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Individual variability in Rune Carving on Rock
A comparison between individuals and workshops

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The aim was to explore intra-individual variability in rune carvers' cutting techniques and how this differs from inter-individual variation. The method used is Surface Structure Analysis by laser scanning, as developed at the Archaeological Research Laboratory, Stockholm University (Freij 1986, 1990; Kitzler 1998, 2000; Kitzler Åhfeldt 2001). The variation in cutting techniques is discussed in the light of a Principal Components Analysis of a reference material consisting of five recently cut rune stones. A selection of rune stones associated with the name Fot is also analysed, the author's interpretation being that at least three individuals were involved in their production. A comparison between the Fot rune stones and some associated with the name Öpir does not show any great differences between the two groups – i.e. the differences between individuals are greater than the common traits within a group.

Introduction

The conclusions of stylistic and runological studies of regional or chronological issues concerning rune stones often include a reservation regarding the possibility of individual variability, which is known in linguistic circles to confuse research into runological trends and introduce uncertainties or even errors into dating attempts (cf. Antonsen 1998, p. 151f). This sometimes means that the runological date is at variance with the archaeological one (K.M. Nielsen 1970). As for style, this has proved in other handcrafts to be a vague criterion for attribution to individual craftsmen, e.g. in bracteate production (Wicker 1994, p. 65; 1998, p. 260). Another example suggesting that craftsmen do not stick to a certain style are motif-pieces, which have been found with both Anglo-Saxon and Scandinavian types of ornament on the same piece (O'Meadhra 1987, 1997). At points where it has been realised that individual variability is a limiting factor for safe dating or attribution of a rune stone, hopes have been placed in analyses of cutting techniques. Unfortunately these have also proved to be subject to intra-individual variability. Some factors implicated in this have been discussed in earlier papers. One is that a carver seems to change his ornament cutting techniques more than his rune cutting ones in the course of a long career. Another is that difficult parts of an ornament require greater care, so that the cutting marks differ from those found in the simpler parts (Kitzler 1998). The aim of this paper is to explore further the individual variability that exists in cutting techniques and to attempt to assess how this differs from inter-individual variation. The method employed to do this is Surface Structure Analysis based on laser scanning and statistical data, as developed at the Archaeological Research Laboratory, Stockholm University (Freij 1986, 1990; Kitzler 1998, 2000; Kitzler Åhfeldt 2001).

Fot is a known rune carver who shows considerable variation in both style and motif on the eight rune stones that he has signed (Axelson 1993, p. 28), or possibly nine, if we include U257 (Wessén & Jansson 1940–43, p. 425). Two stones (U605, U638) are known to have been lost, and on one the signature is known only from a drawing (U464). The remaining five rune stones show a great variety in style, and a great number of other rune stones have also been attributed to Fot (Wessén & Jansson 1940-58; Crocker 1982; Axelson 1993). From a stylistic point of view, it is far from evident that the signed rune stones were carved by the same individual, but even so, conclusions have been drawn on Fot's working habits and characteristics on the strength of this limited reference material. It has been said of one of the rune stones (U464) that it would never have been attributed to Fot, had it not been for the signature (Wessén & Jansson 1945, p. 278), while the irregular distribution of the runes on U678 is said to be 'surprising' (Wessén & Jansson 1949). This material is obviously highly suitable for a discussion of individual variability.

Special attention will be paid here to the rune stone in Skokloster, U678. This monument is particularly interesting because it is a case where the runological date proposed differs from the stylistic date. U678 has been discussed in connection with the Sparlösa monument (Almgren, O. 1940; Almgren, B. 1940; c.f. Kitzler Åhfeldt 2000), and has figured in discussions of the possible revival of the Vendel style in the Viking period (Nerman 1959, p. 200f; Christiansson 1959, p. 152ff; Fuglesang 1980, p. 89f, p. 90; Crocker 1982, p. 125f; Gustavson & Selinge 1988, p. 45). The equestrian on this rune stone is very similar to metal artefacts from the Vendel period, and it has also been argued that Fot added a runic inscription to an older picture stone (B. Almgren 1940, p. 155; Nerman 1947, p. 126), although others think that the ornament and the inscription are contemporary. On the other hand, it has been suggested that the equestrian is an archaism (Jacobsen 1931, p. 108; Gjessing 1934, p. 182). The difficulty entailed in solving this question by surface structure analysis is that if Fot re-cut the equestrian, as has been suggested by B. Almgren (1940, p. 27), he thereby destroyed the cuts made by earlier carvers. Wessén & Jansson presume that the stone mason and the carver were one and the same person (U678; Wessén & Jansson 1949, p. 176) which implies that this person was in possession of more tools for working in stone than merely a chisel and a wooden mallet. The ornament is presumed to have been cut in the order 1) rune frame, 2) equestrian and 3) cross (Wessén & Jansson 1949, p. 177). It should be added that the carving surface had been walked over on a church floor for an unknown length of time (Wessén & Jansson 1949, p. 174).

Sampling and laser scanning

The microtopographies of a number of runes and sections of ornament on each rune stone were recorded by means of a laser scanner consisting of a laser measuring probe mounted on a frame, within which it can move under PC control. Height values can be collected at intervals decided on by the analyst. An interval of 1 mm is used for analysing cutting techniques, but this could be reduced to as little as 0.025 mm for closer microtopographical studies. The vertical measuring accuracy under ideal conditions is reported to be 2 µm (Arrhenius & Freij 1994, p. 104f.). As a routine procedure, ten variables are extracted from the raw data matrix resulting from the laser scanning (fig. 1, Kitzler 2000).

The samples are collected by making casts in plasticine. The recording of a microtopography via a cast naturally implies a source of error, but since the structure in the cut that is of interest with respect to the cutting technique lies within the approximate range 0.5–12 mm, a small error has been judged as being acceptable. A comparison of direct recording versus recording via a cast is shown in fig. 4c. Examples of other materials used for cast and duplication purposes are silicon and latex. Stone conservators Hans Erik Hansson and Jarema Bielawski at the Swedish National Heritage Board have produced casts in silicon, which makes a durable duplicate with minute rendering of details, but is potentially aggressive with respect to a too strong adhesion of the silicone to

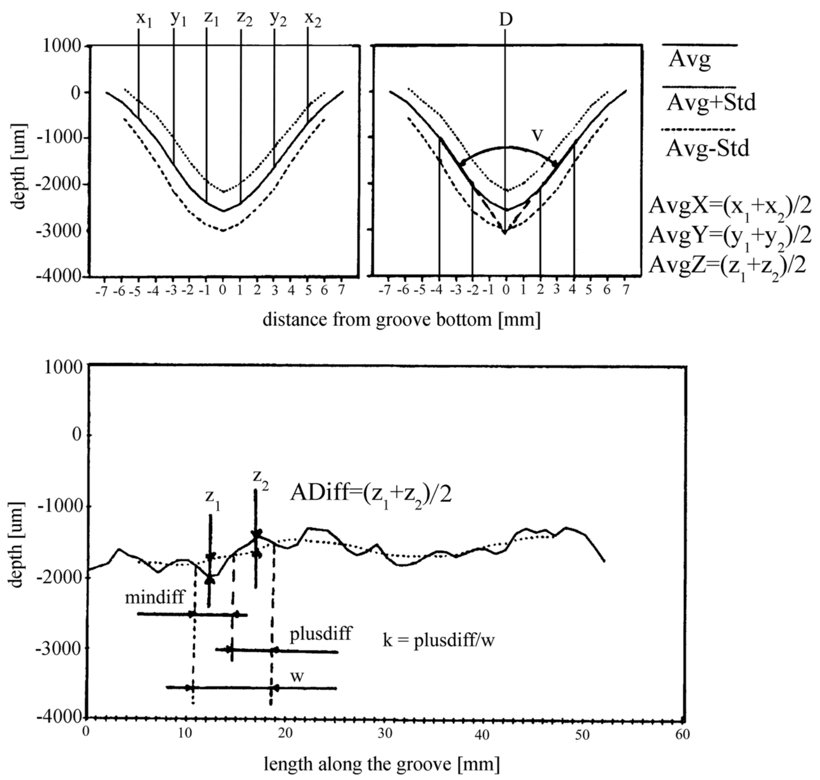
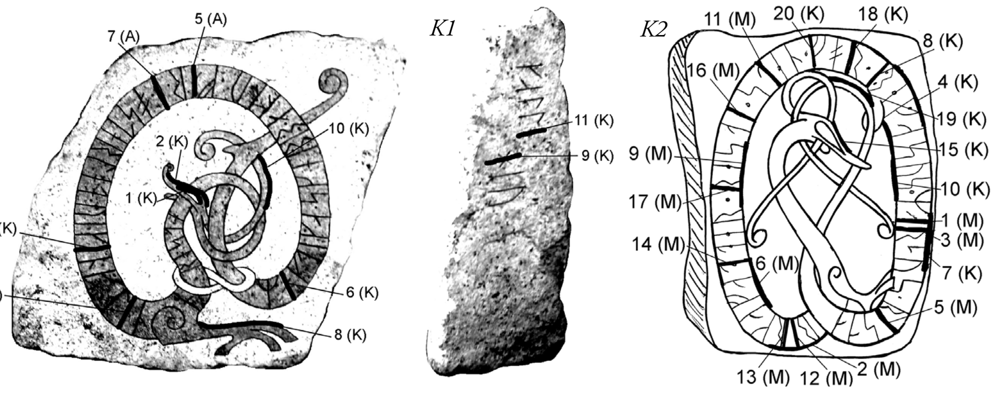


Figure 1. Variables.

a)



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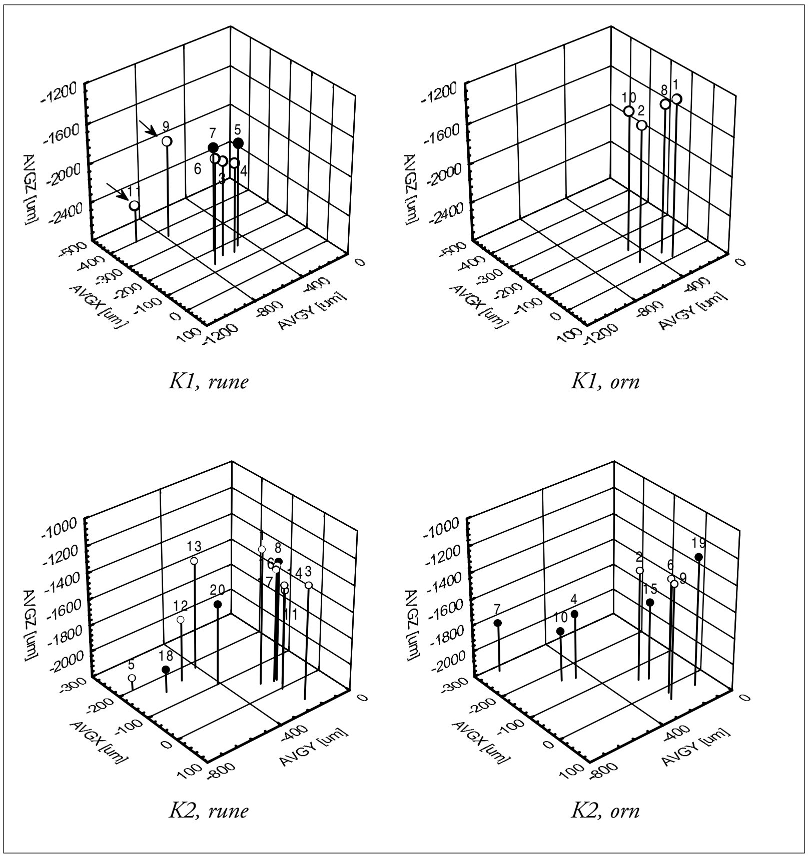
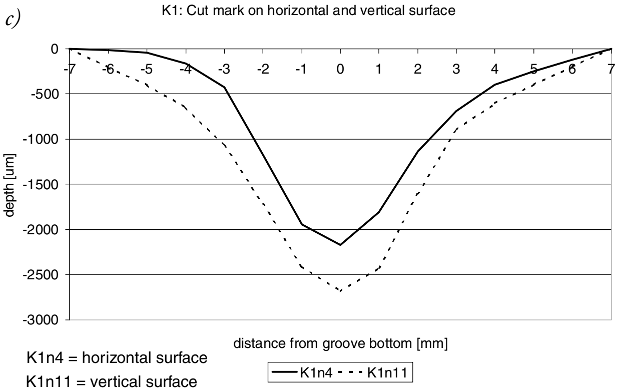


Figure 2. Reference material: K1 and K2, produced by Kalle (K) and his assistants Markus (M) and Anonymous (A). Granite.
a) Samples.
b) Mean profile diagrams.
c) Individual variability in the mean profile. Comparison between horizontal and vertical surfaces.
d) Individual variability in the mean profile. A beginner's cuts on day 1 and day 2.

c)



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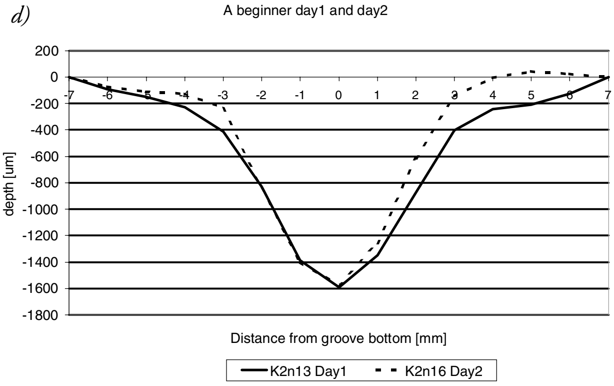


the stone surface. Mould-materials such as silicones can therefore not be used on antiquarian objects unless a protective layer is applied to the stone prior to mould-making. Normally such a protective layer consists of cellulose-glue. The glue needs to be completely dried out before application of silicone, which can pose some problems on-site (Hans Erik Hansson, pers. comm). Cellulose tissue is another potential material for casts, but a preliminary test on a fragmented rune stone from Visingsö has shown that these casts shrink by about 15% relative to plasticine casts. Other materials suggested by suppliers of artists' materials either have the disadvantage that they are viscous and would run off the carving surface or that they need to be heated, are chemically aggressive or are meant for small objects and are simply too expensive for making casts of runes and ornaments in the numbers needed for analysis.

