

# AN OBJECTIVE COMPARISON OF RELIEF MAPS PRODUCED WITH THE SYMAP & SYMVU PROGRAMS

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## Abstract

123 university students answered a series of questions which measured their speed and accuracy in using relief maps produced by the computer programs SYMAP and SYMVU. Most questions produced statistically significant differences between the four types of map investigated and, on all of these, a layer version of SYMAP was superior to two types of SYMVU map. It appears that the pictorial appeal of SYMVU is misleading and that a layer version of SYMAP is better for extracting information. In general, the results are consistent with a previous experiment which tested conventional relief maps.

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A good relief map should allow the map reader to form a clear mental image of the landscape but it must serve several other purposes as well. The map should provide information about height - both absolute height and relative height. It should be easy to search for relief features, and it is important that relief information does not obscure other information on the map.

Clearly, there are many considerations in designing relief maps, and there are likely to be complex trade-offs, where an increase in legibility for one type of map reading task may decrease legibility for other tasks.

A number of experiments have tested relief maps, and similar maps depicting a three-dimensional surface, to study objectively the effect of design on the map readers' performance (Kempf and Pooch, 1969; Shaw and MacLagan, 1972; De Lucia, 1972; Phillips, De Lucia and Skelton, 1975). As more experimental results become available, the cartographer should have a clear picture of the important factors affecting relief map legibility.

One aspect which has not been studied experimentally (to the best of our knowledge) is the relatively cheap, one-off computer produced maps from, for example, the SYMAP and SYMVU programs. Line printer output can mimic traditional contour line and layer tint maps, while drum plotters can rapidly produce perspective views of a landscape (see Figures 1 to 4).

This experiment compares four types of relief map produced using the SYMAP and SYMVU programs developed by the Laboratory of Computer Graphics, Harvard University (Muxworthy, 1972). The experimental method is similar to that used in a previous experiment (Phillips, De Lucia and Skelton, 1975; described more fully in a report by Audley, Bickmore and Phillips, 1974).

## METHOD

### Subjects

SYMAP and SYMVU maps are probably used most frequently for research purposes, and where there is easy access to a computer. As universities must be heavy users, university students seemed an appropriate group to test. Sixty men and sixty-three women, acting as paid volunteers, were tested in three groups. Their median age was nineteen years. They were questioned about their GCE qualifications in geography, or equivalent geography examinations. Thirty had A-levels, forty-two had only O-levels, fifty-one had no geography qualifications. They were studying a wide range of degree courses, including geography.

### Maps

We thought it was appropriate to test maps depicting fairly difficult and unfamiliar type of relief. The bed of the Atlantic Ocean seemed sufficiently unfamiliar for this purpose, and six areas were selected from the Area B map used in a previous experiment (Phillips, De Lucia and Skelton, 1975). The subjects were told the maps portrayed 'a made-up landscape'.

