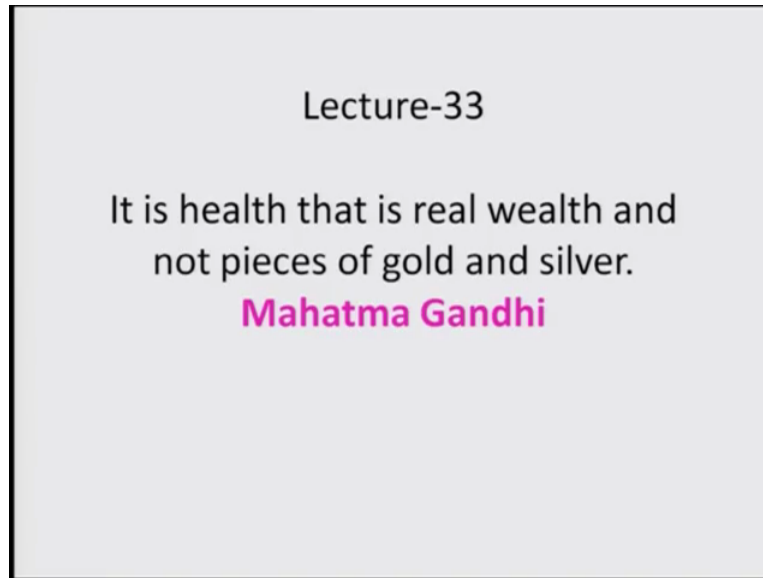


Introduction to Ancient Indian Technology.
Professor D. P. Mishra.
Department of Aerospace Engineering.
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Lecture-33.

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Let us start this lecture with a thought process from Mahatma Gandhi. ‘It is health that is real wealth and not pieces of gold and silver’. In the last lecture we were discussing about how our ancestors were you know, manufacturing the gold and kind of things. And we are discussing about Kolar gold mine and if you look at in India. Basically, three forms of gold can be found.

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Three Forms of Native Gold

- Alluvial sedimentary deposits at shallow depth in the river basin. In **Nilgiri hills, Tamilnadu**, such deposits have been worked upto a depth of **25 m or more**.
- The fine particles of gold are mixed with the sands of several rivers namely **Sindh, Sutlaj, Ganges, Swarna Rekha, etc**
- The metal nuggets and streaks **are found** in quartz veins **at Kolar and Hatti Gold Mines, Karnataka**.



Around 191-230 CE, Vasu Deva I, king standing left, sacrificing over altar, holding filleted trident above altar and resting left hand on sceptre, 2nd trident above altar, Shiva standing facing, holding wreath in right hand and resting left hand on trident, the bull Nandi left behind Him. Diameter: 22 mm, 7.98g

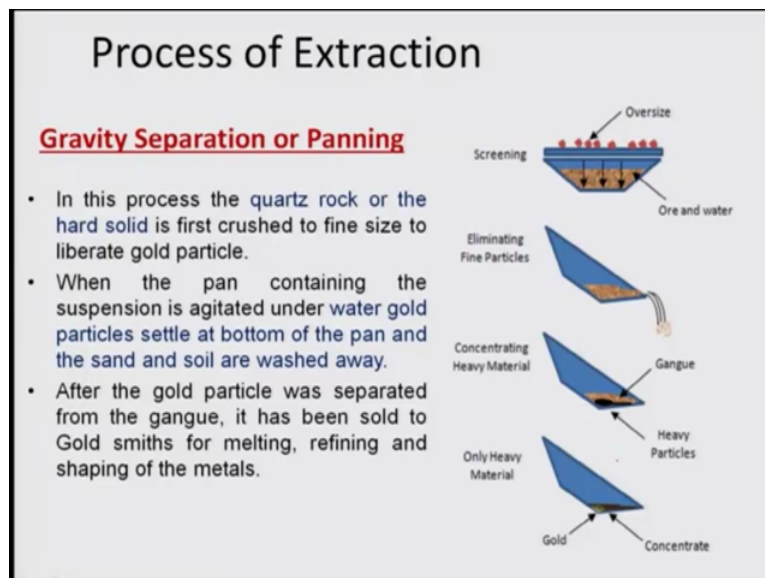
Indian jewellery is as old as Indian civilisation itself. In the sculptures in the temples of Odisha, south India, Sanchi and Amaravati and the paintings at Ajanta can be seen the wide range of jewellery worn by man and woman, and by king, queen and commoner.

