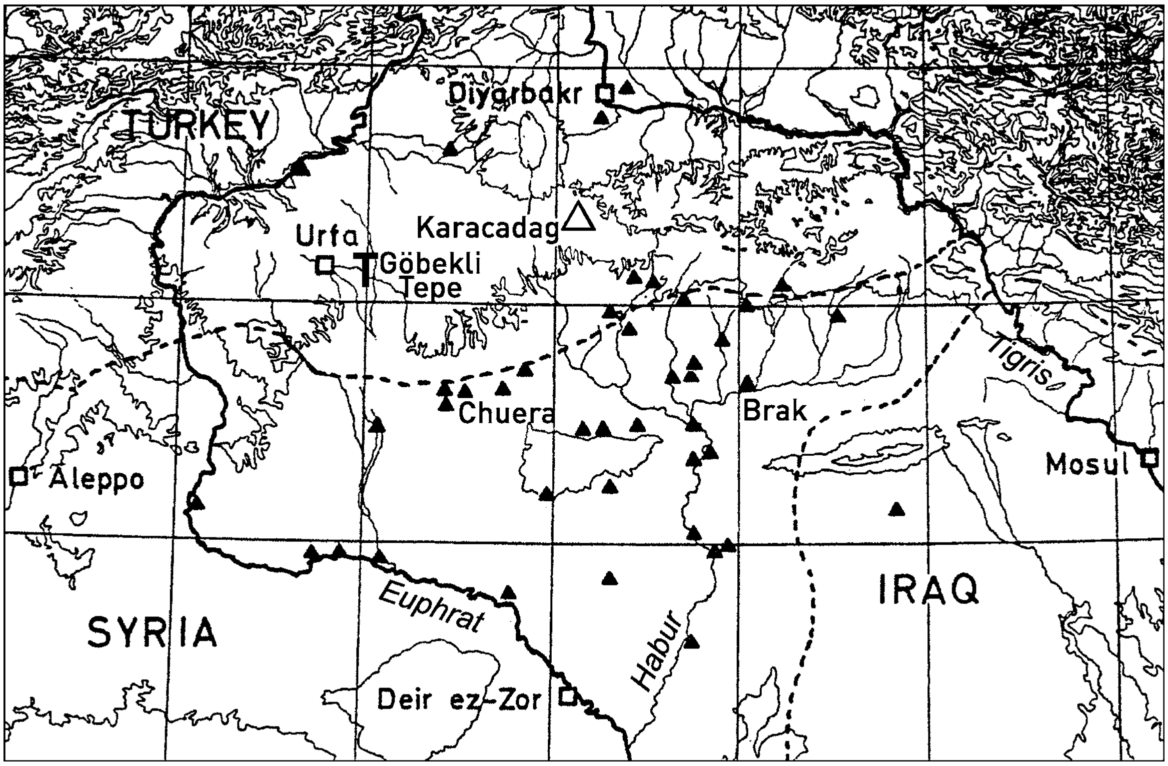
Gustav Weiß

Lost knowledge today

Part 1: Metallic ceramics



ILLUSTRATION

Sites where north Mesopotamian stoneware from the 3rd-4th millennium B.C. was found in the border area between Syria and Turkey. (Border: dotted line).

Metallic ware has been found mainly at Tell Chuera (group A) and Tell Brak (group B).

In Turkey, the volcano Karacadag is situated in the foothills of the Taurus Mountains (elev. 1919 mtr.) Urfa is held to be Abraham's "birth grotto". 2 km east of Urfa is a 11,000 year-old temple complex, the oldest known to humanity, with its T-shaped stone totem poles. It is being excavated by the Berlin archaeologist, Klaus Schmidt. Agriculture originated in this area.

It may be termed the evolution of ceramics if production methods were given up in the course of its development which lost their importance with changing living conditions. Archaeologists discovered such methods during excavations in Northern Syria. What they uncovered suggests that potters in the Middle East had acquired a great store of knowledge, even three to four thousand years B.C. Hitherto their work has only been admired for its appearance. It has only been the result of recent archaeometric research that evidence has been presented of its technological inventiveness. A type of ceramic is of particular interest which in the emerging metal age was equal to metal in hardness. Today, ceramics which are based on technical and artistic characteristics as well as providing "happenings" can profit from this lost store of experience.

Unlike the Far East, where in northern latitudes nature favoured the development of ceramics with suitable clay deposits and firing temperatures, the potters in the Middle East had to make use of the predominantly calcareous clays at low firing temperatures. The clays would have melted to a shapeless lump even at only 1200°C, but they would not have been able to fire so high because they did not have the forests the Chinese did.

Ceramics of great hardness

In the course of excavations in Northern Syria conducted by the Deutsches Archäologisches Institut, shards and vessels made from a metallic ware were discovered, which were archaeometrically examined at the

Freie Universität Berlin by Gerwulf Schneider. They revealed unusual properties, which experts considered to be a sensation. In the age when metals were coming into use, potters had produced a type of ceramic that was impermeable and of similar hardness to copper. Even tools were made from it. This type of ceramic, which was fired to 1,000-1,100°C, corresponded in hardness and impermeability to high-fired stoneware that was only developed some thousands of years later in China (at the end of the Shang dynasty, 1500 – 1000 B.C.).

Stoneware as we know it requires a clay with a wide maturing range. It must be almost free of lime because lime reduces the range between vitrifying and melting. As a result of the uniform geology of the Arabian Plate between the Taurus Mountains and the Arabian Gulf, the clays are lime rich (approx. 6-8% CaO) to very lime rich (exceeding approx. 30%), and no ceramics of stoneware type could be made from them. At the vertex of the Fertile Crescent, the present border region between Turkey and Syria (fig. 1) there are however a number of young volcanoes, which have changed the composition of the soil. In contrast to China and Europe at a later date, the early potters produced a hard impermeable ware, which produces a clear ringing tone when struck, at low temperatures, in which iron is the principal flux, thus in a sense anticipating the Iron Age.