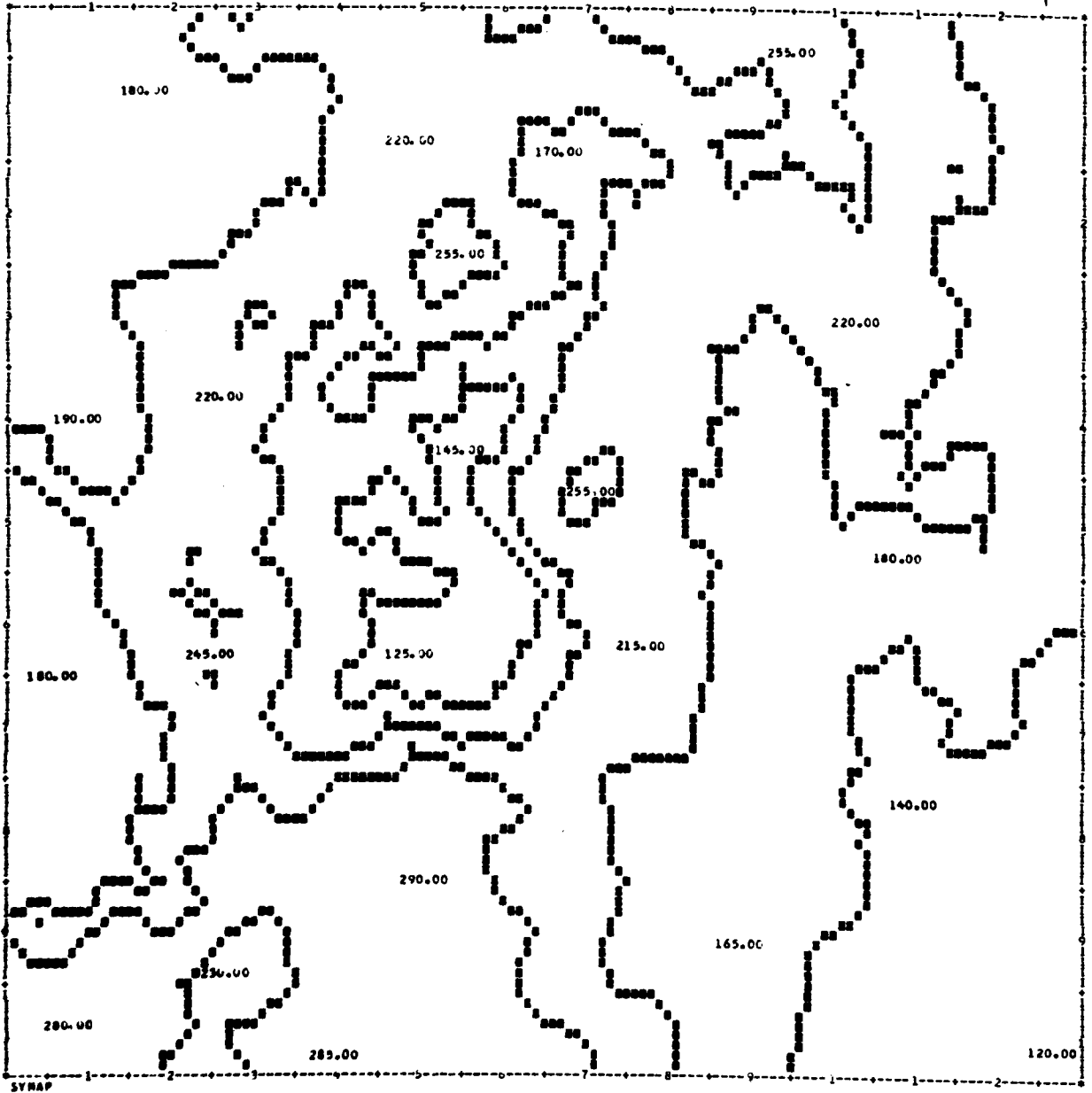


Figure 1. A Contour map.

