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Swedish vitrified forts— a reconnaissance study

By Peter Kresten and Björn Ambrosiani

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Ten vitrified forts in the Mälaren–Hjälmaren–Vättern area of Sweden and one calcined fort (Torsburgen) on the Island of Gotland have been investigated. It was found that at some forts, extensive firing must have occurred over a long period. In the present state of investigations a deliberate, constructive act of man may explain the vitrification observed at, e.g. Broborg. At other forts the porous melts investigated indicate rapid cooling after firing, and thus either incidental firing or destructive burning by an enemy seem plausible. The latter process is certainly the cause of the calcination at Torsburgen. We conclude that there is no universal solution to the problems posed by the vitrified forts. Broad generalizations are unwarranted, and more archaeological excavations are needed.

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Vitrified forts are remnants of stony fortifications in which rock fragments or boulders have been melted and/or welded together by heat, apparently *in situ* (Youngblood et al. 1978). In cases where limestone has been used as construction material calcination, rather than vitrification, occurs.

Vitrified forts have attracted the attention of scientists since the late 18th century. The results of the studies were summarized by Cotton (1954) and Nisbet (1974, 1975) for Western Europe, and Novaki (1964) for Central and Eastern Europe. The theories put forward on the causes of vitrification and calcination can be divided into three principal groups:

1. *Incidental*: The vitrified material is interpreted as being volcanic lava or pumice used in construction. Alternatively, vitrification is considered to be an incidental effect resulting from signal-fires, bonfires, cooking-hearths or forges.

2. *Constructive*: Suitable rocks and a fuel material, such as wood or charcoal, have been

mixed and burned. This process could have taken place either *in situ*, or in specially erected furnaces, from which the material was withdrawn and used for "casting" the ramparts. The purpose was constructive in the sense that the outcome was a more resistant construction.

3. *Destructive*: A timber-laced wall (e.g. of the *muris gallicus* type) was set on fire by enemies or by accident (e.g. lightning). Under certain conditions, the fire resulted in temperatures sufficient to melt/calcine the building material. The outcome was that the fortification was, at least in part, destroyed.

The various hypotheses for an incidental effect have not found many followers. The suggestion that the vitrification was a deliberate art of construction was made already in the 18th century (see Nisbet 1974). It has been accepted by many, particularly among natural scientists (Brothwell et al. 1974, Youngblood et al. 1978, Fredriksson et al. 1983). Vitrification as an accidental effect of the destructive burning of ramparts was first

proposed by Tytler (1790). Somewhat modified by Childe (1935) and strengthened by experiments (Childe & Thorneycroft 1937), the theory is favoured by many archaeologists (e.g. MacKie 1976).

Throughout the rather extensive literature on vitrified forts it has often been assumed that there is one universal solution to the problems which they present. We feel that a more open-minded view is needed. It is highly possible that similar results—the melting of rocks—ensue from a variety of different processes. It may well be that products of incidental vitrification—by fires, from forges—were used as infillings of ramparts. In other cases, enemies may have set fire to a fort, with the intention of destroying the ramparts. Sometimes, this action could have resulted in an improved, rather than destroyed, fortification initiating constructive applications.

Thus, every case has to be judged on its own merits, and broad generalizations are unwarranted. The present study seeks to present a record of all known vitrified (calcined) forts in Sweden, without trying to answer the questions on how and why vitrification occurred in every particular case.

Swedish vitrified forts

Sweden has many forts—more than 1 000 are registered. Most of them are thought to have been constructed during the Migration Period (Ambrosiani 1978), but only a few have been excavated. On the Swedish mainland, the forts are hill-forts, built on geographically favourable sites.

The Swedish record on vitrified forts is meagre. Broborg is mentioned by Erdman (1868) and Gihl (1918). The site, along with Kollerborg and Bårfåna Skans, is briefly discussed by Schnell (1934). Apart from the recent study by Engström (1984) Swedish vitrified forts have occasionally been the subject of undergraduate research projects (e.g. Lorin 1985, Kilsberger 1981). Thus, the Swedish vitrified forts have so far been ranked as "possible occurrences" (Fredriksson et al. 1983).

All Swedish forts where signs of vitrification were reported before 1980 are included in the

present study (Fig. 1). Most of them occur close to the Mälaren–Hjälmaren system of lakes or, e.g. Torsburgen and Darsgårde, near the Baltic (Fig. 1).

We have tried to achieve a synthesis between archaeology and geology. This is important as we are dealing with ancient monuments built of rocks, which were subjected to heat. From all of the sites additional data from thin sections and chemical analyses are available, the results of which will be presented in a forthcoming paper.

The co-ordinates of the sites refer to *Rikets nät* (the Swedish national grid).

Torsburgen, Kräklingbo parish, Gotland; 636880N, 167530E.

Torsburgen is the largest fortified hill-fort in Scandinavia, with an area of 112.5 hectares. The fort has most recently been described in great detail by Engström (1984). In order to avoid unnecessary repetition, only the basic concepts relating to the calcination of the wall are given here.

The wall is about 2 km long and up to 7 m high. A section has revealed five components in the bottom half of the rampart (Fig. 2): A) an outer standing dry-stone wall; B) rubble eroded from the boulders, situated below A; K) an inner, burnt limestone wall; S) a naturally raised beach; G) an upcast gravel rampart, divided into gravel below (Gu) and gravel above (Gö). It has been suggested that "B" forms the oldest phase, followed by "K", which is connected with "Gu". "A" would then form the latest phase.

TL and C¹⁴ dating shows that the wall was probably erected during the Late Roman Iron Age, and that it was enlarged during the Migration, Vendel and Viking Periods.

In the wall component termed K, large amounts of charred wood were found together with yellowish white friable material, resembling the material discovered at e.g. Crickley Hill and Leckhampton Hill. However, it was difficult to obtain conclusive evidence for the action of heat (Engström 1979), and interpretations given varied from natural calcareous sinter to slaked lime (see Kresten, in Engström 1984).

