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REFLECTING
FUTURES

Vitrified wall material from the hillfort Broborg in Sweden – genesis and ageing

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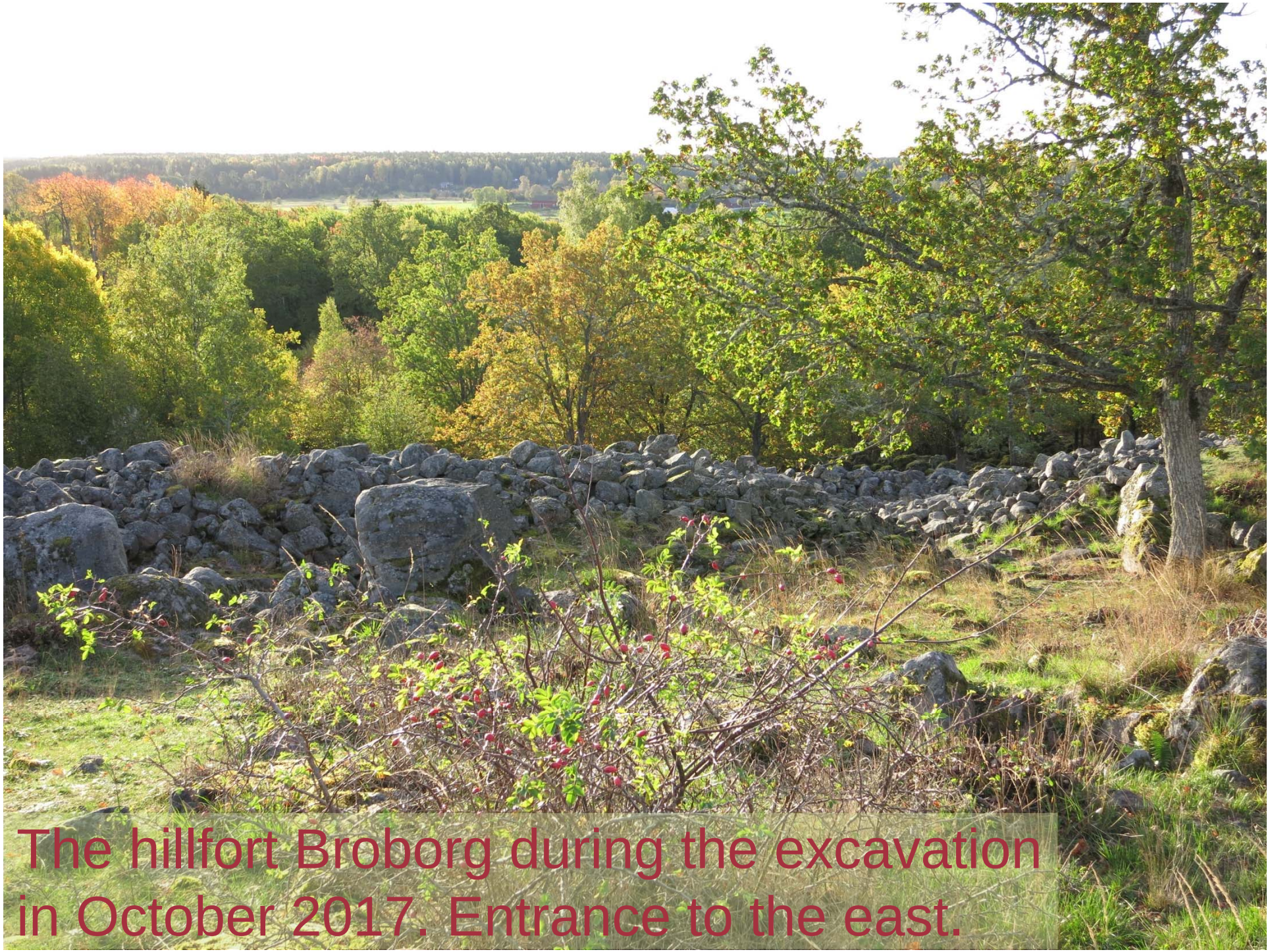

The hillfort Broborg during the excavation in October 2017. Entrance to the east.

The part of our team that participated in the excavation at Broborg in October 2017. You are looking north.

Aerial view of Broborg from April 2018 showing the inner wall. Most of it is vitrified on top. You are looking east.

Purpose of the work

1. To supply an anthropogenic analogue to the nuclear waste management community, and
2. To contribute to the Swedish heritage

- In our case, the anthropogenic analogue relates to the vitrified material in a hillfort wall
- It is appropriate that if a historical site is to be utilised for some purpose, then artefacts as well as information on the site must be salvaged and saved
- In the present case, the two objectives above go hand in hand because we need to understand the hillfort e. t. c. for the purpose of the analogue

What is an analogue?

- We have nuclear waste and we have to dispose of it such that it will never harm future generations, i. e. it must be contained for thousands and tens of thousands of years.
- It is therefore necessary that we can predict the behaviour of the waste in a final storage for such lengths of time
- Theoretical considerations and ordinary experiments are required but are not sufficient
- We also need to compare with reference material that has existed during a long time

What is an analogue? Continued.

- An analogue to a nuclear waste form comprises two parts
  1. A material that has been around for a sufficiently long time (e. g. 1000 – 10 000 years)
  2. The environment that this material has been subjected to during this time

- Decades of studies of analogues to nuclear waste glass have focussed on the following
  - Natural glasses from volcanic activity
  - Anthropogenic glasses in ancient domestic glassware

A novel approach

- It was discovered only a few years ago that hillfort glasses may offer advantages in relation to such ”traditional” analogues
- => the starting point for the present project

About nuclear waste

- The nuclear waste form of interest to our project is a glass containing some long-lived radionuclides
- It has been prepared by mixing a waste slurry with glass forming additives in an electric melter

Historical Overview, Current Status, and Path Forward

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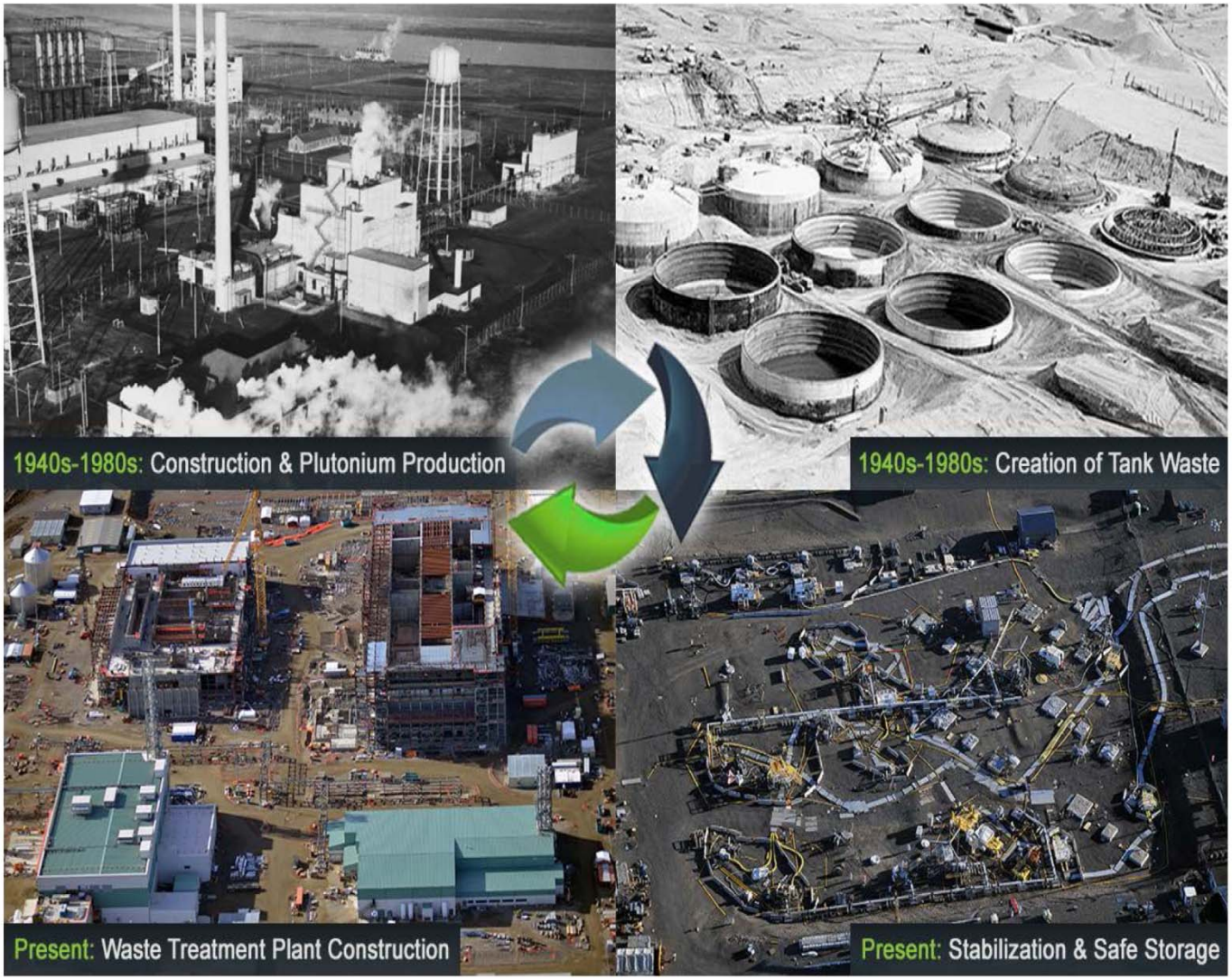