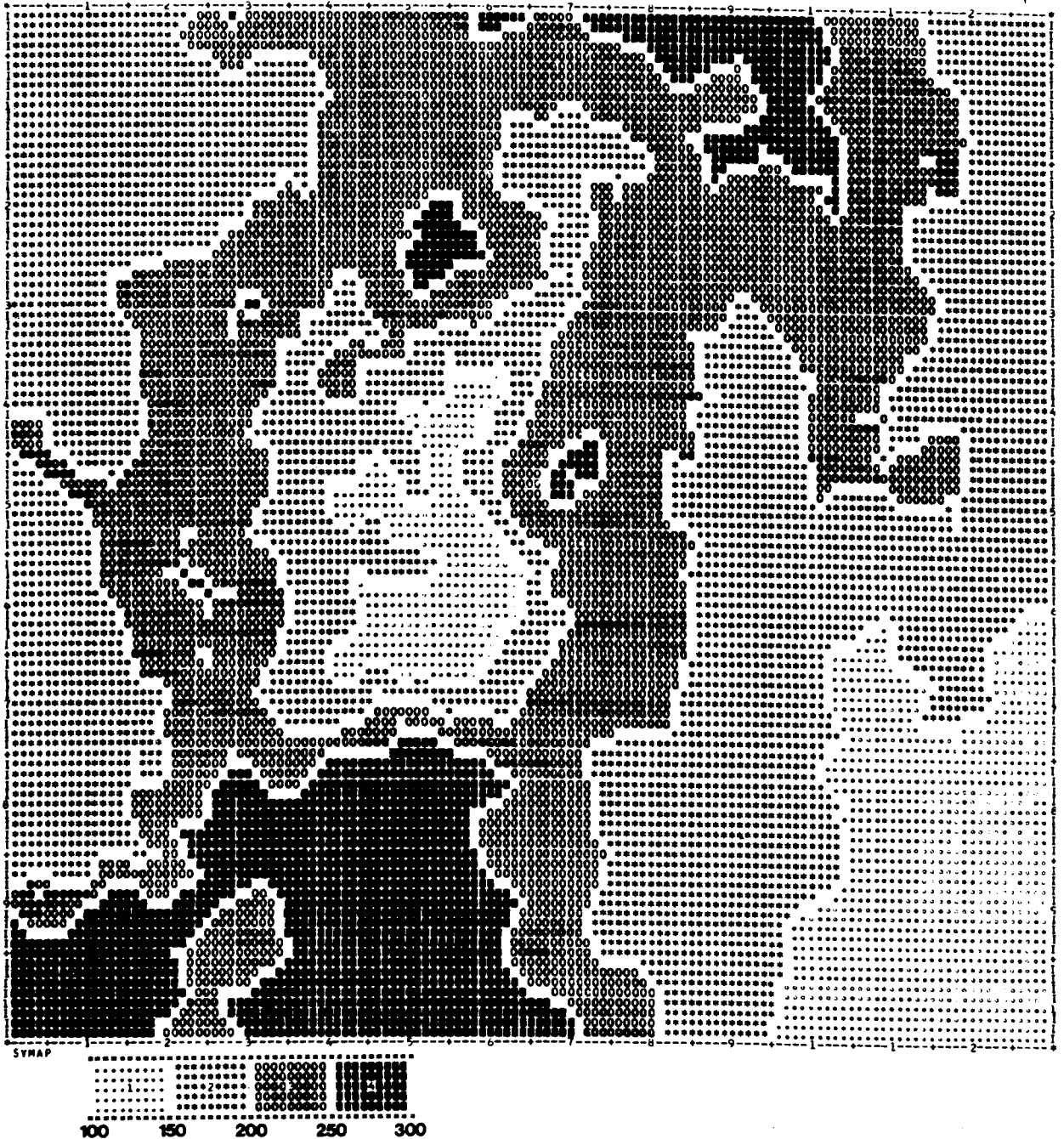


Figure 2. A Layer map.

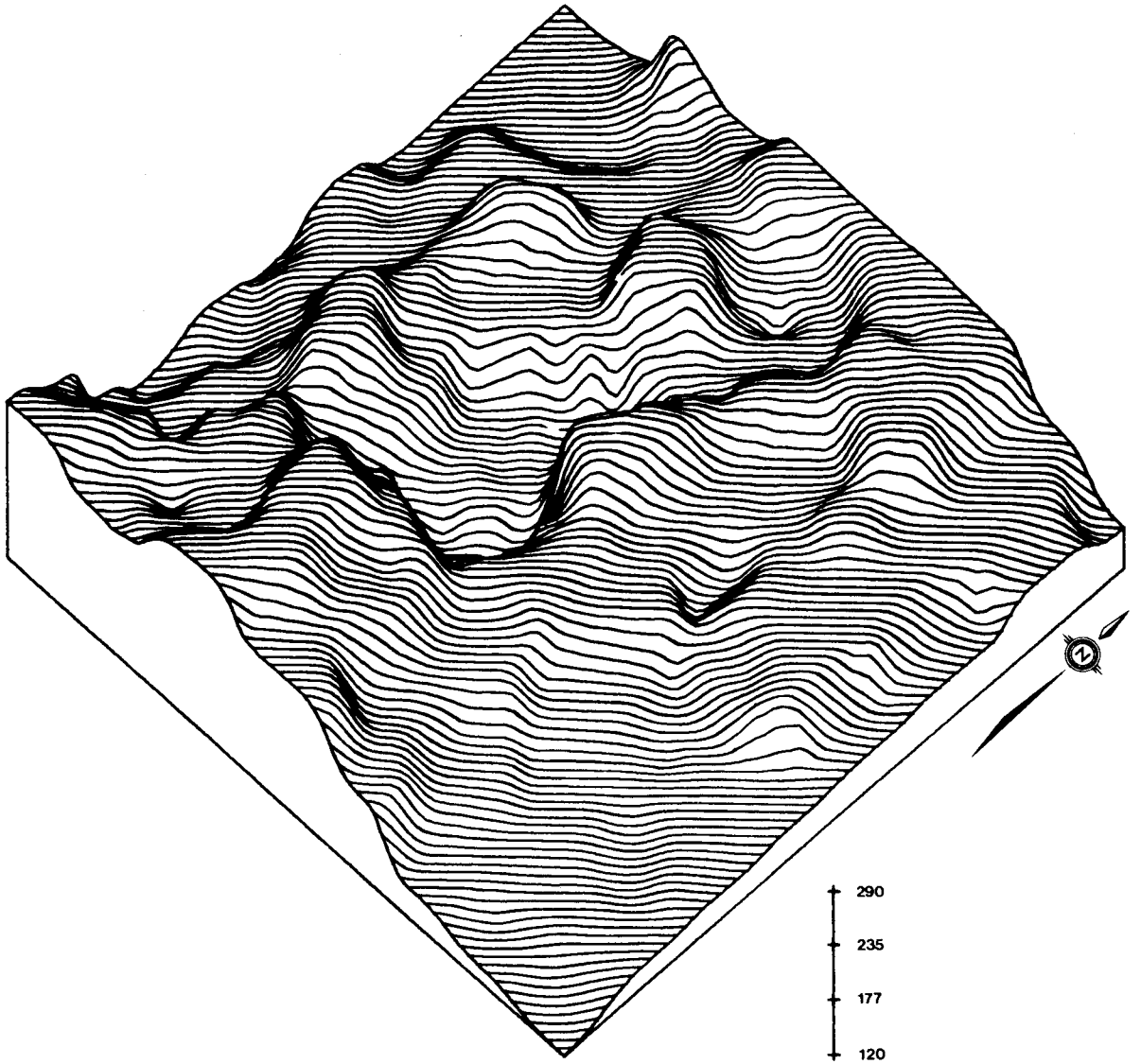


Figure 3. A Diamond map.

