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Shape Analysis of Petroglyphs in Central Asia

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Abstract. New methods to characterize shapes of the petroglyphs in Central Asia and properties of their groups are proposed, and results by the use of these methods are presented. Shapes of petroglyphs were treated by image analysis to obtain simplified shapes called "skeleton". Structures of skeletons are expressed by the use of some symbols, from which quantitative comparison among petroglyphs is shown to be possible. Properties of groups of petroglyphs, i.e. those drawn on the same rock, are expressed by statistics of simple quantities, such as the numbers of animals and men, the numbers of animal species and the ratio of the right-oriented to the left-oriented animals (or men). Some discussion is made on the meanings of these quantities and a possibility of future development of this kind of studies.

1. Introduction

In some regions in Central Asia and Russia a lot of petroglyphs are reserved. They were carved on rocks by habitants of these regions for a long time from the stone age to several centuries AD. An example of petroglyphs is shown in Fig. 1, which one of the authors (Takaki) took photograph when he visited Sarmishsay, Uzbekistan. The petroglyphs has been studied by archaelogists, mainly from these regions but some from other countries (LASOTA-MOSKALEWSKA and HUDJANAZAROV, 2000; TASHVAYEVA *et al.*, 2001; KHUJANAZAROV, 2003). Archaelogists are engaged in excavating new petroglyphs, dating and protecting them from many kinds of damages. A remarkable study of shapes of petroglyphs were made by SHER (1980), where lengths of parts of animal bodies were measured and relations among petroglyphs of several regions were discussed based on these data. However, quantitative treatment of petroglyphs is not much developed yet. There have been some discussion on their styles, but it was still within qualitative description based on impressions and insights of archeologists. It is the purpose of this paper to propose some quantitative methods to characterize styles of petroglyphs. It is

Fig. 1. An example of petroglyphs from the copper age. They are darved on a hard flat rock face in the valley of Samishsay, Uzbekistan (photo by R. Takaki).

expected that they may enable more reliable comparisons between petroglyphs of various regions.

Two different methods are proposed, one is to characterize styles (shapes) of each petroglyph by the use of a computer software for image analysis, and the other is to make statistics of quantities which are considered to characterize the properties of the groups of petriglyphs The group is defined as a group of petriglyphs carved on the same rock. It is assumed here that the group of petroglyphs on the same rock were drawn by the people belonging to the same village at the same age. Although it is not always assured, it will be allowed to begin analysis on this assumption. These methods are neither completed nor approved by many scientists yet, and improvement is necessary in future. However, the present authors believe that it is meaningful to propose new methods and to make them open for criticisms by many people. In the following the basic problems concerned to the present methods are discussed.

The style of a petroglyph can be described in many ways. Sizes (or the ratios of sizes) of parts of bodies are good measures for that purpose, as was done by (SHER, 1980). On the other hand, a total configuration of these parts is also important to identify styles. Different configurations of parts of an animal (or a human) body often give us different impressions. However, there is also a difficulty in characterizing the configuration. Here, as a candidate of characterization of topological properties of an animal shape is observed, since they are defined relatively easily without ambiguity. For that purpose the shapes of petroglyphs

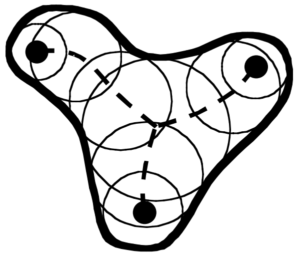


Fig. 2. How to draw a skeleton within a closed contour Trace of centers of circles, which are contact to the contour (thick line), give a skeleton (dashed lines).

must be simplified so that topological parameters can be extracted. Here, a method of image analysis, called "skeleton" is promising for simplification of shapes. Two introductory references for this method are given here; SONKA *et al*. (1999) and WATT and POLICARPO (1998).

The skeleton is a group of center lines within a silhouette, which is defined in the following way. For a given shape made of a closed contour, as shown in Fig. 2, many contact circles are drawn inside the shape. Trace of the centers of these circles gives a combination of curved lines, which is called a skeleton. Here, the ends of the skeleton correspond to the centers of circles whose radii are equal to the radii of curvature of the contour at the contact point. The skeleton gives a branching structure inherent in the original figure. This property will be convenient for analysis of animal shapes, which have many branches such as horns and legs. Technique to obtain skeletons and computer software program for it are well developed; here a free software "Scion Image" is used.

In applying such a software program to figures of petroglyphs some cares must be taken so that meaningless noise on the contour or gray parts in the digitized figure do not affect the results of analysis. After the skeleton is obtained for a particular petroglyphs, there come a problem how the shape of skeleton is characterized. The precise of the present method will be explained in the following sections.

In statistical studies of the groups of animals and humans one should choose such quantities which may show properties and situations of the inhabitants and their societies. It is not clear now what are good quantities for that purpose. What one can do at this stage would be to test some basic quantities which are considered to have certain meanings and can be measured easily. As such quantity the following three were tested.

i) Numbers of animals and men drawn on the same rock.
ii) Numbers of species of animals drawn on the same rock.
iii) Numbers of right-oriented and left-oriented animals (and men) in the same rock.

