she had the practical background knowledge she needed. She showed us some of the beads and vessels that she has made, which were pretty cool! So that gave her the skills she needed to actually do her experiments. She stressed again that this is a work in progress and then told us a bit about what they have done so far. Firstly they had to try and find out what sort of techniques the Egyptians might've been using – but there are no scenes in tombs or any texts depicting glassworking. So instead they based their experiments on Middle Kingdom scenes of metallurgy and used analogous techniques. The metalworkers are shown with blowpipes, and so they used long copper blowpipes in their experiments to create a small focused flame in the fire. When they measured the temperature this reached 900°C, so it was possible to use the lampworking technique (which she'd described earlier). These initial experiments have demonstrated that it's possible to use quite a small fireplace to work glass, and she said that their next experiments will be to test if an even more superficial one can be used (closer to the size of the firepits that the beads were found next to).

Having talked about the evidence internal to Egypt for glass production Hodgkinson moved on to looking at more external evidence. In the Late Bronze Age there is a large network of glass trade amongst the wider eastern Mediterranean region and Mesopotamia. Everyone is using glass, but based on the main components of the glass it's very difficult to separate it into types for each region – it can't be simply analysed in order to find out where it came from. But Hodgkinson said that there are techniques which can help (I think newer technology) – in particular one developed by Andrew Shortland and colleagues using something called LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) that can be used to look at the trace elements in the glass (rather than the main components that the earlier techniques tried). Essentially you get a chemical fingerprint for the glass, which can be used to distinguish between glass from different regions – you can tell if any given piece is Egyptian glass, or Near Eastern glass. So work has been done looking at some objects from Egypt

(though now outside Egypt) to see where they come from. One example was some beads from Gurob, analysed by Victoria Kemp, Andrew Shortland and colleagues, which turned out to be imported glass – perhaps coming with one of the foreign wives of Thutmose III.

Another source of glass to analyse is that from the Uluburun shipwreck which had a lot of dark blue and turquoise glass ingots. These are the right size and shape to fit into the probable glass making vessels that Hodgkinson had excavated at Amarna, and the time period is also right. So she was pleased to find that the three glass ingots from the shipwreck that have been tested have been demonstrated to be Egyptian glass using chemical fingerprinting. And she said she feels more confident that the evidence at Amarna is of actual glass production, but she is still not certain. However she is sadly unable to analyse any of the ingots she excavated at Amarna, because the LA-ICP-MS technique is not currently available in Egypt (although it may be in the future).

Hodgkinson noted in passing that when the Mycenaean glass items were analysed by M. Walton and colleagues the glass is either Near Eastern or Ancient Egyptian (or a mix) but there is no sign of a Mycenaean specific finger print for raw glass – so it looks like the Greeks only imported their glass and didn't make it themselves. After this note she was going to tell us about isotope analysis which can also be used to distinguish between different origins for glass (which is a work in progress) but she skipped over it due to lack of time.

Another way of looking at the origins of particular lumps of raw glass is to use the chemical composition of their colourant. Hodgkinson said that a lot of the Amarna period glass is coloured dark blue. This is done, as she had told us earlier, using cobalt which must be processed first (including heating it and grinding it up). A suite of three "transition metals" that are present alongside the cobalt (Nickel, Manganese, Zinc) can be analysed to provide a chemical fingerprint for the cobalt. Unlike the LA-ICP-MS the equipment to detect the transition metals is portable and so Hodgkinson was able to bring this to Egypt and analyse the glass found on site at Amarna. She has analysed around 600 glass objects from the site, and the first thing she noticed was that over half the cobalt coloured glass also contains copper (which on its own would give a light blue colour). Most of the raw glass from workshops in Amarna does use the same source of cobalt – from the Dakhla and Kharga oases. So this in general backs up the idea that glass was produced (and not just worked) at Amarna.

Hodgkinson now moved on to end of glass working in Ancient Egypt. The last two glassworking sites that she told us about were from the end of the New Kingdom. One of these was at Qantir (or Per-Ramesses) where the stables were built over a large glassworks, this was published by Pusch and Rehren in 2007. Despite it having been built over there is a lot of evidence of glass production (although only a little evidence of glassworking) from this site, including lots of pieces of unfinished glass, beads and vessels. Unlike the Amarna glass workshops most of the glass found at Qantir is red rather than blue. The other site is at Lisht, near the pyramid of the Middle Kingdom king

Amenemhat I – this was discovered in the early 20th Century by a team from the Met Museum, and has been dated to the Ramesside Period (using non-glass evidence). Analysis of the glass that is in the Met by Smirniou, Rehren and colleagues shows that it has its own chemical signature. There is also some overlap with that from Qantir and other sites, which suggests that as well as producing glass at this site they also recycled glass from other sites.

And those were the last glass working sites in Ancient Egypt until the Ptolemaic Period (which is a gap of c. 700 years!). Hodgkinson said we don't actually know why this is – she speculated that perhaps glass was no longer required by the elite or heads of state as a luxury good? Were the High Priests of Amun not interested in glass as a status symbol? When glassworking returns to Egypt in the Ptolemaic Period it's different – there are different types of glass that are popular with a different chemical fingerprint to the earlier types (lower in magnesium and potassium). Blown glass, which Hodgkinson hadn't talk about so far, also becomes popular in the 1st Century CE.

Hodgkinson finished up by summarising what she'd told us over the course of the talk. The origins of Late Bronze age glass-making are not entirely clear, but glass was produced and traded between Mesopotamia and Egypt from early on – since the 14th Century BCE. The origin and raw materials of the glass can be determined through chemical analysis, although that work is hampered by access to the necessary equipment. There are different sorts of workshop – ranging larger scale installations down to small scale household level working of glass (and possibly even production). Experimental archaeology can be used to give an idea of how glassworking took place, but Hodgkinson stressed that one must be careful when interpreting this data. There are still several unanswered questions – the whole Ancient Egyptian workflow is not yet known, and the disappearance of glass use in Egypt at the end of the New Kingdom is not at all explained.

I really enjoyed this talk, particularly the parts about experimental archaeology – it was impressive to see that such relatively unsophisticated equipment could be used to work with glass pretty much at a domestic scale!