In this type of ceramic, known by archaeologists as Metallic Ware, two groups may be distinguished. In Group A, where the findings were centred on Tell Chuera, the clay body contained (average from 54 samples):

5.21% Fe_2O_3,
1.59% CaO (+0.88 MgO)
and
2.29% K_2O (+0.08% Na_2O)

and in Group B centring on Tell Brak (average from 95 samples):

6.84% Fe_2O_3,
1.67% CaO (+1.16 MgO)

4.01% K_2O and
0.11% Na_2O

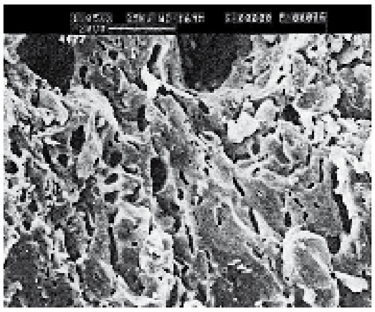
In some of the samples from group B, the potassium oxide content reached a level well above 5%, the most significant distinguishing feature compared with group A. Both groups contained large quantities of trace elements such as vanadium, chromium, nickel, zirconium and others, as is typical of volcanic ash. The raw materials are thus local, they remained the same for thousands of years. This exceptional position with regard to raw material resources in the Middle East may have contributed to the fact that this type of ceramic was restricted to such a small area and that it did not gain further significance.

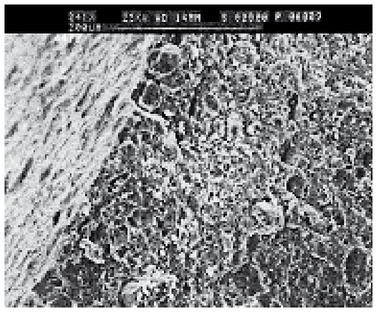
After chemical analyses (i.e. according to main components), they may be presented as follows:

Group A
57.42 powdered white clay
no.1501 from Goerg&Schneider
22.07 powdered quartz
14.32 alkaline frit M 1233
6.22 red iron oxide.

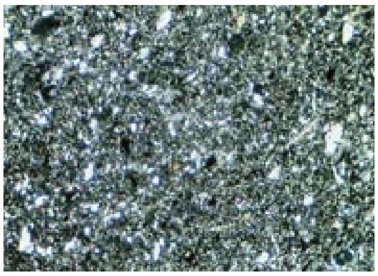
Group B
47.26 powdered red clay 311
from Goerg & Schneider
31.50 Lavalit or basalt
4.06 powdered quartz
15.20 calcite
1.98 red iron oxide

However, if we look for an explanation of the fluxing properties of the iron, these approximate reconstructions will not suffice. If we take the total of all the fluxes including alkalis, earth alkalis and iron (II) oxide (FeO), the total quantity of fluxes in the metallic ware comes to approx. 10%, for the comparable Böttger stoneware it is 15%, and in spite of the lower flux content, metallic ware is fired much lower, viz. at 1,000°C compared with the stoneware, which was fired to around 1,300°C. The alumina and silica content are the same in both



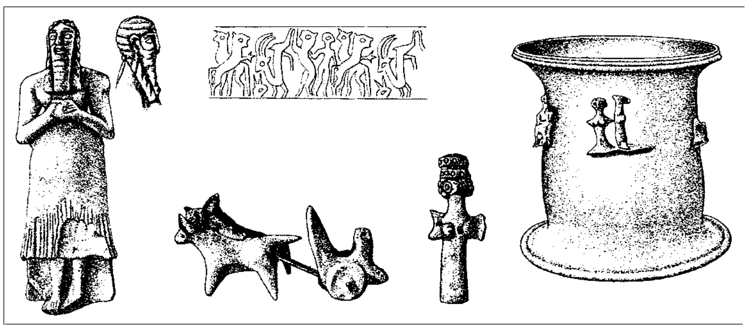


ILLUSTRATIONS
Optoelectronic images of a shard of metallic ware from group A. The high resolution illustration on the left with quartz and feldspar grains and mullite and hercynite fully melted at around 1,050°C. The image to the right from the same sample at lower resolution shows a ridge with a sinter skin (left of the image).



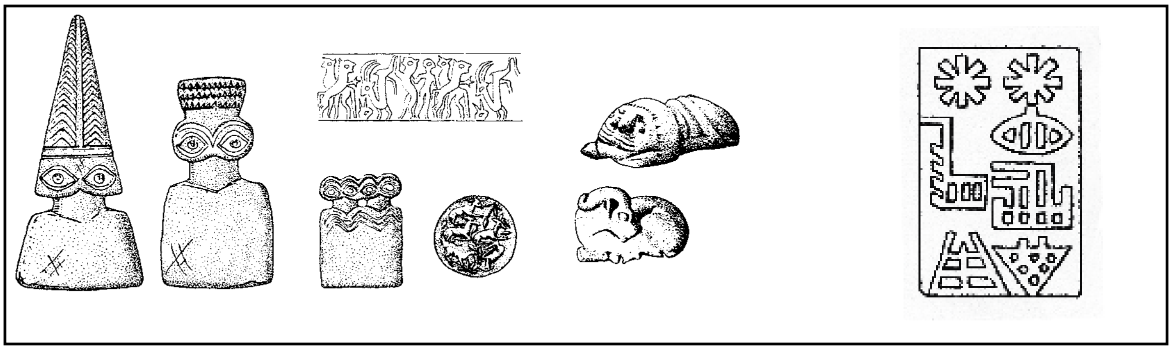
Thin section of metallic ware from Tall Bi'a under a polarising microscope. Undecomposed inclusions of quartz and feldspar (white and grey) as well as ore and mica (black). The height of the image correspods to 1 mm.
image: G.Schneider.

Piercing and cutting tools made of metallic ware from Tell Brak, length 9.6cm.