Numbers of animals and men may be related to population and activity of the villages. Moreover, the ratio of these numbers will give the life style of the people, whether they depended much on animals. Number of animal species will give a hint on how far they have developed a system of food production, i.e. whether they depended much on the wild nature or they have developed domestic animals. Orientations of animals and men are difficult to interpret. It may depend on the right-handedness of the petroglyph artists, or there might

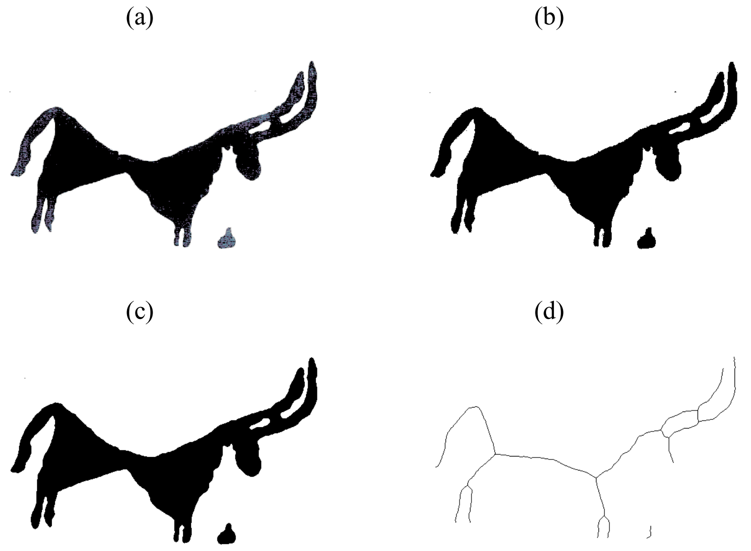


Fig. 3.

be a tendency of respecting a fixed orientation. There is also a possibility that the fixed orientation reflects the situation of the society, i.e. it is moving to one direction and not settled down. Although this kind of discussion is merely based on speculations, it would not be meaningless to try statistical studies.

In this paper the samples of petroglyphs are taken from the figures of the monograph by TASHVAYEVA *et al.* (2001). They were recorded by putting tracing paper on the real petroglyphs, hence they are considered to be quite faithful to original shapes. In the following sections, the process of image analysis to obtain skeletons is explained in Sec. 2, interpretation of these skeletons by constructing a system of codes is shown in Sec. 3, results of the statistical studies are given in Sec. 4. The present methods and results are discussed in Sec. 5.

2. Method of Image Analysis

The figures of petroglyphs expressed as silhouette in the mongraph (TASHVAYEVA *et al.*, 2001) were converted to digital data by the use of an image scanner. These data were named after the figure numbers in the monograph and stored in the computer with data format "jpeg". The processes to obtain their skeletons are given below (see Fig. 3). The commands of image processing in the software are given in the square parentheses with Italic characters.

a) Change image data format to 16-color bitmap, by the use of appropriate software, such as "Microsoft Paint". Start the software program "Scion Image" and open an image data of bitmap.

