The Oseberg Find, its conservation and present state

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Several remains of ships from prehistoric times have been found in Norway in the last 200 years, and those which contained wood in such a state that it has been possible to conserve parts of it were found in mounds of a special construction. Peat, moss and clay had been used in building these mounds.

The most important find of a viking ship was made in 1904 on the Oseberg Farm in the parish of Slagen, County of Vestfold, on the western coast of the Oslo fjord.

The other viking ship which has been preserved — the Gokstad Ship — was found in 1880 about 50 km to the south of Oseberg.

A third ship, the Tune Ship, was found in 1867, also near the coast of the Oslo fjord, but on the eastern side.

The Oseberg Ship was the first of the viking ships to be excavated by more-or-less modern methods, using exact measuring methods and photographs and laying special stress on conservation methods.

The mound in which the Oseberg Ship was found had originally been imposing in appearance, with a cross-section of 40 m and a height of about 6 m; however, when the find was made it had sunk considerably. The distance from the sea is now about 4 km and the height above sea-level 15 m, but it was 11.5 m at the time of the burial. The ship rested in an excavated foundation-trough in the blue clay.

It was covered by an enormous stone cairn, and over this the mound of peat, on which grass subsequently grew, had been built. The peat had been taken from the original surface near the mound and thus contained sandy clay. It has been calculated that the peat used must have covered 3.3 hectares. It consisted of tightly-packed roots of carex with considerable amounts of acroladium cuspidatum (L) mitten.

The figure shows how the weight of the peat, clay and stones had pressed the original surface about 3.5 m below its level at the time of the burial. The ship is 21.6 m long and 5.1 m wide at its widest part. Inside the ship there had been built a burial-chamber constructed of timber. The original height of this hut was 3.1 m over the old surface but it had sunk to 2.1 m below this surface.

The final collapse of the burial chamber did a lot of damage to the most costly objects which had been placed there, when the bodies of two women were buried. The larger part of these bodies and probably all articles of gold and silver had been removed by robbers not very long after the burial.

The mechanism of the serious deformation of the original surface was not understood at the time of the excavation. We now know that it was caused by the consolidation of the clay, which is present to a depth of more than 30 m in this area. The settlement is not only a function of the stress due to the weight of the mound, but also a result of the thickness of the underlying clay and its compressibility, which in this cas was very high; it is caused by the pressing-out of the pore water. Thus the original surface was pressed to a maximum of 3.5 m below its original position.

The mound was calculated to weigh a total of 5750 tons, with a maximum weight of about 8 tons per square metre. Owing in particular to the burial chamber, the weight was unevenly distributed, and this was the reason for the great damage done to the ship and the finds. The keel was broken just near the walls of the chamber because of the lesser pressure inside the chamber; this made the keel look as though it had been pressed upwards.

The bottom of the ship was pressed down into the ground water and in some cases into the clay.

Objects found in the burial chamber and in the place where the robbers had broken into the grave before the collapse of the chamber were directly covered with soil. But the greatest part of the find lay between the stones of the cairn. In excavating, this was a great advantage. After the removal of the stones the finds were visible at once and one had a very useful general view.

The special conditions in the mound had led to the preservation of all kinds of organic material, e.g. wood, grain and flour, plants and fruit, wool, silk and vegetable fibre textiles (some of them dyed), painted wood, several animal carcasses (which had retained their smell), leather and metals.

The presence of two well-defined minerals, viz. native sulphur and red oxide of iron γ-lepidochrokite, Fe O(OH), which had formed in the mound on the same textile, has made it possible to state the Eh/pH conditions in the mound within very narrow limits.

The sulphur had probably formed by bacterial reduction of the SO_4 ++ ions present in the ground water. The post-glacial marine clays

of the type met with at Oseberg have a pore water with nearly the same sulphate content as sea-water (i.e. 2.65 kg per cubic metre of water). Under bacterial activity this may be reduced to sulphide ions, which again, by mild oxidation, may give native sulphur. Similar formation of sulphur is known in lakes

The stability of sulphur itself is therefore restricted to a narrow triangle in the Eh/pH diagram.