Crystallization: Potential Impacts on Melter Processing

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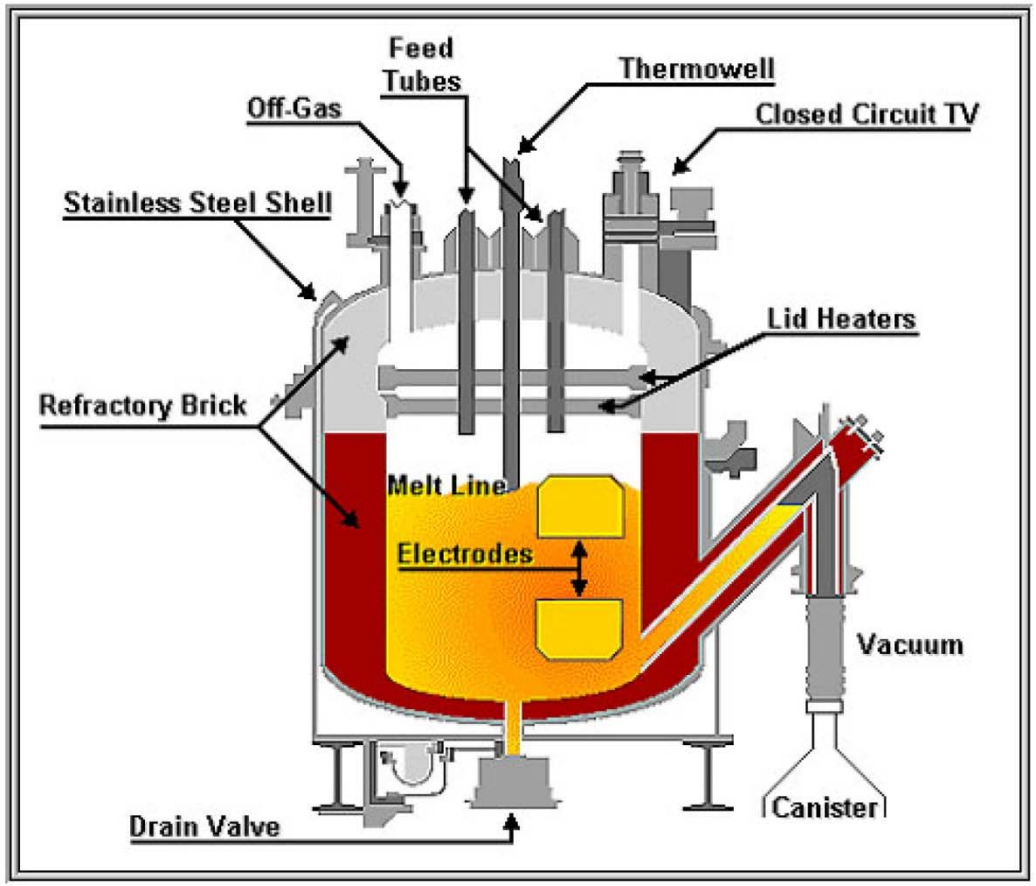

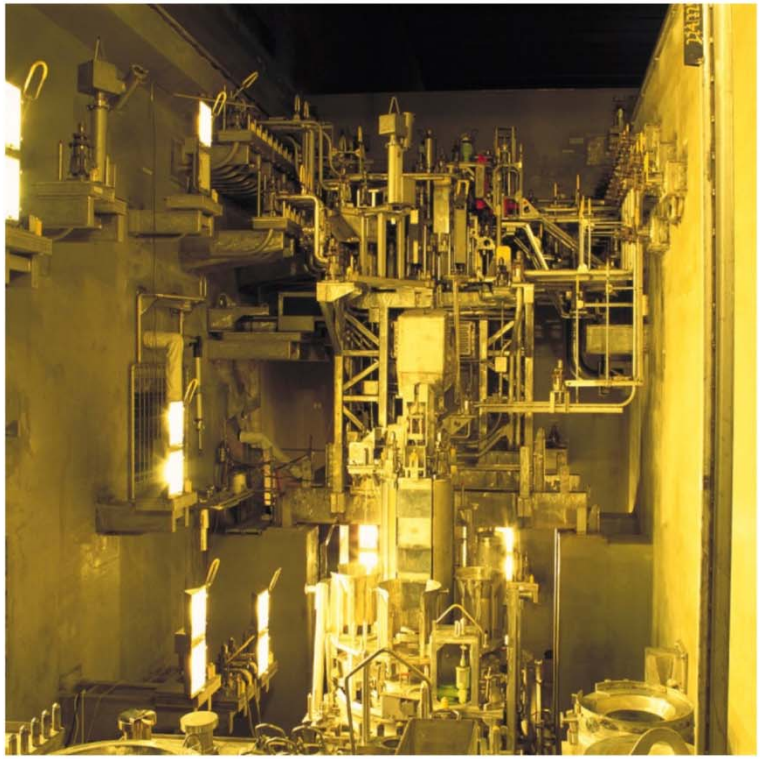

Diagram and photo of DWPF melter

Complexity of HLW Vitrification Process

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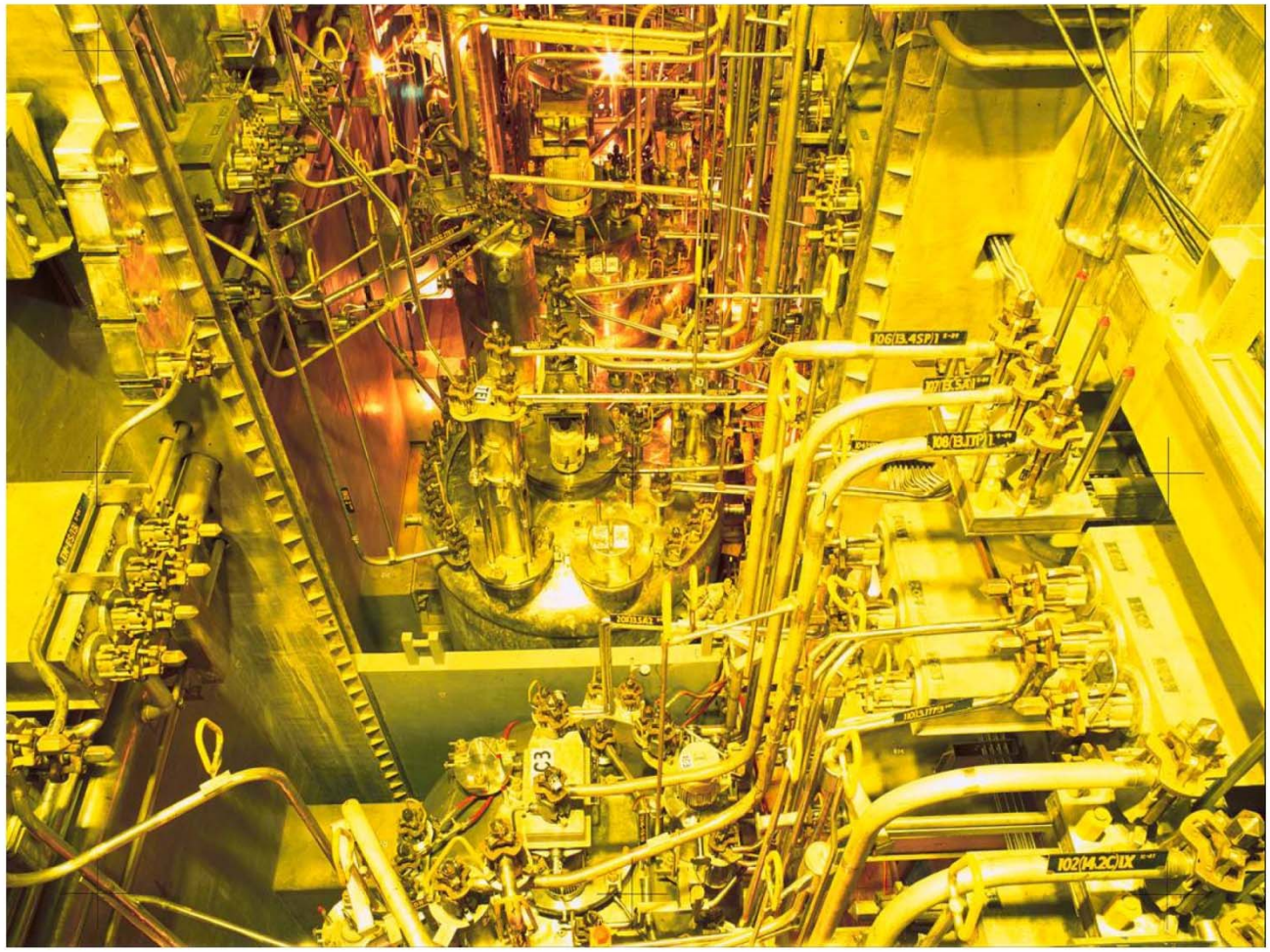

Complexity of Waste: Physical Forms (sludge)