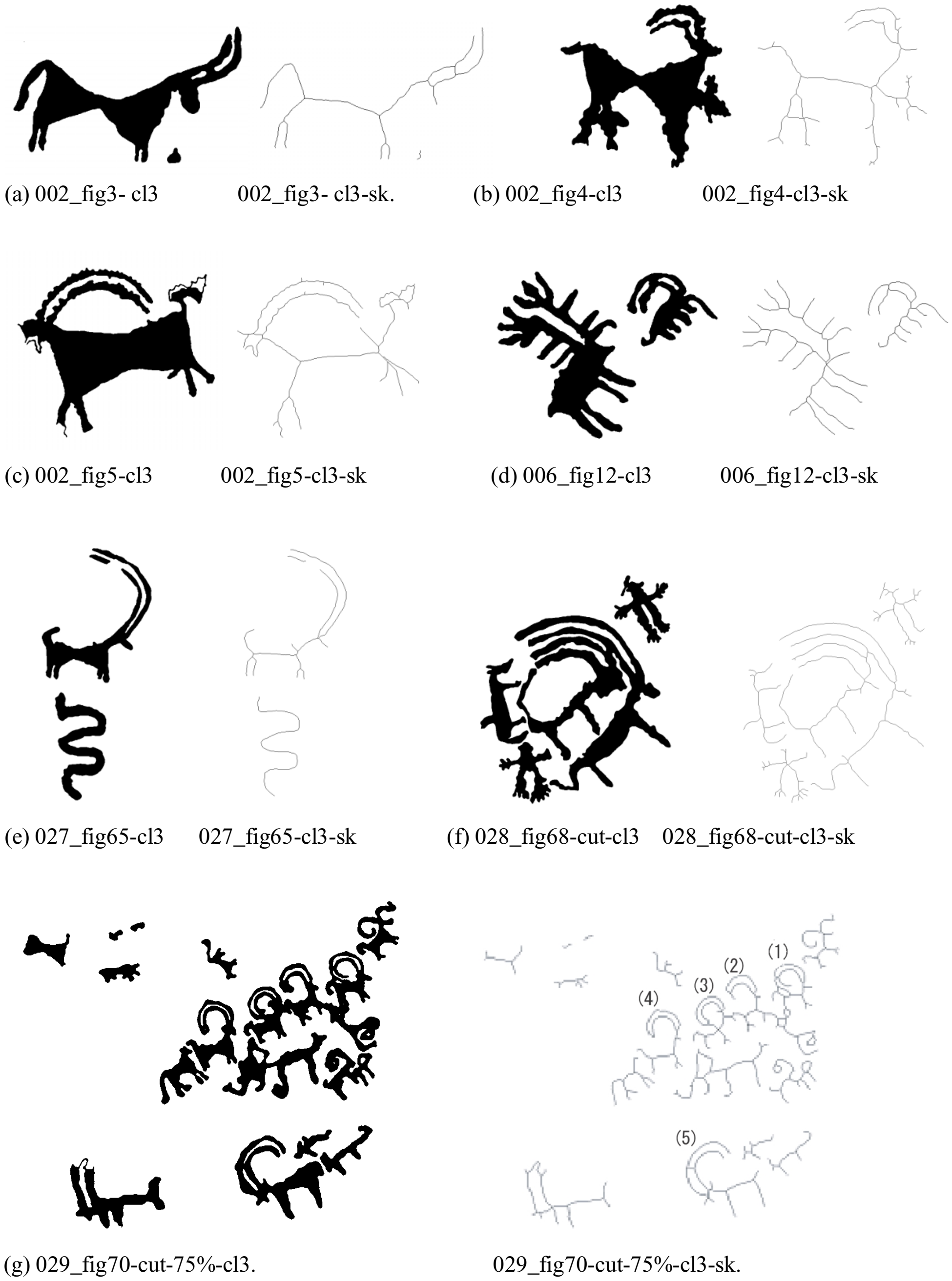
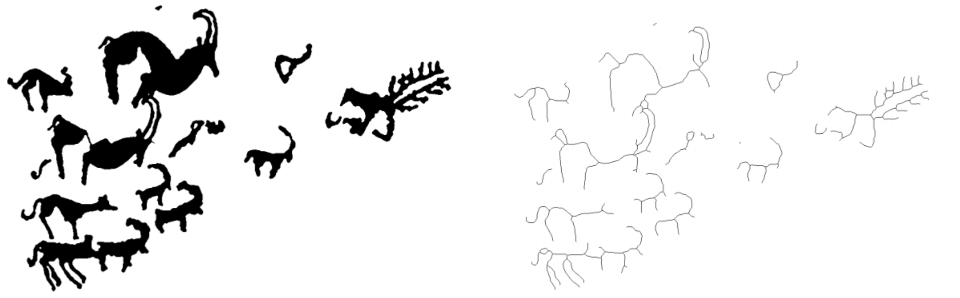


Fig. 4. Results of the smoothing and skeleton processes for petroglyphs including ibexes. Original figures are taken from the monograph by TASHBAYEVA *et al.* (2001). These petroglyphs are from (a)–(j): Saimaly Tash in *Kyrgyzstan*, (k)–(l): Saikhansai in Uzbekistan, (m) Ak Jilga in Tadjikistan, (n) Lyangar in Tadjikistan, (o)–(p) Vybist Dara in Tadjikistan. In the filenames below figures the symbols for data format ".gif" are abbreviated.



(h) 034_fig81-cut-75%-cl3 034_fig81-cut-75%-cl3-sk

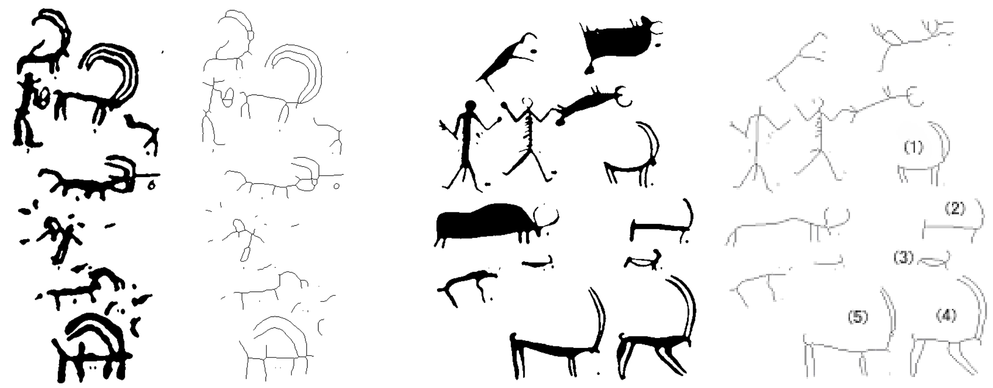
(i) 035_fig83-cut-75%-cl3 035_fig83-cut-75%-cl3-sk (j)037_fig92-cut-cl3 37_fig92-cut-cl3-sk