În Tell Chuera a number of alabaster statues were found in an annexe to a temple, together with the clay model of a chariot, female clay figures and vessels, roller stamps, 70 pieces of silver jewellery and bronze articles from the 3rd millennium B.C. (after Moortgat)

ILLUSTRATIONS



Typical eye figures from the "Eye Temple" in Tell Brack from the Djemet Nasr period (3rd-4th millennium B.C.). Several hundred votive objects of this kind made of alabaster with eye grooves filled with black or green paint were found. Also animal figures, roller stamps and interesting circular stamps. Beside the temple a palace was excavated from the Akkad period (3rd millennium B.C.), made of dried mud bricks, which were stamped with the mark of the builder, "Naramsin" (right of the illustration). (After M. Mallowan)

cases: metallic ware A has 10% flux, 22% alumina (Al_2O_3) and 68% silica (SiO_2), whereas Böttger stoneware has 15% flux, 21% alumina and 64% silica. The relationship among the oxides in the flux group must therefore be different to explain the differences in the firing temperatures. Indeed, iron (II) oxide predominates in the metallic ware. The proportions of the other ingredients in the natural volcanic compounds must also be so favourable that we have a mixture that melts at the lowest possible temperatures (eutectic). This may be deduced with the assistance of the siliceous multi-compound systems described by the American Ceramic Society in three weighty volumes. It reveals that the iron-rich three compound system consisting of the three ingredients FeO (1380°C), SiO_2 (1713°C) and Al_2O_3 (2050°C), which forms the basis, reveals a eutectic point of 1083°C when it the proportions are 48% FeO, 40% SiO_2 and 12% Al_2O_3, which indicates a heavy fluxing influence of the iron. The eutectic temperatures are regularly lowered even further if small quantities of other oxides are added. In the present case, this would be lime, which would reduce the temperature to 1,070°C, but it is the alkalis that have the greatest effect. The lowest eutectic temperature for the system $FeO\text{-}Na_2O\text{-}SiO_2$ is as low as 667°C, with K_2O it is 767°C. Analyses of shards also reveal the presence of approx. 0.1% phosphor (P_2O_5) and several hundred millionth percent of various trace elements that are typical of volcanic ash. These include vanadium (V_2O_5), which in a certain eutectic relationship with iron (II) oxide even melts at 625°C. This means that in a reduction atmosphere and in the presence of small quantities of alkalis and other traces, in a complex multi-component system, iron can reach the composition discovered in the analyses. For this to happen, the alkalis and earth alkalis must come from feldspars to raise the alumina and silica levels. The particularly heavy influence of sodium has made some archaeologists draw the conclusion that the clay body was made up with salt water.

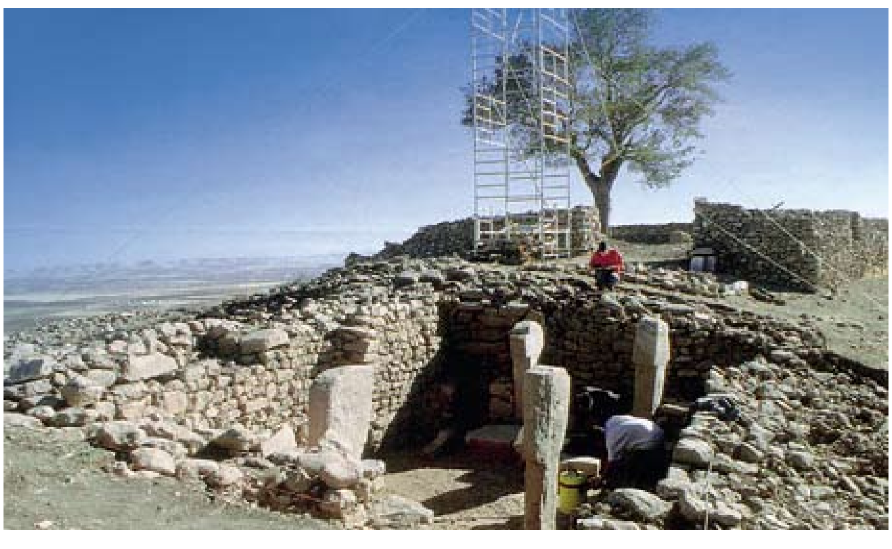
As regards firing, it is believed that two-chamber kilns, which were known in Mesopotamia at an early stage, were used. It is possible that straw and iron were used as fuel, as is still traditionally the case in Iraq. It is however certain, that firings took place in reduction.

Only in reduction is the very hard iron-aluminium spinel, hercynite ($FeO \cdot Al_2O_3$), formed. This does not necessarily mean that the hardness of the body derives from this material: even under oxidation in an electric kiln, a hard, impermeable body was created, in experiments to reproduce this ware, although this was only achieved at 1,100°C. The flux effect of the iron occurs at an earlier stage in reduction than in oxidation. The firing temperature can be determined by the mineral content of the body because up to 1,000°C mica and feldspar do not change, and above 850°C the calcium-magnesium silicate, diopside, and the calcium-aluminium silicate, anorthite are formed - if too a lot of lime is present, gehlenite is also formed. At around 950°C, mullite is formed in kaolin rich clays with the proportion increasing at higher temperatures. The higher the temperature, the more quartz and feldspar melts. Thin sections under the microscope reveal a fine grain in metallic ware (fig. 2). The white or grey inclusions are quartz and in part feldspar. There are also black particles of ores and mica. A firing temperature not significantly above 1,000°C reveals the remains of undecomposed feldspar and mica.

Metallic ware resembles in its appearance Chinese Yixing stoneware and jaspis porcelain by Böttger and the so-called "mulatto porcelain" from the 19th century. It is known that this consisted of:

1 pt. by weight Bavarian basalt
+2 pts Kaolin
+3 pts red clay

All of these European stonewares were fired at the high temperature of hard past porcelain.



below - first excavations at the temple complex of Göbekli Tepe from c. 9,000 B.C.

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Lost Knowledge Today

Part 2: Flame-proof bodies

Gustav Weiß

A second kind of ceramics found during excavations in northern Syria was used for the production of cooking pots and was extremely resistant to thermal shock. It is known as cooking pot ware and can be used for braziers in which a fire can be made, on the balcony or in the garden.