I have argued earlier for the existence of an individual cutting technique that might be discernible in spite of changes in tools or materials, ageing of the carver or increases in his skill (Kitzler 1998, 2000; Kitzler Åhfeldt 2000, 2001). The main argument for consistency in cutting is that human beings are likely to develop their motor performance to a uniform pattern when tasks are repeated (Singer 1980; Welford 1976; c.f. Hill 1978). This motor performance is largely subconscious and individual (Singer 1980; Welford 1976; c.f. Hill 1978). Nevertheless, there is doubtless also a certain amount of individual variability. When interpreting the results of analyses of ancient rune stones, I have earlier relied on two stones cut by the modern rune carver Kalle Dahlberg and two of his assistants in the 1990's. The critical point has been made previously that this reference material is too small and that these two rune stones were cut with modern chisels having steel points. This paper presents the results of methodological studies on a larger reference material, with the aim of distinguishing not only between individual rune carvers but also between workshops.

The reference material

The reference material for the methodological studies consists of four rune stones, all cut in the 1990's, by a total of four carvers. The 'master craftsmen' were Kalle Dahlberg of Uppland, Sweden, and Erik Sandqvist of Jylland, Denmark. They will be referred to in the following discussion of their role as carvers by their Christian names, in the same way as their Viking Age models. These two carvers were responsible for two rune stones each, in addition to which, Kalle had two assistants for his two stones (K1, K2). In addition, Kalle cut two grooves, one with a hand-forged chisel and the other with a steel point, on a small granite sample (K4) to facilitate comparison of the two tools. This sample also made it possible to compare direct recording by laser scanning with measurements made on casts. The influence of a number of factors on the marks cut in rune stones can be studied on the basis of these four modern examples. Individual variability can be compared with the greater differences discernible between two groups of carvers. Common to both craftsmen is the caution needed when cutting certain parts, e.g. the eye of the runic beast or the ᚼ-rune.

A number of papers have been produced with the primary aim of distinguishing between individual rune carvers (Freij 1986, 1990, 1992; Kitzler 1998, 2000; Kitzler Åhfeldt 2000, 2001). Since the modern reference material has now been extended, the issue will be addressed again here.

K1 (fig. 2a). The main carving was cut on a horizontal surface, but the outliers, samples 9 and 11, were cut on the rough gable side after the stone had been erected. Samples 5 and 7 were cut by an assistant (Anonymous), but they are

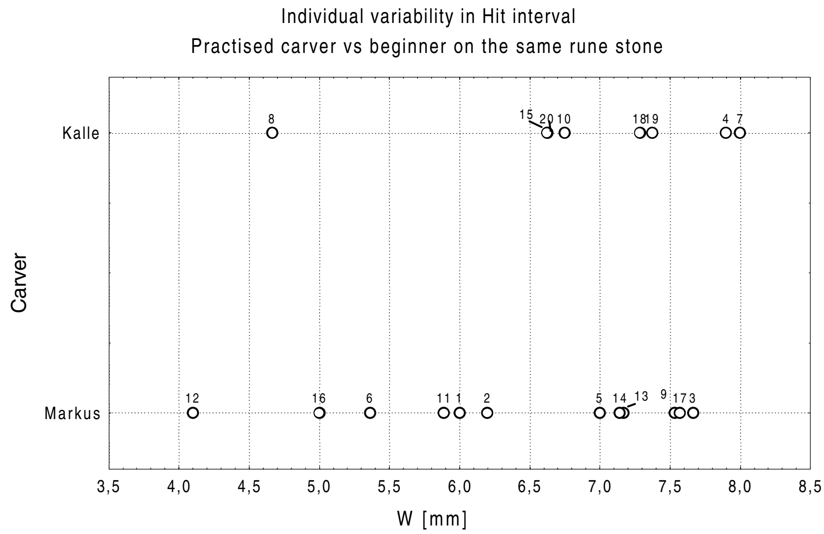
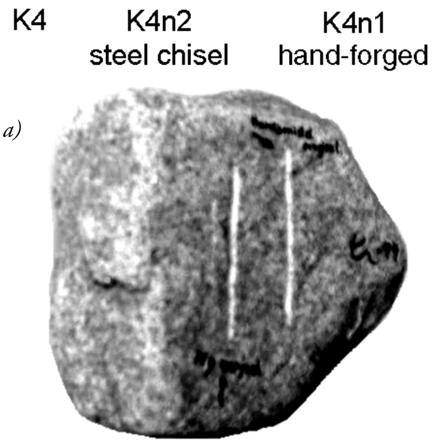


Figure 3. Point diagram of hit interval on K2.

a)



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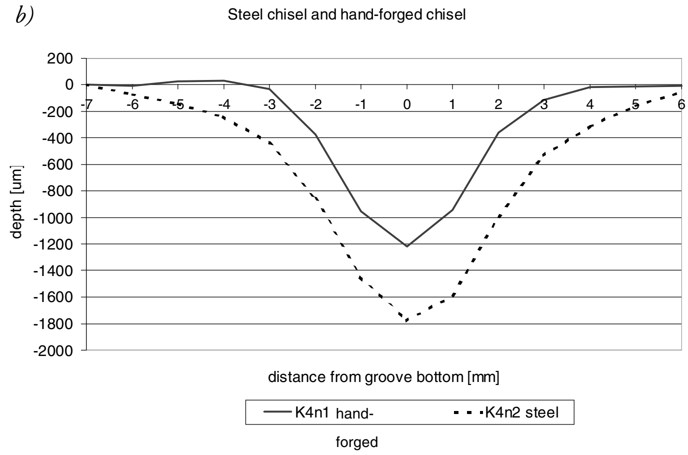

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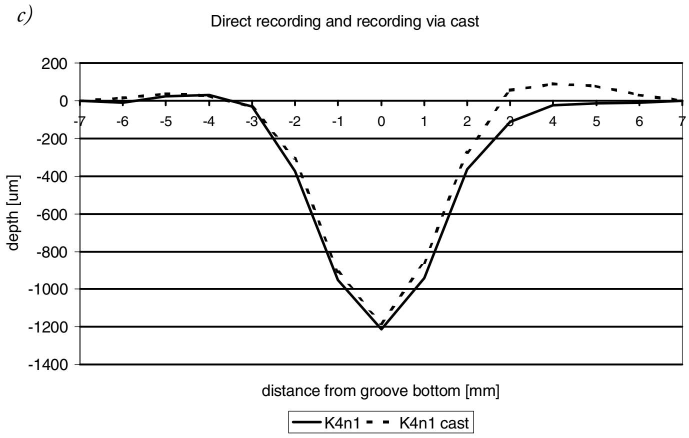


Figure 4. Reference material: K4, 0,25 x 0,2 m, granite.
a) Samples.
b) Steel-pointed chisel and hand-forged iron chisel
c) Direct recording versus recording via a plasticine cast.

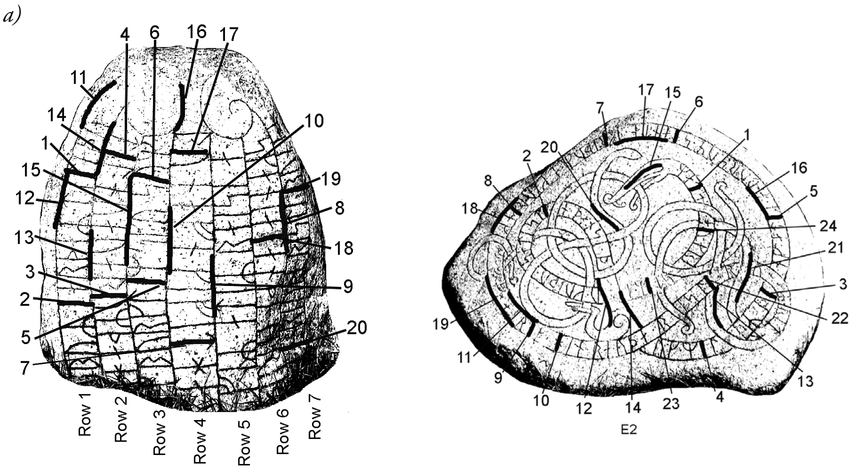
difficult to tell apart from the other runes in the *mean profile diagram* (fig. 2b), in which the shape of the cross-section of each cut sampled is represented by three variables (*AvgX, AvgY, AvgZ*). One possible reason why it is difficult to distinguish between these two carvers is that both are beginners, neither has yet achieved a distinctive individual style of motor performance.

K2 (fig. 2a). The carving was done by Kalle and Markus Hobring, one of the assistants in co-operation, sharing the same range of tools. Markus was cutting his very first runes and ornaments on this stone, under Kalle's supervision. He started on the left side of the carving and worked his way upwards along the rune animal. Kalle noticed that one of Markus' problems was that he could not hold the point steady, so that it 'jumped'. This ought to have the effect of causing the deeper pits in the groove bottom indicating hits with the mallet to appear at irregular intervals (Dahlberg, pers.comm; cf. Kitzler 1998) and should be quantifiable in terms of the standard deviation of the hit interval for all the samples. In the point diagram for *w* (fig. 3) it can be seen that Kalle's cutting is more uniform, and it can also be noted in the mean profile diagrams (fig. 2b) that the beginner cut grooves of lesser depth than the more skilled carver engaged on the same work, and consequently removed less material. The probable explanation for this is that the more experienced carver had a more efficient cutting technique (Freij 1996; Kitzler 2000; Kitzler Åhfeldt 2000, 2001). Kalle cut the more difficult parts of the ornaments, the same ones as required particular caution in E2, e. g. the eye of the runic beast.

K4. (fig. 4a). Two grooves were cut by Kalle, one with a steel-pointed chisel and the other with a hand-forged iron chisel, with the intention that they should be visually as similar as possible.

E1. (fig. 5). The inscription has been cut from left to right. One tendency that can be noted in the mean profile diagram (fig. 5b) is that the beginning of the inscription is cut deeper than the end part. The deepest runes are on text rows 1–4, the intermediate position is taken by samples 5, 6 and 17 in text rows 3–4, and by the end of text row 4, after about half of the inscription has been completed, sample 7 is definitely more shallow than the earlier runes. Finally the shallowest runes of all are samples 18 and 20, in text rows 6–7. The same tendency appears in the ornamentation, but it is less consistent. In actual values, the difference in *AvgZ* between the deepest mark and the shallowest one is 1.6 mm. This carving was made on a vertical surface, which may account for the steadily decreasing input of energy from the carver.