(k) 060_fig26-cut-75%-cl3 060_fig26-cut-75%-cl3-sk

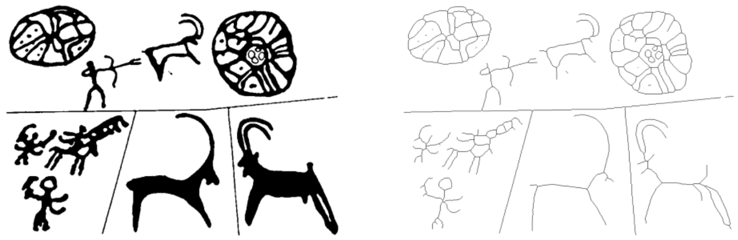
Fig. 4. (continued).

b) Change the image data to a black-white one by the binary function of "Scion Image": [*option*: *threshold* (adjust threshold level) - *process*: *binary*: *make binary*]. Store the changed data by adding the ending "-bw" to the filename.

c) Make the contour of the image smooth (close process) as follows (repeating three

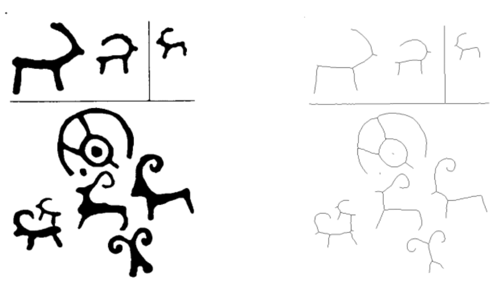


(l) 061_fig27-45%-cl3 061_fig27-45%-cl3-sk (m) 071_fig9-65%-cl3 071_fig9-65%-cl3-sk



(n) 078-fig18-65%-cl3 078-fig18-65%-cl3-sk

(o) 079_fig19-70%-cl3 079_fig19-70%-cl3-sk



(p) 080_fig22-80%-cl3 080_fig22-80%-cl3-sk

Fig. 4. (continued).

(a) (b) (c)

N- HH C1 - N- LB- B- LB- T N- HB S3- N- LLS8-B-L BC1S3 -T S1 NC1S 1- HHS 3- N-
LBS1 -B-L BS1- TC2S2

Fig. 5. Examples of symbol arays for skeletons of Figs. 4(a), (b) and (c).

times): [*process*: *binary*: *close* - *process*: *binary*: *close* - *process*: *binary*: *close*]. Store the changed data by replacing the ending "-bw" with "-cl3" in the filename.

d) Make skeletons by the operation: [process: binary: skeletonize]. Store the skeleton data after adding the ending "-sk" to filename.

In some cases preliminary processes are necessary before applying the above processing in order not to obtain meaningless results.

e) If two parts of the original figure are very much close to each other, they may touch in the "*close*" processing (the process 4). Then, the topological nature of the figure changes. In this case the spacing between these parts is made wider with a function of "Microsoft Paint" before processing. The filename is changed by adding "-cut". Note that the parts contact each other already in the original image are not separated.

f) If the original image has a large scale and some part goes out of the frame of "Scion Image", the image is contracted by a certain fraction before processing. In this case an ending is added to the filename, for example, "–75%".

Finally, if the obtained data at each stage of processing is too heavy for computer memory or for sending by email, they are changed to gif-data. The results of processing shown in Figs. 3 and 4 are gif-data.

As the first trial of application of this method the petroglyphs of ibexes (wild goats) were chosen, because ibexes are easily identified owing to their long curved horns. All petroglyphs shown in the monograph (TASHVAYEVA *et al.*, 2001) including ibexes were processes, and the results of processes c) and d) are shown in Fig. 4. The first impression of the authors is that the styles of original petroglyphs are apparent also in their skeletons. Characterization of the skeletons is explained in the next section.

3. Characterization of Petroglyphs Based on Their Skeletons

Skeletons are composite curves with several branches. Their quantitative characteristics are expressed in terms of numbers of edges, end points, branch points, etc. However, these parameters do not seem to be effective, because a skeleton could be deformed freely to

Table 1. Symbol arrays for the three skeletons of ibexes shown in Figs. 5(a), (b) and (c). Dots indicate blanc fields. Inclined symbols indicate different fields between (a) and (b). Arrays (a) and (b) are different at 14 fields. The difference between (b)–(c), and (c)–(a) are 13 and 16, respectively.

(a)	**N•••••••H*H*•*C1* ••N•••••••L*B*••••••B•••••••LB••••••T•••••••**
(b)	**N•••••••H*B*•••*S3*•N••••••• L*L*•• *S8*••B•••••••LB*C1S3* ••T••*S1*•••**
(c)	**NC1S1•••HH•••S3•N••••••• LB••S1••B••••••• LB•••S1••TC2S2•••**

another shape (hence with another style), without changing values of these parameters. Here, the present authors assume that the identification of styles depends much on a fixed image of animals owned by researchers, that is, a variation of a shape of an animal from a standard one of the animal is looked upon as a style.

If this is the case, we must first fix the standard shape of the ibex. It is composed of a nose (tip of the face), two horns, a neck, two fore-legs, body, two rear-legs and a tail. They are given symbols, N, H, L, B, L, T, respectively, and these symbols are arranged from the nose through the tail as N-HH-N-LL-B-LL-T, where doubled symbols indicate the numbers of respective parts. Then, variation of the style is expressed as that of the array of these symbols. For example, the second ibex from the top in Fig. 4(l) has three horns and is expressed as N-HHH-N-LL-B-LL-T, and the ibex lower-right in Fig. 4(p) (a single horn, a single fore-leg, a single rear-leg and no tail) is expressed as N-H-N-L-B-L. In this way all ibex figures can be labeled with symbols of variation. However, this way is still not strong enough because many ibexes, which seem to have different styles from each other, have the same arrangement of symbols. Therefore, we must express the variations more precisely.