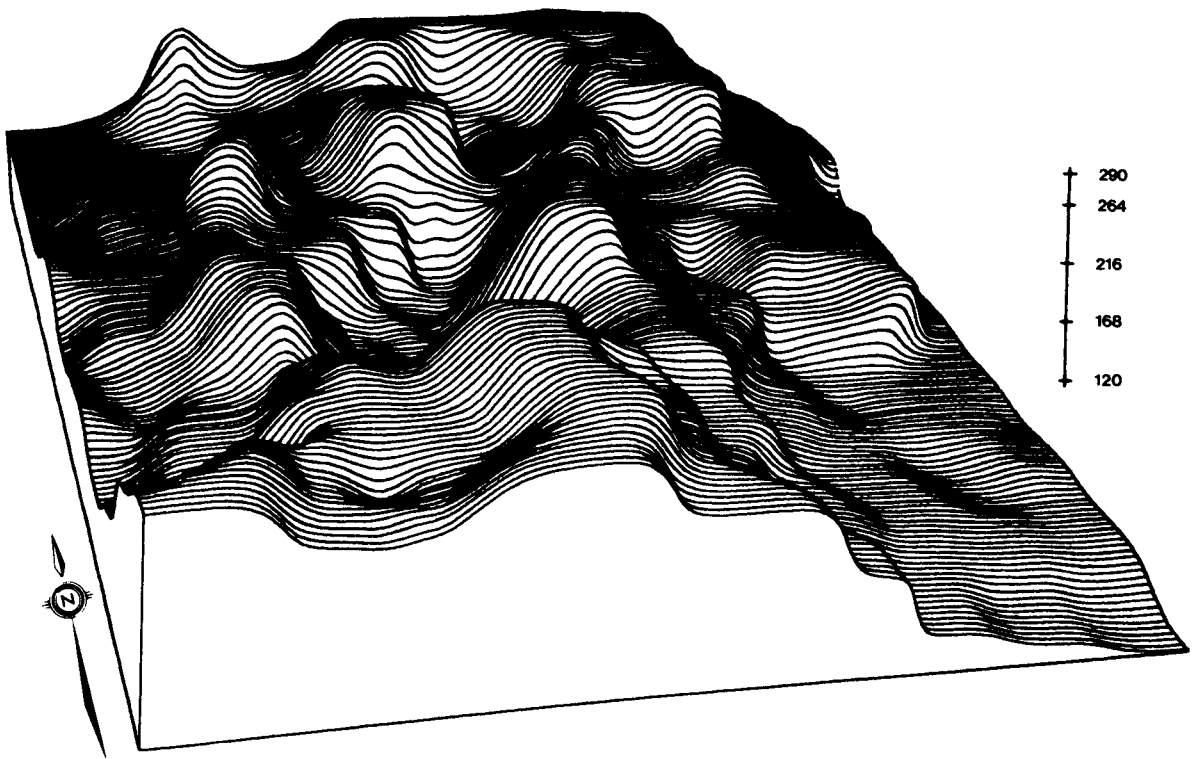


Figure 4. A Square map.

An average of 305 data points were coded for each area as data for the SYMAP and SYMVU programs. Following the advice of Liebenberg (1976), we spent some time exploring the options provided by the programs, and our final choice of four types of map was made from a much larger number. Our aim was to produce four types of map which were good examples of their kind. The four types are illustrated in Figures 1 to 4, and some of their features are listed in Table 1.

Table 1. Details of the Four Types of Maps

<u>Name</u>	<u>Program</u>	<u>Printed Size</u>	<u>Notes and Program Options</u>
Contour	SYMAP	205mm square	The spot heights are not the actual data points but have been added manually.
Layer	SYMAP	205mm square	The symbolism is standard except an asterisk replaces the plus sign.
Diamond	SYMVU	175mm wide 180mm high	Drawing projection: orthographic (2-3). Direction of lines: along diagonals (2-4). One binomial smoothing (2-5). Plot every second line (2-8). Altitude: 65 deg. (3-1). Azimuth: 315 deg. (3-2). Width: 7 in. (3-3). Height: 3.5 in (3-4).
Square	SYMVU	180mm wide 115mm high	Drawing projection: two point perspective (2-3). Direction of lines: along rows (2-4). Two binomial smoothings (2-5). Plot every line (2-8). Altitude: 45 deg. (3-1). Azimuth: 10 deg. (3-2). Width: 10 in. (3-3). Height: 2.5 in. (3-4).

The layer version of SYMAP is perhaps the most familiar type of computer-produced map. Because it is such a densely inked map, it has the disadvantage that any superimposed information is difficult to read. The Contour version overcomes this. It should be noted that the spot heights in the Contour version have been added manually.