E2. (fig. 5a). The rune samples are located in a broad swarm in the mean profile diagram, but with no interruptions that would indicate the presence of an assistant. One interesting feature in this carving is the variation in ornamentation. There are two outliers. At the time of sampling, *a)*



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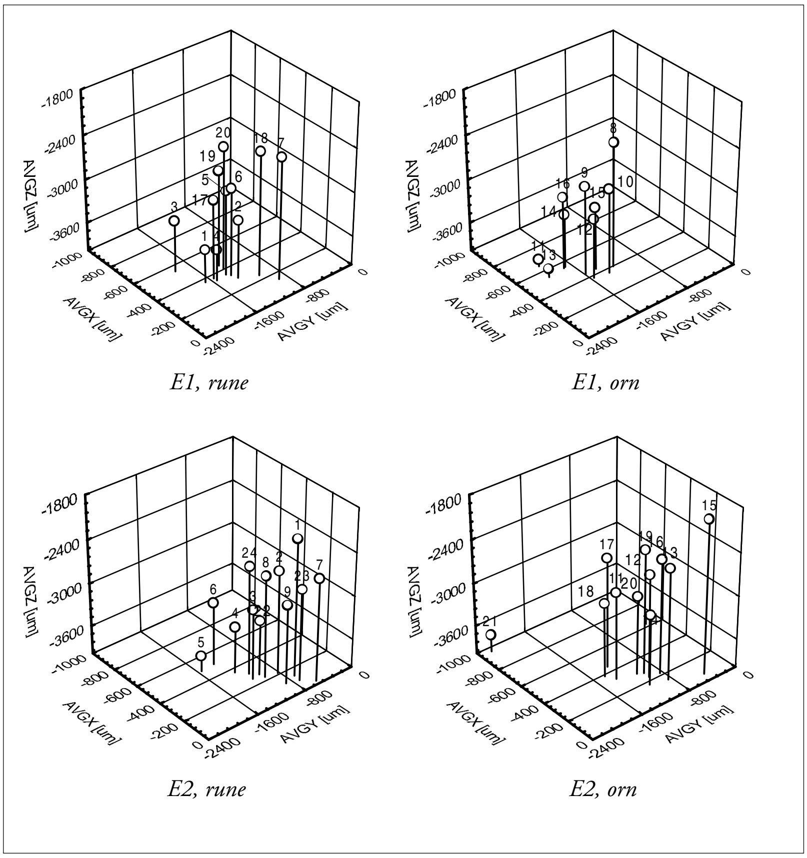
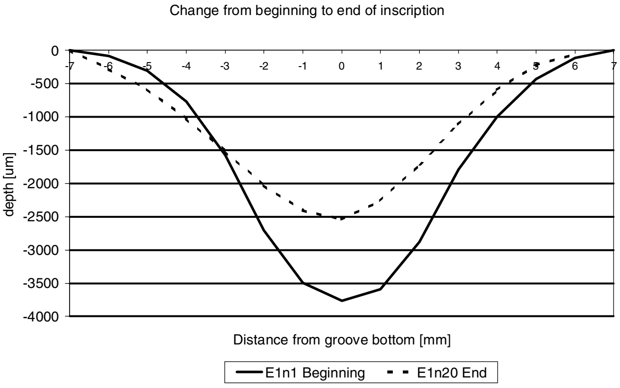


Figure 5. Reference material E1 and E2 produced by Erik.
a) Samples, E1=left picture, E2=right picture.
b) Mean profile diagrams.
c) Individual variability due to fatigue. Comparison of runes at the beginning of the inscription and at the end.
d) Individual variability in ornamentation. A 'normal line', an eye of a runic beast and a sample cut made when very tired.

c)



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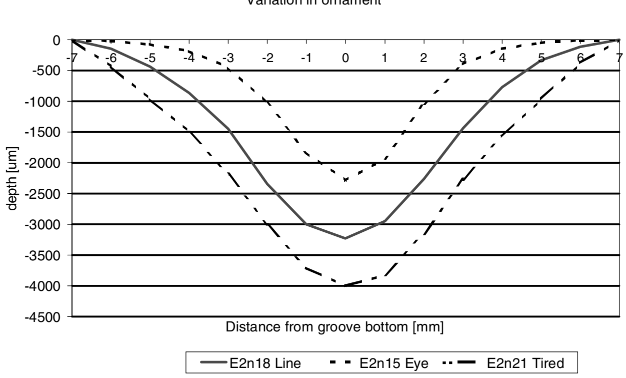


Figure 6. Stone masons' chisels. Examples from the ethnographical collection in Stockholm City Museum.

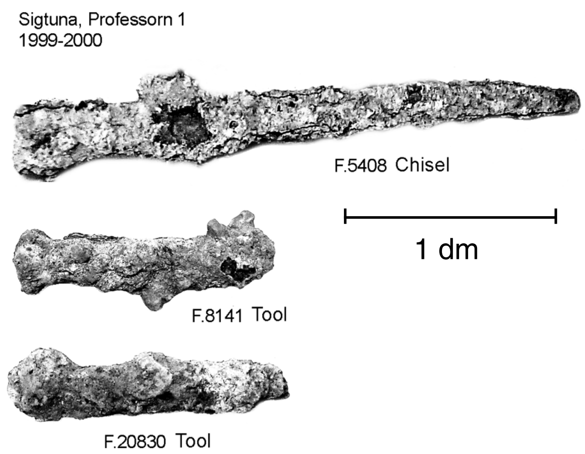


Figure 7. Finds from Sigtuna, Professorn 1 1999–2000.

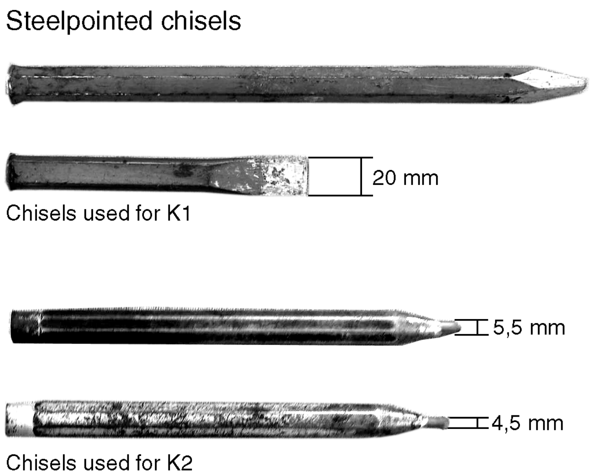


Figure 8. Some of the chisels used by Kalle Dahlberg.

Erik explained that he had cut sample 21 on E2 when he was very tired and in a hurry. He usually finishes his work in the evening by drawing the chisel along the groove bottom, but he had not done this in the case of sample 21. Thus sample E2n21 actually appears as an outlier in the mean profile diagram, reflecting the fact that this cut is not representative of its carver. Another outlier is E2n15, the eye of the runic animal, which had to be cut with special attention and caution. Interestingly enough, exactly the same was noted with regard to the eye of the runic animal in Kalle's carving K1. Erik also remarked that he was bored while cutting the parts represented by E2n16–19 and had not been paying much care to their execution. These samples do not deviate from the main cluster, but they are slightly shallower than the other marks, indicating less expenditure of energy.

Stone mason's tools in ethnographical and archaeological collections

As far as I know, no chisels that can be connected with rune carving have been found. The assumption is that the tools used in the 11th century AD were similar to those in the Middle Ages, as observed in medieval manuscripts, for instance (Svanberg 1983). Since the rune carvers appear to have held Christian beliefs and probably had a deep knowledge of Christian doctrine, their tools cannot be expected to be found as grave gifts. It would be more likely to find them in early medieval handicraft contexts, possibly in or around Sigtuna. To judge from the photograph, a find from Lund classified as a punch (id. number KM 66166; Bergman & Billberg 1976, p.205, fig.147) would be very similar to the chisels contained in ethnographical collections of stone masons' tools, were it not for its length, being only 8.5 cm.

The sets of stone masters' tools in the ethnographical collections of Stockholm City Museum include items with a wide range of shapes and dimensions (fig. 6), the shortest chisel being 10.5 cm long. The artefacts in the archaeological collections of the same museum that are most similar to stone chisels are classified as isolated finds (Sw. *lösfynd*) and nothing can be said either of their age or of the context in which they were discovered. A broken chisel may not have any distinctive features and may well be classified as a blank or an unidentified object. The iron blade may have been reforged in some other form when the chisel was beyond repair. The edge of the chisel would be either pointed or about 8–20 mm wide, with a handle 10–20 mm thick and a length greater than the width of a man's hand. Judging from illuminations in medieval manuscripts (Svanberg 1983), it would have been hit with a wooden mallet, which in archaeological contexts would have required exceptionally good conditions to escape destruction. Several objects found in the 'Professorn 1' quarter of Sigtuna in the excavations of 1999–2000 may have originated from a stone mason's tool chest, but nothing can be said for certain. Work on the report is still in progress, but preliminary dates place the most interesting chisels in the late 12th/early 13th centuries AD (fig. 7, F.5408, F.8141, F.20830) (Kerstin Fogelberg, pers.comm). According to the staff at the Sigtuna-excavations, several wooden mallets have been found there. Some of the chisels used as reference material by Kalle Dahlberg can be seen in fig. 8.

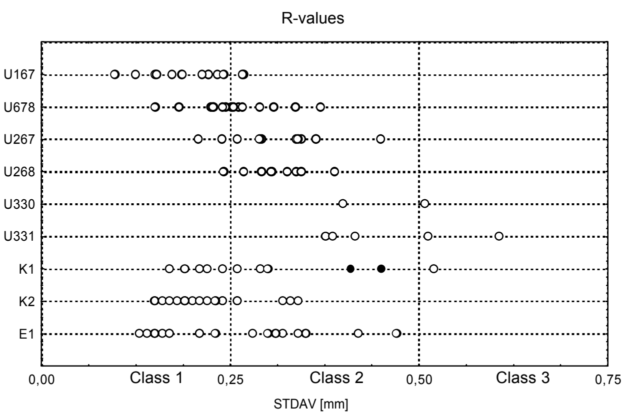


Figure 9. Roughness of the rock surface. The method is modified after Swantesson 1989. Black dots = rough gable side of K1.

Grain size and surface roughness

The shape of the cut may have been influenced by the quality of the stone. Freij concluded in another context that different chisels were used for different types of stone (Freij 1990, p.152). Also, the cuts may have been damaged by weathering over time. Thus a coarse-grained slab may be suspected of being more difficult to shape according to the plans of the carver than a fine-grained one, and also to be affected by weathering in a different way, so that it will be rougher as its grains disintegrate and fall away from the surface. The modern carvings examined here were made on various materials. Kalle Dahlberg used granite slabs produced in a stonemasonry at Vätö in the Stockholm archipelago, while Erik used natural granitoid slabs found in the south coast region of Sweden.

Table 1. Surface roughness.

Rune stone	R (mm) median	Class 1)	Rock/Colour	Comments on the carving surface2)
U167	0,20	1	blue grey	Very even and smooth, 'worn and shiny' by trampling
U267	0,32	2	blue grey gneiss, with glimmer	Uneven surface, in the lower part worn by trampling
U268	0,31	2	red granite	The carving is clear and well preserved
U678	0,25	2	red granite	Traces of wear, 'prolonged wearing'
U329 3)	–	–	light grey granite	well preserved
U330	0,45	2	light grey, almost white granite	smooth and even, well preserved
U331	0,42	2	–	Flat rock. Well preserved. 'flakings' in the lower part
K1	0,24 (0,43) 4)	1 (2)	grey granite	Front surface has been burnt, gable is raw
K2	0,22	1	grey granite	The surface has been burnt
E1	0,26	2	grey granite	–

1) According to Swantesson 1989
2) Sveriges Runinskrifter by Wessén & Jansson 1940–1953, Free translation.
3) Data for calculation of R is not available.
4) The first value is for the front surface, value in parenthesis is for the gable side.

Example: Simplified model of how trampling may effect a cut mark	AvgZ [mm]	AvgY [mm]	AvgX [mm]	v°
Original cut mark	3	1	0,25	106°
Stone surface lowered 0.5mm	2,5	0,5	0	106°
Relative change	**17%**	**50%**	**100%**	**0%**
Stone surface lowered 1mm	2	0	0	127°
Relative change	**33%**	**100%**	**100%**	**10%**

Table 2. Simplified model of how trampling may effect the variables referring to the shape of the cross-section of a cut mark.

Example: Simplified model of how weathering may effect a cut mark	AvgZ [mm]	AvgY [mm]	AvgX [mm]	v°
Original cut mark	3	1	0,25	106
Lowering of surface due to weathering	-0,5	-0,5	-0,5	
Differential change due to weathering	0,1	0,25	0	
New values	2,6	0,75	-0,25	114
Relative change	**13%**	**25%**	**100%**	**13%**

Table 3. Simplified model of how weathering processes may effect the variables referring to the shape of the cross-section of a cut mark.