The reconstruction of this type of ceramics is also based on archaeometric measurements of the shards discovered. In this case, it is not only the chemical composition which is important; the interaction of the so-called matrix formed by the clay with the aggregates must also be considered. The thermal expansion of the matrix must be approximately equal to that of the calcite that is added to have a positive effect on the thermal shock resistance. But this can only be achieved if the crystals of calcite do decay through the loss of their carbon dioxide during firing, for which the ceramic must not remain in the kiln at above 700°C for an extended period in an oxidising firing. In reduction, the temperature can be higher. However, the firing temperature must be high enough so that the majority of the clay minerals can react with the other ingredients of the body so that a hard ceramic resistant to water can be achieved. Depending on the duration of the firing, this is the case between 500° and 600°C. This kind of cooking pot ware can be fired without constructing a kiln, in a bonfire firing or even when the thoroughly dried pot is well heated for the first time on the stove.

The average chemical analysis of this kind of ceramic corresponds to a blend of 100 parts by weight of red clay + 40 parts of calcite with a coarse sandy grain (corresponding to 71% clay and 29% calcite). In the reconstruction, the proportion of calcite can be adjusted according to plasticity; the samples tested showed a considerable latitude from 20 – 54% CaO (1 CaO is contained in 1.8 CaO_3 = calcite). The mixture quoted of 71% powdered red clay plus 29% coarse calcite corresponds to a CaO content of 22.7% in the chemical analysis. The plasticity can be improved with the addition of bentonite.

Thin section of a ceramic sample fired in the laboratory to 700°C. The material has enormous resistance to thermal shock. It is made from clay deposits from the lower Habur River near Tall Sheikh Hamad. Coarse calcite "grog" in a matrix of marl containing quartz. If the body were fired to over 700°C, the calcite($CaCO_3$) would decay to form calcium oxide (CaO) and carbon dioxide (CO_2). The resistance to thermal shock would be lost. The height of the picture corresponds to 1mm. Photo: G.Schneider.

Remarkably, there is a peasant potter in the Serbian village of Zlakusa near Uzice (200km south of Belgrade) who still produces ceramics of this type. It is said that this technique has been in use there for 300 years. Among the Indios too cooking pot ware of this type is still produced with the addition of coarse limestone. None of them ever thought of weighing out the ingredients.

Flame-proof bodies are also available from pottery suppliers here in Germany that have been developed for such purposes:

Body no. 2 sg 0-5 from Witgert. This flame proof ceramic can only be fired to 800 - 850°C.

Creaton bodies no. 592 and 599 from Goerg & Schneider with a low coefficient of thermal expansion. The lower the firing temperature, the lower the thermal expansion.

The body "Ceraflam 4010" from WBB Fuchs, which can be used for temperatures as high as 1300°C but should not be fired to above 1050°. It is recommended to light a fire in the finished piece with it standing on a bed of sand.

It is not possible to make a body flame proof simply by adding grog, particularly if the grog is fine. Coarse grog on the other hand prevents cracks spreading. This is a further beneficial effect of the coarse-grained calcite. Using coarse quartz as a "grog" on the other hand would have a detrimental effect because it expands every time it is heated to 500-600°C and contracts again on cooling, weakening the ceramic every time. An addition of 5% magnesite to a body has a different effect: magnesite only begins to form cordierite at above 1000°C, which has a very low thermal expansion and is used to make kiln shelves.

What kind of people were they in Mesopotamia in the 3rd millennium B.C? How did they live, what were their social norms and what did they believe?

The clay shards examined which date back to early history, originating in northern Syria and neighbouring Turkey, are from the third millennium B.C., the Early Dynastic period. This region, which is irrigated by the Euphrates and a network of tributaries, was culturally influenced by the great cities to the south. Here in the north, the villages were threatened by nomads. The few towns had grown to importance through trade. The region was known for its outstanding pottery tradition. As early as the first half of the 5th millennium B.C., ceramics from Tell Halaf, which is situated in the central part of the region, dominated the Aeneolithic culture in the whole of Mesopotamia. But after 4500 and until 3600 B.C., the style of ceramic art came from the south, from Obed near Ur, the home of Abraham. From this point on, the potter's wheel spread everywhere.

A characteristic feature of cultural achievement in comparison to megalith grave and Bell-Beaker culture in western Europe at that time were the towering temples or ziggurats (including the Tower of Babel) in sacred districts, which corresponded structurally to the Egyptian pyramids and were given overall architectural form. Each temple was dedicated to a specific god. Parallel to these, the splendid palaces were also architectural masterpieces.

The third millennium B.C. is full of interesting insights into life at that time, which is illuminated by written sources besides the archaeological monuments. Not only that these millennia followed the Neolithic revolution with property, fraud, quarrels with neighbours and war, the potter's wheel and mass production and finally in the third millennium the advent of cuneiform script, they also followed an evolution in consciousness. Awareness of experiencing the individual ego in its confrontation with surrounding nature had grown. Dependence on natural events had made way for a desire to achieve greater independence, expressed as belief by intellectually coming to terms with the unknowable. In primitive, prehistoric groups, according to Walter Nippold ("Individuum und Gesellschaft", Braunschweig 1960), those who formed cultures had a clearly defined sense of individuality. The phenomenon of personality brought with it the need to express the inexplicable power, the cosmic and earthly laws of creation and destruction in human terms. The developing consciousness of human dependence on this inexplicable power that transcended the visible world, and subordinating oneself to it in all situations in life from birth to death, were at the heart of religions from the very beginning. In a social context, religion prescribed individual behaviour,

4 cm steatite tablet from the sacred mountain of Göbekli Tepe with a carved tree and snake.

which was punished or rewarded by a god who was now imagined as a person. Besides the major gods, there were also minor ones who were asked to intercede with those of higher standing.