One is alluvial sedimentary deposit at a shallow depth in the river basin. In Nilgiris of Tamil Nadu, there have been some deposit which were dig upto the depth of 25 metre or more. And beside this; of course there are some sands of several rivers like Sindh, Sutlaj, Ganges, Swarna Rekha and others which contains the fine particles of gold. So beside this, the metal nuggets and streaks are found in quartz veins at Kolar and Hattii gold mines, Karnataka, if you recall, the Karnataka was one of the oldest gold mine in the entire world.

Here I am showing you two parts of a single gold coin which was during the Vasu Deva I , around 191 to 230 CE. On the left hand side you can see that a king is standing and which is sacrificing the things in altar here. This is the altar kind of things and it is having a Trident here. And the resting on the left-hand on the sceptre which is generally being used as a symbol of you know power by the King. It is basically kind of a stick which was used earlier days by kings.

And second Trident, this image is Corresponding to the Shiva because it was having bull Nandi is there on here. It is having also a Trident so therefore this corresponding to Shiva. So this was the gold and beside this there are several gold jewellerys were found in various parts and we always feel that Indian jewelry is as old as Indian civilisation itself. And you will find lot of evidences in the sculptures in the temple of Orissa, South India, Sanchi, Amravati and several also Ajanta paintings and several places.

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And these jewellerys were being used by common man, king and even men, women and other things. Let us look at how they were separating the gold and this method is being used

even today in some remote areas of India. That is gravity separation or some people call it panning. Why because they use a pan and as shown in this figure, what they will be taking this quartz rock or the hard solid, first is to be crashed into fine particles and then of course the oversized particles can be screened out and put into a pan.

This of course you can use in you know water. Pour the water into this pan and then agitate it so that you know suspended particles which are later will be going out with the water. And some of the other particles which are lighter than the gold itself will be remaining here on the bottom. There is a heavy material like gold which will be remaining here and this you call, we call gangue which is a useless ore and not a much importance.


Basically the gold particles settled down at the bottom of the pan and the sand and soils and other which you call as the gangue are to be washed away. After this you know you obtain these gold particles, it can be separated very easily from the gangue and it is to be sold to the Goldsmith or melting refining or shaping of the metal. So this you can see this process looks to you quite simple and people do use even today across the country.

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Technology of Gold/Silver Working

- Pure Gold melts at 1063°C,
- The Gold sand obtained by panning was melted in a crucible and refined by addition of fluxes like **Borax (sodium borate/sodium tetraborate)** and a mixture of **Ammonium Chloride, Borax and Ammonium nitrate in the ratio 6:1:3.**
- The method of separation of silver from Gold was known as '**Niyaria**' and the craftsman practicing the separation of **Gold and Silver** were known by this name.
- **The granulation technique** was also used to make gold jewellery in India around the late 1st millennium BC to early Christian era. **Surface tension was used to turn melted gold filings into spheres.**

Goldsmith in British India 1856



The artisan on the left is using a blow tube to introduce oxygen to enhance the heat, and in manipulating the metal with tongs