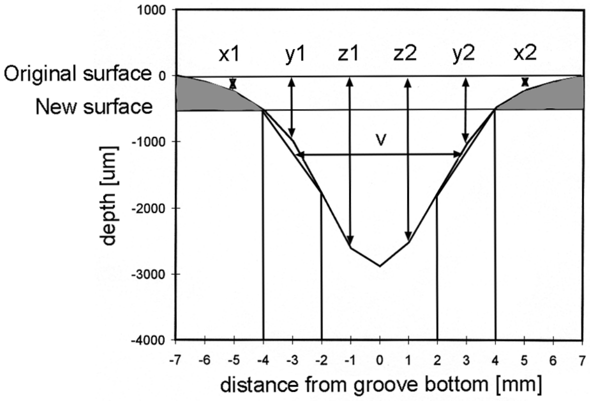


Figure 10. Simplified model of how trampling may influence a cut mark.

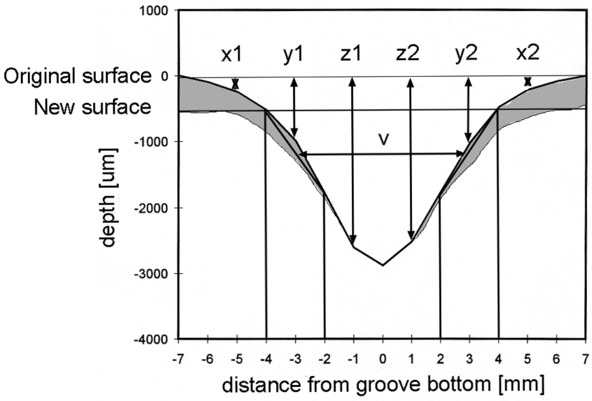


Figure 11. Simplified model of how weathering processes may influence a cut mark.

As suggested above, the grain sizes in a rock will affect its surface roughness, and roughness differences can also arise on account of exposure and be related to its duration (Betts & Latta 2000 and further references). One way of classifying the surface structure of a rock sample is to measure the standard deviation of its microtopography (Swantesson 1989, p.135ff). In his study of weathering processes, Jan Swantesson examined rock surfaces by laser scanning at 1 mm intervals and then divided the microtopographies of the surfaces (or rather the data matrix representing these) into rectangles of approximately 20 x 20 mm = 400 mm^2 and calculated the best fit of a sloping plane and its regression coefficient for each rectangle. This enabled him to use the standard deviation of the height values from this plane as a measure of surface roughness, dividing them into 12 roughness classes ranging from <0.25 mm to >2.75 mm (Swantesson 1989, p.136). I have adapted this method in order to classify the rock surfaces in the rune data. For each recorded sample of runes or ornamentation, data are available for a strip of the original rock surface on each side of the cut, and the standard deviation of the height values within 5 x 5 mm squares and the mean value of the standard deviation for the whole sample is calculated. Calculation of the sloping plane was omitted as unnecessary due to the smaller squares used. The number of squares, each consisting of 25 height values, varies between 20–70 for each sample. The standard deviation of the rock surface is based on a total area varying between 1 and –2 dm^2 for each rune stone (K4 and E2 excluded).

The median roughness value *R* for all the rune stones considered here falls within the first two classes of Swantesson's classification system for surface roughness (fig. 9, table 1). It may be, however, that this system is too coarse to distinguish between the rune stones, either (1) because the smaller squares cause less variation, or (2) because Swantesson's system was developed for use with a great variety of rock types, whereas all the present rune stones are composed of granitoid rock. The results are nevertheless used here to provide a relative grouping in terms of surface roughness (fig. 9). There seems in fact to be an area of slightly rougher character on K2 that is represented by a group of samples that stand out from the others (K2n3, n7, n15). E1 has not been polished by any artificial means, and E1 shows a great variety in roughness within its carved surface. The surface of K2 was burned away at a modern stone masonry, and this stone is in any case slightly more homogeneous than E1. The rough gable side of K1 has higher R-values than the front side.

The ancient rune stones are comparable to the reference material in this respect, as the granite slabs for the ancient rune stones seem to have been chosen for their smooth surfaces. U167 is extremely smooth, U331 is somewhat rougher.

Table 4. Principal Component Analysis. Eigenvalues. 96% of the total variance is accounted for by four Principal Components.

Eigenvalues
Extraction: Principal components

	Eigenval	% total Variance	Cumul. Eigenval	Cumul. %
1	5,1762	51,7624	5,1762	52
2	2,5958	25,9577	7,7720	78
3	1,2337	12,3371	9,0057	90
4	0,6295	6,2946	9,6352	96
5	0,2922	2,9220	9,9274	99
6	0,0365	0,3648	9,9639	100
7	0,0213	0,2129	9,9852	100
8	0,0129	0,1293	9,9981	100
9	0,0019	0,0192	10,0000	100

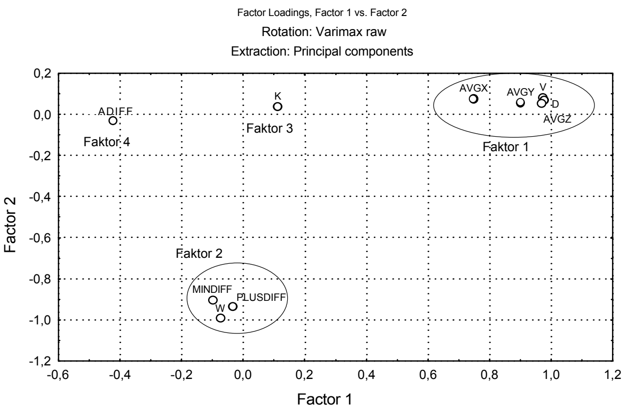


Figure12. Principal Component Analysis of the reference material. Factor loadings.

If the roughness of the rock surface was of any significance for the carver, it may be presumed that there should be a correlation between the R-values and the variables depicting the cuts made, a higher R-value correlating with shallower cuts within the production of one individual (cf. Kitzler Åhfeldt 2001). If a high R-value is indicative of a higher degree of weathering, there could be a correlation between roughness and groove angle. U268 is the only stone where there is a vague correlation between surface roughness and the groove angle (r = 0.84). This may indicate that the groove angle has been affected by weathering, but since this is the only example in this study it could be a mere coincidence.

Weathering and treading

In the case of recently produced cuts, individual masons are distinguishable by means of a set of variables referring to the shape in the cross-section and longitudinal characteristics, but when the method is applied to ancient material the varying degrees of weathering may constitute a serious source of error. The normal weathering pace for granite has been estimated to be around 1–1.5 mm/1000 years (Swantesson 1989). On the other hand, the weathering of rock is not a linear process, but rather occurs in steps (Löfvendahl et. al. 2000, p.122), and it is therefore not easy to construct a mathematical model for compensating for weathering. Also, different rock types are affected by weathering in different ways (Betts & Latta 2000, p. 211f). Another common form of damage to rune stones is that they have been used as flooring, e.g. in a church door, as in the case of U678 studied here, and their surfaces have often been worn smooth.

A simplified model of how treading may affect the cross-section of a cut is provided above (fig. 10, table 2). The level of the surrounding rock surface will sink in relation to the cut, reducing its depth, but the runes and ornaments as such may be more or less undamaged and their shape relatively intact, now represented by the bottoms of the grooves. The depth values are thus affected by treading, but the groove angle *v* may be assumed to be more or less intact. It can be seen in this constructed example that the groove angle would not be affected at all by a lowering of 0.5 mm in the surrounding rock surface.

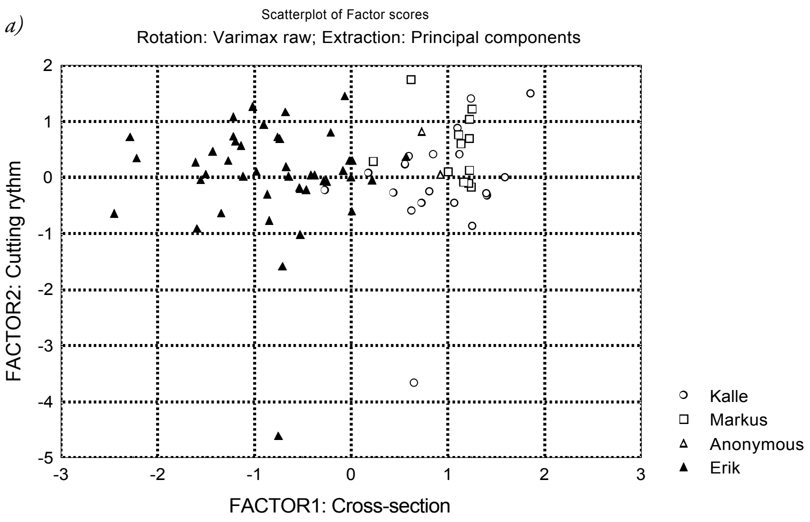
In a simplified model of weathering (fig. 11, table 3), the surrounding rock surface sinks in relation to the cut and the edges of the cut become bevelled. If weathering influenced the whole cut to a similar degree, it would retain its depth, but this is not the case, for the cuts on weathered stones are generally fairly shallow. The degree of damage caused by weathering varies from one rune stone to another and depends on the raw material and the environment, but in general more material ought to disappear from the surrounding rock surface than from the cut. Consequently, the groove bottom should be more intact than the edges of the cut. This is depicted in the example, where the groove angle appears to be less affected than the actual depth values. On the other hand, the cut has been produced by blows that may have produced invisible microfissures in the rock, which could increase the weathering rate.

For the reasons given above, the analysis of ancient rune stones subjected to different degrees of weathering should give consideration to the shape of the groove angle rather than the depth values. This is especially the case when comparing rune stones. When studying cuts within one carving, it may be hoped that weathering has affected all of them in similar ways. This is also a simplification, of course, but it is my opinion that this simplification has to be accepted until the weathering process for each rune stone and each cut can be quantified in a way that can be defined in a mathematical model.

Selection of variables by Principal Components Analysis

The 10 variables extracted from the microtopographies of the cuts are shown in fig. 1. Not all of these are used for further analysis, however, as use of all the available variables without consideration of their significance is not the way to achieve a meaningful result (cf. Aldenderfer & Blashfield 1984, p.16). It should be noted that the variable *w* is not the

a)



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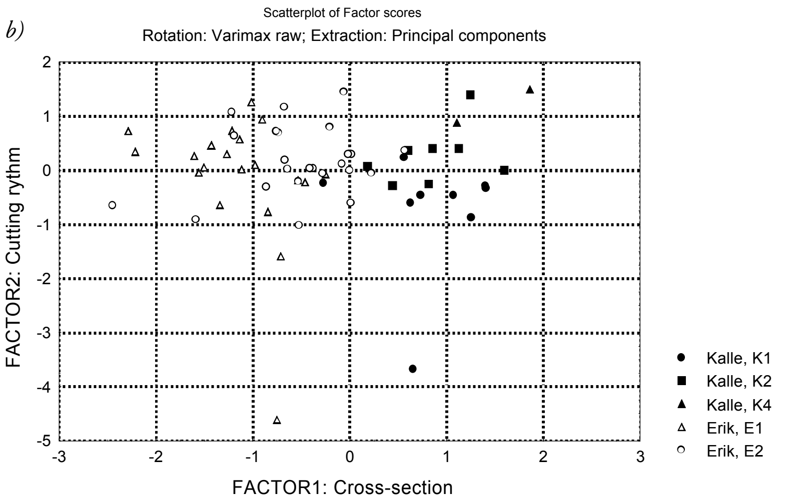


Figure13 a–b. Principal Component Analysis of the reference material. Scatterplots of the first two principal components.

a) The carvers Kalle, Erik, Markus and Anonymous on K1, K2, K4, E1, E2.

b) The carvers Kalle and Erik.

Table 5. Individual variability due to increasing skill. The hit interval becomes more uniform. This is shown by a lower standard deviation (Std.Dev.)

	Runes	W [mm] Means	Std.Dev.	N
Kalle	K1	9,3	3,0	5
	K2	6,2	1,6	3
Erik	E1	8,5	3,1	11
	E2	7,3	1,6	12
	All Grps	*7,8*	*2,3*	

distance between consecutive hits with the mallet, but that between the deeper pits in the groove bottom marking a rhythm of lighter and heavier hits. The reason for not using the depth in the deepest part of the cut as a variable in the analysis is that this is presumed to be most sensitive to the wear on the chisel's edge. The main variables used earlier were *v*, *AvgZ*, *k* and *w*, but since the reference material has been extended the question of selecting variables has to be addressed again. What characteristics are useful in order to trace an individual artist or workshop?