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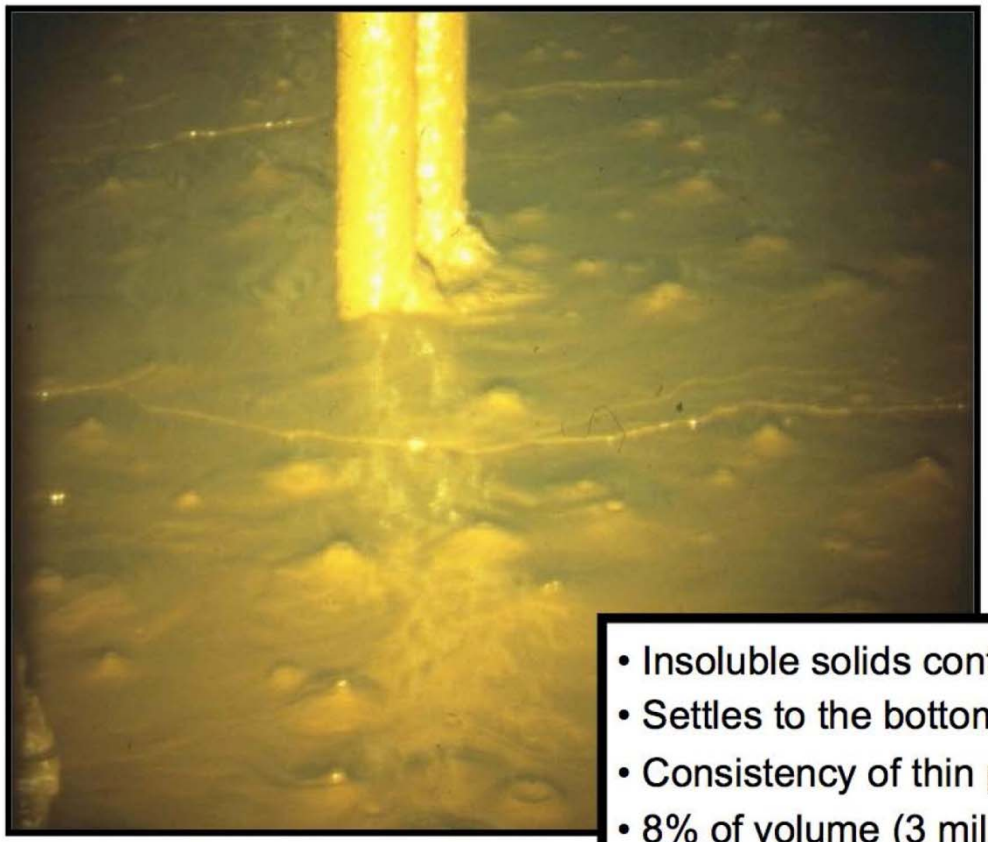
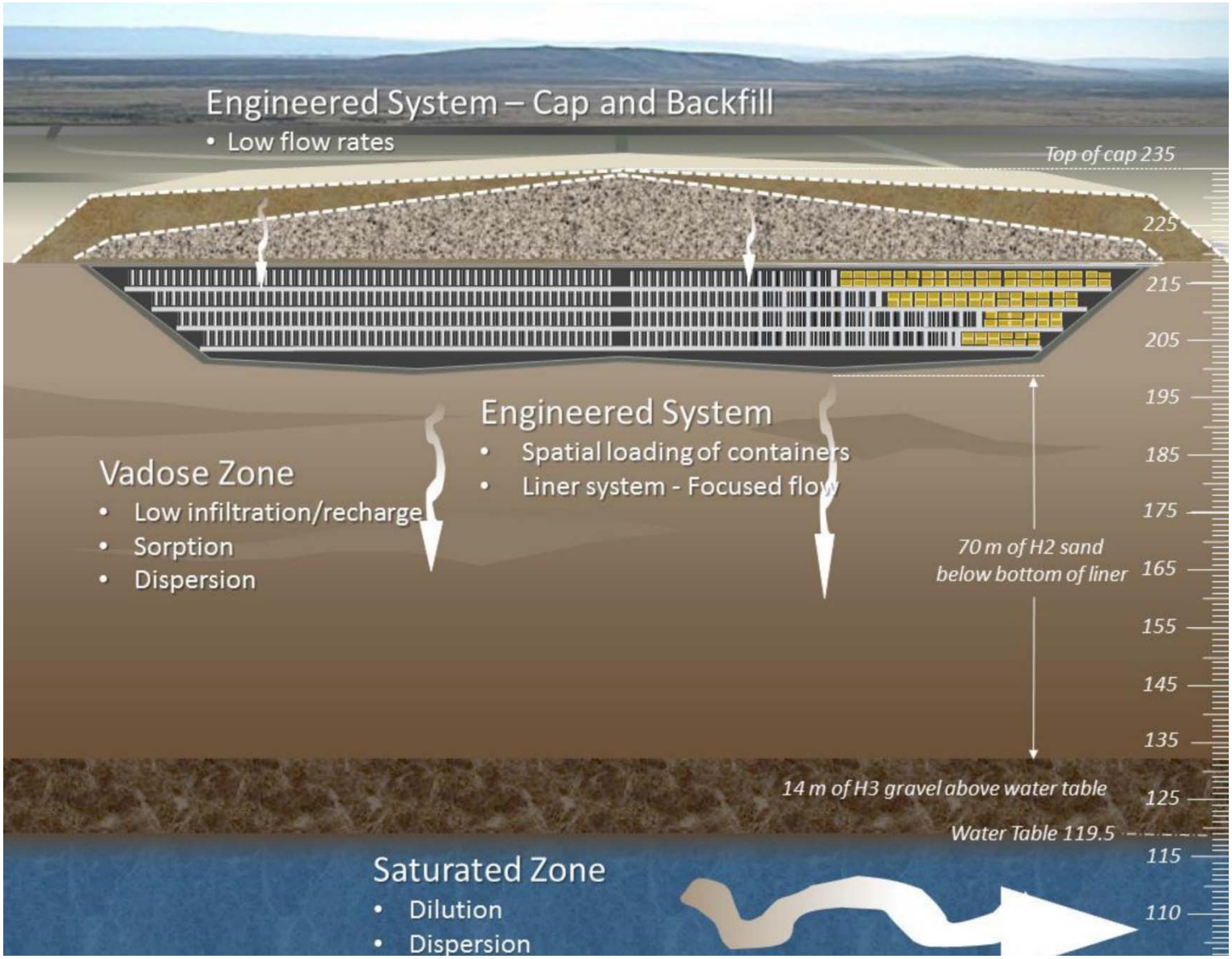


- Insoluble solids contained in the waste
- Settles to the bottom of the tank
- Consistency of thin peanut butter
- 8% of volume (3 million gallons)
- 55% of radioactivity (220 million curies)

Volumes and radioactivity for SRS waste only



An example of a layout for a final repository for stainless steel drums containing glass

History of Sweden (simplified)

yellow = prehistoric = hardly any written records,
blue = historic = written records

13000 – 1700 BC	Stone age		
1700 – 500 BC	Bronze age		
500 BC – 1050 AC	Iron age	500 BC – 1 AC 1 - 375 375 – 550 550 - 800 800 – 1050	Pre-roman iron age Roman iron age Migration period **(Broborg)** Vendel period Viking age
1050 - 1520	Middle ages		
1520 - present	New times		

Actually,
the following is to be illuminated

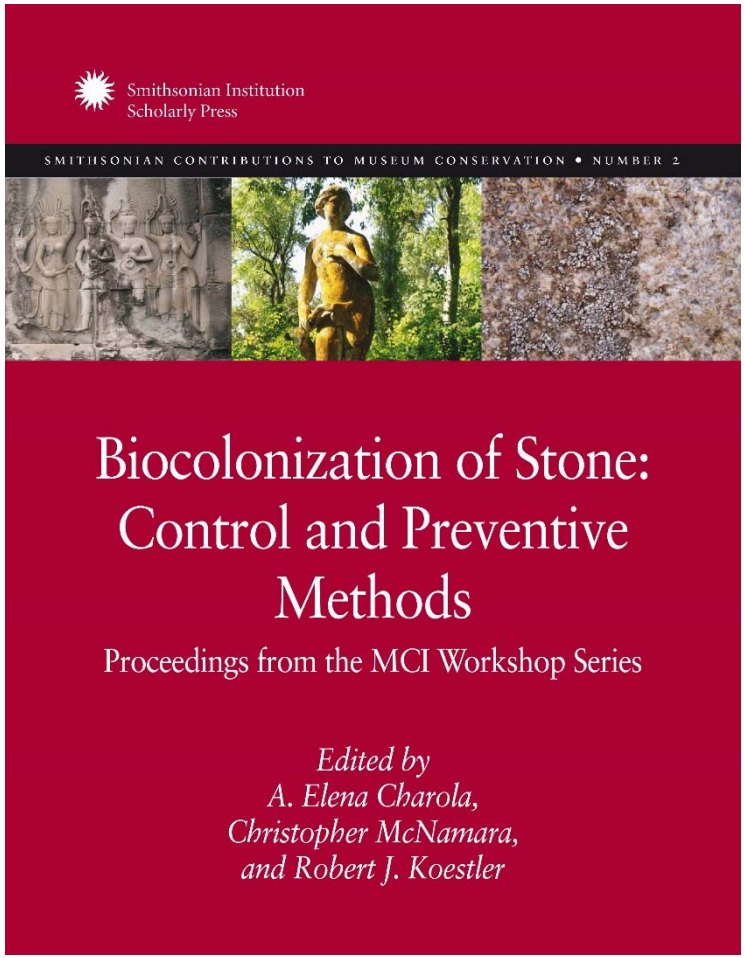
	Inside the wall	**Outside the wall**
Initially	The genesis of the vitrification, how it was carried out and why	The objective and role of Broborg
Over time	The local chemistry, especially in view of any effects of the fire cracked material	Development of the landscape: land upheaval, increased farming, deforestation, fimbul winters

This is similar to a performance assessment, but runs ”backwards” in time. I. e. it might be referred to as a ”reverse performance assessment”.

We are preparing a special issue of the Smithsonian journal "*Smithsonian contribution to museum conservation*" to appear in a year or so.