We observe the following additional characters in skeletons:

- In some skeletons two lines come out of its body as horns or legs, while in others a single line comes out which branches to two. In the former case symbols HH or LL are given while in the latter case these symbols change to HB or LB (B stands for "branch").
- In some skeletons two horns or legs are connected by a line after they have come out of the body, thus making a loop. If horns or legs have *n* connections, this variation is expressed by adding symbols Cn, thus for example HH is changed to HHC1.
- In many skeletons several spines come out of some parts of the body, which may reflect of the roughness of the contour or some special parts of the body, such as the ear or the penis. Here, these are treated simply as spines without identifying their meanings. If a part of the skeleton, has *n* spines, we add symbols Sn, for example the neck with two spines is expressed as NS2 instead of N.

By including these additional symbols the skeletons of ibexes can be characterized precisely enough for comparison of their styles. For example, the three skeletons of Figs. 4(a), (b) and (c) are given the symbol arrays as shown in Fig. 5.

In order to compare arrays of symbols of skeletons it is convenient to give a fix number of fields to input symbols for each part of skeleton, i.e. nose, horn, neck, etc. Here, we give eight fields to each parts (56 fields in total). Then, the arrays shown in Fig. 5 are again rearranged as shown in Table 1. Symbol arrays for all skeletons obtained in this work are listed in Table 2.

Table 2. Symbol arrays for the skeletons of all ibexes. Data from TASHVAYEVA *et al.* (2001).

Fig. Number	Location	Nose	Horn	Neck	Fore Leg	Body	Hind Leg	Tail
002_fig3	Saimaly	N•••••••	HH•C1•••	N•••••••	LB••••••	B•••••••	LB••••••	T•••••••
002_fig4	-	N•••••••	HB•••S	N•••••••	LL••S8••	B•••••••	LBC1S3••	T••S1•••
002_fig5	-	NC1S1•••	HH•••S	N•••••••	LB••S1••	B•••••••	LB••S1••	TC2S2•••
002_fig12	-	N•••••••	HB•C1•••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
027_fig65	-	N•••••••	HH••••••	N••S1•••	LB••••••	B•••••••	LB••••••	T•••••••
028_fig68-1	-	N••S1•••	HB••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
028_fig68-2	-	N•••••••	HB••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
029_fig70-1	-	N•••••••	HB•C1•••	N•••••••	LB••••••	BC1•••••	L•C1••••	T•••••••
029_fig70-2	-	N•••••••	HB•C1•••	N•••••••	LB••••••	B•••••••	LB••••••	T••S1•••
029_fig70-3	-	N•••••••	HB•C1S1•	N•••••••	LB••••••	B••S1•••	L•••••••	T••S1•••
029_fig70-4	-	N•••••••	HB•C1•••	N•••••••	LB••••••	B•••••••	L•••••••	T•••••••
029_fig70-5	-	N••S1•••	HH•C1•••	N••S1•••	L•••••••	B•••••••	L•••••••	T•••••••
034_fig81-1	-	N•••••••	HB•C1S1•	N•••••••	LBC1••••	B•••••••	L•••••••	T•••••••
034_fig81-2	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
034_fig81-3	-	N••S1•••	HH•••S	N•••••••	L•••••••	B•••••••	L•••••••	TC1•••••
034_fig81-4	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
034_fig81-5	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	D•••••••
034_fig81-6	-	N•••••••	H•••••••	N•••••••	L•••S1••	B•••••••	L•••••••	T•••••••
035_fig83-1	-	N•••••••	HH•C1•••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
035_fig83-2	-	N•••••••	HH••••••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
035_fig83-3	-	N•••••••	HH•C1•••	N•••••••	L•••••••	B•••••••	LL••••••	T•••••••
035_fig83-4	-	N•••••••	HH••••••	N•••••••	LL••••••	B•••••••	L•••••••	T•••••••
035_fig83-5	-	N••S1•••	HH••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
035_fig83-6	-	D•••••••	HH•C3•••	N•••••••	LL••••••	B•••••••	LB••••••	T•••••••
035_fig83-7	-	N•••••••	HH••••••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
035_fig83-8	-	N•••••••	HH•C2•••	N•••••••	LL••••••	BS1•••••	LL••••••	TS1•••••
035_fig83-9	-	N•••••••	HH••••••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
037_fig92-9	-	N••S1•••	HH••••••	N••S1•••	L•••••••	B•••••••	L•••••••	T•••••••
060_fig26-1	Saikhansa	D•••••••	HHHC6•••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
060_fig26-2	-	N•••••••	HHH••S1•	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
060_fig26-3	-	N•••••••	HHHC2•••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
060_fig26-4	-	N•••••••	HH••••••	N••S1•••	L•••••••	B•••••••	L•••••••	T•••••••
060_fig26-5	-	N••S1•••	HB••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
061_fig27-1	-	N•••••••	HB•C2•••	N•••••••	LL••••••	B•••••••	L•••••••	T•••••••
061_fig27-2	-	N•••••••	HHHC1•••	N•••••••	LB••••••	B•••••••	LB••••••	T•••••••
061_fig27-3	-	NC1•••••	HH•••S1•	NC1•••••	LL••••••	B•••••••	LL••••••	T•••••••
061_fig27-4	-	N•••••••	HH••••••	N•••••••	LL••••••	B••S1•••	LL••••••	T•••••••
071_fig9-1	Ak Jilga	D•••••••	HB••••••	N•••••••	LL••••••	B•••••••	LL••••••	T•••••••
071_fig9-2	-	D•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
071_fig9-3	-	D•••••••	H•••••••	N•••••••	L•••••••	BC1•••••	L•••••••	D•••••••
071_fig9-4	-	N•••••••	HH••••••	N•••••••	LL••••••	B•••••••	LLC1••••	T•••••••
071_fig9-5	-	N•••••••	HB•C1•••	N•••••••	LB••••••	B•••••••	LL••••••	T•••••••
078_fig18-1	Lyangar	N•••••••	HB••••••	N•••••••	L•••••••	BC1•••••	L•••••••	T•••••••
078_fig18-2	-	N•••••••	HB••••••	N••S2•••	L•••••••	B••S1•••	LBC1••••	T•••••••
078_fig18-3	-	N••S1•••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
079_fig19-1	Vybist	N•••••••	H•••••••	N•••••••	L•••••••	BC1•••••	L•••••••	T•••••••
079_fig19-2	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
079_fig19-3	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
080_fig22-1	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	D•••••••
080_fig22-2	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
080_fig22-3	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
080_fig22-4	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	D•••••••
080_fig22-5	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	D•••••••
080_fig22-6	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••
080_fig22-7	-	N•••••••	H•••••••	N•••••••	L•••••••	B•••••••	L•••••••	T•••••••