As an initial exploration of the data structure, a *Principal Component Analysis* (henceforth PCA) was performed. For an introduction to this statistical method, see Wold et al. (1987). All the variables and all the cases were included. The eigenvalues (table 4) show that 90% of the variance is explained by 3 factors, or *principal components*, and 96 % by 4 factors. The plot of the factor loadings (fig. 12) shows that the variables can be divided into those referring to the cross-section of the cut (Factor 1) and those referring to the hit interval in a longitudinal direction (Factor 2). These two groups of variables can be replaced by one variable each. The third influential factor refers to the rhythm, *k*, in the cutting sequence (Factor 3) and the fourth factor is the amplitude of the variation in a longitudinal direction, *ADIFF* (Factor 4). The division of the variables into those referring to the cross-section and those referring to the longitudinal direction makes it clear that it is not enough to take into account the depth or the groove angle of a cut when attempting a characterisation of the cutting technique, as the cross-section accounts only for about a half of the variance. According to the PCA, the choice of variables representing both the cross-section and the longitudinal direction is justified.

Difference between carvers as shown by PCA

Scatter plots of the factor scores (fig. 13) for each sample reveal that Erik may be distinguished from Kalle and his assistants mainly in terms of Factor 1, i.e. in the shape of the cross-sections of the cuts. The overlap between these two 'masters' is relatively small. The work of the assistant Markus forms a tight group within the area covered by Kalle's samples, and that of the other assistant also falls within the Kalle area (fig. 13a). Earlier studies have concentrated on the Kalle group,

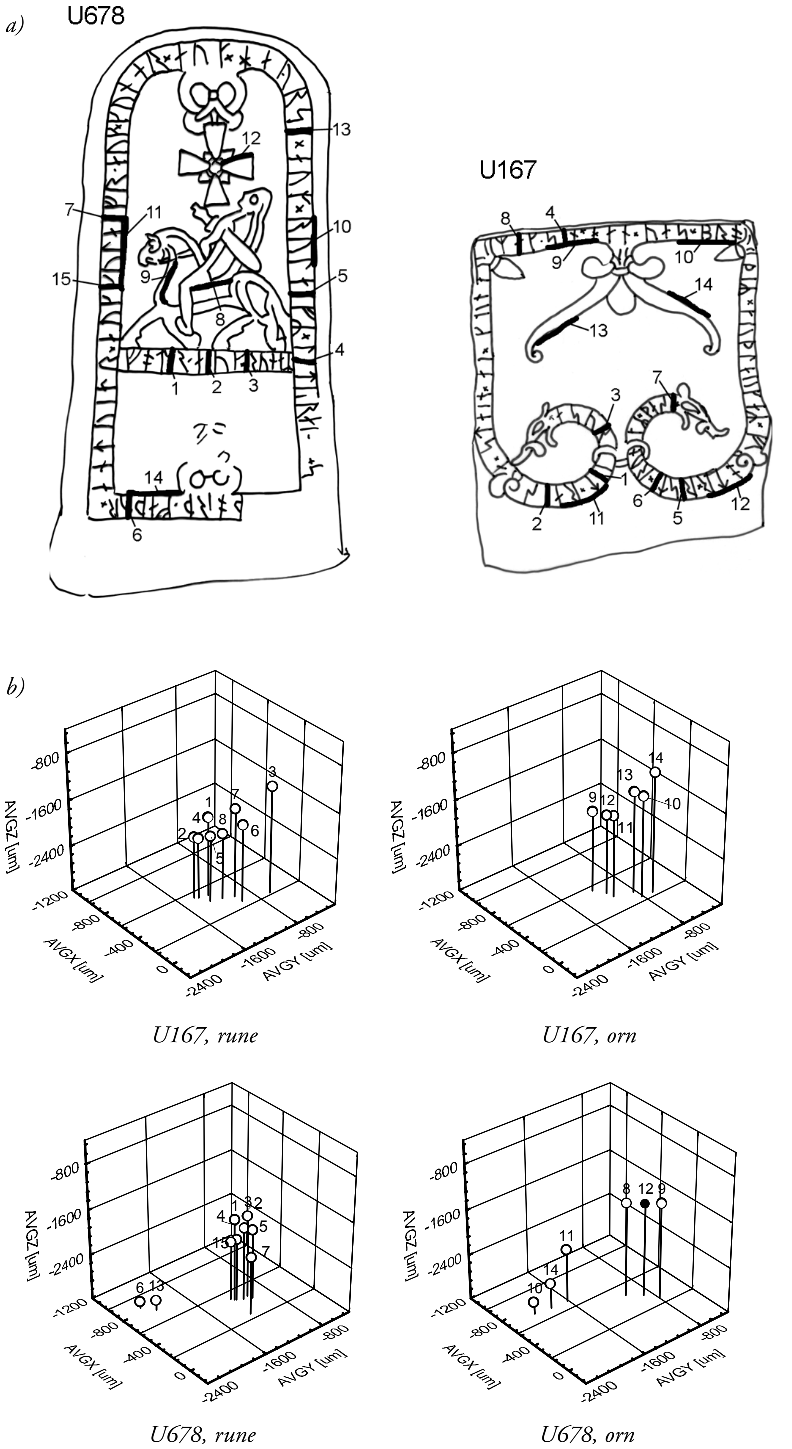


Figure 14. U678 and U167.
a) Samples
b) Mean profile diagrams

and hence on distinguishing between craftsmen who have been working on the same carving and who have shared the same set of chisels. The groove angle *v*, the depth 1 mm from the groove bottom *AvgZ*, the hit interval *w* and the rhythm variable *k* were used in those analyses (Kitzler 1998, 2000; Kitzler Åhfeldt 2000, 2001). It can be seen in the present PCA, however, that the difference between the carvers is even greater when another 'group' or 'tradition' is involved, as Erik's work can be contrasted with that of Kalle and his assistants. The groups of carvers are mainly distinguished by Factor 1, i.e. the shape of the cross-sections of the cuts.

Individual variability

A scatter plot of the PCA factor scores for the two 'masters' only, on which each carver's rune stones are marked (fig. 13b), reveals that there is a variation from one rune stone to another even within the work of a single carver. It can be seen that E2 covers a slightly different register on Factor 1 *a)*

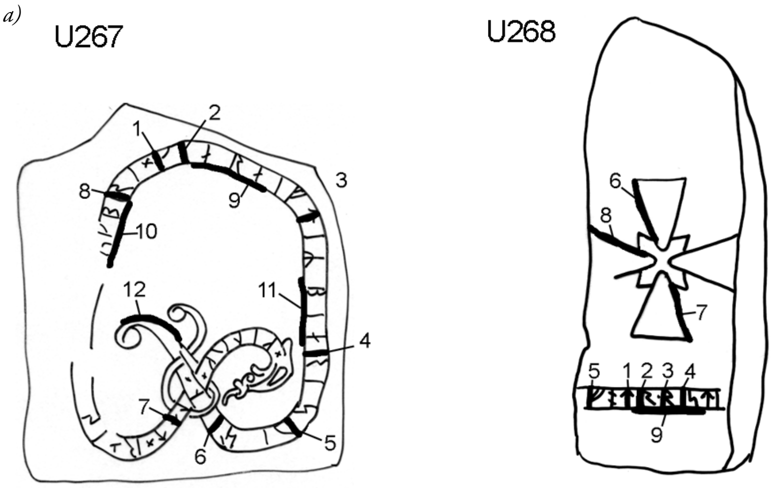
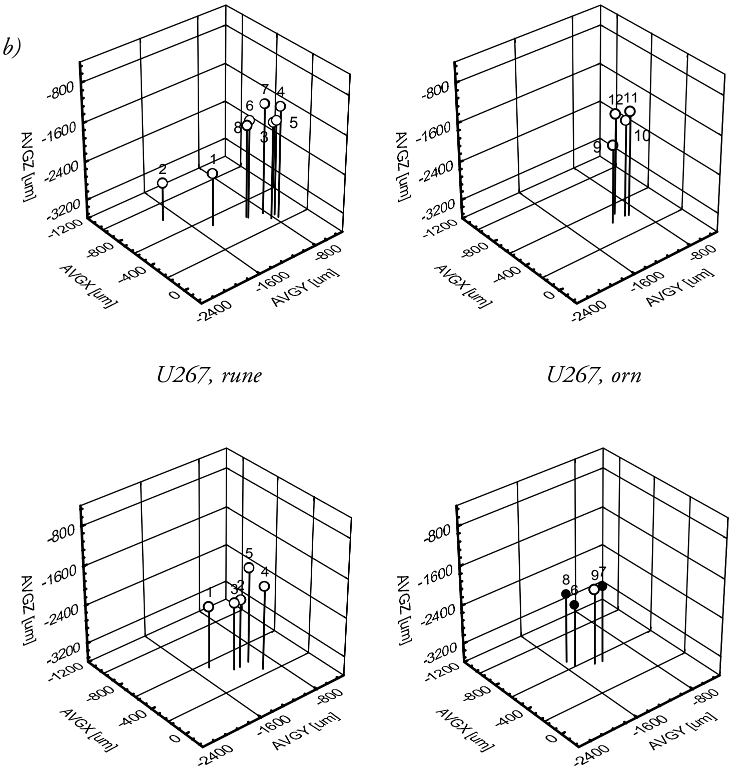


Figure 15. The couple stones U267 and U268.
a) Samples
b) Mean profile diagrams

b)



U267, rune *U267, orn*

U267, rune *U267, orn*

than E1, indicating a small but consistent difference in groove shape. The patterns of Erik's samples are slightly more spread than those for Kalle, indicating a larger intra-individual variation. There may be several reasons for this. Part of the variation may be explained by the fact that Erik took less time to produce a rune stone than Kalle. Kalle's cutting may be slower, but it is more uniform. Another reason could be that Erik uses a set of about 20 hand-forged iron chisels at a time, changing his chisel when it is blunt and sharpening the whole set when the work is finished. This arrangement may be more analogous to the technique used on the ancient rune stones. A third possible reason is that Erik was cutting on a vertical surface (E1) or a sloping surface (E2), whereas the two reference stones by Kalle have been cut on horizontal surfaces. The aim of PCA is to explain the total variation, and the variation in the cuts made by each individual can be studied more closely in the mean profile diagrams (fig. 2b, 5b).

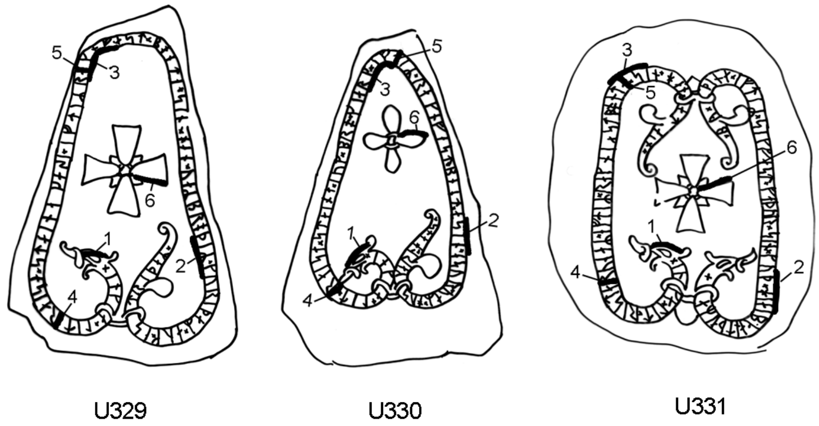
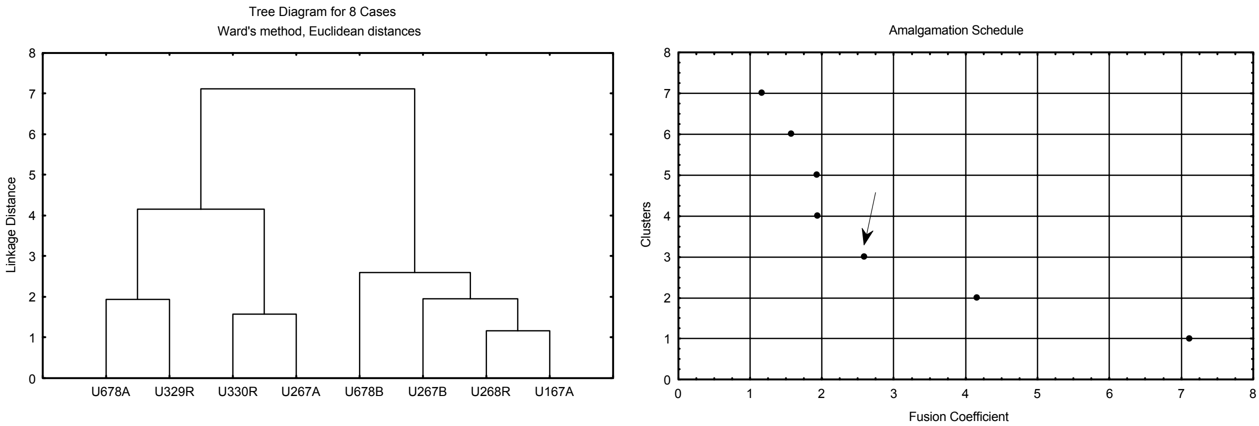


Figure 16. The Snåttsta-group U329, U330, U331.



a) Tree-diagram

b) Amalgamation Schedule.