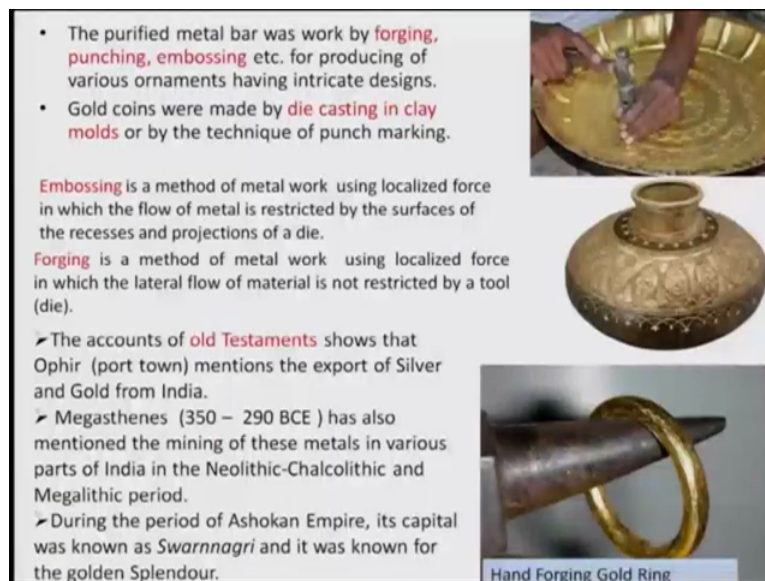
Particularly the poor people use this method. There are various technology people have used to make jewellery and various items, these items I have shown some of them which were in ancient India. Of course nowadays people are using. These are the gold ornaments were being designed and developed by in an ancient India. Pure gold melts around 1063 degree Celsius kind of things, for that you need to have a furnace. As I told earlier the gold particles of by panning method was melted in a crucible refined by addition of fluxed like Borax which is

basically sodium borate or sodium tetra borate. And this flux basically will be in ratio of 6 is to 1 is to 3 corresponding to the mixture of ammonium chloride and borax and ammonium nitrate.

And this is basically used so that the slag and other thing can be flowed out very easily so that the gold can be purified further. There is another method of separation of silver from gold was being used in ancient India which is known as Niyaria. The person who will be doing the separation of gold and silver was known as Niyaria. There is a another techniques which is used to form the gold particles or the gold spheres that is known as granulation technique which was in vogue in around the late first millennium BC in India.

I will just show you a picture which was taken during the British time of a Goldsmith was working in this painting around 1856 this painting was made. If you can see from here, the artisan is on the left side, this side, is using blower tube to introduce more amount of oxygen so that temperature will be going around maybe 1000 degree Celsius. such that he can make the gold and also work with you know it.

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- The purified metal bar was work by **forging, punching, embossing** etc. for producing of various ornaments having intricate designs.
- Gold coins were made by **die casting in clay molds** or by the technique of punch marking.

Embossing is a method of metal work using localized force in which the flow of metal is restricted by the surfaces of the recesses and projections of a die.

Forging is a method of metal work using localized force in which the lateral flow of material is not restricted by a tool (die).

- The accounts of **old Testaments** shows that Ophir (port town) mentions the export of Silver and Gold from India.
- Megasthenes (350 – 290 BCE) has also mentioned the mining of these metals in various parts of India in the Neolithic-Chalcolithic and Megalithic period.
- During the period of Ashokan Empire, its capital was known as **Swarnnagri** and it was known for the golden Splendour.

Hand Forging Gold Ring

Of course beside this there are several other processes being done for zinc and then embossing kind of thing which we will be discussing. So the purified metal bar was basically made by forging, punching or embossing etc. for producing various ornaments having intricate designs. If you look at beside this gold coins were made by die casting in clay moulds or by the technique of punch marking.

Embossing if you look at is a process of metalwork in which localised forces are to be used such that metal can flow depending on the design which will be there on the projection of a die. In this picture the artist with the help of a hammer and a tool is trying to emboss the plate and the tool is having a dye which is on the bottom, not shown in this figure, which is being used for making this design that embossing design which is shown here.

And this is a beautiful pitcher which has been embossed by the artist and which needs a lot of patience and also very good perseverance for to do that and also the skill. The forging the method of metal work that is being used to apply the force in a such that lateral flow of material is not restricted by the tool or the die. I will just show you that what is being done is an anvil, right where a gold ring is being made by the hammering it by using the basically forging and those are the marks of hammering as shown here kind of things. And this will be very delicate work one has to do and they have a control over the force being applied by the artist.