The work on our project in general is well reflected in the intended content:

- Selecting an Analogue: Criteria and Considerations
- Vitrified Hillforts and the Role of Broborg
- Excavating for Analogues: Broborg Hillfort Case Study



We are preparing a special issue e. t. c., continued

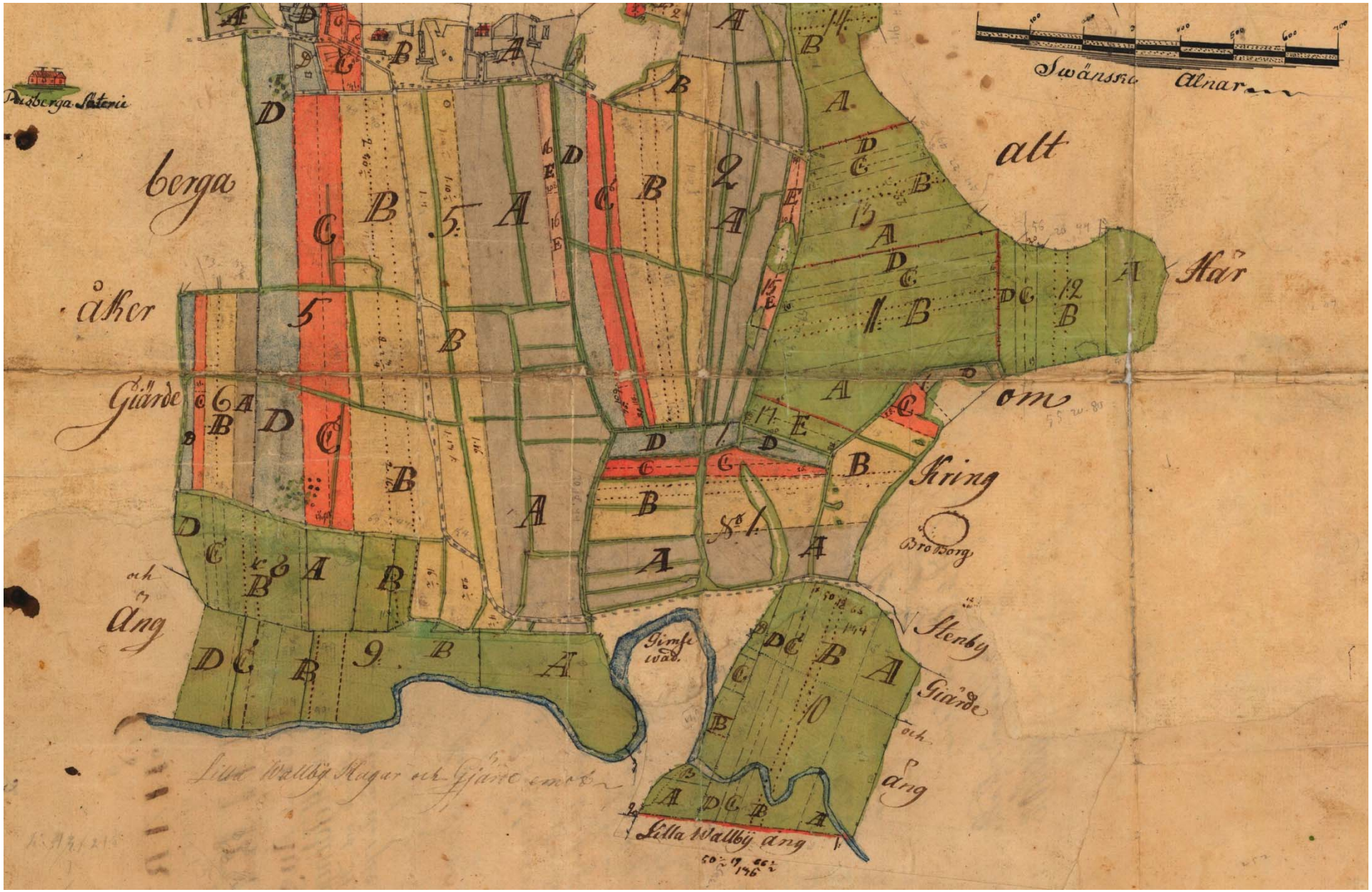
Intended content, continued

- The Geological and Geochemical Setting of Broborg
- Modern Analyses of Ancient Materials
- Reconstructing Ancient Vitrified Hillfort Technology through Experimental Archaeology
- Aging and Durability of Ancient Glasses to Predict Long-term Performance of Vitrified Waste
- Natural Deterioration of Vitrified Materials
- An “inverse” performance assessment for Broborg
- Looking Forward: Considerations for Future Sampling, Natural Analogues, and Microbial Effects

Some further information can be found at www.broborg.org

Broborg, near Uppsala in Sweden. You are looking southwest.

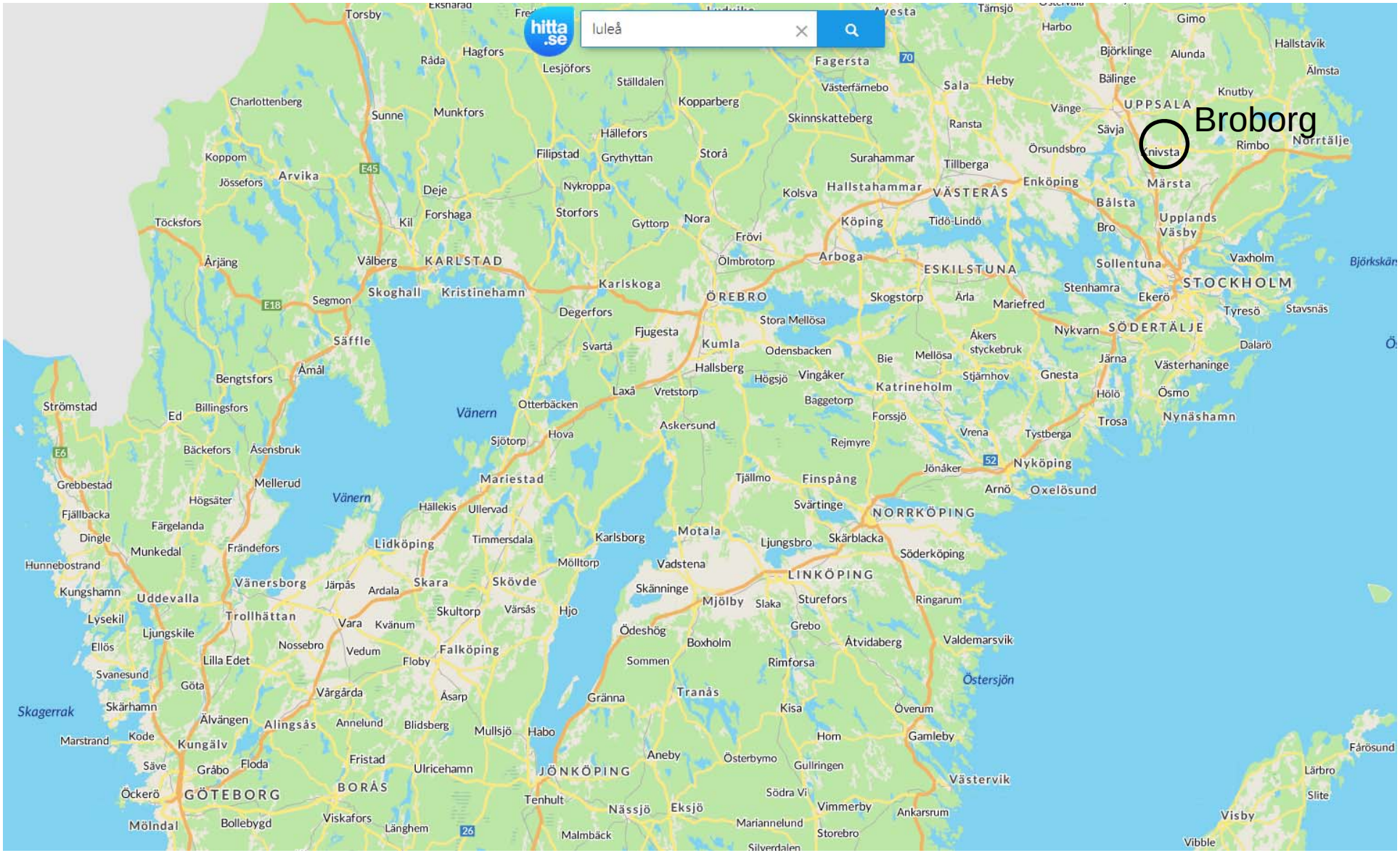
The level and course of the river Storån have been altered by drainage operations carried out during the 18th century



Map over the Broborg area from the year 1782.