Figure 17. Hierarchical Cluster Analysis of the Fot-material, Ward's method, Euclidean distances. Runes.

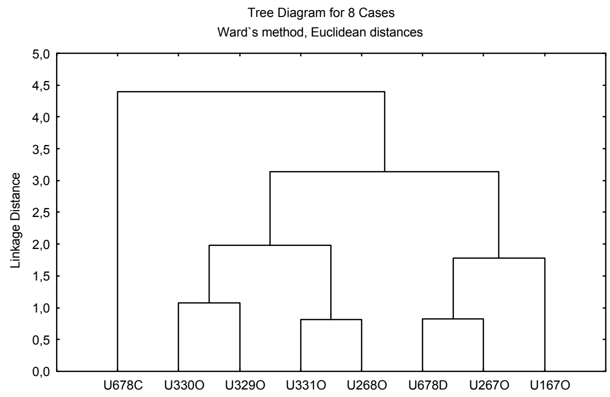
Variation from one rune stone to another

Although the two main carvers are represented in this material by two rune stones each, both had cut other rune stones in the meantime. Three years passed between Kalle's work on K1 and K2, and about the same time elapsed between Erik's E1 and E2. In both cases, the carvers had cut about ten rune stones in between. Kalle's development has been studied earlier (Kitzler 1998), leading to the conclusion that the ornamentation was more subject to change than the runes, the hit interval becoming longer with increasing skill, and uniformity increasing at the same time. The PCA of Erik and Kalle adds further nuances to the earlier observations. The difference between Erik's two carvings lies along the X-axis in the scatter plot of factor scores (fig. 13b), which means that there is a difference in the shape of the cross-section (groove angle and depth), whereas the difference between Kalle's carvings lies along the Y-axis, which means that the variables referring to the cutting direction (hit interval) have been affected. The individual variation which can be specified to be due to increased skill seems to be very little in this example. The conclusion is that intra-individual variability may occur in terms of groove shape as well as cutting rhythm. One feature common to both carvers is that the standard deviation in the variable *w* decreases in the runes with time, implying that the runes become more uniform and that the hit interval is more regular (table 5).

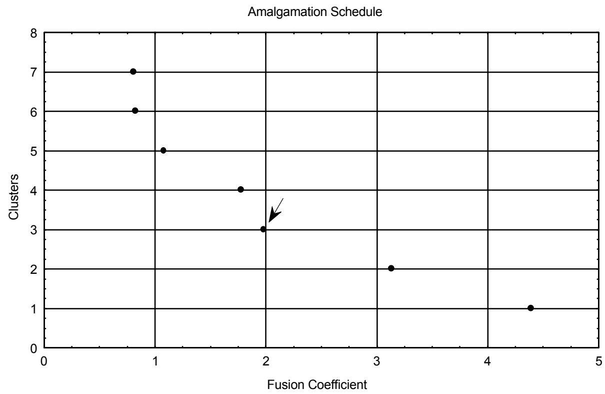
Conclusions based on the reference material

1) Change of tool set and steel chisels versus hand-forged chisels

Kalle used different sets of tools for K1 and K2, but the problem is that three years had passed in between K1 and K2, so that it is difficult to say which differences in the cuts are due to the change in tools, which to his increased skill and which just to individual variability. It is interesting, however, that even though the chisels used on K1 and K2 were very different, Kalle is still identifiable in both. On K4 he cut one groove each with a hand-forged chisel and a steel point, and the groove angle is seen to be larger in the cut produced with the hand-forged chisel. The two cuts are similar in shape in the deeper part of their cross-section, although the one cut with the steel point is deeper (fig. 4b). Could this possibly be understood as suggesting that the carver's view of what the groove should look like is more influential than the actual chisel?



a) Tree-diagram



b) Amalgamation Schedule.

Figure 18. Hierarchical Cluster Analysis of the Fot-material, Ward's method, Euclidean distances. Ornament.

Erik changes chisel several times on the same carving, after which he sharpens the whole set. This may be part of the explanation for the diffusely spread pattern in the plot of factor scores. I have earlier interpreted a spread pattern in the mean profile diagram as a sign of a less experienced carver (Kitzler 2001), but possession of a great number of chisels could be another explanation.

2) Effect of fatigue

According to psychological research into motor performance, a person who is skilled in a certain handcraft is less likely to suffer from fatigue while working at it. He *'has less to think about',* since he performs his actions more or less automatically and therefore has to process less information than a beginner who has to concentrate on what he is doing (Welford 1976, p.123). The achievement of skill results in more effective performance and *'reduces susceptibility to stress, fatigue and monotony'* (Welford 1976, p.124, quotation p.147). In rune carving, this will influence the amount of material removed from the stone, i.e. a skilled carver will remove more material because he makes deeper cuts. It is noticeable in Viking Age inscriptions that the cuts are often shallow by the end of the work. One possible reason, of course, is that the carver was tired and maybe also uninterested. It has been noted that *'Long-continued performance tends to become not only slower but also less regular'* (Welford 1976, p.142). Mental fatigue may cause a slowing down of the performance rate, irregularity of timing, but also temporary improvement in performance (Welford 1976, p.141ff). This is comparable to the irregular hit interval that has been recognised by the modern rune carvers. Timing is comparable to hit frequency. The conclusion to be reached from the mean profile diagrams is that fatigue is a factor that causes the carver to cut shallower grooves by the end of his work. Continuity in the spread pattern may indicate a wearying carver, while a distinct gap may be caused by co-operating individuals. The carver who would be easiest to recognise from his cuts is one who is skilled enough not to be easily impeded by fatigue.

3) Effect of cutting on a vertical surface

The effect of cutting on a vertical surface is related to the effect of fatigue, as this demands considerably more energy than cutting on a horizontal surface. E1 was cut entirely on a vertical surface, and the samples seem to be more irregularly spread in the mean profile diagram than those representing E2 (fig. 5b) are. The deepest cuts appear at the beginning of the inscription and the shallower ones towards the end. The carving was produced in about a week, with 6–7 hours of cutting a day, but Erik apparently became tired or bored by the end of the inscription, which shows in the fact that the cuts are about 1 mm shallower than at the beginning. It may not be possible to follow this sample by sample, but the tendency is remarkably clear in the ornamentation as well, which was cut before the inscription. The samples located in the middle of the diagram can be found in the middle of the inscription.

Kalle added his signature on the rough gable side of one rune stone (K1) after the stone had been erected. The two samples of this signature appears as outliers in various diagrams, and as such they are not representative of the rest of the carving.

4) Difference between workshops

Nancy Wicker has remarked that the potential of runic inscriptions to elucidate contacts and the organisation of handcrafts has not yet been explored (Wicker 1998, p. 262). In this reference material, two 'masters' who have developed their skills independently serve to shed light on the differences between individuals and workshops. One of them had assistants, who could be said to belong to the same workshop. The relation between the carvers as reflected in the

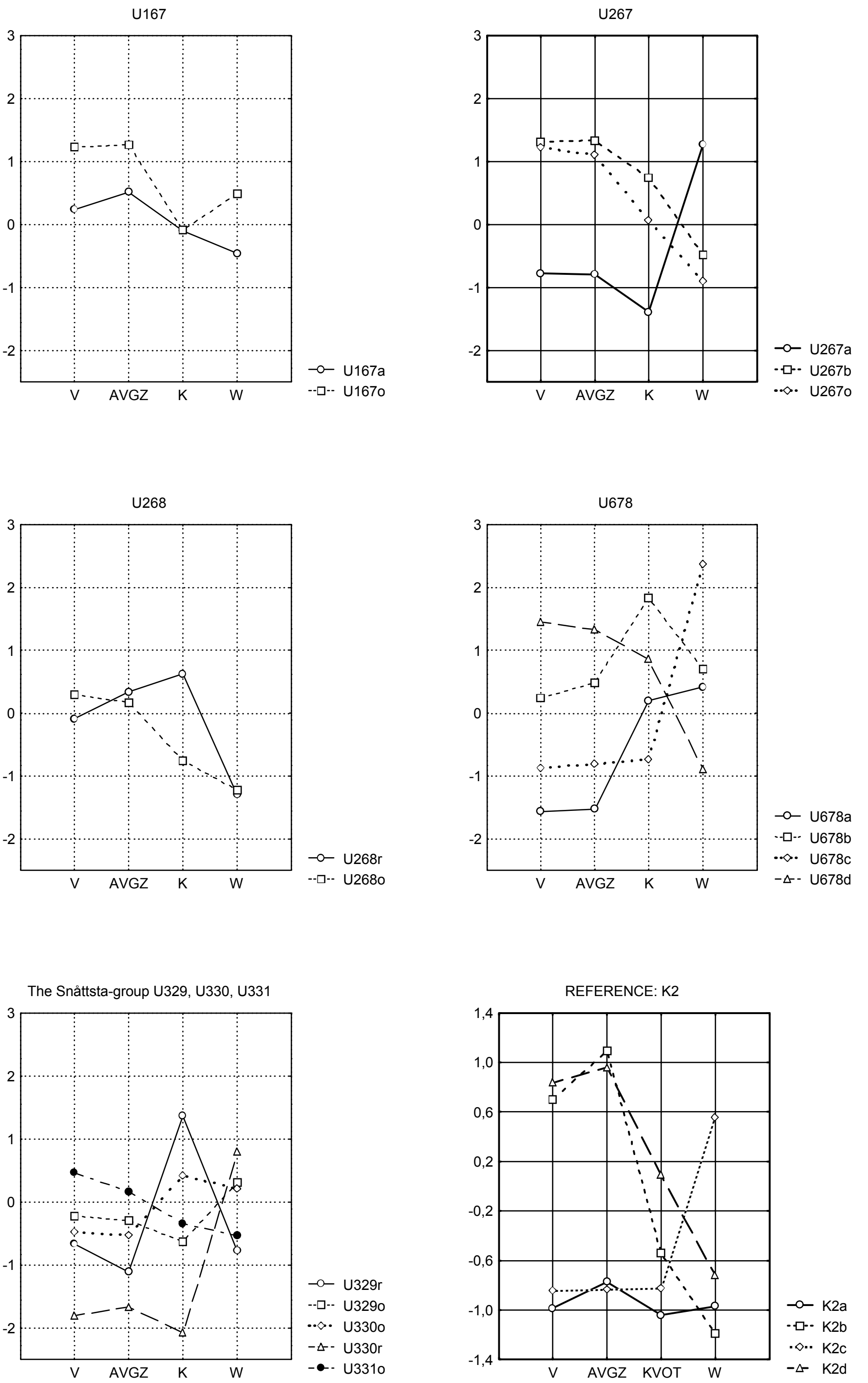


Figure 19. Case profiles of clusters identified in the mean profile diagrams. The mean values for each cluster has been standardised.

cuts examined, has largely been resolved above by means of the introductory PCA. It is clear that there is a larger difference between Kalle from Uppland and Erik from Jylland than there is between Kalle and his own assistants. The main difference may be due to opinions regarding the proper appearance of a rune or the perception of what a smart rune stone should look like. Although some individual variability can be observed between the earlier and later work by Kalle and Erik separately, the distinction between the two groups of rune stones is greater than that caused by development or other personal factors. The cuts made by Kalle's assistants rank alongside his own, possibly because they shared the same set of chisels. The hypothesis can be formed that ancient workshops should differ in the same way as Kalle and Erik, and that carvers within the same workshop should relate to each other just as the assistant Markus does to Kalle. When applying these ideas to ancient material, in this case the Fot stones, it may be more relevant to rely on the analysis of Kalle and his assistants rather than on the comparison between two completely different carvers.