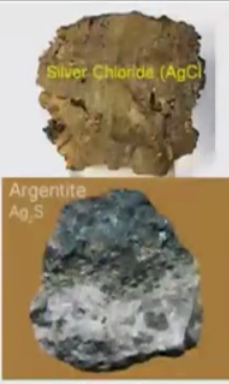
Let us look at little bit history, the old Testament indicates that the Ophir which is a port town, mention about export of silver and gold from India. Of course this Ophir town is basically a mystic town which is not known where it is located. Some people claim it is to be located in South India, some people claim is to be located in Gujarat. Some people located in you know in some other countries like Greek or in the Africa. So therefore it is not really very much known however the Megasthenes who visited India around 350 to 290 BC has mentioned about the mining of the golds in various parts of India in the Neolithic to Chalcolithic and Megalithic periods.

And during the period of Ashokan Empire, its capital was also known as Swarnnagari and it is known for the golden Splendour. So from this evidence one can see that the gold were being used in ancient India also still we are fond of gold.

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Silver and Lead

- The swarna (gold) has been related to Sun or Sanskrit word Jval (to shine), the brilliant white metal silver has been related to Moon and earlier it was called **luna**.
- Silver nitrate is still called Lunar Caustic.
- Silver (Melting point = 962°C) has been found to occur in natural **Chlorargyrite** (mineral form of Silver Chloride (AgCl)) and **Argentite** (Silver Sulphide: Ag_2S) associated with Galena and/or **Sphalerite** ($(\text{Zn,Fe})\text{S}$) or mixed sulphide ores, the extraction of this metal is said to be started in 3rd or 4th Millennium BCE with the development of the technique of treatment of sulphide minerals viz. roasting and reduction smelting.



During the extraction of lead from Lead Sulphide (PbS) or Lead Oxide (PbO), Ag_2S also gets decomposed and reduced easily at 470°C and it readily alloys with this metal at 1000°C . Hence the metallurgy of lead is being described along with silver.

Note that lead is one of the softest and heaviest metal having shining grey luster which leaves a black streak on paper. It is used mostly for making of cheap jewellery dies/pattern and mixed with copper to harden it. **Lead artifacts have been reported from the Harappan period, but it did not find much used in this period due to its softness.**

Let us now look at Silver because silver and lead always talked about it as it is you know together. As the gold is related to the sun, the Sanskrit word Jval to shine, the brilliant white metal silver has been related to moon, earlier it was also called Luna. And silver nitrate is still called the lunar caustic. So the silver melting point is around 962 degree Celsius. It has been found to occur in natural form like chlorargyrite, basically the mineral form of silver chloride which I have shown here an ore here of silver chloride, argentite which is a silver sulphide associated with the Galena and Sphalerite which is either it can be zinc sulphide or the ferric sulphide kind of things is a mixed sulphide ores.

This extraction of this kind of ores is said to be started in India around 3rd to 4th millennium BCE with the development of techniques to treat the sulphide mineral particularly the roasting and reduction method. And this is the Argentite what I have shown this you know from this colour one can make out that is a silver sulphide. And during extraction of lead from the lead sulphide or the lead oxide, the silver sulphide also gets decomposed and reduced easily at around 470 degree Celsius. And the problem with that it readily alloys with you know this metal at around 1000 degree Celsius.

So therefore that is the reason why the metallurgy of lead is being describe along with the silver. Note that lead is one of softest and heaviest metal having shining grey lustre which leaves a black streak on the paper and it is used mostly for making cheap jewellery, dies/pattern mixed with copper to harden it. The lead artifacts have been reported from the Harappan period but unfortunately it was not being used very much during that period due to

its softness. But later on people started using it and in South India the lead coins have been used in 1st to 2nd century BCE and it was the chief coinage metal for considerable time.