Figure 4 shows the Eh/pH diagram of the sulphur species.

Above the triangle it is oxidized to sulphate; below it, we have reduction to sulphite. Now the borderline between tri- and bi-valent iron hydroxydes follows very close below the upper line of the sulphur stability triangle. Thus the Eh/pH limits in the mound are fixed, as shown in figure 5.

At pH 8 this corresponds to Eh + 130 millivolts.

At pH 4 it will be Eh + 10 millivolts.

It is of course difficult to say when the finds came under ground water owing to the slow compression of the mound, but it seems unlikely that they could have stayed dry for long periods of time.

The annual average temperature of the ground at its present level in this part of the country is about 7° C and it never exceeds 12° C.

Frost cannot penetrate to a level below 1.5 m in this area, so that the material has never been frozen.

Many colleagues have come to Oslo to study the conservation of the viking ships, but I do not think they have learned much from them about conservation. Because of the unusually favourable conditions — which I have described at some length — the Oseberg Ship itself did not give rise to the most serious of the conservation problems met with in connection with the find as a whole. The same can to some extent be said about the other two viking ships in Oslo; in these cases the ships had been filled with clay at the burial and variations in deformation were less, probably because the clay underneath was not so deep. The parts of the ships which were above the clay had rotted away.

In all cases the ships had been built of oak with minor features made of pine.

The Oseberg Ship had been dug 0.75 m into the clay, the Gokstad Ship 1.25 m, and the Tune Ship is described as being placed on a clay surface from which the earth had been removed. The wood in the ships was so well preserved that it was possible to steam the parts and bend them back to their original shape.

The Oseberg Ship was taken to pieces and transported to Oslo by boat. It was stored for nearly two years before means of restoring it could be found.

The only treatment which the ship had received at the place of excavation was a coating with creosote and linseed oil. This impregnation was continued until the wood seemed saturated. The treatment was very successful on the oak, but not so much so on the oars, the mast and other parts of the ship which were made of pine. A mat lacquer was used to protect the surface.

The restoration was completed in nine months and very little new wood was used.

Figure 6 shows the rebuilding of the Oseberg Ship.

Some of the rivets were replaced by new ones; already at the time of restoration in 1907 it was noticed that the new rivets corroded more rapidly than the old ones. The presence of phosphates from the bones of the many animals may have given the iron a surface protection. No special treatment was given to the iron, apart from the procedure used early in this century, which consisted in boiling it in paraffin. No rust has been observed so far.

The Oseberg Ship was subsequently exhibited, as were the other ships, for nine years in a shed near the University Museum in Oslo. In 1926 it was transported to a new museum at Bygdöy, then just outside the town.

Figure 7 shows the Oseberg Ship being moved, in 1926.

During the last war the ships were covered with sandbags and the museum was closed and left unheated. Since 1952 a hydrothermograph has recorded the relative humidity in the museum. As usual, the RH becomes rather low in the winter, though seldom lower than 40 %. In May it rises slowly and can reach nearly 90 % in wet summers. In October when heating has been resumed it goes down again.

It would not seem that these fairly large variations have done any harm to the ships. Accurate measurements of any possible movements occuring in them have shown them apparently to be stabilized. In 1956 they received a coating of linseed oil in white spirit. The greatest difficulty now is to keep them clean. Nearly 200,000 people visit the museum every year, mostly in the summer months. They bring with them a great deal of dust. This dust consists mostly of textile fibres, but also of very fine quartz particles rubbed off the sandstone floor by the grit brought in on visitors' shoes. The architects do not allow impregnation of the floor, because this would change its colour; the ships thus have to be vacuum-cleaned, though as seldom as possible. A scaffolding has to be erected for the purpose, and although every care is taken by the trained personnel, there is risk of damage to parts made of woods other than oak.

The ships contained a great number of objects. Only those from the Oseberg Ship have received systematic conservation treatment.

After removal from the ship the wooden articles were packed in moss and sacking and transported in a wet state to the museum. The woods used were oak, ash, birch, yew, pine, spruce-maple and beech; the order given here is the descending order of hardness established by the excavators. The objects were stored in water containing a sublimate until they could be treated.