Replica and find for a boat for a waterway

Modern map of south-central Sweden



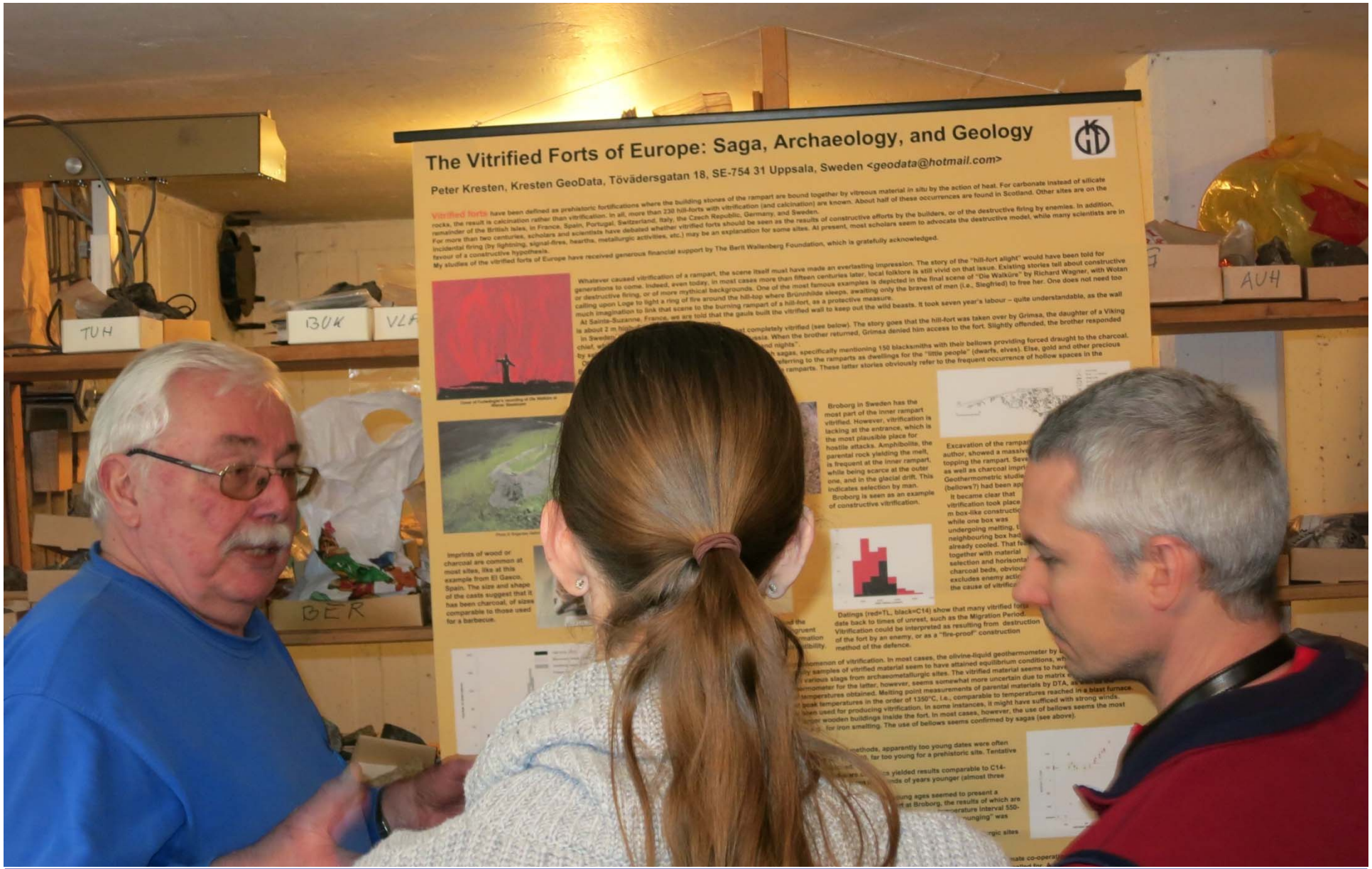
Map of south-central Sweden from 1645 - 1664

Extract from *Carta Marina* from 1539

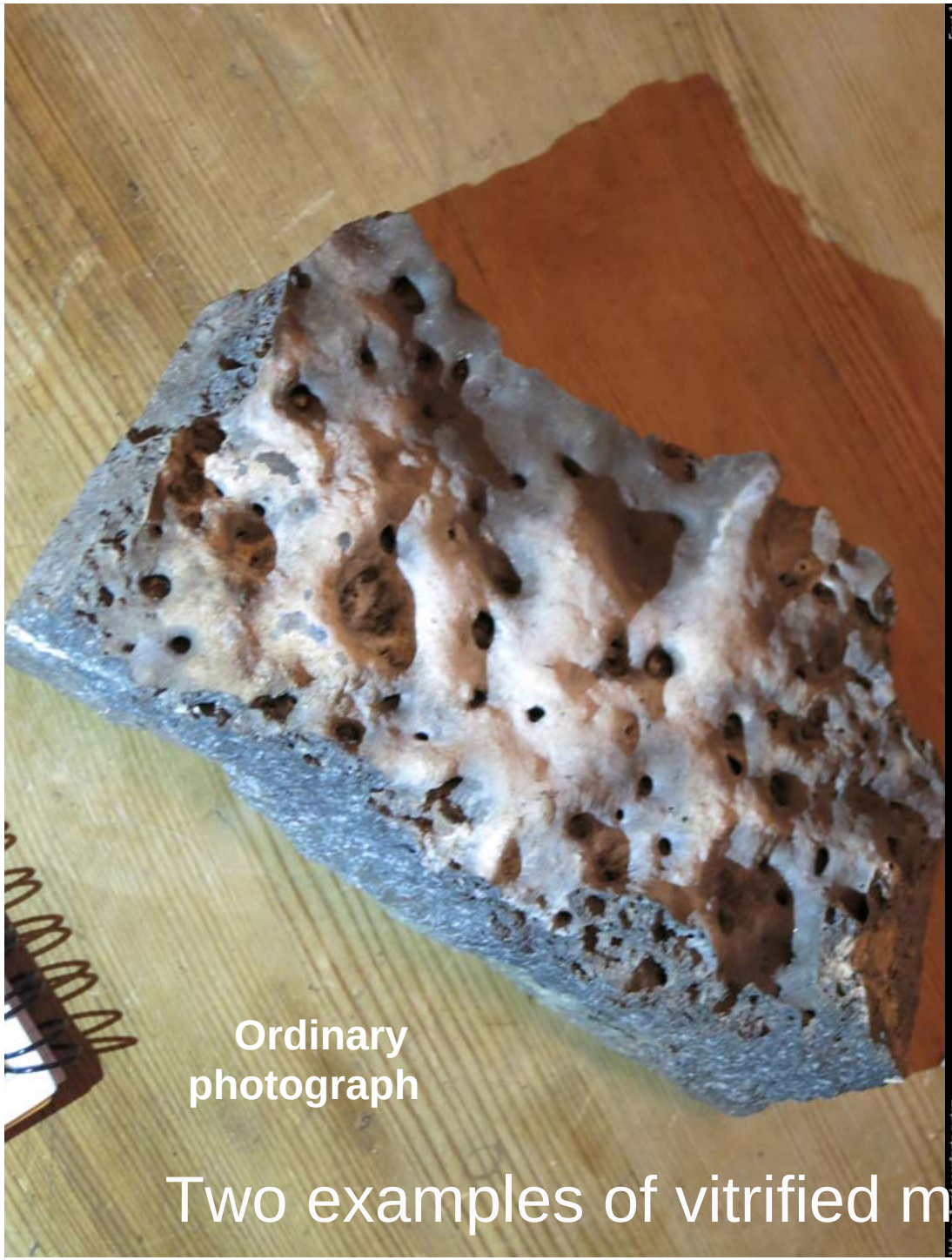
The figure shows the shore line level of the Baltic Sea 1500 years ago. The water level downhill from Broborg and upstream (southeast) of the ridge Vallbyåsen was probably higher since it took time before the ridge became eroded at the ford. Map from the services of the Swedish Geological Survey.

Role of Broborg

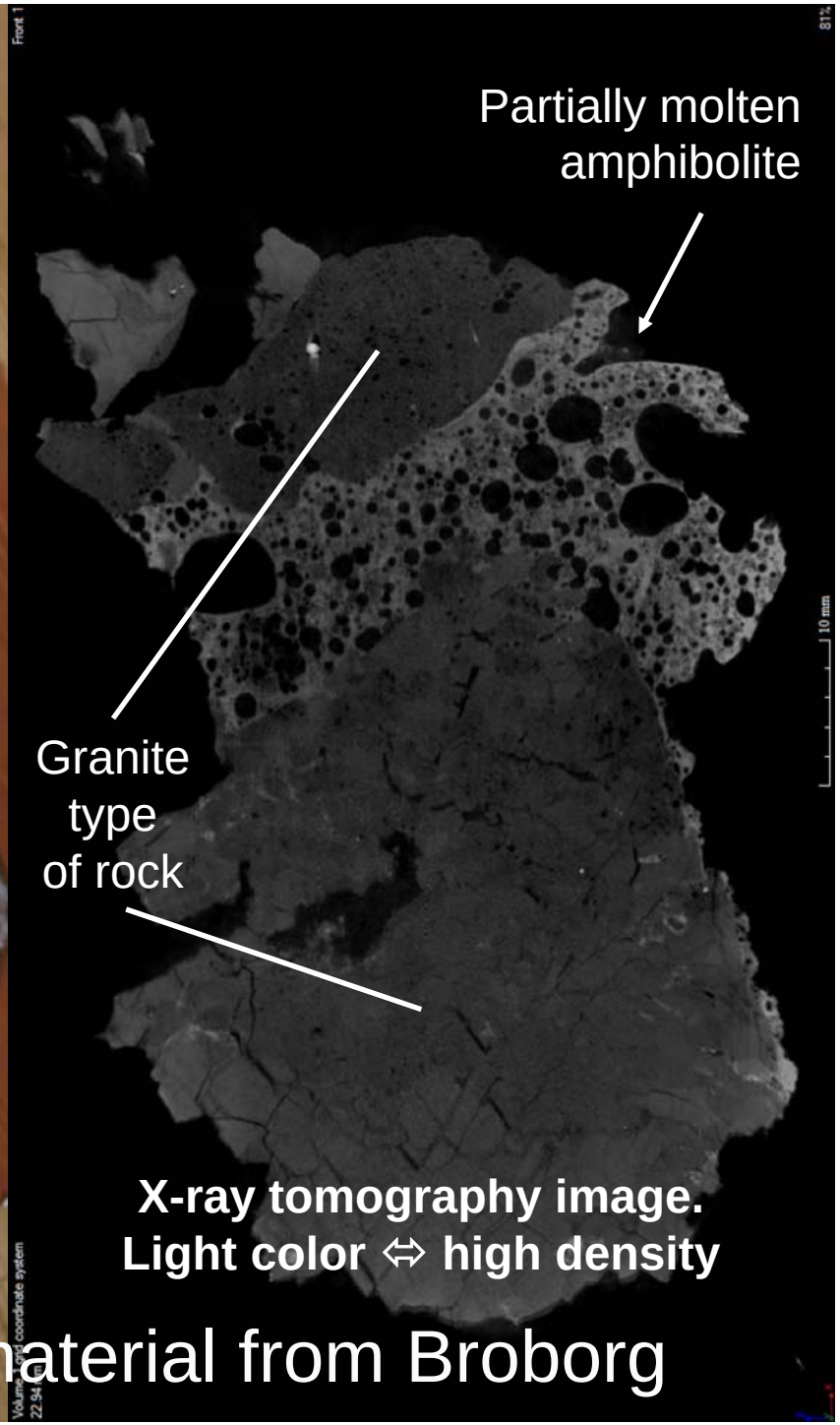
- We interpret that the fortified constructions at Brobrog served the purpose of security.
- It also appears that the fort has been used for control of the waterway and the road
- We do not know for how long the fort was in operation, but it is likely that it has been used for the following
  - In peacetime: support for civil order & taxation
  - In wartime: protection against intruders



Peter Kresten, here with Jamie Weaver and John McCloy, has kindly supported our project with knowledge and samples.