The Square version of SYMVU was intended to exploit the pictorial aspects of the program: it employs perspective foreshortening and the impression of shading is enhanced by plotting every line. The Diamond map was intended to be less pictorial. By using less lines and by showing two sides of the square edge, we considered it might be a better map for extracting detailed information.

Contour, Layer, Diamond and Square maps were produced for each of the six areas, but the majority of questions used only areas 1 and 2. The maps were reduced photographically to fit into an A4 page and were printed by offset lithography.

### Procedure

The experiment employed a 2 by 3 by 4 by 2 factorial design with a minimum of one subject per cell. The factors were sex of subject, GCE geography qualifications, type of map, and the order of tackling the two map areas.

Each subject was assigned to one type of map which was used throughout the tests. The first booklet consisted of a series of questions using the same map throughout. The second booklet consisted of the same series of questions using a map of the same type, but depicting the other geographic area. Half used Area 1 for the first booklet and Area 2 for the second booklet, and the other half had the reverse order. The third booklet tested subjects' ability to match all six areas of map to a plastic relief model.

Every question was carefully explained before subjects attempted it. Accurate time limits were maintained by inserting blank pages in the booklets between the maps, so that the maps were only visible when a question was actually being answered.

On arrival, subjects were given an example of the type of map they were to use (Area 4) and some printed notes on it. For the SYMVU maps, these notes included an explanation of the height legend and some hints on how to estimate heights. Before starting, the subjects were briefed on the purpose of the tests, and it was strongly emphasised that everyone should do as well as they could, regardless of their opinion of the maps.

Question 1. Warm up.

The questions are numbered in the order they appeared in the booklets. Previous experience has shown that the first of a series of questions is particularly likely to be misunderstood. Therefore, this first question was a simple one, intended to familiarise subjects with the maps. They were asked to mark, with crosses, the highest and lowest points on the map. The time allowed was one minute. A cross was scored as correct if it fell within the highest or lowest contour interval, or the equivalent area on the SYMVU maps. The test yielded a score of either zero, one or two.

Question 2. Short lines.

Each map was overprinted with twelve straight lines about 2 cm long. Subjects were instructed to mark the higher end of each line with a circle. The score was the number of correct responses, minus the number incorrect. The time limit was half a minute.

Question 3. Profiles.

Subjects were asked to visualise the profile along a straight line printed on the map, and then to choose the best match from six profiles printed on a different page. This was repeated for another two lines. Subjects had thirty seconds to visualise each profile and a further thirty seconds to make their decision. Subjects using SYMVU maps were warned that the printed profiles would not look exactly like the shape on the map because of differences in vertical exaggeration. The score was the number of correct responses.

Question 4. Heights.

Subjects were told to estimate heights to the nearest 10 metres. Ten locations on the map were indicated by lines linked to circles above the map where subjects wrote their answers. The time limit was a minute and a half. The correct answers were determined by a similar method to that used by Phillips, De Lucia and Skelton (1975). The score was the number of responses within plus or minus 15 metres of the correct answer.

Question 5. Sketch.

Subjects were asked to study the map for a minute and then had a further minute to draw from memory a simple sketch map showing the whole area. Before starting, they were shown a sample sketch map showing seven unlabelled contour lines with plus and minus signs indicating maxima and minima. They were told their maps should be drawn in a similar way, showing only the most prominent features and making it clear whether they were hills or valleys.

This question may have been biased in favour of SYMAP which is based on contour lines. But the scoring system attempted to reduce this bias by taking little account of the shape or size of features in the drawing, and scoring points for features in the correct position and with the correct sign. The maximum score was eight. It was a difficult question to score.

Question 6. Long lines.

This was similar to Question 2 except there were only six lines and these were about ten times the length of those in Question 2. The time limit was half a minute and the score was the number correct minus the number incorrect.

Question 7. Route.

Subjects had a minute and a half to draw a route across the maps from a verbal description printed at the top of the map. The description for Area 1 was "Start at X. Go due west to the top of the hill. From there, keeping as low as possible all along the route, make your way to the large area of high ground lying furthest north on the map. Then follow the ridge to the south, stopping at its highest point. Finally, go downhill by the steepest route."

Question 8. Model.

Unlike previous questions, Question 8 could only be given once. Subjects were given a white plastic relief model (described fully by Phillips, De Lucia and Skelton, 1975) and were asked to locate areas of map on the model. The model was at a smaller scale than the map, so that the whole map area was a 6 cm square on the model. To help subjects, a square this size was printed above each map, and subjects were shown the direction of north on both the model and the maps. The subjects' task was to match the map to the model and draw a cross on the model at the same location as a cross printed on the map. This was done for six areas of map with a time limit of one minute each. The first two were Areas 1 and 2 used previously, and for Area 1, subjects were told exactly where to look on the model so nearly everyone was correct. Less precise hints were given for Areas 2 and 3, for example, 'somewhere near the north end of the model'. No hints were given for Areas 4, 5 and 6. The first three (1, 2 and 3) and the second three (4, 5 and 6) were scored separately, with one point for each correct answer.