Hand in hand with this anthropomorphization, humankind felt dependent on and orientated towards the deity with regard both to their origins and to their fate. this was initially true only for kings, later for further sections of society. This led on the one hand to a belief in a life after death and on the other to a deification of kings and other individuals.

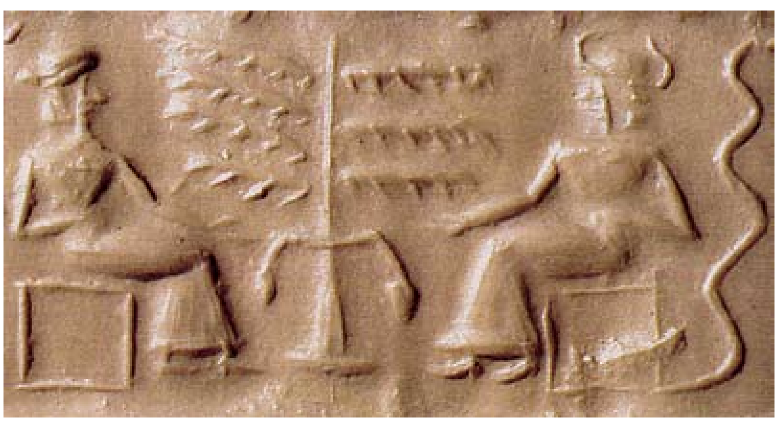
In this process of religious evolution that dominated thought a thousand years before Abraham and one thousand five hundred years before Moses, we find much that is familiar to us. Legends are preserved on cuneiform tablets, i.e. secular stories as well as myths referring to the hereafter that can be found again in the Bible.

As early as 8500 B.C., human figures in clay had appeared in large numbers, which were perhaps related to the legend that human beings had been created from clay. And Venus figures carved from bones may have led to the legend that woman was created from Adam's rib. In the Sumerian language, "ti" means both rib and life. Trees and snakes may well have had a mythical significance too. They are carved on a steatite tablet found at the sacred mountain site of Göbekli Tepe, and a winged being resembling an angel is to be found on one of the roulettes invented in the 4th millennium. On another roulette, a man and a woman are shown beside a seven-branched tree of life. Behind the woman, a snake is coiled.

In the third millennium, the scribes wrote down the sagas of the gods and heroes which were recited by singers in the temples and at court, in the Early Dynastic period accompanied by the harp, the lyre or the

Impression of a 3500 year-old roulette depicting a winged being.

below -
Impression of a 4000 year-old roulette depicting a hero and heroine; behind the woman, there is a snake (British Museum London).



wooden flute (Hermann Müller-Karpe: Handbuch der Vorgeschichte, vol. III. Munich: C.H.Beck 1974). A learned scribe at the court of King Solomon is said to have written down the cultural memory of humanity in 950 B.C.

Humanity, which was created to save the gods the labour of digging rivers and canals, had multiplied to such an extent that they disturbed the sleep of the highest deity, Enlil. He therefore wanted to visit a flood on them. The lower ranking deity Enki tipped off the hero of the story of the deluge, telling him to build a ship. After the flood, the gods agreed on the terms under which humanity would be allowed to survive, particularly that among humans, fertile as well as barren women should exist and also that there should be a demon to steal newborn babies from the mother's womb.

These cuneiform texts are from around 2900 B.C. They contain expressions of social ethics that were to reappear in the Law of Moses in c. 1225 B.C., when his society got out of hand and danced around the golden calf.

According to the law of Enlil, the sun god, who saw and supervised everything, it was considered a sin to repress the weak, not to release prisoners, to utter falsehoods, to persecute the righteous, to dishonourably approach the wife of another, to commit fornication or adultery, to study evil, or to be guilty of pride or fraud. For sinners, the punishment of god was expected, and for the righteous, a long and happy life. For the hereafter there was a belief in a final judgement.

Like in the story of Moses, the mother of Sargon, the king of Akkad, who ruled there in the 3rd millennium, placed him as an infant in a rush basket coated with pitch in the waters of the Euphrates. A water carrier found him, and after the king fell out of favour with Enlil, he himself became king. As a great conqueror who was "victorious in thirty-four campaigns", he was considered the ruler of the world.

Just as Jahwe instructed Moses to lead the People of Israel to the Promised Land, the kings of the city states were instructed by their gods to go to war. In c. 1290 B.C., king Lugalzagesi from the southern Mesopotamian city of Umma justified his raiding with instructions from the deity, Enlil, that all of the countries from the Persian Gulf along the Tigris and the Euphrates to the Mediterranean should belong to him.

Cuneiform tablet from the late 2nd millennium B.C. with the Sumerian epic of king Gilgamesh of Uruk, who lived in the 3rd millennium B.C.

The most important work of Babylonian literature was the Gilgamesh epic, written in cuneiform on tablets of clay, a saga of king Gilgamesh, ruler of the city of Uruk, who live in around 2600 B.C. and was worshipped as a god. In this epic, the following story is contained, which is characteristic of the ideas of the hereafter and the religious world in which the people of the third milennium B.C. lived:

The Sumerian goddess of Uruk, Innana (in Babylon, "Ishtar"), owned a tree from which she wanted to have a chair and a bed made. But the tree could not be felled for evil demons had taken possession of it. Gilgamesh came to the assistance of the goddess, drove away the demons, felled the tree and as a reward he was given a magic wand made from its roots, which however fell down, "into the earth, into the underworld". Gilgamesh's servant Enkidu offered to retrieve it for his lord. Gilgamesh gave him advice for his journey into the underworld. "You should not put on your clean garments: they (the dead) would recognise immediately that you are alien. You should not anoint yourself with fine oil from a bowl: they would surround you at its scent. You should not hurl throwing sticks in the nether world: those struck down by the throwing sticks would surround you. You should not not hold a cornel-wood stick in your hand: the spirits would feel insulted by you. You should not put sandals on your feet. You should not shout in the nether world. You should not kiss your beloved wife. You should not hit your wife even if you are annoyed with her … The outcry aroused would detain you in the nether world." Enkidu ignored all this advice and was thus "detained in the nether world". As he could no longer leave the underworld, Gilgamesh grieved for him, and he turned to Enlil, the god of the land, Sin, the god of the moon, and Ea, the god of water, for help. The first two were silent. But Ea ordered a hole to be made in the earth, so that his servant could be brought up "with his breeze from the nether world". They hugged and kissed and sat down together. Enkidu told his friend of the order of the nether world, about which the living would weep. "My body, which your heart rejoiced to touch, worms infest it like an old garment; my body is disfigured by decay, it is full of dust." Then Enkidu told of all the deceased he knew and saw in the underworld, where one appeared like a companion of the gods, full of goodness, another, whose body had been thrown on the plain, was a spirit that "roamed the underworld".