Before the conservation treatment started, a drawing was made of each object and in some cases wooden copies were made or casts taken. The planning of the conservation work was greatly influenced by experience gained from the material found in the Gokstad Ship, since objects from this had been drawn at the time of discovery and had been compared with the originals twenty-five years later.

The necessity of finding new methods was obvious at that time, and already in 1904 the professor in charge of the find, Gabriel Gustafson, visited Denmark, Germany and Switzerland to study methods of conservation for waterlogged wood. As a result of his trip, it was decided to use the alum method. The objects made of oak, ash and yew were mostly very well preserved and could be steamed back to shape and coated with lacquer. The majority of the objects, however, had to be impregnated in baths of saturated solutions of potassium-aluminium sulphate. Experiments were carried out to determine the concentrations of the alum solution, the duration of the treatment and the temperature of the bath best suited to the different woods and the different states of preservation in which they happened to be. The concentration of the solution decided on was higher than that used elsewhere at that time. It contained 209.3 parts of alum in 100 parts of water at 90° C. For very soft wood higher concentrations were used and treatment was longer. This is the description given in the publication of the find and no further details are known of the actual concentrations used.

It was found that the best result came from " cooking " the wood in the most highly-concentrated solutions for 12 to 30 hours at temperatures between 80° and 90° C; this was the procedure used for the majority of the objects. Sometimes the treatment had to be repeated and temperatures up to 100° C were also occasionally used.

From these experiments it was concluded that with the alum treatment the wood kept its shape completely.

The wood is described as having a faint violet colour and being very brittle and powdery when it came out of the bath. The impregnation was carried out in copper vessels heated by gas burners and went on continually day and night for some years.

The assistant in charge of these operations, Mr. Paul Johannessen, acquired an exact knowledge of how to treat the different kinds of wood in their various states of conservation.

The product effectively used must, roughly speaking, have been a solution of alum in its water of crystallization. The wood was washed with hot water as soon as it came out of the alum solution, to avoid formation of crystals on the surface. The pieces were then weighed and dried in the air until constant weight was obtained. One piece from the animal head on one of the sledges, after being " cooked " for 24 hours, lost 41 % of its weight in 9 days. The loss of weight the last day was 11 gms., and it was then coated with linseed oil on one side only, to allow for further evaporation of water. This treatment was continued about every other day. After 23 days the loss of weight per day was 1 gm. Some pieces had to be dried for 3 months to obtain constant weight.

At the beginning, before the importance of very highly concentrated solutions was discovered, some cracking of the wood was experienced and it was also found that oak tended to crack and could not be treated in this way.

The impregnation with linseed oil was continued over the whole surface until a bright film formed, which was taken as a proof of saturation. As a surface-protection a matt lacquer was used generally after assemblage of the pieces.

Restoration of the objects from the many fragments recovered was no small task. The objects not treated with alum could be restored by joining the pieces together with ordinary joiner's glue, and then painting them with linseed oil and lacquer. For the wood treated with alum a different kind of glue was used; this was made of 5 parts of gypsum and 1 part of dextrin, with pigments added to give the colour of the wood. This same substance was used to replace missing parts where this was considered absolutely necessary.

Figure 8 shows pieces of one of the sleigh runners and part of the front of a sledge before preparation. In all, the sledge consisted of 1068 fragments.

Figure 9 shows the sledge restored.

I have gone into all this detail in describing the procedure used 50 years ago because it seems that this case is one of the few where the alum method has been completely successful. In September 1939 the objects exhibited were taken down to the basement for protection. They were not removed from there until 1954, because the exhibition rooms had meanwhile been disposed of for other purposes. This situation finally led the Ministry to provide the fund for the building of a new wing for the Find, as part of the Viking Ship Museum at Bygdöy.

In the period between 1912 and 1939 the Find had been exhibited in showcases in rooms with central heating and no provision had been made to control humidity. In 1939 a hydrothermograph was placed in the basement where the objects were, and it was found possible to keep the

relative humidity between 40 and 70 % by such simple means as throwing water on the floor and using $CaCl_2$ and silicagel.