### Other questions.

Two other questions were attempted but abandoned. An intervisibility question asked for judgments on whether people standing at marked locations would be able to see each other. The difficulty occurred in marking accurate locations on the SYMVU maps. Another question was made up of three items of the type, 'What percentage of the whole map is over 220 metres?' This caused frequent misunderstandings and so was also abandoned.

### RESULTS

The results are presented in the form of graphs shown in Figures 5 to 12 (see Note 1). The outline circles show the mean score for the different types of map used in the first booklet, and the solid circles for the second booklet. Each point on the graph represents the data from about thirty subjects, and it should be noted that the graphs do not distinguish between the data for Area 1 and Area 2 maps. On most graphs the points for the second booklet appear above the points for the first and this indicates a general improvement in performance with practice. The fact that the lines joining the two sets of points are often nearly parallel indicates that similar results were found on both booklets, and provides a check on the repeatability of the test questions.

It is important to know for each question whether there is a real difference between the scores on the four types of map, or whether the difference could have occurred by chance. An analysis of variance, adopting the  $p < .01$  level, was carried out on the data for both booklets on every graph. If the scores differed significantly this is shown on the graph as either  $p < .01$  or  $p < .001$ . If the differences could have occurred by chance more often than one time in a hundred, the results are considered to be 'not significant' and this is shown by the abbreviation 'n.s.' on the graph.

When there was a significant difference between the different types of map, a Duncan's Multiple Range Test, adopting the  $p < .05$  level (see Edwards, 1968, p.131) was used to discover how the maps differed and the results of this are shown on the graph. Abbreviations for the four types of map are placed in order of magnitude. For example, L S C D indicates layer maps produced the best performance, square maps came second, contour maps third, and diamond maps fourth. When letters are underlined by the same line, there is no statistically significant difference between the corresponding types of map, and conversely, when they are not underlined by the same line, they do differ significantly. For example, S L D C indicates that the square maps did not differ significantly from the layer maps, and the diamond maps did not differ significantly from the contour maps, but all other pairs did differ significantly from each other.

The analysis of variance had four independent variables: type of map, map area, sex of subject and GCE geography qualifications. There were not statistically significant interactions between any of these on any question (adopting the  $p < .01$  level). The mean scores were higher for men than for women on every question but this difference only reached statistical significance twice (Question 6 - first booklet,  $p < .01$ ; Question 8 - first three,  $p < .001$ ). There was also a slight tendency for higher mean scores from subjects with A-level or O-level geography qualifications, but this never reached statistical significance.

### DISCUSSION

#### Similarity of the SYMVU maps

In general the two types of SYMVU map produced similar levels of performance. Significant differences were found on only two questions with better performance on the Square map in one case (Question 3 - first booklet) and the Diamond map in the other (Question 7 - first booklet). Looking at the means, on three questions Diamond maps were better and on five questions the Square maps were better. No clear interpretation can be put on these differences, and it is assumed that there is little to choose between the two types of SYMVU map.

#### Cluster Analysis

It is useful to group together questions which show a similar pattern of results. One way of doing this is to use a cluster analysis program. Means from the Contour maps, the Layer maps and the combined means from the two SYMVU maps were fed into CLUMP, a program by A. Walbridge. The program clustered twelve sets of means from all those questions where there was a statistically significant difference between the maps. The questions fell naturally into four clusters and these are shown in Table 2.

It should be emphasised that cluster analysis is an exploratory technique, no more or less reliable than a grouping of the graphs in Figures 6 to 12 by visual inspection. However, an examination of each cluster in turn does suggest a reasonably coherent picture.