Even when Gilgamesh was ruler of Uruk, the potters in this region, like everywhere else in the Middle East, knew how to make cooking pots from a calcareous clay with additions of coarsely ground limestone, which could even be placed unfired on a naked flame. This invention was lost in the following period, just like the extremely hard ceramic material that could not survive the emergence of the age of metal.

Translator's note

In the first part of this series, I regrettably translated Gustav Weiß' text to say that metallic ware was fired with straw and iron. This is of course nonsense. The correct version should read:

"As regards firing, it is believed that two-chamber kilns, which were known in Mesopotamia at an early stage, were used. It is possible that straw and **oil** were used as fuel, as is still traditionally the case in Iraq."

My profound apologies to readers and author alike! *David Erban*

Lost Knowledge Today

Part 3: Glazes with water-soluble substances and what has become of them

Gustav Weiß and Rolf Wihr

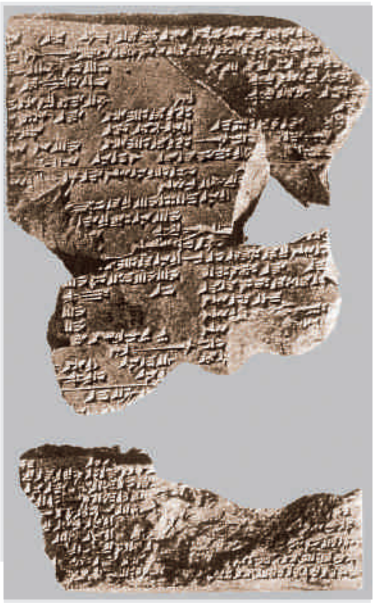
The following piece began with the interpretation by Rolf Wihr of a recipe in cuneiform script, which he actually only wanted to pass on as a practical procedure. However, the recipe pointed to evidence that led to new findings on the origins of glazes.

The ball was set in motion by Rolf Wihr visiting the Pergamon Museum in Berlin, as a consequence of which he discovered the translation of a glass recipe, from the cuneiform library of Assurbanipal in Nineveh, in A. Leo Oppenheim's book, "Glass and Glass Making in Ancient Mesopotamia". It consisted of

10 parts immanaku stone
15 parts aga plant ash
1 $^{2}/_{3}$ parts white plant

Rolf Wihr interpreted this as a glaze recipe consisting of 10 parts = 40% glass former (probably quartz) and 15 parts = 60% of an initially indeterminate vegetable ash containing a flux. It was the "white plant" that seized his attention. In Oppenheim (p. 75) he found that the sap of the "white plant", i.e. the poplar tree, was used medicinally in the ancient Middle East. Its mention in a recipe for glass was inexplicable even to Oppenheim, one of the leading experts in the field of glass. But for Fritz Wihr, it was clear from the start that it could only be a glaze recipe. And he related the use of the vegetable gum with the solubility of the alkalis in the ash because their absorption by the clay body could thus be prevented. This insight alone would have sufficed to give contemporary potters the practical hint that a frit is dispensable by making up a glaze of water soluble substances not with pure water but vegetable gum dissolved in water. And he undertook a series of experiments in which he discovered that gum arabic is suitable for this purpose but not tragacanth.

However, historically things had developed quite differently; it was not an attempt to avoid using a frit. Rolf Wihr's assumption that this might indeed be a glaze had far-reaching



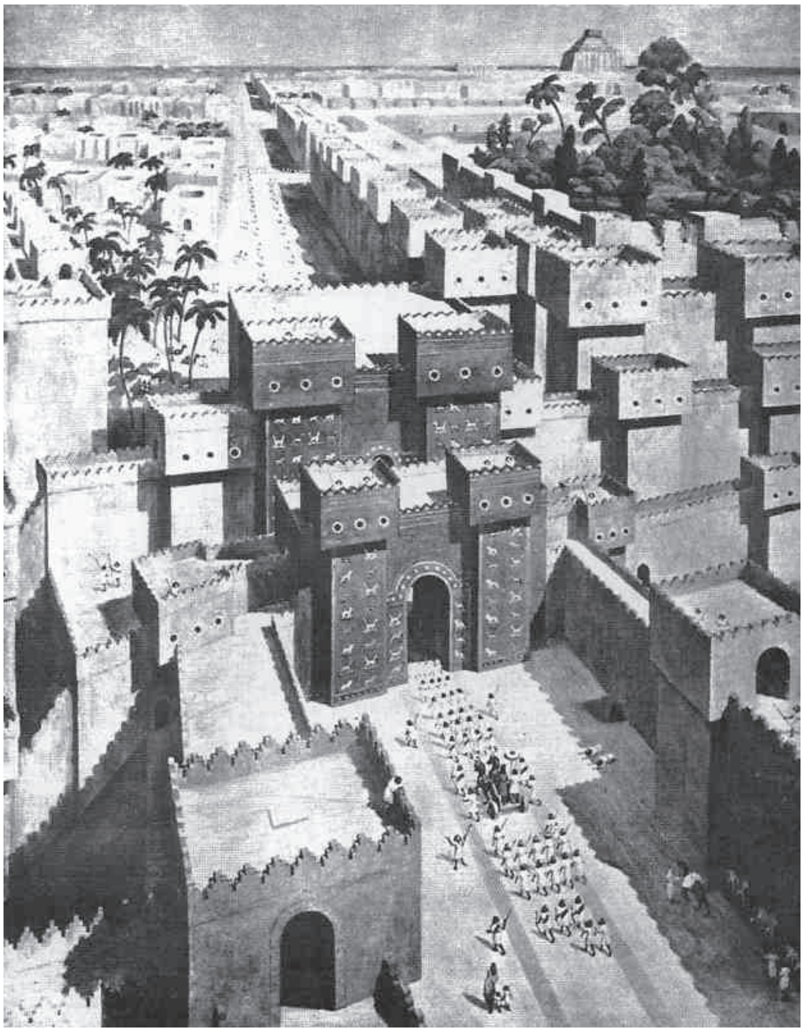
Cuneiform tablet with the glaze recipe from Nineveh, in which a white ash is mentioned. After Oppenheim.