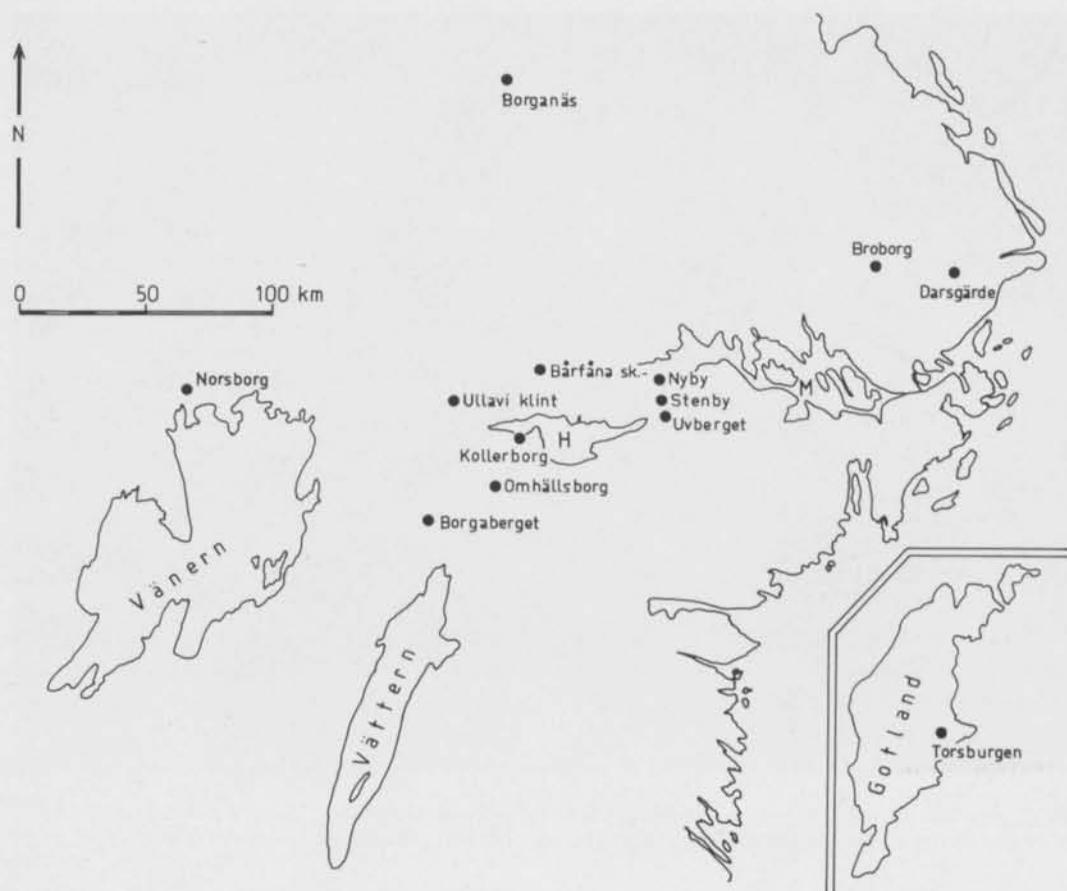


Fig. 1. Locations of the Swedish forts discussed in the text. H = Lake Hjälmaren, M = Lake Mälaren. – Läget för de svenska fornborgar som diskuteras i texten. H = Hjälmaren, M = Mälaren.

Investigation of the acid-insoluble residue provided proof of the action of heat. The basic concept was that the minor constituents would conserve the record of elevated temperatures better than the major phase, calcite. Treatment with acetic acid (12%, commercial vinegar) was successful. Inspection of the residues from calcined and not calcined material showed marked differences. In the first case, the residue was sandy, almost black and strongly magnetic. In the latter case, the residue was a clayey to silty, yellowish brownish material.

X-ray diffraction analyses (Fig. 3) confirmed the principal differences. In the reference material, quartz, clay minerals (montmorillonite interstratified with chlorite) and illite

were found, an accessory mineral assemblage frequently occurring in Silurian limestones. In the calcined material some quartz was still present but the other materials were replaced by magnetite, maghemite, fayalite and hedenbergite, an association typical of e.g. metallurgical slags.

The mineral assemblage found in the calcined material is indicative of temperatures exceeding 1 000, possibly 1 100°C, and fairly reducing conditions (oxygen fugacity of about 10^{-11}). The formation of maghemite at the expense of magnetite must have taken place later, during the recarbonization of the burnt lime. An important phase is illite, which is thermally rather stable and is restored even after heating to 1 000°C. The absence of illite



Fig. 2. Section through the wall at Torsburgen (photo: J. Engström). Inner, burnt wall marked by "K". - Snitt genom muren på Torsburgen (foto: J. Engström). Det inre, brända partiet utmärkt med "K".

in the calcined material (Fig. 3) suggests minimum temperatures of about 1100°C.

Engström (1984) has argued that the wall was set on fire by an outside enemy with the intention of destruction. This idea was supported by the results of practical experiments, whereby Torsburgen-type walls were built, then destroyed by fire. Most likely, the calcination at Torsburgen is an example of destructive firing of the walls of ancient forts.

Darsgårde, Skederid parish, Uppland; 662432N, 165100E.

Excavations at Darsgårde were performed during 1957-60. Large amounts of vitrified material were found. The general stratigraphy of the fort is as follows.

At the end of the Bronze Age, a settlement existed on the crest of the 35 m high hill. This is reflected by a soot-black layer, rich in ce-

ramic remains, found in crevices and lower levels at the site. The dating is confirmed by, inter alia, a find of a bronze axe of Mälars valley type. The settlement was not then fortified.

At the end of the Early Iron Age, c. 500 AD, the settlement was fortified. In both the western and northern walls several layers were found, despite the moderate height (1-1.5 m) of the wall.

The oldest layer is made up of red-burnt, sometimes brick-burnt clay, with humus and pieces of charcoal. These are perhaps the remnants of a timber-framed construction filled with earth. In the western wall, this layer is poorly represented.

The walls were reinforced with an outer standing dry-stone wall and an inner rampart of sharp-edged quarried stone. In the western wall was the main entrance, a gate with possi-