Some bombs which fell in the neighbourhood caused damage to the brittle wood which had undergone alum treatment, making unsupported pieces fall to the floor and naturally be smashed to pieces. Otherwise the only change which could be observed by comparison with the photos was a kind of " bloom " on many of the objects, formed of very small white crystals.

When in 1954 the find was subjected to a complete new conservation treatment before removal to the new wing at Bygdöy, the white powder was removed, together with the dust and dirt, by brushing, and also by treatment with ethanol and white spirit. To seal off the humidity present in the atmosphere, the objects were given a new coating of a lacquer on an oil base. This was necessary owing to the fact that the wood had previously been impregnated with oil and none of the lacquers had adhered satisfactorily.

Very few substances, if any, whether organic or inorganic, are impervious to water-vapour; the oil lacquer was chosen because microcrystalline wax was found to give the objects a still more unnatural look. To improve the appearance of the surface, left glossy by the oil lacquer, a thin layer of a dull, matt lacquer was subsequently applied.

The Find was transported to Bygdöy in Februari 1957, in special lead-weighted vans, under police escort, at 10 o'clock in the morning when traffic was known to be at a minimum. In their new premises the objects were put into the show-cases which I have described in my paper published in Conservation 1959. The relative humidity in the cases is controlled by saturated solutions of $Ca(NO_3)$ at 58 % RH.

For the past twelve years this arrangement has worked satisfactorily, the only flaw discovered lying in the choice of the trays to contain the salt solutions, which were made from perspex sheets glued together. In two cases the gluing came apart and the solution flowed out.

4 samples of the wood from the Oseberg Find have been analysed by the Research Institute of the Paper Industry, Oslo. The results of the analysis are given in Table N° 1. The following samples were analysed :

1. Oak from the ship (X-ray diagram, fig. 3).
2. Beech, N° 288, treated with alum and coated with linseed oil on the surface. The alum and oil were partly removed (X-ray diagram, fig. 5).
3. Pine, N° 289, from a bed, treated with linseed oil. The oil-layer was cut away.
4. Maple from the waggon. Impregnated with alum all through. The alum was partially leached out with hot water (X-ray diagram, fig. 3).

TABLE NO. 1

Analyses of acetone-extracted material, calculated in % of oven-dried original material

Sample number	Extracted with acetone in % of oven-dry original material	Oven-dried weight %	Lignin	Ash	Glucose	Xylose	Copper number	Undetermined rest, organic material ca %	Dry volume-weights (dry weight - dry volume) g/cm^3
1	2,7	92,44	29,4	3,2	46,6	15,8	6,6	2	0,736
2	6,6	70,60	33,3	21,8	spor	0	3,3	38	0,212
3	9,7	71,76	41,0	17,6	5,2	0	5,9	27	0,213
4	7,7	69,59	26,7	47,3	0	0	7,8	18	0,461

Methods of analysis:

Extractable by acetone and lignin: CCA 5.

Ash in pulp: SCAN-C6:62.

Glucose and Xylose: Thin-layer chromatography.

Copper number: SCAN - C 22: 66.

Dry volume weight: The outer part of the material was removed, the wood was paraffined, and the volume-weight determined by displacement of water. Analysed by the Research Institute of the Paper Industry.

The undetermined rest is probably mostly holo-cellulose which has been broken down, so that it can be neither shown nor determined by thin-layer chromatography.

The high ash-content and the low content of oven-dry material (103° C) for samples 2, 3 and 4 indicate that the alum KAL $(SO_4)_2$. 12 H_2O) has not been completely removed, but already at 64° C loses its 9 molecules of water of crystallization.

Sample 1 from the ship gave the X-ray pattern of fresh wood and had the highest dry-volume weight and the highest glucose-xylose content in the acetone extract.

The state of *present-day preservation of the oak from the ship* is further demonstrated by the X-ray diffraction diagrams of the wood parallel to the annular rings (fig. 4).