consequences, beginning with the linking of this glaze with glazes made shortly afterwards in Baghdad for the Ishtar Gate and other structures. Nobody had ever done this before because the five recipes in Nineveh and more in Babylon and Bogazköj were thought to be glass recipes, which in fact they all were. At that time, 600 years before the invention of glass that could be freely shaped in Syria, glazes were not much different from glass. Glaze was a variant from the field of glass technology and had nothing to do with pottery.

The ingredients in the cuneiform recipe

In the chapter of Oppenheim's book on "The Chemical Interpretation of Texts", Robert H. Brill made a series of assumptions as to which raw materials could be meant. He analysed 15 plant ashes and 20 varieties of Mesopotamian glass. He also interpreted the two-stage production procedure for the glass as a sintering process at low temperature in which a frit is created that in the second stage, ground to a powder, is melted at a higher temperature in a crucible. And he smelted the glasses, finding that they melted at 1050 – 1100 °C and could be used from 700 – 1000°C. As far as the glaze is concerned, that does not leave many open questions. Nevertheless, one wonders whether the two-stage system only served to allow the glass to be coloured in the second stage. It should not be overlooked that the mixture absorbs energy which – the faster it is cooled or quenched – is retained, and that his energy contributes to a reduction in the energy requirement for the smelting in the second stage. The addition of colouring agents leads to a further reduction in temperature. Copper, cobalt, manganese and iron are all fluxes. The colouring agents often contain lead impurities. The frits from the first stage could just as easily be stuck to the clay tiles as a powder as they could be made to melt in a crucible in the second. According to this assumption, there is no need to search for any specific glaze recipe, and Brill's glass analyses can be used for further research. This led to the conclusion that zuku glass from the cuneiform tablet was largely identical to the assumed Babylonian glazes, if suitable ingredients are mixed in a ratio of 40:60.

For the ingredient with the glass forming characteristics Brill quotes



Reconstruction of Babylon with the Ishtar Gate. The smaller outer gate is in the Pergamon Museum, Berlin. In the background, right, the hanging gardens are visible and on the horizon, the Tower of Babel. After Seton Lloyd: "Building in Brick and Stone" in Charles Singer et al. (Ed.): "A History of Technology", Vol. 1, 3rd edn., Oxford: Clarendon 1956.

the cuneiform text which describes the material as "like river silt with pebbles". The sand at the mouth of the Belus River in Syria (today known as the Na'amat River) was full of shells, which may have created this impression. It was well-known for centuries. R. Campbell Thompson ("A Dictionary of Assyrian Chemistry and Geology", Oxford 1936) suggests that the Sumerians may well have used this river sand several thousand years B.C.

With the computer glaze program a comparison with zuku glass shows that a glaze batch using the shells would be far too rich in lime, thus making a dull-looking glaze. This implies that the sand alone without shells was used.

Oppenheim assumes that the plant in the cuneiform recipe is a type of glasswort (salicornia), in which he follows Thompson ("On the Chemistry of the Ancient Assyrians", Merton College, Oxford, n. d.). It had to be a sodium plant as the finished glazes show little or no potassium content. Halophytes – plants that thrive on salty soils – store sodium and chlorine from the soil in their cells. A number of plants would be usable in the cuneiform recipe: of the goosefoot species (chenopodium) especially haloxylon salicornicum from the Jezazi Desert in Iraq and the tamarisk, tamarix meyerii from the banks of the Belus River.

R. H. Brill analysed these and other varieties of salicornia and published the results in 1999. It must be taken into account that the components of the ashes of these plants are involved in glass forming as oxides, whereas in the plant they are present as chlorides or sulphates. Chlorine and sulphur would spoil the quality of the glass and must be driven off before the glaze melts. Haloxylon has 38% of such volatile components, the tamarisk 43% so that of the 60 parts of ash in the recipe only 38 or 34% respectively are involved in the glass forming process and appear in the chemical analyses of the final glaze. An examination with the computer programme shows that the haloxylon ash mixed 40:60 would give the glaze too little silica for it to be comparable to zuku glass. Thus in all probability, tamarisk from the Belus River will have been used.

Stefan Fitz, who analysed the colours of the glazes at the Pergamon Museum, demonstrated among other things that the lions' manes matched in outline, but that in the emission spectrochemical analysis, the glazes revealed clear differences in the secondary materials. This indicates materials with various impurities, i.e. that they are from differing locations. Analyses of the glazes also demonstrated remarkably that as an opacifier not tin had been used as was long assumed but antimony. Antimony ore is rarely pure, however. With lead impurities it produces opaque yellow glazes (Naples yellow) as lead antimonate stains yellow. Lead antimonate of this kind with copper and small quantities of cobalt produced opaque green glazes. From lead-free antimony ore, calcium antimonate could be obtained that produced an opaque white. With copper and cobalt, this produced a pale blue to turquoise opaque glaze. That firings for certain colours had to be in reduction is proved by iron green and copper red, where according to Brill, lead and traces of tin and antimony were also present.