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- In South India lead coins have been in use in 1st-2nd century BCE and it was the chief coinage metal for considerable time.
The reactions occurring during the roasting of Galena are:
$$2\text{PbS} + 3\text{O}_2 \rightarrow 2\text{PbO} + 2\text{SO}_2$$
$$\text{PbS} + 2\text{PbO} \rightarrow 3\text{Pb} + \text{SO}_2$$
And finally PbO is reduced by Carbon at 500°C or by CO even at lower temperature:
$$\text{PbO} + \text{C} \rightarrow \text{Pb} + \text{CO}$$
$$\text{PbO} + \text{CO} \rightarrow \text{Pb} + \text{CO}_2$$
- As the liquid lead alloys with silver easily, hence it was first produced this alloy by co-reduction of Pb and Ag minerals and then produced pure silver by process of Cupellation.
- This Cupellation process was also known during Harappan period.
- In Indian subcontinent, Galena is found in Rajasthan at Zarwar and in small amounts in Kashmir, Gharble in Uttar Pradesh, Bihar and Kerala.
- One of the biggest deposits of Galena and Ag₂S is found at Burma. Burma is one of the major Silver producer even today.

And the reactions occurring during the roasting of Galena, if you look at it will be Two moles of Lead sulphide is reacting with Three moles of Oxygen going to the two moles of lead oxide and sulphur dioxide. And this again lead sulphide and lead oxide will be reacting. It will be going to the lead and sulphur dioxide. And additionally lead oxide can be reduced by the carbon at 500 degree Celsius or even the carbon monoxide which maybe formed during this process can also react with lead oxide giving the lead and carbon dioxide.

During this process what happens the liquid lead alloys with the silver easily. Hence it was you know first to be produced this alloy by co-reduction of lead and silver minerals. Then the pure silver is to be produced by the process of cupellation. As I told earlier, the cupellation process was also known during the harappan period. Of course we used the galena in indian subcontinent which is found in rajasthan at zarwar. In small towns in Kashmir, Gharble in Uttar Pradesh, Bihar and Kerala.

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Production of Lead and Silver

- The process used in ancient India and Zarwar, Rajasthan was most probably 'Ore Hearth Process' where the **roasting and reduction of rich Galena** is carried out in an open pit furnace.
- In such furnace temperature as high as **1000°C** can be easily obtained under natural draft and the reduced metal flows out and gets collected in the **front pit**.
- Silver metal was obtained from the alloy of Pb-Ag by reheating it in a shallow hearth furnace having the bottom prepared with bone charcoal.
- At this temperature **Ag₂S** also gets **decomposed and forms an alloy with molten lead**.
- During remelting of the alloy it is subjected to oxidizing condition by blowing excess air when lead gets preferentially oxidized to PbO (**litharge**) which was a very low melting point.
- This molten litharge is skimmed off and partially absorbed by the furnace hearth.
- This process is known as '**Cupellation**'

The diagram illustrates the 'Ore Hearth Process' for lead and silver production. It shows a cross-section of a furnace built into a hillside (Bayla Hill) with a stone wall on the right. The furnace contains layers of faggots and peat, a stone wall round fire, and a puddled clay layer. Melted lead is collected in a pit at the front. A top-down view shows a bowl-shaped hollow with a pig and dry walling, and openings for wind. The diagram is labeled with SW, NE, Bayla Hill, Gunners Beck, faggots, peat and ore, stone wall round fire, puddled clay, melted lead, section on AB, openings for wind, bowl shaped hollow, pig, dry walling, section on CD, and Z R O P.

One of the biggest deposits of galena and silver sulphide is found at Burma and you people might be knowing that Burma is one of the major silver producer even today. Let us look at how you know lead and silver can be separated. The process used in ancient India particularly Zarwar of Rajasthan was most probably the ore hearth furnace which I have shown here and this is the schematic of a ore hearth furnace and where the roasting and reduction of rich galena is carried out in an open hearth pit furnace.

This is an open hearth pit furnace and if you look at it, it has stone walls here and there are faggots and peat. Peat basically you can say is kind of coal or charcoal and the ore together. It is being placed in this layer by layer. And then it has to be of course generally being placed in hilly regions such that you will get a you know this melted lead can be collected in this pit.

They choose that place suitably so that slope will be there. And this is of course a cross section which is being taken here, these are the stone walls right, these are the stone walls. And it will be in such furnace the temperature around 100 degree Celsius can be obtained easily because of natural draft and the metal gets reduced and flows because of slope will be there and then it is collected in a pit.