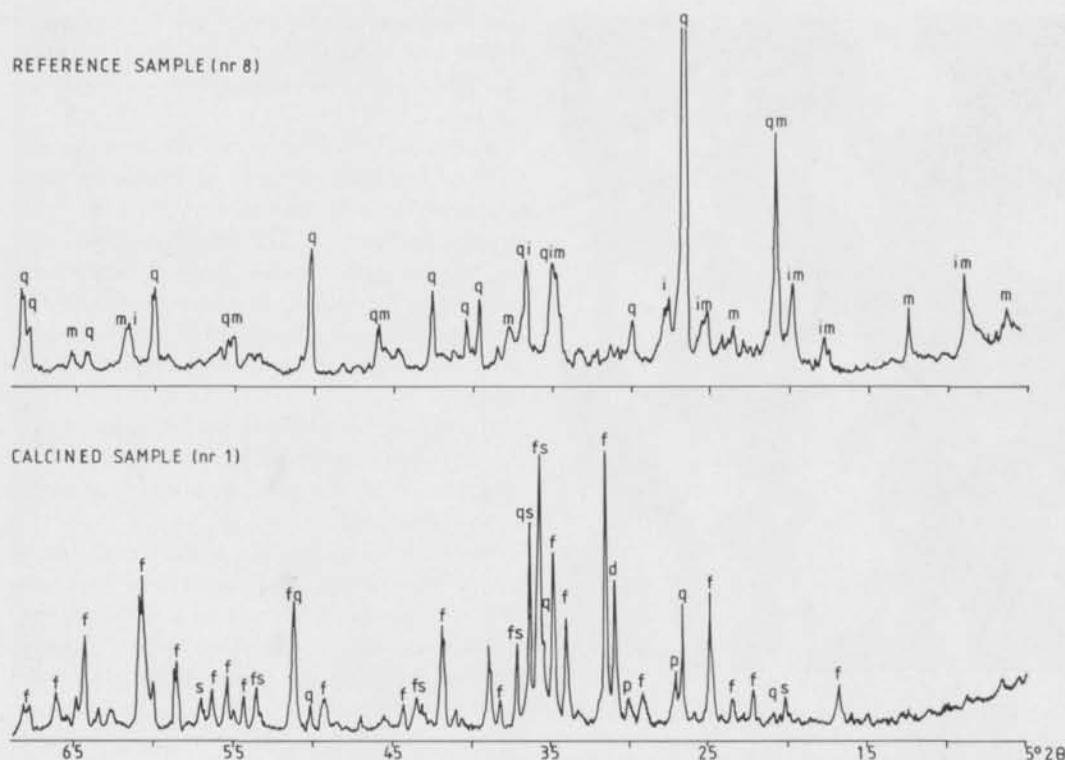


Fig. 3. X-ray diffraction patterns of the acid-insoluble minerals in unburnt limestone (top) and calcined material (bottom) from Torsburgen. d = dolomite, f = fayalite, i = illite, m = montmorillonite/chlorite, p = pyroxene (hedenbergite), q = quartz, s = spinel (magnetite \pm maghemite). Cu-radiation. - Röntgendiffraktionsmönster av de syra-olösliga mineralen i obränd kalksten (övre) och kalcinerat material (nedre) från Torsburgen. d = dolomit, f = fayalit, i = illit, m = montmorillonit/klorit, p = pyroxen (hedenbergit), q = kvarts, s = spinell (magnetit \pm maghemit). Kopparrstrålning.

ble remnants of tower constructions (Ambrosiani 1958). The inner rampart merged without marked breaks into the courtyard of the fort. Within the fort, house foundations are dated to the Migration Period. The widespread occurrence of vitrified material within the foundations seems to indicate that the house burned down.

The third stage is represented by infilling of the gate in the western wall, and deposition of vitrified material (some 25 m², up to 0.5 m thick) in the northeastern part of the wall. The material consists of pieces of soil, clay and rock, cemented together by a very porous melt. It seems plausible that the material was taken from the upper parts of the house constructions within the fort, where similar mate-

rial was found, and dumped at the northeastern wall.

The archaeological report indicates that Darsgårde burnt down—either due to an accident or due to enemy action—and that the vitrified material formed was exploited as handy source of building material.

The vitrified material is commonly grey to brownish black, very porous, and, like pumice, floats on water. Thin section shows that it is composed of medium to dark brown glass (Fig. 4), with only very rare crystals (probably SiO₂). Contacts between the glass and the incorporated rock pieces are usually sharp. The rock fragments investigated do not seem to have participated in the melting to any significant extent. They are sometimes cracked, with

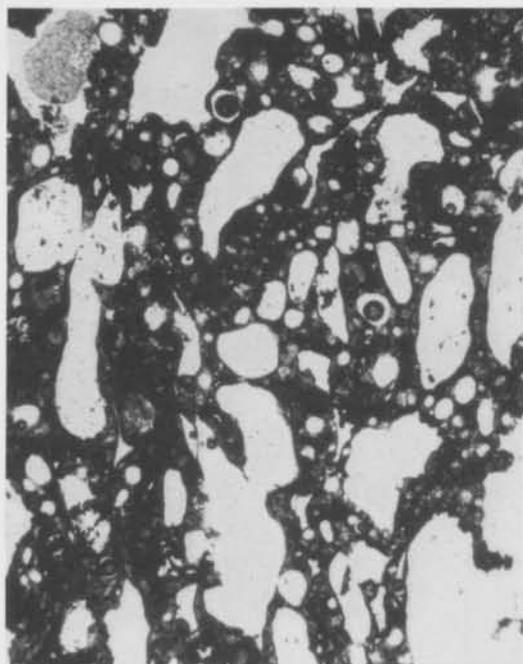


Fig. 4. Darsgårde. Micrograph of dark brown, highly porous melt. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. – Darsgårde. Mikrofoto av mörkbrun, mycket porös smälta. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

veins of glass, but appear to lack the "glazing" with a thin surface layer of melt, characteristic of many other sites. The microprobe analyses (one example in Table 1) show a rather potassic glass with highly variable contents of silica, titanium, aluminium, iron and magnesium.

Mineralogical considerations do not exclude the incidental formation of the vitrified material. The samples examined show evidence of a highly viscous, gas-charged melt which poured over material on the ground—soil, clay, rocks—without prolonged heating that would cause partial melting of these materials. Instead, the melt seems to have cooled fairly quickly after reaching the ground.

Broborg, Husby-Långhundra parish, Uppland; 662818N, 162066E.

Broborg overlooks and controls the "Långhundaleden" (Ambrosiani 1962), an ancient waterway. The first descriptions of the vitri-

fied ramparts of Broborg are by Erdmann (1868) and Gihl (1918). The latter assumed that the vitrification was caused by fire inside the fort.

A partial excavation of Broborg commenced in 1982, carried out mainly by amateurs under the supervision of Lars Löfstrand. Preliminary TL- (Mejdahl 1983) and C^{14} (Löfstrand, unpubl. report) determinations have shown an age span within the Migration Period, a dating which has been confirmed by a find of a glass bead typical of this period.

During the excavations, several house foundations were discovered and it seems that Broborg has to be classified as a fortified settlement (Löfstrand 1983).

The most characteristic feature of Broborg is the omnipresent vitrification of the wall. The wall seems to have been a standing dry-stone wall, made of rather large boulders, with an inner upcast gravel rampart. In the southern and eastern parts an outer dry-stone wall complements the inner wall (Fig. 5a). No vitrification has been observed in the outer wall. The main entrance to the fort was the gate in the south-east.

Vitrification can be seen at many places around the inner wall. Often the vitrified wall has a much smoother relief than the non-vitrified sections.

The building materials are mainly a granitic gneiss and a medium- to fine-grained amphibolite. Boulders of metavolcanic rocks are occasionally present. Already at an early stage of the study it was realized that amphibolite played an important role in the vitrification process (Kresten 1983), an assumption which was subsequently verified by chemical analyses of the molten material and amphibolite.