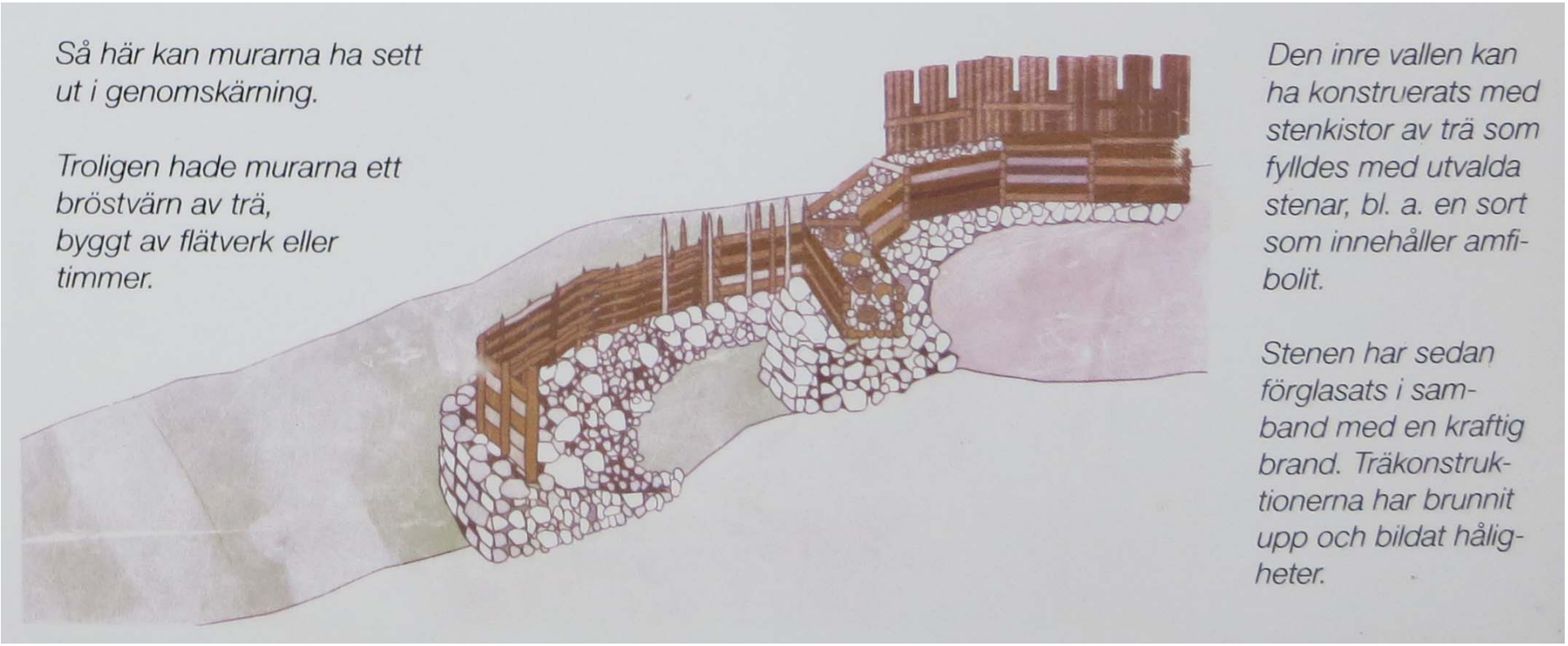


Ordinary photograph



X-ray tomography image. Light color ⇔ high density

Two examples of vitrified material from Broborg



The Broborg wall and its vitrification

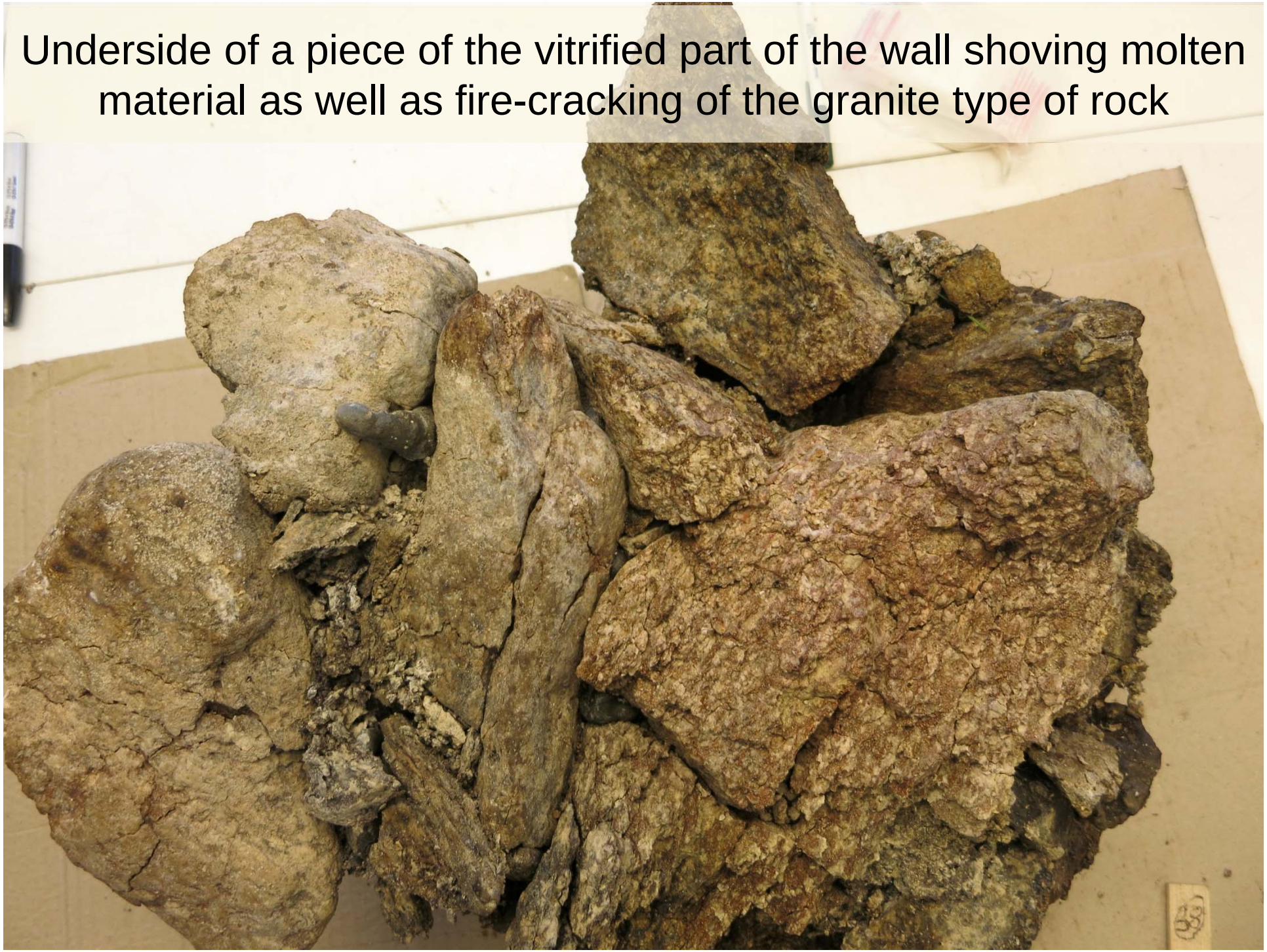
The Uppsala County Administrative Board has an information board at the Broborg site, and above is a photo of a part of it. The figure shows two dry-wall types of structures of which the upper one is reinforced with timber, similarly to that of a log house with notches (British English *cog joints*) or equivalent (Kastenbau). The part of the wall with a timber reinforcement has become disintegrated, but the vitrified part just underneath it is quite intact. It is 0.8 – 1.0 meters wide and 0.3 – 0.4 meters high. It comprises cobble sized (0.1 – 0.2 m) pieces of granitic type of rock which had been joined by partially molten amphibolite. This vitrification extends throughout most of the inner wall.