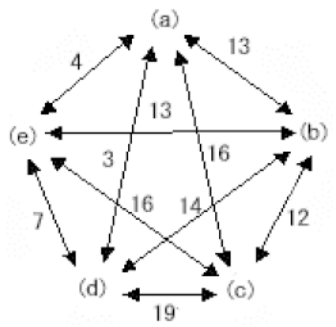


Fig. 6. Mutual distances among five isolated ibexes (Figs. 4(a)–(e)). The average distance is 11.7.

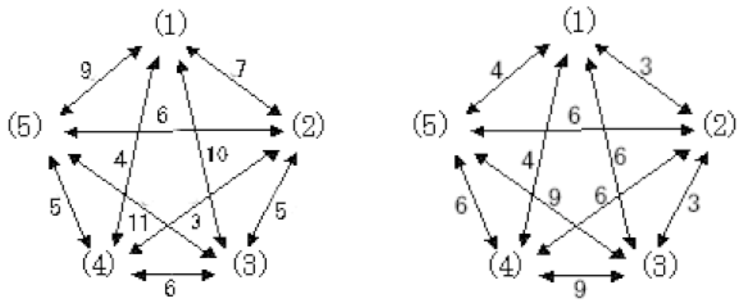


Fig. 7. Mutual distances among five ibexes drawn in the same figures, Fig. 4(g) (left) and Fig. 4(m) (right). The average distances within these figures are 6.6 and 5.6, respectively.

The distance between any two skeletons is defined as the number of different symbols at corresponding fields. For example, the arrays (a) and (b) in Table 1 are different at 14 fields as indicated by red symbols. Hence, the distance between the ibexes shown in Figs. 5(a) and (b) is 14. In the same way the distances between (b)–(c), and (c)–(a) are 13 and 16, respectively. The mutual distances among five isolated ibexes (Figs. 4(a)–(e)) are shown in Fig. 6. Among these five ibexes (a), (d) and (e) are relatively close to each other, while (b) and (c) are separated from any of others. The average of these 10 distances is 11.7.

Ibexes drawn in the same petroglyph, i.e. on the same rock, are expected to have similar styles, hence they would have relatively small distances to each other. In fact two ibexes in Fig. 4(f) have mutual distance of 2. Mutual distances among several ibexes within Figs. 4(g) and (m) are shown in Fig. 7, where ibexes are labeled with numbers in parentheses as shown in these figures. The average distances in Figs. 4(g) and (m) are 6.6 and 5.6, respectively. These values are smaller than the average distance 11.7 for isolated ibexes shown in Figs. 4(a)–(e).

On the other hand, it should be examined whether these groups have large distances from other groups or other isolated ibexes. Since full survey of this test is associated with

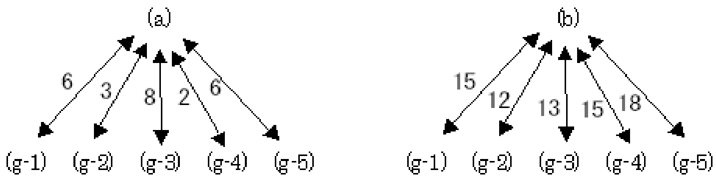


Fig. 8. Distances from ibex of Fig. 4(a) or (b) to each of five ibexes in Fig. 4(g). Average distances from (a) and (b) are 5.0 and 14.6, respectively.

a lot of data of distances, in this paper the two sets of data are shown, i.e. distances from Fig. 4(a) or (b) to each of five ibexes in Fig. 4(g), as shown in Fig. 8. From these results we can say that (a) is close to the group in (g), while (b) is far from this group. The first impression of the shapes of ibexes seems to support these results.