The (incongruent) melting of amphibolite produces spinels (magnetite and/or hercynite) not present in the original rock. Thus, the partially or totally molten amphibolite has a higher magnetic susceptibility than the starting material. For the granitic gneiss, the situation is the reverse: the rock contains magnetite which, on strong heating, is oxidised. Thus, the magnetic susceptibility is lowered during heating:

Material	Susceptibility Range	(10^{-5} SI) Average
Granitic gneiss	80-2 500	1 400
Granitic gneiss affected by heat	200-1 500	600
Amphibolite	50-600	140
Amphibolite partially molten	500-5 500	2 700
Vitrified material	400-4 500	3 000

Totally, vitrification results in a higher susceptibility. A preliminary magnetometric survey of Broborg (Fig. 5b) shows that the differences in magnetic susceptibility are sufficient to outline the extent of the vitrification of the wall. The generally higher magnetic readings within the northern half of the hill-fort are possibly caused by less glacial overburden there.

Measurements of the solidus (= beginning of melting) temperature of an average glass from Broborg in static air by differential thermal analysis yielded 1 130°C. In a nitrogen atmosphere, melting starts at somewhat lower temperatures, at about 1 075°C. The liquidus (= completely molten) temperature in nitrogen was determined to 1 235°C.

Experiments carried out in a small furnace charged with granitic gneiss and amphibolite from the area around Broborg, with charcoal fuel, showed that in an open furnace no melting occurred, not even when forced draught was applied. If the hearth was covered with turf, melting readily occurred when forced draught was employed.

As most of the vitrified walls have remained seemingly intact, it can be stated beyond all doubt that melting at Broborg occurred *in situ*. Hanging droplets of melt, or stringers of melt pouring down, provide sufficient evidence for this statement. The fuel was most likely charcoal, rather small pieces with straight terminations. This is shown by the "wood casts" (or: charcoal imprints) preserved in the melt. They are usually some 2-3 cm in diameter and 2-4 cm long. They often occur grouped together, even in small beds. Casts or cavities, which can be ascribed to the former presence of timber logs, are missing in the sections inspected.

The wall seems to be sub-divided into minor

cells, some 1 1/2-2 m long, and spanning the crest of the rampart. They are either remnants of a timber-framed construction (*murus gallicus*), or else had some other constructive function.

Vitrification has occurred mainly in the present top layer, which has a thickness of about 30 cm. Beneath, either fire-cracked boulders of granitic gneiss, or else large cavities are found. In the one section investigated, the floor of the rampart was again covered with a thin layer of melt.

In thin section, opaque, translucent brown, and colourless glasses (all with or without crystals) are found (Figs. 6, 7). The presence of droplets of pyrite and metallic iron, commonly associated with "wood-casts", indicates fairly to strongly reducing conditions.

It is obvious that the amphibolite played the most significant part in the vitrification process. The gas-charged melt penetrated the space between the gneiss boulders, invaded all open fractures in the fire-cracked rock, and also served as a flux to initiate melting of the gneiss, thus firmly cementing the whole vitrified mass.

The crest of the rampart shows a significant number of commonly fist-sized amphibolite pieces. This is remarkable, as this particular rock is rare in the bedrock and glacial boulder material at the site. Moreover, the amphibolite pieces are not glacial boulders, pebbles or the like. They seem to be hewn pieces, chopped to about fist-size or smaller, and do not fill any specific purpose, apart from being essential for the vitrification process.

Why would one collect amphibolite from the surroundings, work it into about fist-sized pieces and incorporate these in the rampart, n. b. in certain layers thereof (top surface, and a layer about 1 m beneath top), unless for a particular purpose? And the only possible purpose would be the formation of a voluminous melt when heated. Without amphibolite, the vitrification would have been much more difficult to achieve, if at all possible.

At the present state of investigations, we regard the vitrification at Broborg as intentional, a deliberate and constructive act of man.



Fig. 5a. Broborg, near-vertical aerial view (photo: B. Fredén, Uppland's Museum). – Broborg, nära vertikal flygbild (foto: B. Fredén, Upplandsmuseet).

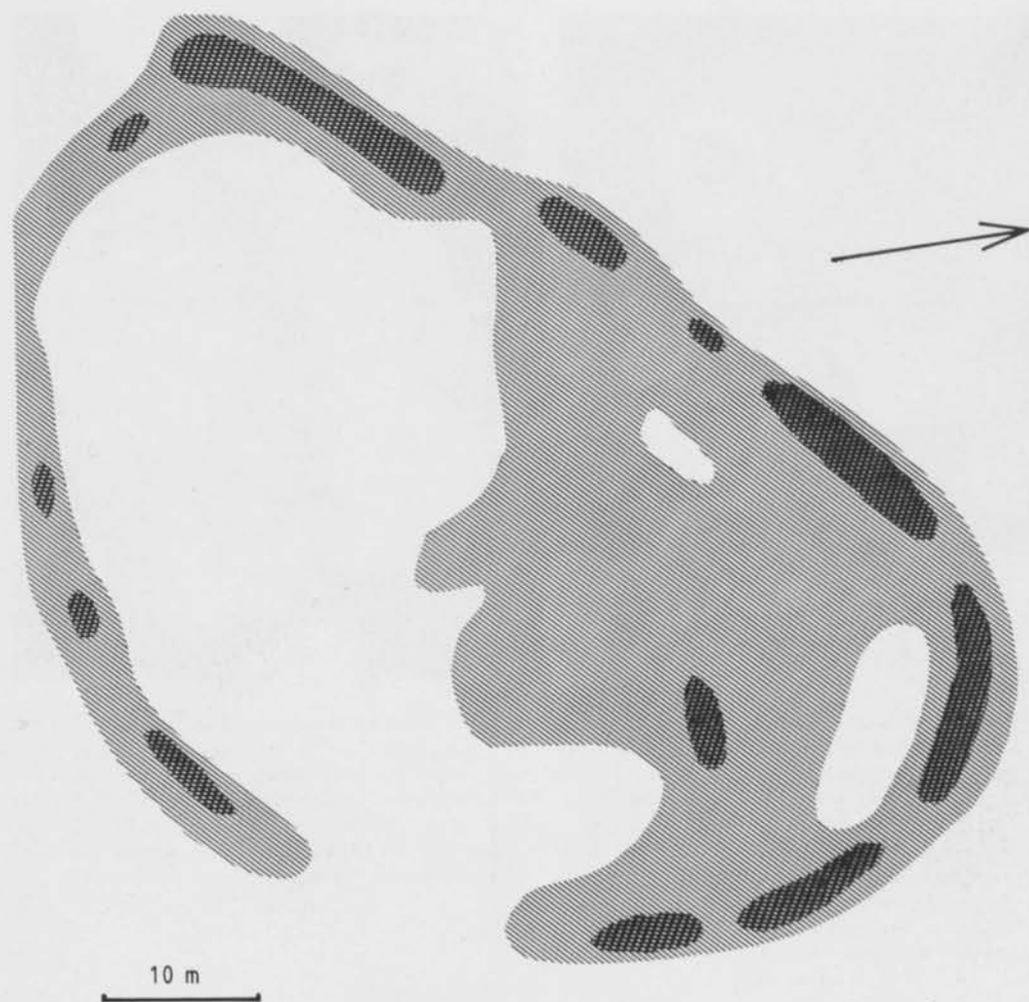


Fig. 5. *b.* Broborg, preliminary magnetometric survey. Area as shown by Fig. 5. *a.* Cross-hatched: > 51200 nT; hatched: > 51000 nT (total magnetic field). – Broborg, preliminär magnetisk karta. Område som i Fig. 5. *a.* Rutat: > 51200 nT; streckat: > 51000 nT (magnetiskt totalfält).