As I told earlier the silver metal was obtained by alloy of lead and silver by reheating it in a shallow hearth furnace, this is a hearth furnace having the bottom prepared with the bone charcoals. See what will happen this melted things will be coming over here and this will be

aligned with the bones, charcoals, such that you know cupellation method can be utilised to separate the silver.

At this high temperature the silver sulphide also get decomposed and forms an alloy with the molten metal. And during remelting of alloy, it is subject to oxidising condition by blowing excess air when the lead gets preferentially oxidised to PbO which you call it as a litharge, because it has a very low melting point. The molten litharge is skimmed off and partially absorbed by the furnace hearth.

As I told there is a bone charcoal which will be there and that will be absorbing this litharge or the lead oxide so that it will be separated easily. And this process is basically known as cupellation.

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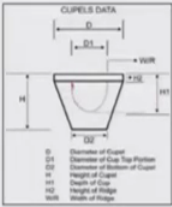

Cupellation Method

Cupellation is a refining process in metallurgy, where ores are treated under high temperatures and have controlled operations to separate noble metals, like gold and silver, from base metals like lead, copper, zinc, arsenic, antimony or bismuth present in the ore.

Cupel is a smaller vessel shaped in the form of an inverted truncated cone, made out of bone ashes which was used for small scale cupellation for processing gold and silver in Ancient India.

According to Kautilya's Arthashastra, details of cupellation for purification of silver:

"The pure and impure silver may be heated 4 times with CuSO_4 (Suskatutha) mixed with powdered bone (Asthitutha), again 4 times with equal quantity of lead and again 4 times with CuSO_4 , again 3 times in a skull and lastly twice with cow dung. Thus silver is purified."



D1	Diameter of Cupel
D2	Diameter of Cup Top Portion
D3	Diameter of Bottom of Cupel
H	Height of Cupel
W	Width of Cupel
W1	Width of Ridge

So cupellation if you look at is a refining process in metallurgy where ores are treated under high temperature, have control operation to separate noble metal like gold, silver or any other metal from the base metal like lead, copper, zinc and others present in the ore. The cupel which I have shown here is basically a small vessel shaped in the form of inverted cone because if you look at this like a inverted truncated cone because if you look at this is like a inverted truncated cone made out of bone ash like this generally you know surfaces, inner surfaces will be having bone ashes, which are used for the small scale cupellation for processing gold and silver in ancient india.

Of course nowadays in modern time it is having proper dimensions you know like which I have shown here like D1 and this is the total D and there is certain thickness and you know

like height is maintained and this are the place where the metal will be kept. And according to Kautilya's Arthashastra, detail about the cupellation for purification of silver is given. He has mentioned in this way. The impure silver maybe heated four times with the copper sulphate Suskatutha and mixed with powder bone that is asthitutha and again four times with equal quantity of lead and again four times with the copper sulphate, games three times in a skull and lastly twice with a cow dung. And by this process the silver is purified. He has mentioned that. That means it very clearly state that the skull will be having the bone itself you know and then that will be nothing but your acting like a you know separating the metal by the cupellation process.

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So it clearly indicates that this process was being used in ancient India, the cupellation method. And there are also the evidences of crucibles found in different sites of India like if you look at this one to two, he Terracotta in Lothal regions and of course the three also the stone in the Lothal region, four to five Terracotta in Ahar in UP, 6 to 7 is the the Atranjikhhera, that is 6 to 7 this kind of cupel were found during excavations and Rajghat is 8 to 9 kind of, 11 to 16 in if you look at 11, 12, 13, 14, like 16 are in Taxila and seventeen twenty one in early history of Bhokardan you know people found.

That means, you know if you look at this evidence, it is very clear that people were using that cupel and also the crucibles for melting the silver and also the separating the from out of it in ancient times. So with this I will stop over here, and we will be discussing the next lecture about the copper which is a part and parcel of Indian life because of fat that it is related to our rituals. Thank you very much.