Although data of distance measurement are not yet obtained much, trials made so far seem to suggest that the distance defined in this paper gives a good measure for discussing styles of ibexes. A rough criterion would be that two ibexes were drawn with the same style if their mutual distance is less than 10, and with different styles if it is larger than 10. It is noted here that an effective method should be developed to estimate a distance between two groups of animals.

4. Statistics of Parameters Characterizing Groups of Petroglyphs

In this section some possibilities are examined to characterize properties of groups of petroglyphs quantitatively by observing the following three properties. As is already given in Sec. 1, they are the numbers of animals and men, the number of species in the petroglyphs and the orientations of the body axes of animals (or faces for men) in the petroglyphs on the same rocks. These quantities were chosen because they are quite simple and basic ones; they are considered to reflect situations of ancient people about the concept of space, their life styles and industries.

As in the shape analysis described in the previous sections a group of petroglyphs is defined here by the group shown in one figures in the monograph (TASHBAYEVA *et al.*, 2001). Since the purpose of this research is to characterize the societies by statistical method, those regions should be chosen which have a lot of petroglyphs. As the first trial the three such regions, Saimaly Tash, Sarmishsay and Saikansay, were chosen.

The result of counting the numbers of animals and men in these three regions is shown in Fig. 9, where one dot in the figure corresponds to one figure in the monograph cited above. The data are rather scattered, and it is not easy to extract clear conclusions. However, there are observed slight differences among these regions. The degree of data scatterings is different, larger scatterings in Saimaly Tash (from 0 to 12 men) and Saikhansai (from 0 to 29 animals), while a smaller in Sarmishsai (6–14 animals, and 0–5 men). The average ratios of the number of animals to that of men are seen to differ among these regions, i.e. the maximum ratio in Saikhansai and the minimum in Saimaly Tash, while Sarmithsai is at the middle.

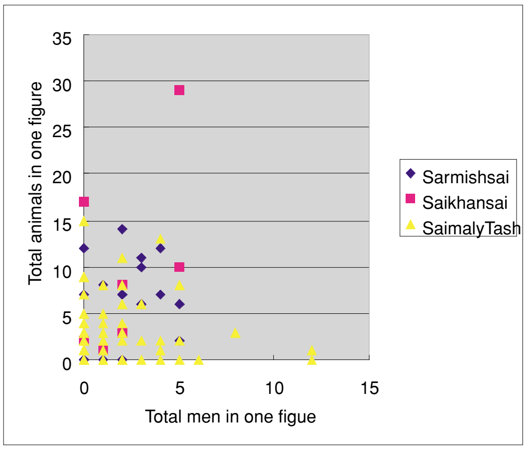


Fig. 9. Numbers of animals and men carved on one rocks in the three regions, where petroglyphs on one rock are assumed to be shown within one figure in the monograph (TASHBAYEVA *et al.*, 2001).

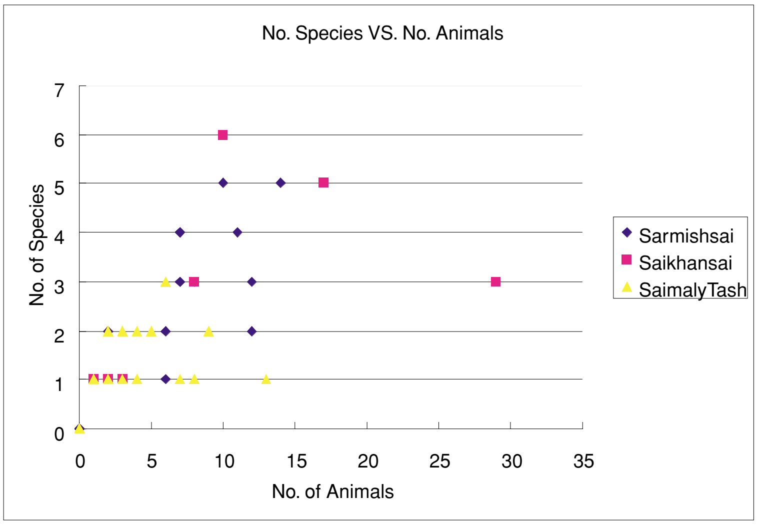


Fig. 10. Numbers of animal species vs. the numbers of animals carved on one rocks in the three regions. Data from the monograph (TASHBAYEVA *et al.*, 2001).