Nyby hill-fort, Torshälla parish, Södermanland; 658930N, 153728E.

The hill-fort at Nyby overlooks the River Nybyån. The fortification has a double wall towards the north-east; all its other boundaries are natural cliffs. Excavations of the inner wall (Lorin 1985) revealed the following stratigraphy (from top to bottom):

Soil with angular (fired?) rock fragments,
Gravel, in part vitrified,
Soot and pieces of charcoal,
Stony soil.

The whole section measured only about 0.3 m. The sample of vitrified material investigated consisted of coarse sand held together by a vitreous material. In the microscope, grains of quartz and feldspar are seen, often cracked, but rarely molten, in a matrix of various glasses (Fig. 8). Three major glass types can be distinguished: 1) clear, colourless glass; 2) clear, brown glass; 3) opaque, dark brown glass.

Varieties 1) and 3) seem immiscible and both show limited miscibility with glass 2). Melting of several source materials must have

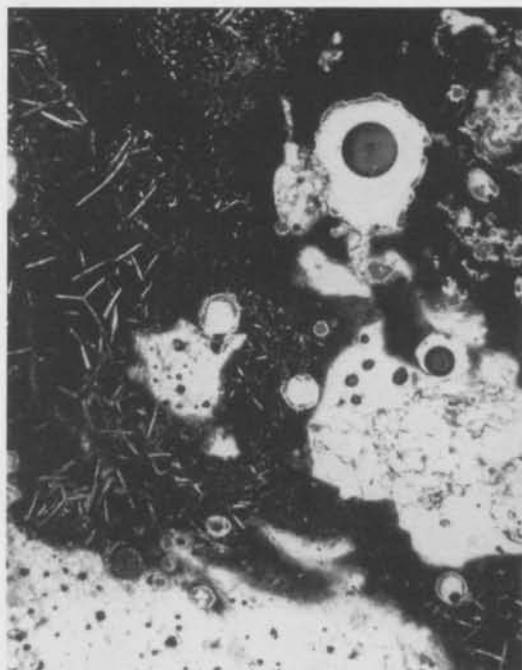


Fig. 6. Broborg. Dark brown, almost opaque glass with laths of plagioclase, derived from the melting of amphibolite. Also colourless glass, derived from the partial melting of granitic gneiss. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. – Broborg. Mörkbrunt, nästan opakt glas med lameller av plagioklas, uppkommen genom amfibolitens smältning. Dessutom färglöst glas från smältningen av granitisk gnejs. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

taken place. In view of the chemical composition of some glasses (Table 1), particularly of high to very high contents of alumina, one of the most important source materials must have been clay. The compositional heterogeneity of the glasses indicates fire, affecting several different materials, with locally extensive heat, but during a rather short period.

All the evidence suggests that a house burned down, rather rapidly and violently. As clay must have been a significant component, and both ample fuel (wood) and a fairly forceful draught seem essential for the process, a clay-lined building is the most obvious choice.

During the fire, droplets and splashes of silicate melt fell onto the ground—coarse

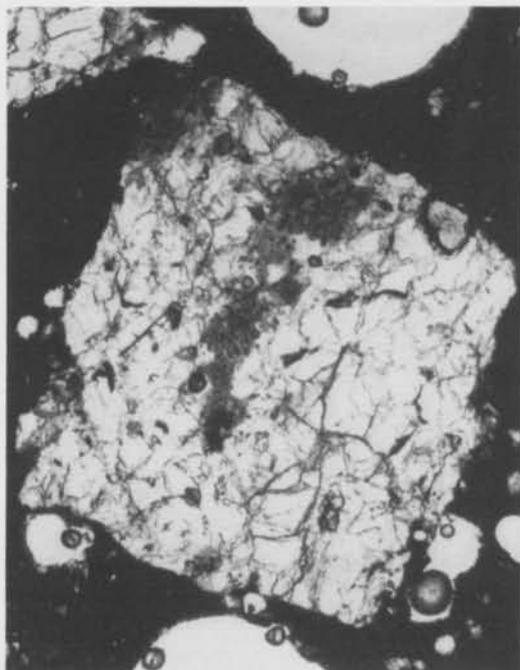


Fig. 7. Broborg. Opaque glass, with embedded feldspar grain showing incipient melting (grey areas with vesicles). Transmitted, plane polarized light. Field of view 3.5×2.7 mm. – Broborg. Opakt glas med inneslutet fältspatskorn som visar begynnande smältning (grå blåsrika områden). Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

sand, gravel—thus “cementing” it. The area was tidied up after the fire, and portions of the wall were used as waste-dumps.

Additional evidence in favour of this scenario was elicited by further excavations some 10 m from the wall, where clay lining, slag, burnt bone and several large pieces of rectangular clay lining were found (Lorin 1985).

Nyby hill-fort is therefore regarded as a good example of incidental vitrification. A C^{14} age of about 1300 A. D. was obtained on material from the bottom of the wall. It is thus comparable to *Borganäs*, a fortress in Borlänge, Dalecarlia (670883N, 148050E), which was set on fire at midsummer 1434, during the revolt led by Engelbrekt Engelbrektsson (Mogren and Svensson 1988). At this site a large quantity of porous melt was found, cov-

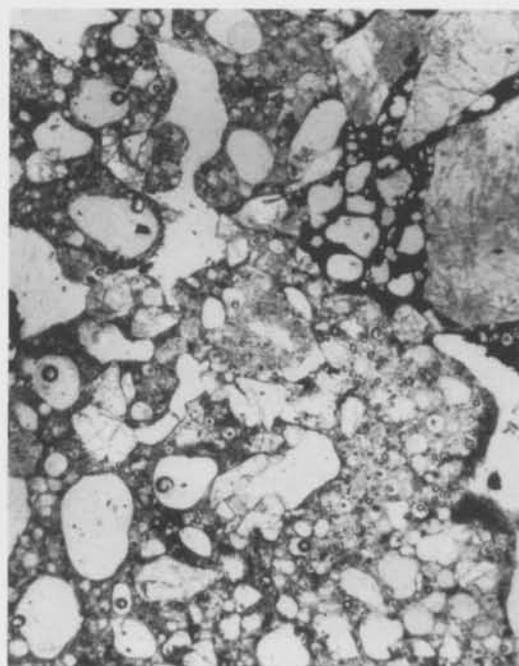


Fig. 8. Nyby. Opaque and clear glasses with vesicles and embedded mineral fragments (angular, not resorbed by the melt). Transmitted, plane polarized light. Field of view 3.5×2.7 mm. – Nyby. Opakt och klart glas, med blåsrum och inneslutna mineralkorn (kantiga, inte resorberade av smältan). Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

ering brick, gravel, or bones. The melt is similar to the vitreous material found at Nybyborgen.