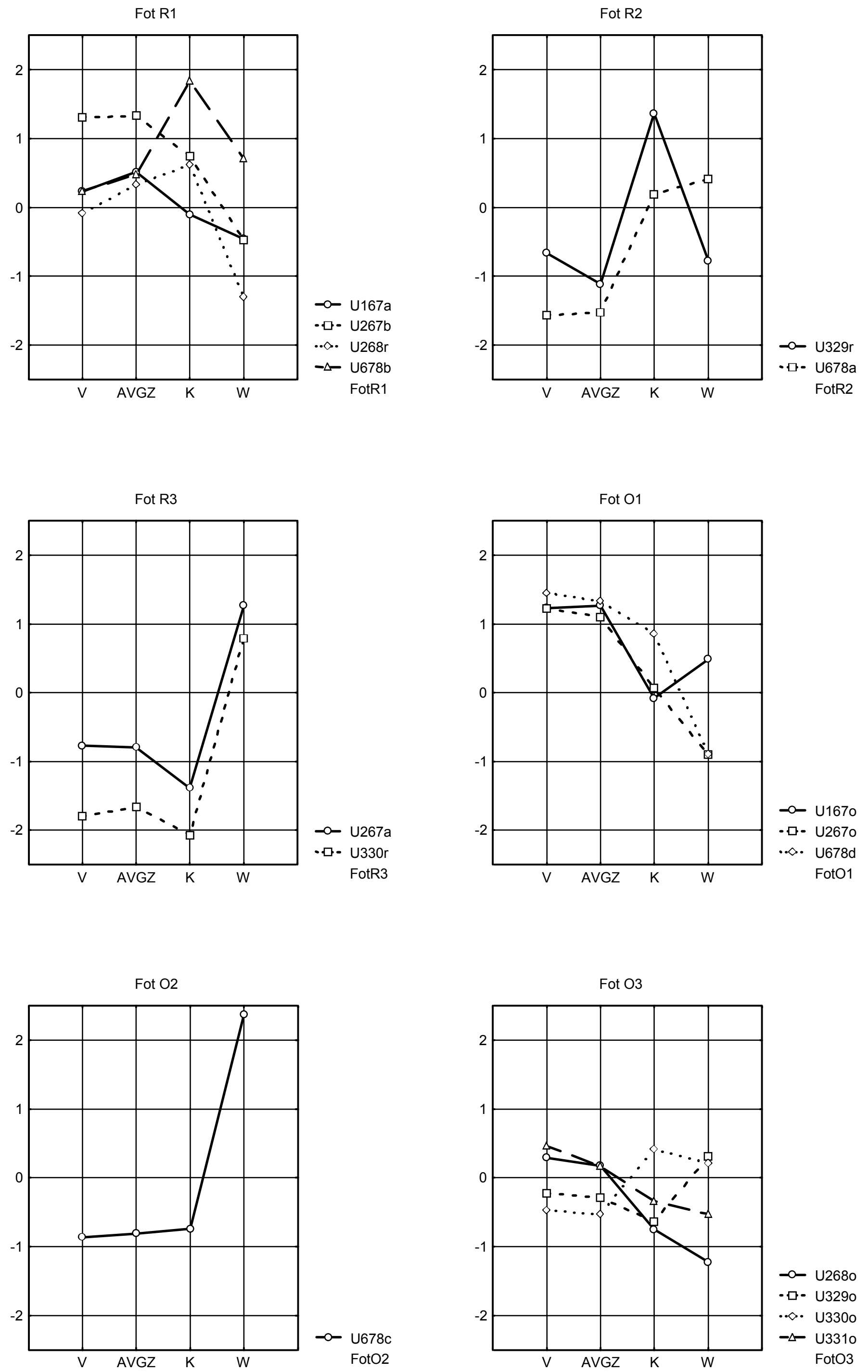


Figure 20. Case profiles of the runographers and ornament-types identified by Hierarchical Cluster Analysis.

Identification with known carvers by Surface Structure Analysis

Discriminant Analysis (henceforth DIS) is a useful method for classifying samples of unknown origin by comparing them to a set of reference data. If ancient carvers could be identified, this might be a powerful way of classifying unsigned rune stones. A DIS was performed on the earlier of the rune stones by each 'master', K1 and E1, to provide reference material. The hit ratio for a data set comprising all the samples except for the two runes produced by the anonymous assistant, taking both runes and ornaments together, was 97%. The variables were chosen to represent each factor indicated in the PCA (*AvgZ, w, k, ADIFF*). The accuracy in the classification of K2 and E2 to their respective carvers was then extremely good, only 3 out of 24 samples cut by Erik on E2 being wrongly assigned to Kalle, while all Kalle's samples were correctly classified. Not unexpectedly, when K2 and E2 were used as references, the errors in the classification of samples from K1 and E1 mainly appeared between Kalle and Markus, who co-operated on the same stone. The classi-

Table 6. Discriminant Analysis, standard method, tolerance 0.01. Relative distances between groups expressed by p-levels. a) U167 b) U267 c) U268 d) U678.

a)

DISCRIM. ANALYSIS	p-levels	
	U167a	U167o
U167a	–	**0,02**
U167o	**0,02**	–

b)

DISCRIM. ANALYSIS	p-levels		
	U267a	U267b	U267o
U267a	–	**0,01**	**0,03**
U267b	**0,01**	–	0,71
U267o	**0,03**	0,71	–

c)

DISCRIM. ANALYSIS	p-levels	
	U268r	U268o
U268r	–	**0,10**
U268o	**0,10**	–

d)

DISCRIM. ANALYSIS	p-levels			
	U678a	U678b	U678c	U678d
U678a	–	**0,00**	0,16	**0,00**
U678b	**0,00**	–	**0,00**	**0,08**
U678c	0,16	**0,00**	–	**0,00**
U678d	**0,00**	**0,08**	**0,00**	–

fication performed by DIS naturally only applies to carvers introduced in the reference material (cf. discussion in Kitzler Åhfeldt 2001). Markus is therefore classified to the carver that is most similar, i.e. Kalle, who is at least in the same workshop. It should be noted that Kalle and Markus are distinguished better by the groove angle variable (*v*) than by *ADIFF*, as in the selection of variables used earlier. This tells us that the variables that distinguish groups are not the same ones as distinguish individuals within a group.

Analysis of the Fot stones

Fot is represented by three signed rune stones (U167, U267, U678) and by the stone U268, which forms a pair with U267. A number of rune stones have also been attributed to him (Crocker 1982), but only a few will be touched upon in this paper, namely the three preserved monuments of the Snåttsta group (U329, U330, U331). The object is to relate some of the signed Fot stones to those of another workshop, i.e. the Öpir stones.

U167 in the church of Östra Ryd (fig. 14) served as a step until 1924 (Wessén & Jansson 1940, p. 253). The contours of the block have been worked and the text band follows the edge, possibly on the model of a gravestone (Wessén & Jansson 1940, p. 255). Many carvings seem to have been attributed to Fot due to similarity to U167. The runes are shallowest at the beginning and end of the inscription, and the ornamentation is shallowest in the palmette, possibly indic-

Table 7. Mean values for runographers and ornament-types identified in the Fot-material.

Summary Table of Means

Fot	V			AVGZ			K			W		
	Means	Std.Dev.	N	Means	Std.Dev.	N	Means	Std.Dev.	N	Means	Std.Dev.	N
FotR1	137	8	25	-1874	282	25	0,52	0,07	25	7,10	1,50	25
FotR2	121	9	4	-2942	320	4	0,52	0,05	4	7,24	1,14	4
FotR3	120	6	4	-2896	336	4	0,42	0,03	4	8,62	1,65	4
All Grps	*126*	*8*	*11*	*-2571*	*313*	*11*	*0,49*	*0,05*	*11*	*7,65*	*1,43*	*11*
FotO1	145	5	13	-1570	224	13	0,50	0,04	13	7,15	1,19	13
FotO2	124	11	3	-2671	378	3	0,46	0,07	3	10,14	2,93	3
FotO3	133	5	15	-2291	241	15	0,48	0,03	15	7,04	0,94	15
All Grps	*134*	*7*	*10*	*-2177*	*281*	*10*	*0,48*	*0,04*	*10*	*8,11*	*1,68*	*10*

Fot. Based on 64 samples from 7 rune stones.

Table 8. Mean values for runographers and ornament-types identified in the Öpir-material (after Kitzler Åhfeldt 2001).

Öpir	V			AVGZ			K			W		
	Means	Std.Dev.	N	Means	Std.Dev.	N	Means	Std.Dev.	N	Means	Std.Dev.	N
ÖpirR1	127	7	17	-2627	212	17	0,50	0,07	17	7,57	1,60	17
ÖpirR2	136	7	43	-1884	293	43	0,49	0,06	35	6,72	1,47	35
ÖpirR3	146	7	28	-1597	294	28	0,53	0,05	26	6,66	1,53	26
ÖpirR4	131	6	11	-2439	217	11	0,47	0,06	9	5,82	1,26	9
All Grps	*135*	*7*	*25*	*-2137*	*254*	*25*	*0,50*	*0,06*	*22*	*6,69*	*1,46*	*22*
ÖpirO1	139	6	19	-2017	211	19	0,51	0,03	19	6,98	0,89	19
ÖpirO2	148	7	15	-1449	280	15	0,51	0,03	15	7,62	0,88	15
ÖpirO3	150	4	10	-1317	173	10	0,52	0,04	10	6,80	1,18	10
ÖpirO4	145	3	4	-1590	188	4	0,44	0,04	3	7,00	1,22	3
All Grps	*145*	*5*	*12*	*-1593*	*213*	*12*	*0,49*	*0,03*	*12*	*7,10*	*1,04*	*12*

Öpir. Based on 147 samples from 11 rune stones. After Kitzler Åhfeldt 2001.

ating that this was the last part of the ornamentation to be cut, but the reason could also be differential treading.

U267 and U268, from Harby in the parish of Fresta (fig. 15), are regarded as forming a pair (Sw. *parstenar*) because they are situated close together, although only one of them is signed. Traditionally, such paired stones are attributed to the same carver (cf. Axelson 1993, p. 28), but this cannot be taken for granted, and the question will therefore be addressed in this paper.

U678. Fifteen samples were collected from the front side of *U678,* by the church in Skokloster (fig. 14), but the back, which is lacking in inscriptions, was not sampled. Two clusters can be seen in the mean profile diagrams for both the runes and the ornaments. The question is whether these

Discriminant Function Analysis Summary, Forward stepwise method
Step 5, N of vars in model: 5; Grouping: WORKSHOP (2 grps)
Wilks' Lambda: ,90276 approx. F (5,205)=4,4163 p< ,0008

	Wilks' Lambda	Partial Lambda	F-remove (1,205)	p-level	Toler.	1-Toler. (R-Sqr.)
V	0,9123	0,9896	2,1573	0,1434	0,0308	0,9692
MEDDIFF	0,9410	0,9594	8,6777	0,0036	0,8655	0,1345
W	0,9250	0,9759	5,0598	0,0255	0,9242	0,0758
AVGX	0,9125	0,9893	2,2157	0,1382	0,0663	0,9337
AVGZ	0,9090	0,9932	1,4119	0,2361	0,0152	0,9848

Table 9. Discriminant Analysis, forward stepwise method, tolerance 0.01. Variables in the analysis. The analysis shows which variables are best at distinguishing between the Fot workshop from the Öpir workshop.