The wall
and the
start of the
excavation

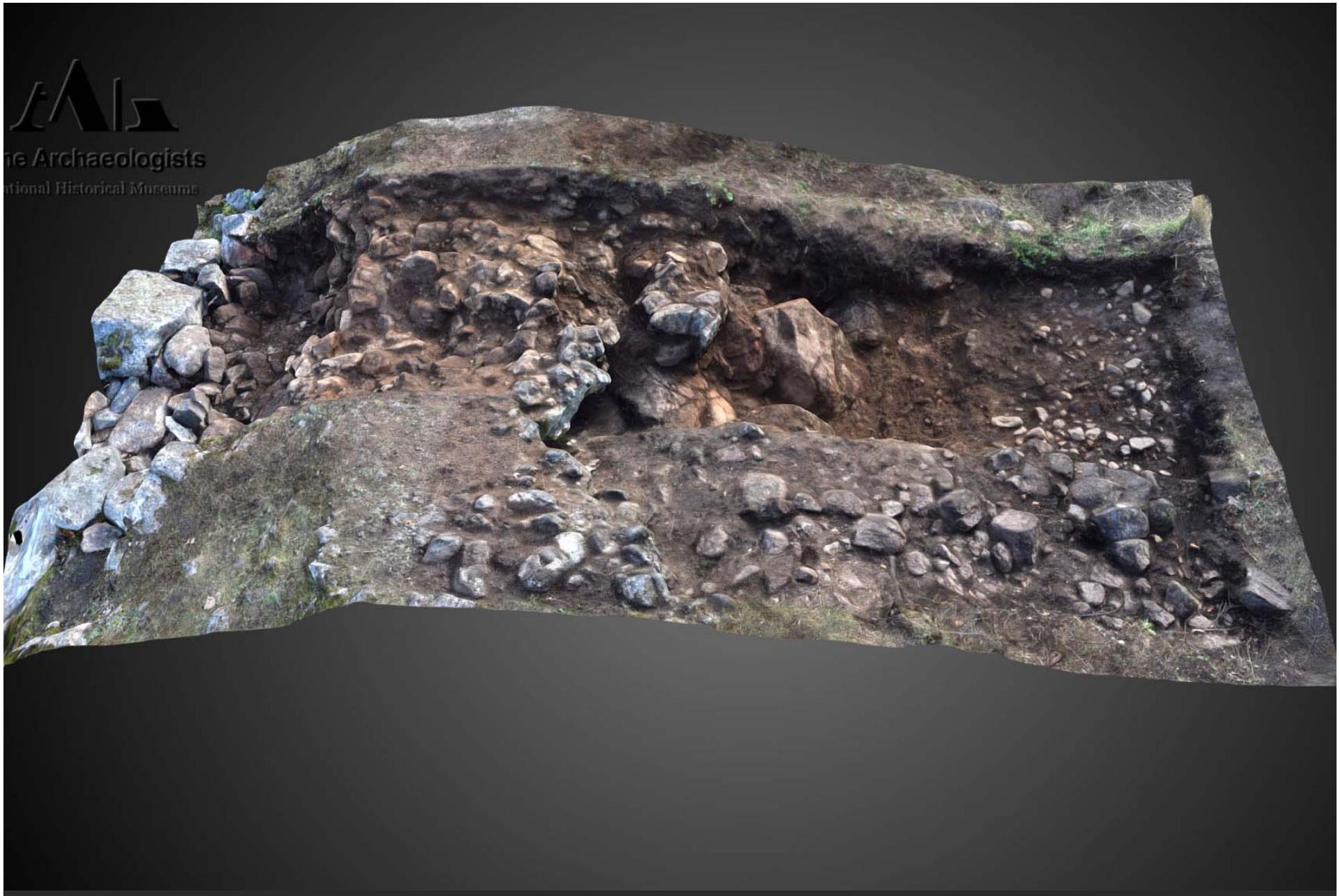
The top of the vitrified part of the wall


The vitrified part of the wall removed.
Note the red color from the heat / fire-cracking

Underside of a piece of the vitrified part of the wall shoving molten material as well as fire-cracking of the granite type of rock



Screen print from a 3-D scan



Screen print from a 3-D scan

Screen print from a 3-D scan

Screen print from a 3-D scan

Screen print from a 3-D scan

Now to the elephant in the room …

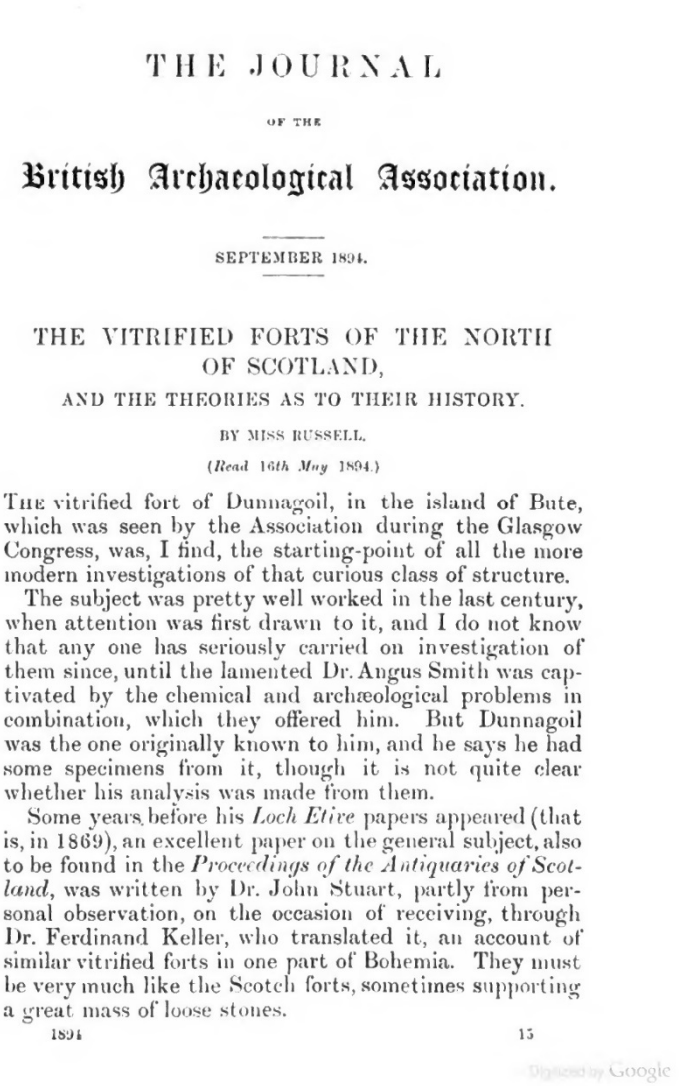
A. ***Destruction***: Was the vitrification intentional and for the purpuse of destroying the hillfort?

B. ***Accident***: Did the vitrification come about as a result of some accident with fire or strike of lightening?

C. ***Construction***: Was the vitrification intentional and for the purpose of construction of the hillfort?

Argued about since the year 1777

- Theories on vitrification reviewed in the year 1894
- Mr Williams was a mining engineer and published his findings and thoughts in the year 1777
- He believed in ”construction”
- And so does Peter Kresten who has worked extensively with Broborg



THE JOURNAL

OF THE

British Archaeological Association.

SEPTEMBER 1894.

THE VITRIFIED FORTS OF THE NORTH OF SCOTLAND,

AND THE THEORIES AS TO THEIR HISTORY.

BY MISS RUSSELL.

(*Read 16th May* 1894.)

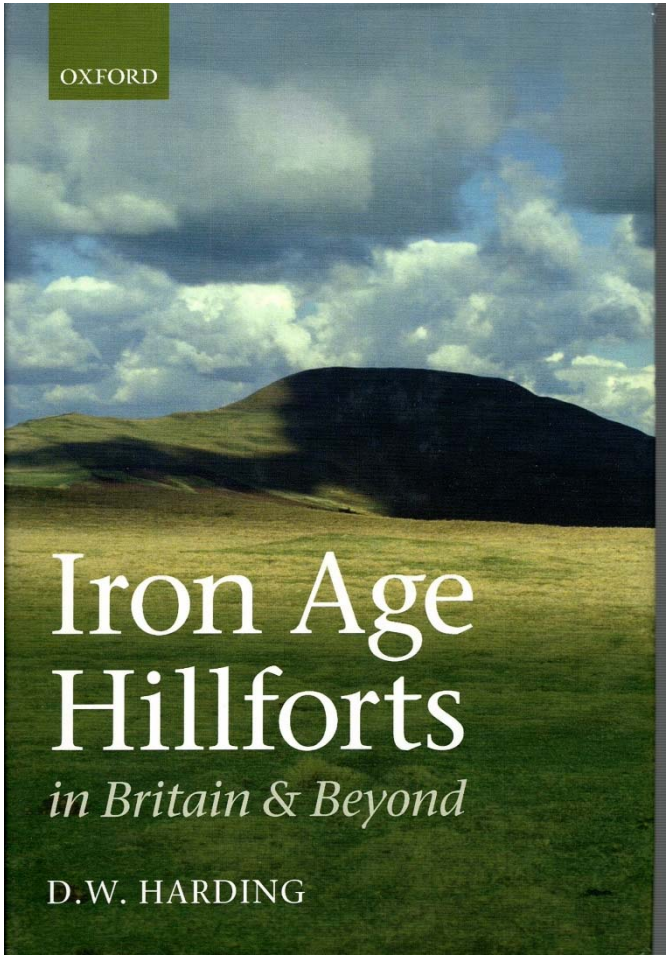
The vitrified fort of Dunnagoil, in the island of Bute, which was seen by the Association during the Glasgow Congress, was, I find, the starting-point of all the more modern investigations of that curious class of structure.