Stenby hill-fort, Eskilstuna parish, Södermanland; 658340N, 153752E.

Stenby hill-fort, near Fors, Eskilstuna, is located on the top of a hill and measures about 50 m in diameter. It is surrounded on all sides by a wall with a maximum height of about 2.5 m, which in the north and south is complemented by outer walls.

Excavations in the northern part of the inner wall (Lorin 1985) have produced vitrified material. Boulders of gneissic granite are, on the downward side, covered with glassy material, which also incorporates gravel and clay. In connection with this layer, charcoal and pieces of charred wood were found, notably

one charred log, 5 cm thick and 1 m long, resting on fine sand. The layer containing vitrified material was about 0.5 m thick. TL- and C^{14} datings have yielded ages in the range 445–500 A. D.

A sample made up of chunks of granitic gneiss, somewhat cracked, cemented and veined by a grey porous melt was investigated. Minor amounts of white melt, glazing the gneiss, were observed.

In thin section, the penetration of the basic melt into the gneiss can be followed in detail. In some cases, thin stringers of melt penetrating along the cleavage planes of plagioclase in the gneiss were observed. In contrast to e.g. the sample from Nyby, the various glasses from Stenby appear to be miscible. The chemical compositions of the glasses (e.g., Table 1) are much more homogeneous, and the process seems comparable with e.g. Broborg.

Kollerborg, Stora Mellösa parish, Närke; 656933N, 148013E.

Kollerborg is situated on a hill, 45 m above sea-level, overlooking Lake Hjälmaren. The eastern boundary is a steep natural cliff. The hill-fort measures 45×22 m, and is surrounded by a wall, about 53 m long, 2–4 m wide and 1–2 m high, to the north, west and south. The wall is constructed of boulders 0.2–0.7 m in diameter. The first report on vitrification was given by Schnell (1934, p. 34), who had not visited the site himself. Kilsberger (1981) did not find any vitrified material, but abundant red-heated blocks in the southern wall.

On a visit to the hill-fort by P. Kresten, no signs of vitrification could be seen in the main wall. Two samples of vitrified material were found inside the hill-fort, at a structure which is interpreted as an inner wall. It runs in the south-central parts of the fort, about 8–10 m north of the southern (outer) wall, and measures about 4 m in length, 2 m in width, and 0.2–0.4 m in height. The samples were not *in situ*. On a subsequent visit, vitrified material was found in the southern parts of the main wall, possibly *in situ*.

The samples collected resemble those found at e.g. Broborg and Stenby. Blocks of granitic gneiss are held together by a dark,

Table 1. Selected electron microprobe analyses of glasses. – Valda mikrosondanalyser av glas.

Nr	1	2	3	4	5	6	7	8	9	10	11
SiO ₂	68.5	51.1	61.7	32.5	51.5	57.1	54.3	49.3	54.6	51.3	65.4
TiO ₂	0.61	0.85	0.12	3.1	2.2	2.7	1.5	8.8	0.23	1.7	0.0
Al ₂ O ₃	13.7	16.5	22.1	23.7	19.1	14.5	15.9	9.2	13.5	18.4	20.2
FeO tot.	5.6	9.4	1.0	20.1	9.4	14.2	13.9	20.7	11.1	11.0	0.34
MnO	0.13	0.25	0.0	0.60	0.28	0.14	0.18	0.25	0.21	0.10	0.0
MgO	1.7	6.2	0.26	13.3	5.7	1.2	2.5	2.2	1.7	1.5	0.0
CaO	1.5	9.8	1.40	0.94	4.9	3.1	1.2	2.6	12.5	5.8	0.62
Na ₂ O	1.6	2.8	5.8	1.4	5.1	3.0	2.2	1.1	4.2	5.5	5.0
K ₂ O	4.2	1.3	5.9	1.8	1.6	2.8	5.1	4.0	0.0	1.8	6.6
P ₂ O ₅	0.0	0.27	0.24	0.0	0.12	0.24	1.1	0.35	0.0	0.17	0.0
Total	97.54	98.47	98.52	97.44	99.90	98.98	97.88	98.50	98.04	97.27	98.18

- 1 Darsgårde, medium brown glass. – Mellanbrunt glas.
- 2 Broborg, average opaque glass. – Genomsnittligt opakt glas.
- 3 Broborg, clear glass. – Klart glas.
- 4 Nyby, opaque glass. – Opakt glas.
- 5 Stenby, opaque glass. – Opakt glas.
- 6 Kollerborg, opaque glass. – Opakt glas.
- 7 Omhällsborg, dark brown glass. – Mörkbrunt glas.
- 8 Borgaberget, opaque glass. – Opakt glas.
- 9 Ullavi Klint, brown glass. – Brunt glas.
- 10 Norsborg, opaque glass. – Opakt glas.
- 11 Norsborg, clear glass. – Klart glas.

greyish black, very porous melt. Rarely, a thin glazing of porcelain-white melt covers parts of the gneiss.

The thin section reveals opaque glass, commonly studded with crystals of spinel, pyroxene, or plagioclase. Further, a medium brown translucent glass without crystals, and a clear colourless glass, evidently the product of incipient melting of feldspar from the gneiss, is seen (Fig. 9).

Bårfåna Skans, Fellingsbro parish, Västmanland; 659300N, 148892E.

Bårfåna skans is situated on the top of a hill, 35 above sea-level. The western parts of the hill-fort are defined by a natural escarpment, other boundaries by a wall, some 120 m long, 3–10 m wide, and 0.3–1.2 m high. The size of the hill-fort is about 30 × 45 m. Schnell (1934, p. 30–31) reports that the boulders in the northern parts of the wall had been heated so they had disintegrated into sharp-edged gravel. On P. Kresten's visit to the site, the sharp-edged gravel was found, but no decisive signs

of extensive heat applied to the rocks seen. For the time being, the question of whether or not Bårfåna Skans is indeed vitrified remains open.

The same applies to *Uvberget*, Kloster parish, Eskilstuna city, Södermanland (657957N, 153888E), where sharp-edged boulders with no clear signs of vitrification are reported to occur (Lorin 1985). The heat cannot have been too high, as is indicated by the presence of radioactive haloes around zircon in biotite. Temperatures in excess of about 400°C would have annealed the haloes.

Omhällsborg, Sköllersta parish, Närke; 655195N, 147183E.