The production process

With regard to the way the mixture of raw materials was prepared and used, various pieces of evidence indicate that once a procedure had been developed, it was adhered to for many centuries and it spread over a wide area. In the book of stones by Abulqâsim (published in Kashan, Persia in 1301 A.D., in the translation by Ritter, Ruska, Sarre and Winderlich), it states that glaze batches made up of one part "sugar stone" (quartz) and one and a half parts of ash from Tebriz or Baghdad, referred to as potash, (i.e. in a ratio of 40:60) were "roasted" for eight hours in a metal pan, continually stirred with an iron spoon, and then quenched in a pit of water. The correct temperature is indicated by the powder forming a slag – 840°C. The kiln atmosphere in such firings alternated between oxidation and reduction with the stoking (clear flame = oxidation, smoky flame = reduction), which is important for the decay of the sulphur compounds. The resultant product was powdered on a long, narrow rubbing stone and "applied with gum". A. Houtum-Schindler describes a pottery in

Qamsar thus in "Eastern Persian Iraq", London 1897, p. 115 f.

Aside from this method of preparing glaze borrowed from glass technology, applying slips of the terra sigillata type led to the development of applying water-based glazes. With the disappearance of casting glass over sand moulds and the advent of freely formed glass in the last century B.C., glazes began to develop separate from glass, following the ceramic terra sigillata tradition, now in the form of lead glazes. On the clay body, the lead glazes did not have so many hairline cracks as their alkaline forerunners. Lead oxide in a glaze only produces a third of the thermal expansion of the alkaline glazes made with sodium oxide. Until the mid-twentieth century, lead glazes were the norm. The dominant producers of terra sigillata were not interested in glazes, however. They could not become established in Rome but they did in Byzantium. An influence from China then followed - a white glaze said to resemble porcelain. For this, the potters from Baghdad under the 9th century khalifs remembered the old two-stageprocess described above, this time using tin and lead in a 2:1 ratio, as it was later described in the book of stones. The resultant product was then added as a pigment to the glaze batch, a procedure that survived in the West until the 20th century for the production of faience glazes.

The faience of the age of the manufacturies was followed in Europe by the earthenware of the industrial age. Lead borax glazes were typical of this type of ware, which consisted mainly of frits. The frit was now of a more complex composition: it was heated until of very low viscosity and then quenched in water. Ten percent kaolin or white "glaze clay" were added to the 90% frit at the end of the grinding process in the ball mill to keep the powder in suspension in the water and to stick it to the clay body. This was an entirely different technology from in ancient times. But the complex experience that led to this procedure lives on today and is part of the tradition.

Attempts at Reconstruction

To reconstruct the glazes of the Ishtar Gate and the Processional Way, the two-stage technique must be used if the temperatures are to be determined. As a reconstruction today is only possible with pure raw materials containing no chlorine or sulphur, 40 parts Belus sand must now be calculated with only 34 parts tamarisk ash instead of 60. That makes a glaze consisting of

32.61 calcinated soda
4.66 potash
9.93 chalk
5.37 magnesite, caustic
4.63 kaolin
0.56 iron oxide
42.24 quartz

This mixture was calcinated in this experiment to 840°C in an electric kiln with a 30-minute soak, a part being allowed to cool and a part being quenched in water, crushed, mixed with 2% copper oxide and cobalt oxide respectively, applied to a raw yellow firing clay containing 30% lime ($CaCO_3$ corresponding to 9% CaO, in analogy to clays in the Middle East) with 4.6% gum arabic and then fired in a gradient kiln.

It is remarkable that in the cuneiform text, referring to zuku glass, it is stated that to obtain copper oxide, pure metallic copper must be melted. Theoretically this means 1083°C, in practice somewhat more. The melting point of copper could have been a guideline for the firing, just as the melting point of silver was used to indicate a firing to 960°C for pottery glazes. This is the principle upon which Hermann Seger based his pyrometric cones.

A clear influence of the cooling process became visible in the gradient kiln: the following maturing temperatures were found for the material quenched in water: a) without a soaking period 1100°C, b) after soaking for 30 minutes 1070°C, c) after 1 hour's soak, 1030°C. This will have corresponded to the facts, if we consider that the white glazes opacified with calcium antimonate contain diantimonate according to Stefan Fitz's studies, which is only stable to 1050°C. To melt the mixture to form glass in a crucible the viscosity must be lower and the temperature correspondingly higher. This is why the melting point of copper may be assumed to be appropriate, i.e. 1080°C. This is especially the case as calcium pyroantimonate, which is stable at high temperatures, is present in the glass. The soaking times may well have been even longer: in a fragment of fired glaze that Eva Marie Schulz reheated, so much energy was contained that it melted at 630 and 650°C. But this is not the production temperature. One reason why the soak matches practical conditions in a woodfiring is that it is difficult to reach higher temperatures in spite of continued stoking, especially if the kiln is poorly insulated.

The glaze made from the heated and quenched ingredients with 2% copper oxide and 0.1% cobalt oxide after the cuneiform recipe, applied with gum arabic to a raw, lime-rich body fired to 1030°C and soaked for 1 hour. The differing circumstances that stem from using an electric kiln and pure ingredients have been taken into consideration as far as possible. In such archaeological experiments, there is no guarantee that the actual processes from the past have been reproduced.

In recent years, many scientists have gone into the secrets of these first glazes from Mesopotamia. They have reached partly contradictory conclusions which are now being resolved by resorting to ceramic experience.

Independently of this, Rolf Wihr has shown through his research mentioned at the start that glazes with water-soluble fluxes do not need to be fritted because they can be applied with gum (especially gum arabic), and applied to the raw pots, achieving very beautiful results. In this way, it is possible to avoid alkaline Egyptian paste glazes settling rock hard, which makes it difficult to work with glazes of this type as a glaze slop. This method is appropriate if a new glaze is to be applied on top of a fired one.

In the field of art and crafts, this technique clearly offers obvious benefits and attractions, because for one thing newly developed glazes can be tested without the need to frit them. For practical work, it goes without saying that this technique cannot be recommended for production in series because of the inherent risks. Classic frit glazes cannot be avoided here.

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