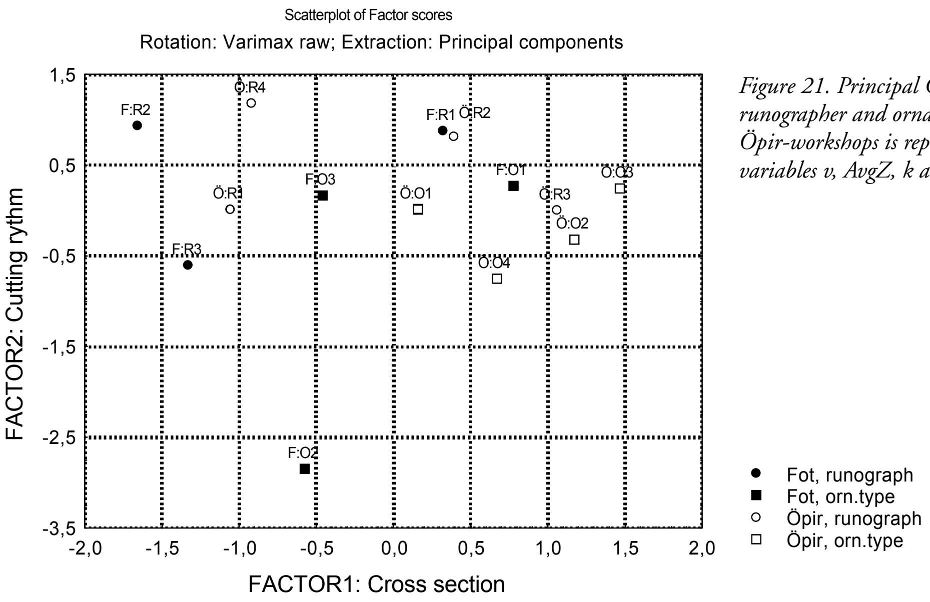
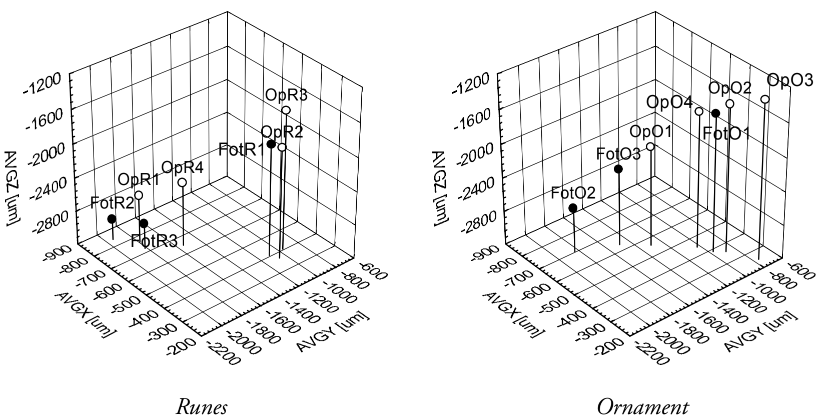


Figure 21. Principal Components Analysis. Each runographer and ornament-type identified in the Fot- and Öpir-workshops is represented by a mean value of the variables v, AvgZ, k and w.



Runes *Ornament*

Figure 22. Mean profile diagrams for runographers and ornament types identified in the Fot and Öpir workshops. Each runographer or ornament type is represented by a set of mean values for the variables AvgX, AvgY and AvgZ. Black dots = Fot. White dots = Öpir.

clusters represent different carvers or individual variability in the work of a single carver. If the ornaments had been of equal degrees of complexity, I would not have hesitated to interpret the distribution as indicative of two carvers. But since the equestrian and the cross can be assumed to have demanded greater caution than the text band, the distribution of the samples may be comparable to the eye of the runic beast in the reference material. The lines run close to one another in the figure. The material is blue-grey gneiss (Wessén & Jansson 1949, p. 174), and the rounded top has been manufactured. The shallowest runes are those in the signature, the horizontal text row, possibly a sign that this was the last part of the inscription and indicating growing fatigue.

U329, U330 and U331 at Snåttsta in the parish of Markim (fig. 16), are all situated on the same farm and the inscriptions refer to the same family. These rune stones were sampled while I was an undergraduate student (Kitzler 1995). Only a small number of samples were taken, and on the recommendation of Freij, those from the same inscription were combined into a single sample for the scanning procedure. Today I would have made more samples and would have treated the runes separately. I have nevertheless included these rune stones in the analysis.

The rune stone U177, which is signed by Fot, is not included in this analysis, but has been subjected to surface structure analysis earlier by Henry Freij, who concluded that it was most probably produced by two carvers, one of whom had removed less material in his cuts, achieving grooves of similar width but with less depth. The surface of the lower part of U177 is of a rougher structure, but the difference between the carvers is systematic (Freij 1992).

The analysis performed on this Fot material was analogous to an earlier one of 11 rune stones associated with the signature Öpir (Åhfeldt Kitzler 2001). Hierarchical Cluster Analysis of the variables *v, AvgZ, k* and *w* allowed three cutting techniques to be distinguished in the runes and three groups of cuts in the ornamentation. It has been shown that the groove angle (v) is the variable that is least vulnerable to weathering and treading, even though the model for compensating for this may be oversimplified. Also, the hit interval variable (w) is thought to be less affected by damage than the depth of the cut. Weathering and treading are complicating factors which may explain why the results do not always concur with the methodological observations.

In short, the steps in the statistical analysis were as follows: 1) clusters were defined in the mean profile diagrams (fig. 14b, 15b), 2) the relative distances between these clusters in DIS within the same carving (table 6 a–e) were used as a basis for combining some of them, one-sample clusters / outliers being excluded from further analysis, 3) mean values of the variables *v, AvgZ, k, w, ADIFF* were calculated for the clusters, 4) these mean values were standardized , and finally 5) Hierarchical Cluster Analyses (by Ward's method (Ward 1963) and Euclidean distances) were performed for the runes and ornaments separately. Ward's method was chosen because it also takes account of variance. The result is illustrated in *tree diagrams* (fig. 17a, 18a). The number of clusters was decided by plotting a graph of the amalgamation schedule (fig. 17b, 18b) and using the 'stopping rule' referred to by Aldenderfer & Blashfield (1984, p. 54ff) – that the true number of clusters is to be sought where the curve flattens, since a large step in the amalgamation coefficient means that two dissimilar clusters have been joined.

The result is that there appear to be three clusters in the rune samples from the Fot material (FotR1–FotR3) and three in the ornament samples (FotO1–FotO3), leading to the interpretation that the runes were cut by three individuals and that the ornament samples represent three types of cut. In the case of the ornamentation, in the difficult parts skilled carvers may be mistaken for beginners (Kitzler 1998, 2000). Greater confidence can be assigned to the interpretation of the runes, however, and an additional procedural step was possible (6), in that in favourable instances, runographers can be connected to ornament groups by means of *case profiles* (fig. 19) in combination with the relative distances in the Discriminant Analyses (table 6a–e) (cf. Kitzler 2001). The case profiles were constructed by taking the mean values calculated for the variables *v, AvgZ, k* and *w* in each group of samples and standardizing them, i.e. recalculating them to a value in a normal distribution in which the mean for the whole group is zero. This standardization renders variables of varying magnitudes comparable. Such case profiles have already proved useful for connecting a runographer to the right ornament in the reference material (Kitzler Åhfeldt 2001). Thus the ornament on U267 seems to be associated with the rune cluster U267b, cluster U678a is associated with the ornament U678c, and U678b with U678d. In the Snåttsta group, the runes of U330 deviate from the runes and ornaments of the other carvings. U167 seems to have different carvers for its runes and ornaments, while for U268 the relation cannot be decided. To carry the analysis a step further (7), the case profiles in fig. 20 illustrate how the rune stones are related within the groups. Mean values are calculated for the runographers and for the ornament types (new clusters) and for the whole group, or workshop (table 7). These values can then be compared with those for the Öpir workshop (table 8).

Comparison between Fot and Öpir

It was concluded in an earlier study of a number of rune stones broadly associated with the signature Öpir that these represented the work of four runographers and that the ornamentation could be divided into four types of cuts. It was also noted that the ornamentation on a rune stone that had been proved not to have belonged to Öpir but had nevertheless figured in discussions of this signature, namely U1140, also had to be rejected on the grounds of the surface structure analysis, although it seems as if the runographer of U1140 may have been an assistant to the Öpir-group (Kitzler Åhfeldt 2001). Comparing the Fot group with the Öpir group simply in terms of the mean values for all the samples (table 7, table 8), it appears that there is a general tendency for the cuts of the rune carvings attributed to Fot to have a narrower groove angle (*v)* and be deeper (*AvgZ*), and that the same is true of the ornaments. The hit interval (*w*) also appears to be longer, although there are only small differences in the cutting rhythm (k). But these two groups representing Fot and Öpir include 3 and 4 runographers respectively, and just as many ornament types (although these cannot be related directly to the runographers). What is it that distinguishes one group of runographers from another? This question has been approached by means of a number of analyses:

1) A Discriminant Analysis was performed by the forward stepwise method in order to distinguish which variables would be useful to distinguish between the two groups of carvers, the underlying assumption being that some cutting characteristics would be transmitted from one artisan to another within the same group and that common norms for the appearance of a rune stone would influence their manner of working. DIS indicated that the three most influential variables were the groove angle (v), the amplitude in the groove bottom (Adiff) and the hit interval (w) (table 9).

2) A Principal Component Analysis taking both the longitudinal variables and the cross-section of the groove into account shows only a vague tendency for a distinction between the two workshops (fig. 21).

3) Mean profile diagrams for the individuals in the Fot and Öpir groups (fig. 22), each represented by a mean value, illustrate that there is no tendency whatsoever for the two groups to be distinguished by their groove cross-sections, nor for individuals within one group to produce cuts that are more similar to those of the other members of his group than to those produced by someone else.

These three analyses all contradict the assumption that members of a group have similar cutting techniques. One of several possible reasons for this could be that the carvers in a workshop did not share the same set of chisels, as Kalle and Markus did when producing the reference material. If each carver had chisels of his own, the individual differences may have been greater than the common characteristics of the workshop. On the other hand, it can be noted that the runographers who are most frequently represented in each group, FotR1 and ÖpirR2, are similar in their groove shapes. Likewise, FotO1 produces a similar groove shape to ÖpirO2. Is it possible that the strongest connection is not between a rune master and his assistants, but between the masters of different groups? Does this indicate that the masters of the schools or workshops had learned their trade from a common source? In the case of the reference material, the 'masters' had very little contact with each other and had developed their skills independently. For the Fot and Öpir carvers, however, acting in the same region for overlapping periods of time, the differences between groups may indeed have been less than the differences between individuals. It has been remarked earlier that beginners are not as easily distinguishable as more skilled carvers (Kitzler 2000a; Kitzler Åhfeldt 2001), and if there are several beginners, the picture can be confused. Also, carvers may have changed groups. Another alternative that should not be neglected is that differential weathering may have blurred the differences, and that these had originally been sharper, but it is not likely that the Öpir stones as a group were systematically subjected to more serious weathering than the Fot stones. If the results were interpreted at their face value, it could be that it is the same group of carvers produced the Fot and Öpir monuments, but with different leaders or authorities behind them. This is probably carrying the analyses too far, but it illustrates what results may be achieved if serious attempts are made to bring in cutting techniques as identification criteria.

Discussion

The samples of runes and ornaments were sorted in this analysis according to the shape of the cut rather than by signature or style. The assumption that groups of carvers working together should develop similar cutting techniques cannot be confirmed for the 11th century AD, however, as the individual characteristics as distinguished by surface structure analysis seem to be stronger than the collective ones. What, then, happens to the cutting technique as a criterion for attributing rune stones, as is often mentioned in the runological literature? The present results suggest that cutting technique can scarcely be used as a criterion for identifying rune carving workshops, contradicting Muller's hypothesis that clusters identified in such an analysis should indicate social interaction groups (Muller 1978, p. 24). This may also contradict earlier field experience with rune stones, where it has often been noted, for example, that the cuts on Fot stones are likely to be deep and rounded (Wessén & Jansson 1940–58). It should be remembered, however, that the analytical procedure has been developed so far to distinguish between *individuals*, as far as possible regardless of chisels and changing skills, so that some modifications may be needed to distinguish between workshops. Another possibility is that the Fot group and the Öpir group each consisted of carvers who had earlier belonged to other interaction groups.

It is generally the case that a more skilled carver will produce tighter clusters, i.e. with less variance in the variables. Changes may appear both in hit interval and in the shape of the cross-section, but a carver's cuts were distinguishable from those of other carvers in the reference material even when affected by fatigue, tool changes or variations in the slope of the rock surface.

It has been shown that characteristics visible to the unaided eye are not enough for distinguishing between individuals, and that only a combination of variables both in the cross-section of the cut and in the direction of cutting can offer a possibility of identification. Greater accuracy can be achieved if only samples of uncomplicated ornaments are chosen, neglecting more demanding parts such as the feet and head of a runic animal (cf. Kitzler 1998). Attempts have been made to describe the effect of treading and weathering on cuts by means of simplified models, and it may be possible to develop these models further, so that a high degree of weathering may be compensated for by a percentual change in the variables referring to the cross-section of the cut, for example. It is the author's opinion that modern material may be used as a relevant reference for comparisons within single carvings and that a surface structure analysis may show whether a carving has been produced by more than one craftsman, and possibly if anything has been added on a later occasion. Co-operation also seems to have existed on small monuments, even though it would not appear to have been needed. The size of the monument was not decisive with regard to whether it was cut by several masons in co-operation or not. This must have depended on other factors.

In comparisons between carvings, however, the sources of error are more influential, but even so, if cutting techniques are to be used for comparison or identification purposes at all, a quantifying surface structure analysis may be a better starting point than visual inspections, which can easily result in vague, impressionistic formulations.

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