Omhällsborg is situated on the summit (105 m above sea-level) of a hill, which slopes steeply towards the north, north-east and north-west. To the south and south-west, the hill-fort has double walls, 10 m apart. The inner wall is 80 m long, the outer 140 m long, both are about 10 m wide and 1.5 m high.

Samples of vitrified rocks have been stray

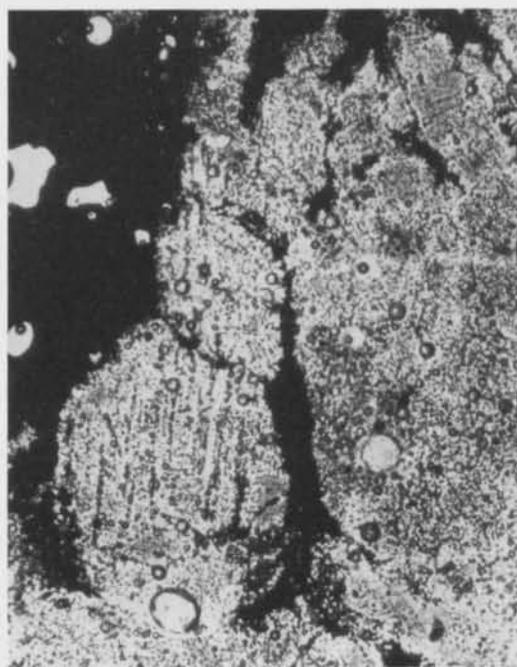


Fig. 9. Kollerborg. Opaque and clear glass. Note that the clear glass was obviously derived from the melting of feldspar—vesicles follow paths of cleavage planes in the original mineral. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. — Kollerborg. Opakt och klart glas. Lägga märke till att det klara glaset uppenbarligen uppkommit genom smältning av fältpat — blåsruman följer spaltytorna i det ursprungliga mineralet. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

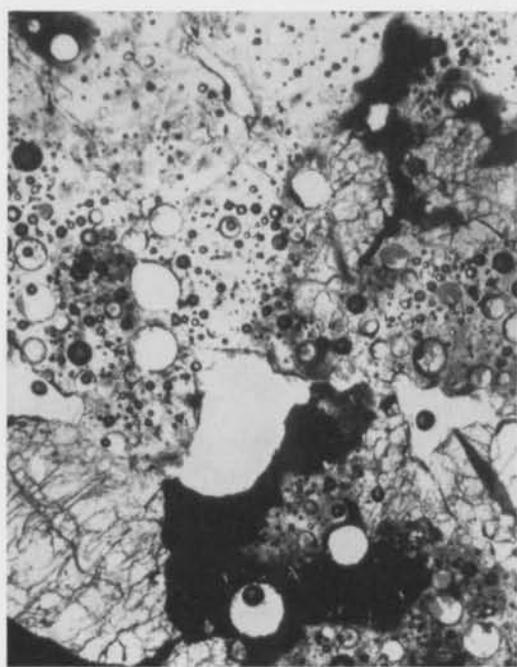


Fig. 10. Omhällsborg. Opaque, brownish and clear glass, together with remnants of the granite. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. — Omhällsborg. Opakt, brunaktigt och klart glas, samt rester av granit. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

finds, mainly from the centre (highest point) of the hill-fort. It was assumed that in Omhällsborg, fires for signalling have been lighted, and that the vitrified material was an effect of these (see Kilsberger 1981).

One of these stray finds was investigated. It is a piece of granite with adherent dark grey, porous melt. In thin section, three types of glass are visible (Fig. 10): a dark brown, almost opaque glass with tiny laths of feldspar; a dull brownish glass with abundant gas inclusions and feldspar laths; and a colourless glass with abundant gas inclusions. The colourless melt is obviously derived from the melting of feldspar in the granite, and all three glasses vein through the granite. Thus, the petrographic

situation is similar to that at Broborg, or Kollerborg.

Borgaberget, Snavlunda parish, Närke: 653792N, 144495E.

Borgaberget is located on a 130 m high hill, along a 40 m steep cliff to the west. The size of the hill-fort is about 120×70 m, and it is bounded to the north and east by double walls, some 100 m long, about 1 m high.

The material investigated consists of a single stray find of vitrified material, found under the roots of a tree near the wall. No excavations have been made, so nothing can be said regarding the amounts of vitrified material present at the site.

The sample is a piece of granitic material, with ample adhering grey vesicular melt, with typically flattened vesicles. The melt has superficially penetrated the granite. In thin section, the melt is opaque and crowded with

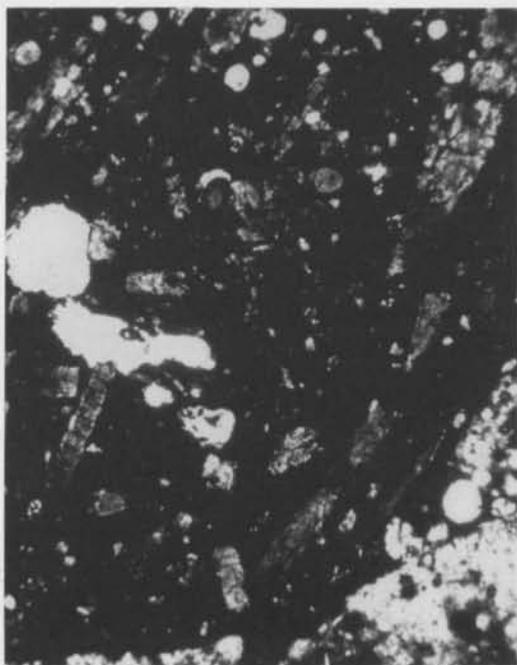


Fig. 11. Borgaberget. Opaque melt with abundant laths of plagioclase feldspar. Small amounts of colourless melt. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. – Borgaberget. Opak smälta, rikligt med lameller av plagioklas. Små mängder färglös smälta. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

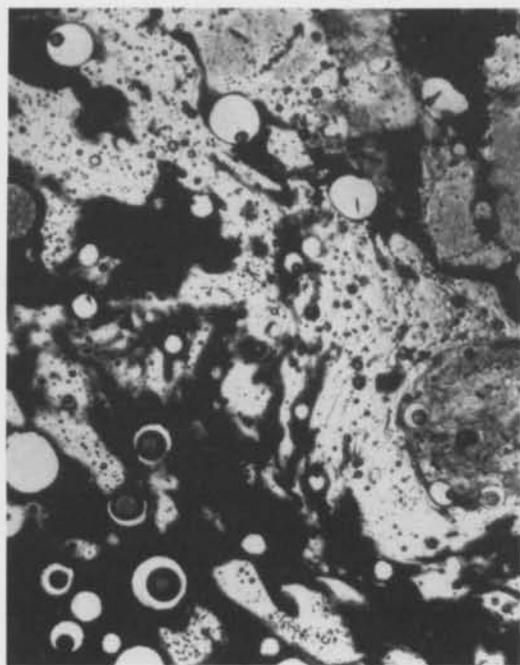


Fig. 12. Ullavi Klint. Mixture of brown (almost opaque) and colourless, highly vesicular glasses. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. – Ullavi Klint. Blandning av bruna (nästan opaka) och färglösa, blåsrumrika glas. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

vesicles and laths of feldspar (Fig. 11). The contacts are rather sharp and only minor amounts of locally developed melt are found in the granite. The composition of the opaque glass (Table 1) deviates markedly from all other analyses reported in this paper and elsewhere from vitrified forts: titanium contents are high to extremely high. One of the two analyses made even shows very high phosphorus contents.