The numbers of species of animals and the numbers of animals carved on one rocks are shown in Fig. 10. Although the data are scattered, it can be seen that the petroglyphs in Saimaly Tash have less number of species than those in Sarmishsai and Saikhansai. It is not clear what the number of species means. Here, the speculation by the present authors

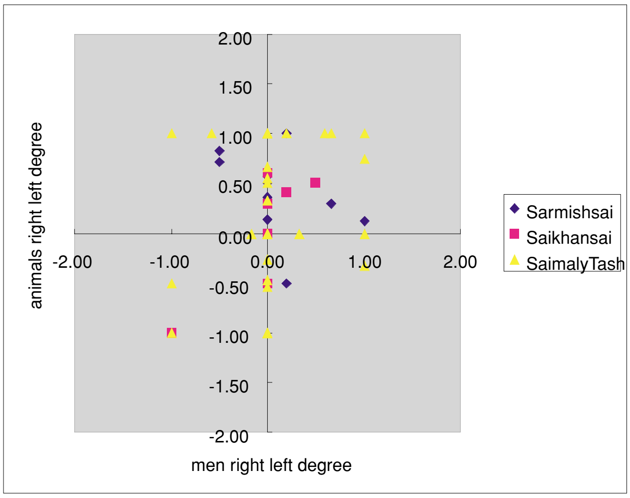


Fig. 11. The right-left degrees of animals and men carved on one rock in the three regions. This quantity is defined by Eq. (1). Data from the monograph (TASHBAYEVA *et al*., 2001).

is given. The ancient people would have chosen the animal species in which they were interested. The main animals carved in the three regions are bulls, ibexes and dogs. These animals occupy 62% of all animals carved in Saimaly Tash, while the percentages in Sarmishsai and Saikhansai are 48% and 24% respectively. This fact would mean that the people in Saimaly Tash were interested in these main animals and less interested in other ones.

The orientations of animals and men are expressed quantitatively by a quantity called "right-left degree". Let the numbers of right-oriented, left-oriented and middle-oriented animals (or men) (those oriented to perpendicular to the rock face, or their orientations are difficult to judge) carved on one rock be denoted by Nr, Nl and Nm respectively. The right-left degree is defined by the following equation:

$$\text{right - left degree} = \frac{Nr - Nl}{Nr + Nl + Nm}. \tag{1}$$

This quantity varies between –1 and 1, where the values 1 and –1 correspond to totally right-oriented and left-oriented animals (or men), respectively.

The results of calculating this quantity for the three regions are shown Fig. 11. Data are also scattered, but a difference among the three regions is seen. No preference of orientation is recognized in animals and men in Saimaly Tash, while animals in Saikhansai and Sarmishsai are rather right-oriented (no preference for men).

It is not easy to relate these results with social situations in the ancient ages. Some comments based on speculations of the authors are given in the next section.

5. Discussion

In this paper two methods are proposed to analyse the petroglyphs quantitatively, a shape analysis based on the image processing, and a statistical analysis of some quantities concerned to properties of petroglyphs.

The former is aimed at judging similarities of styles among petroglyphs, and so far as it is applied to those of ibexes this method seems promising. It is assumed here that petroglyphs on the same rock were drawn at the same age by people belonging to the same group, hence they should have similar styles. However, this assumption should be examined by comparing results of the present method with established knowledge in archaeology.

As for the latter method the most important problem is to find what are meaningful and effective quantities to guess the social situations of ancient ages. The quantities proposed in this paper, number of animals and men in one rock, number of animal species and the right-left degree, are the simplest ones to be tried first. There is another problem of how to interpret the results of these statistical results.

Some ideas are given here on the meanings of the proposed quantities, which are simply based on the speculations of the authors. It would be natural to guess that the numbers of animals and men in one rock are correlated with the population and the development of the societies.

The number of animal species would indicate the situation of the communities, because people depending more on the natural surroundings would be familiar to more number of animal species. In Saimaly Tash they were interested in a small number of sepcies, bulls, ibexes and dogs, hence they might have kept these animals for cattle breeding. This result might mean also that the communities in Saimaly Tash were already settled down and engaged in a stable industry, while communities in Sarmishsai and Saikhansai depended more on the nature.

The orientation of animals and men is more difficult to interpret. There seems to be a tendency also at present to draw animals, cars, airplanes, etc. with their head oriented to the right. It may depend on the physical condition of humans, i.e. the right-handedness of humans. However, since difference of this tendency was observed among the three regions investigated in this work, another factor must be considered. A possibility is suggested that the uniformity of orientation means that the people had a sense of geometrical direction of some kind, either they had a holly place to that direction, or they were emigrating to that direction. On the other hand, if animals and men are carved with various orientations, it might mean that they had already settled down in that region.

The ideas given above seem to be worth investigating, although it is still not based on any evidence. Since statistical data become more reliable for more number of samples, analysis of petroglyphs should be continued further. It should be noted here that the discussion of the properties of societies is based also on the assumption noted above that the petroglyphs carved on the same rock were made at the same time by the people in the same society. This assumption would be confirmed if the method of classification of styles proposed in this paper is established. Therefore, the statistical study is closely connected with the image analysis of petroglyphs.

Identification of styles should be extended to comparing animals of different species, which is more difficult than in the case with the same species. It is desired to improve the present method to enable such comparisons.

Finally, it is pointed out that the petroglyphs are the only messages addressed to us by the people in pre-historic ages. Analysis of petroglyphs is an effort to interpret their messages and is really an attractive work.

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