Figure 5

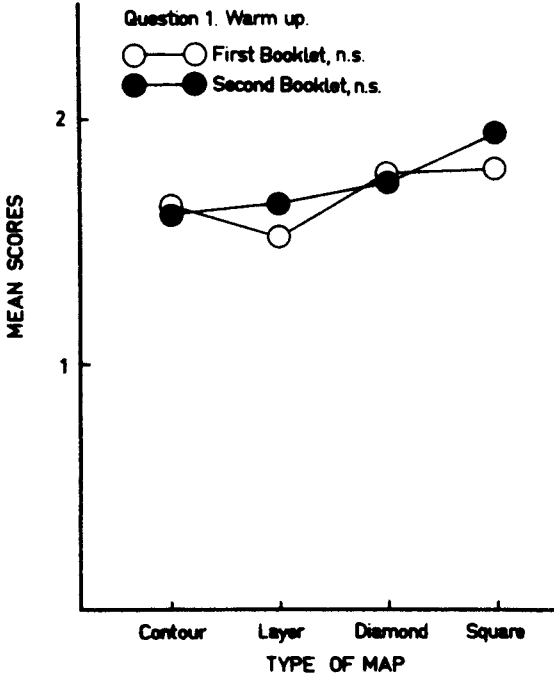


Figure 6

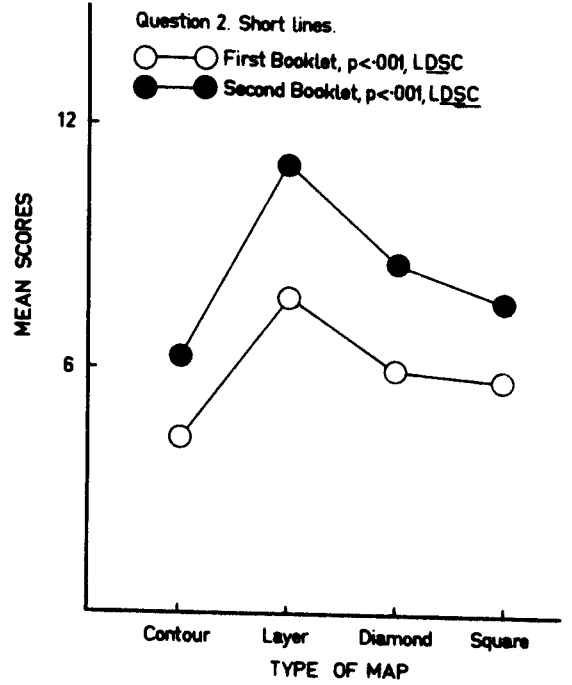


Figure 7

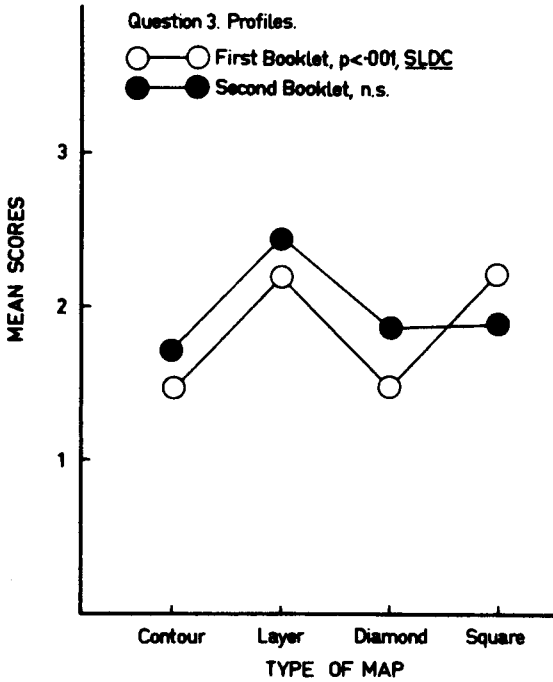
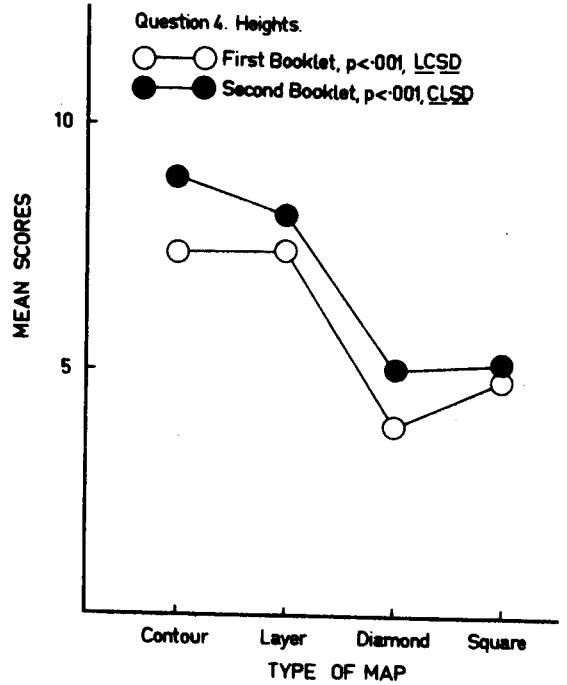


Figure 8



Figures 5 to 12.

These graphs present the mean scores for each question together with the results of analyses of variance.