Ullavi Klint, Kil parish, Närke; 658415N, 145497E.

Ullavi Klint is situated on a hill (185 m above sea-level) with steep slopes towards the north-east, east, south and south-west. A crescent-shaped wall, 100 m long, about 12 m wide and 3–4 m high, encloses the hill-fort to the north, north-west and west. A single sample of vitrified material has been found just outside

the south-western flank of the wall (Kilsberger, pers. comm.), which was donated to the present investigation.

The sample is again made up of granitic material, covered and veined by grey vesicular melt. In thin section, brownish and colourless glasses are distinguished (Fig. 12), with or without crystals (Table 1).

Norsborg, Nor parish, Värmland; 659055N, 135350E.

Norsborg is the westernmost hill-fort. It is situated on the flanks of a steep hill-ridge ("Hökberget"), 95 m above sea-level. Towards the east and south-east, the hill dips steeply; towards the north, west and south, a 100 m long about 6 m wide and about 0.5 m high wall surrounds the hill-fort. In parts of the wall, vitrification is both evident and intense, with slag stringers up to 5 cm across.

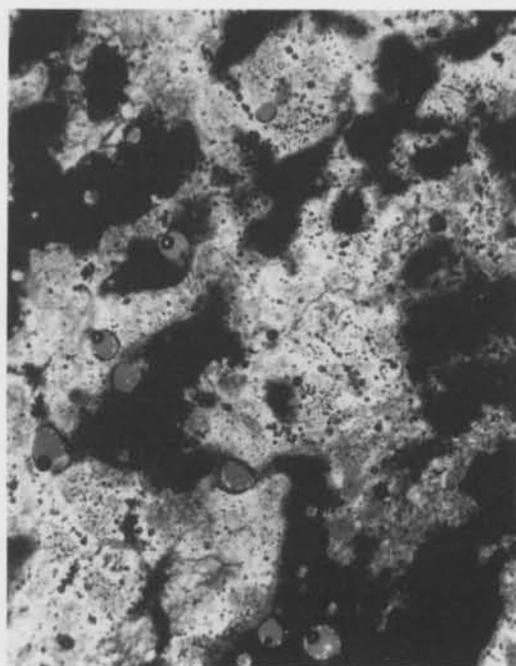


Fig. 13. Norsborg. Opaque, brown, and colourless glasses with distinct flow texture. Transmitted, plane polarized light. Field of view 3.5×2.7 mm. — Norsborg. Opaka, bruna och färglösa glas med tydlig flytstruktur. Genomfallande, planpolariserat ljus. Bildfältets storlek $3,5 \times 2,7$ mm.

The building material of the wall is a granitic gneiss. When vitrified, it is covered with, and penetrated by, a grey vesicular melt, and the gneiss fragments are rounded off, smoothed and covered with a glaze of porcelain-like melt.

In thin section, various glasses are distinguished—opaque, clear brown, and colourless (Fig. 13). Some of the glasses contain crystals of spinel and feldspar.

Summary

The hill-forts investigated can be sub-divided into several groups:

1. *Extensive firing resulting in more than one melt*: Broborg, Stenby, Kollerborg, Omhällsborg, Ullavi Klint, Norsborg. Vitrified hill-forts *sensu stricto*, according to the definition by Youngblood *et al.* (1978). At Broborg, the vitrified material is found *in situ*, constituting

the top level of most of the inner wall. The presence of two different rock components, both of which are essential for a durable vitrified product, implies that we here have a deliberate and constructive act of man. The other occurrences are represented by only a few finds, most of them without proper documentation by archaeological excavations.

2. *Commonly porous melt, rapidly cooled, not in place*: Darsgårde, Nyby, Borganäs. For all three cases it has been shown that burning house constructions were involved. For Borganäs, the historical record gives us the details of a revolt leading to the destruction of the Castle by an attacking enemy. In the other cases, either incidental firing or destructive burning seem possible.

3. *Destructive firing of a limestone rampart*: Torsburgen. A "calcined" fort with all evidence of destruction by fire caused by enemy action.

4. *Fire-cracked stones only*: Bårfåna skans, Uvberget.

5. *Unclassified stray-finds*: Borgaberget. Groups 4 and 5 require more observations and/or excavations.

The problem of the vitrified forts (*sensu lato*) seems to have several facets, and certainly not only one universal solution. Despite the efforts of scholars and scientists during some two hundred years, we are still struggling with the problem, and much more work will be required, with regard to both archaeology and geology.

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Sammanfattning. Svenska vitrifierade fornborgsvallar – en översiktlig studie

Vitrifierade fornborgsvallar är sammankittade av ett glasigt material, uppkommet genom smältning av bergarter vid höga temperaturer. De undersökta fornborgarna kan indelas i följande grupper:

1. Utdragen upphettning som resulterade i flera olika smältor: Broborg, Stenby, Kollerborg, Omhällsborg, Ullavi Klint och Norsborg. Endast i vällen vid Broborg förekommer vitrifierat material *in situ* och utgör det överst bevarade lagret i större delen av vallens längd.

Urvalet av två komponenter (amfibolit och granitisk gnejs), vilka båda behövs för att uppnå en hållbar vitrifierad produkt, gör det troligt att vitrifieringen uppkommit genom en planerad och konstruktiv handling. Uppnådda temperaturer var i intervallet 1130–1230°C. Övriga förekomster representeras av enstaka fynd. Flertalet borgar är inte grävda.

2. Vanligen blåsrök smälta, snabb avkylning, inte på platsen: Darsgårde, Nyby, Borngnäs. För samtliga dessa borgar har det kun-

nat visas, att nedbrunna huskonstruktioner varit inblandade. Borganäs har bränts i historisk tid.

3. Destruktiv bränning av en kalkstensmur: Torsburgen (se Engström, 1984).

4. Enbart skörbränd sten: Bårfåna skans, Uvberget.

5. Oklassificerade ströfynd: Borgaberget.

Således kan somliga vitrifierade fornborgsvallar vara konstruktiva bildningar, medan andra sannolikt eller säkert är bildade genom destruktion. Varje förekomst bör utvärderas för sig; generaliseringar är olämpliga. Fler utgrävningar behövs, liksom arkeologisk och geologisk forskning.