The regular pattern of rings and dots indicates polycrystalline structure oriented with one axis of the little crystals parallel or nearly parallel to the wood fibre.

Alum-treated beech from the waggon was boiled in water to leach the salt, and an X-ray diagram was made (fig. 3).

Figure 3 shows that some of the alum is left and that the wood has lost its oriented crystalline state. For comparison, an X-ray diagram of fresh maple is shown, together with maple from one of the carved animal heads, treated with trimethyl-carbinol (fig. 4).

Many of the objects in the find were so badly damaged that no attempt was made to restore them. These pieces were treated with alum for a short time, so that the impregnation reached only a few millimetres below the surface, and then oiled. This treatment resulted in a great deal of shrinkage and warping.

Here there is random orientation and probably smaller crystals and variations of unit cell-dimensions, indicated by broadening of the lines.

The wood treated with alum has kept its structure, even if the material in the cell-walls has degenerated.

An X-ray diagram of the piece of beech from the waggon when ground to powder proved the crystalline phase to be alum (KAL $(SO_4)_2$. 12 H_2O) with contaminations less than 5 %.

The crystals were quite clear and dissolved in water without any observable residue.

On the surface, which had been oiled and lacquered in 1905, very small crystals had formed and were identified as alum.

In the course of the new conservation treatment in 1954-'56, these crystals were removed and "Epolakk" was applied; this lacquer is an epoxy ester of the fatty acids in linseed oil. The very bright surface resulting from this treatment was dulled with "Mattolakk" 565 A.

All the objects from the Find which were on show were treated in the way described. Two or three years after treatment it was a disappointment to find that a white, fine powder containing bright crystals had formed on the surface of nearly every object in the exhibition.

The white powder was at first believed to be the same kind of alum formation as observed previously. But the speed with which it had occurred, in comparison with what had taken place in the whole of the first 50 years after the original conservation treatment, seemed remarkable, and an analysis of the white layer was therefore undertaken.

The crystals could be brushed off the objects and had even in some cases fallen on to the glass shelves. It was found that the same crystals also formed on the surface of the gypsum-dextrin which had been used for restoration, and that it followed the strokes of the brush which had applied the mat lacquer.

The crystals were insoluble in water and the only ion which was found consisted in traces of Al. The substance was organic and was soluble in xylene, vaseline and white spirit. It proved to be a part of the matting agent in the "Mattolakk" 565 A. This is a natural resin — linseed and Chinese oil-lacquer — into which is ground a small percentage of di- and tri-A stearate and $Al_2O_3 \cdot 3\,H_2O$, Aluminium oxide trihydrate. Probably some free stearic acid was present.

The manufacturer informed us that the lacquer was no longer being produced because of the formation of an unsatisfactory grey layer. The aluminium oxide trihydrate is in a very reactive state and may have formed resinates with the lacquer. The X-ray diagrams of the white layer gave diffuse lines and very weak lines, difficult to interpret. The diagram of a sample of the "Mattolakk" itself gave no lines at all.

As a conclusion it can be stated that the Epolakk has proved satisfactory in sealing off the water-vapour from the alum inside the wood. The newly-formed white layer consists of an organic substance, slowly crystallized from the Mattolakk. It can easily be removed with white spirit, which will not attack the lacquer underneath.

RESUME

LA DECOUVERTE D'OSEBERG, SA CONSERVATION ET SON ETAT ACTUEL

La découverte d'Oseberg date de 1904. Elle se composait d'un bateau avec une chambre de sépulture dans laquelle se trouvaient les restes de deux corps féminins. La plus grande partie de la découverte était constituée de toutes sortes d'objets nécessaires à une reine qui part en voyage.

Le bois de la chambre où se trouvait la sépulture étant C-14, il a été daté A.D. 720 ± 80 (Code chiffre T37-1). On estime que le bois était déjà vieux au moment de la construction de cette chambre.

Une expertise sera faite sur les points suivants :

1. Les conditions spéciales qui ont favorisé la préservation du matériel organique dans la butte.
2. Les méthodes de conservation appliquées.
3. L'histoire ultérieure de la découverte.
4. L'état actuel du bois conservé.