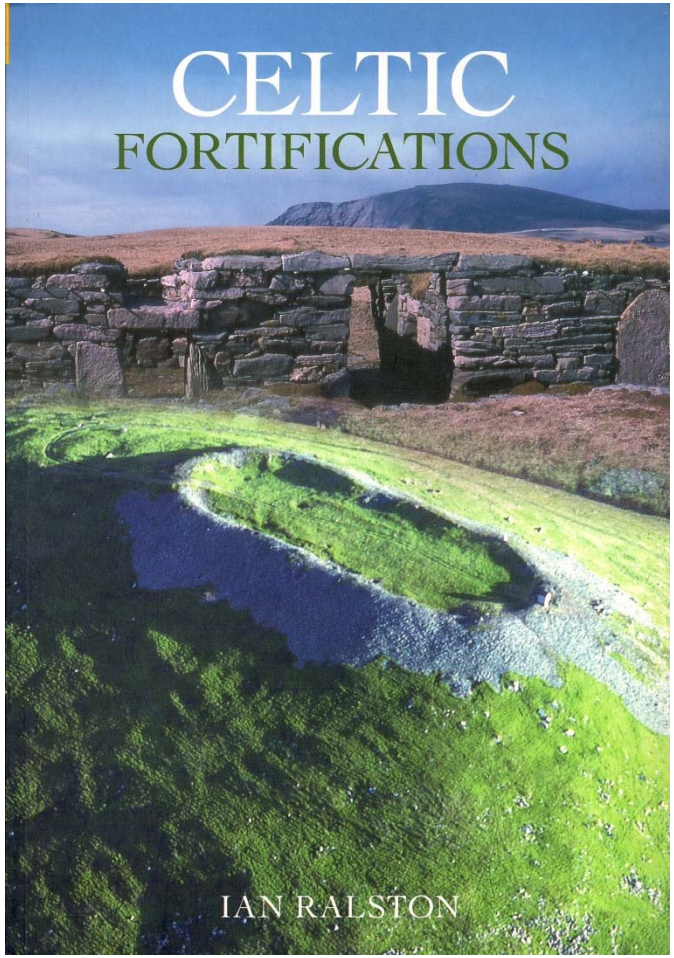
The subject was pretty well worked in the last century, when attention was first drawn to it, and I do not know that any one has seriously carried on investigation of them since, until the lamented Dr. Angus Smith was captivated by the chemical and archæological problems in combination, which they offered him. But Dunnagoil was the one originally known to him, and he says he had some specimens from it, though it is not quite clear whether his analysis was made from them.

Some years before his *Loch Etive* papers appeared (that is, in 1869), an excellent paper on the general subject, also to be found in the *Proceedings of the Antiquaries of Scotland*, was written by Dr. John Stuart, partly from personal observation, on the occasion of receiving, through Dr. Ferdinand Keller, who translated it, an account of similar vitrified forts in one part of Bohemia. They must be very much like the Scotch forts, sometimes supporting a great mass of loose stones.

1894 15

Today, most archaeologists support ”destructive” but do not entirely rule out ”constructive”





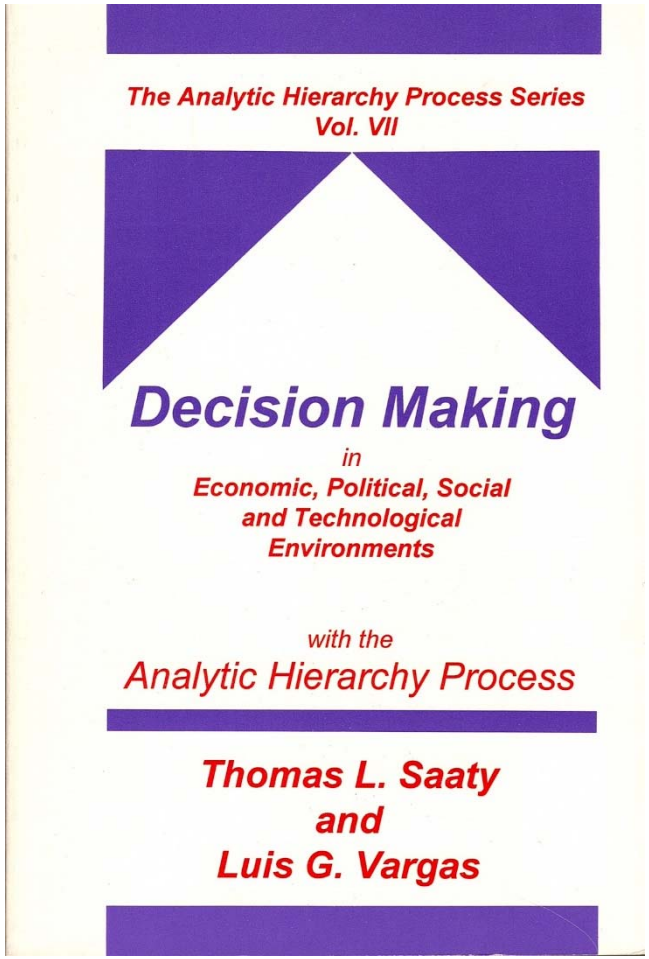
Perspectives

”Destructionists”	May emphasize ”culture”, e. g. stratigraphy (according to Harding)
”Constructionists”	May emphasize the high temperature needed for the partial melting and the associated vitrification

But how to avoid fruitless conflicts of opposing positions e. g. through approaches like *decide, announce and defend?*

Our approach

- To identify and use a decision making tool
- ⇔ Improve transparency & decrease bias
- Decision processes can be very complex
- But preliminary analyses indicate that a simple method is appropriate for the case of Broborg



Our approach, continued 1

- Specify the problem
- Identify circumstances that are relevant for the decision
- Assess weights for each of these circumstances
- Evaluate each circumstance for each of the alternatives
- Sum up and check for adverse outcomes
- Make decision and assess uncertainty / validity

Our approach, continued 2

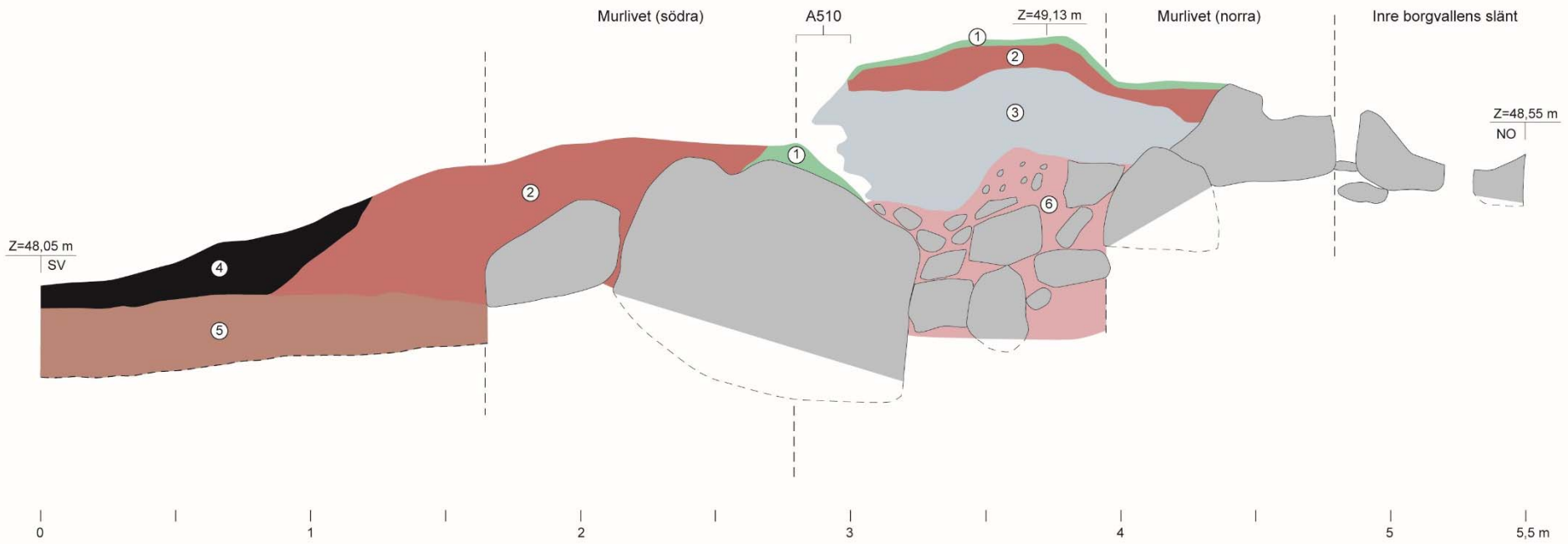
- Hillforts are different and have to be evaluated individually
- It is likely that some hillforts with vitrified material belong to the categories ”destruction” and ”accident”
- It needs to be shown if a certain hillfort might to be assigned to the category ”construction”

Examples of circumstances to be included in an evaluation

- Stratigraphy
- Incentive
- Did the vitrification make the wall (as a whole) stronger?
- Is the vitrification incidental or does it cover a large part of the hillfort wall(s)?
- Has the wood versus charcoal question been evaluated with regard to the issue of quality of heat (i. e. the heat required at above the solidus melting point of the rock in question)?
- Did the ancient people reasonably have access to the technology needed?
- E. t. c.

Our conclusions this far

- Work is underway, and it is the full results that should be used in any evaluation
- And we should, in any case, be open for re-evaluation
- A few of the ”circumstances” have been dealt with earlier in the present presentation
- They appear to support the alternative ”constructive”
- And so does also the stratigraphy …



1. A413, torv
2. A531, rasering av mur
3. A668, förglasad del av mur
4. A506, kulturlager
5. A608, kulturpåverkad undergrund
6. A697, fyllning skalmur

Please observe that the cultural layer (4) is located above the debris from the heating of the wall (2). The former has been C-14 dated to around 500 AD, thus indicating that the vitrification is at least 1500 years old.

This drawing was digitalized by Henrik Pihl at the Archaeologists in Lund, Sweden.

Thanks a lot for listening, not only from our team here at Broborg,

But
also from
our colleagues
in the US