Figure 9

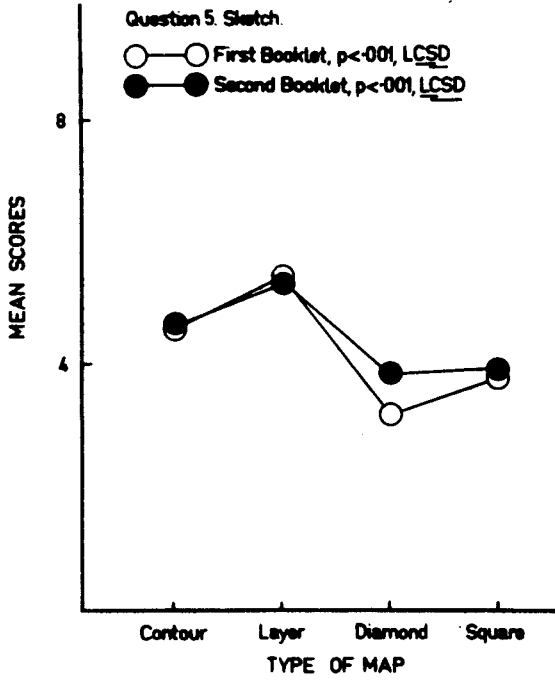


Figure 10

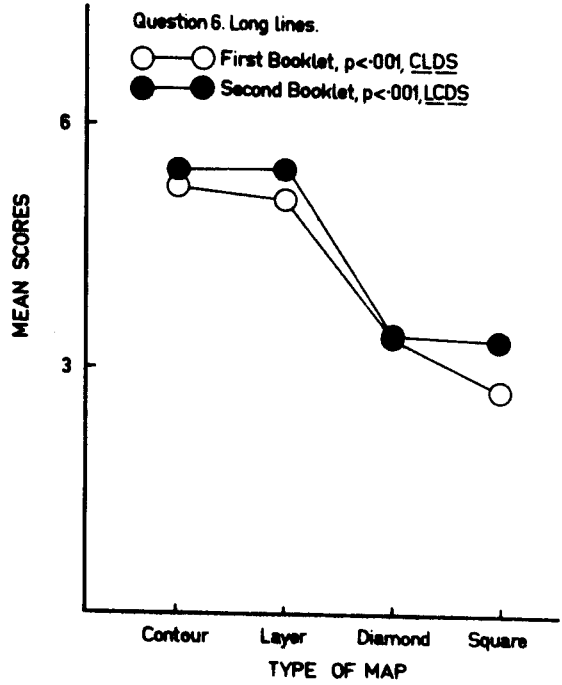


Figure 11

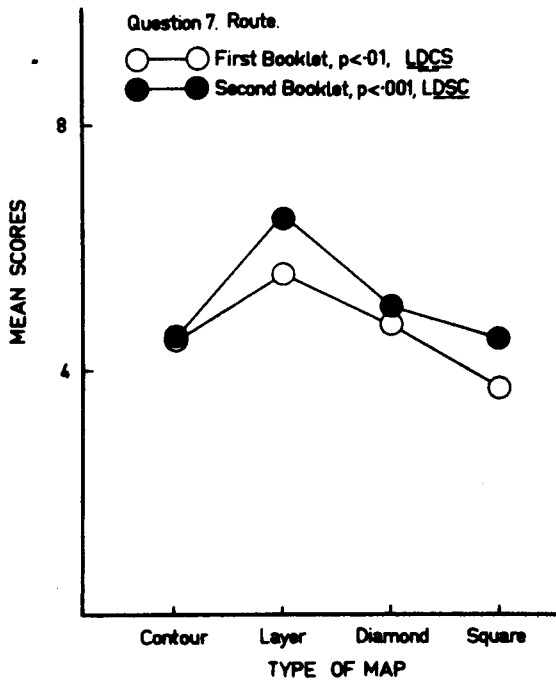


Figure 12

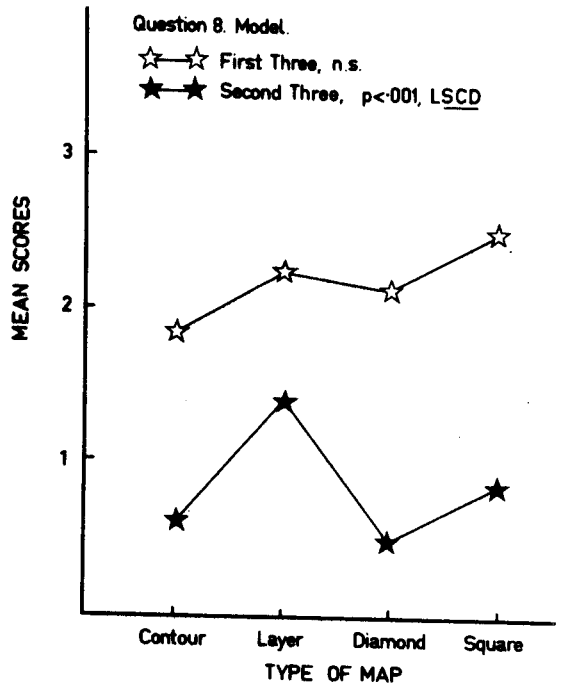


Table 2. The Results of a Cluster Analysis on the Means

## Cluster 1.

- Question 4 (Heights) - first booklet.  
 Question 4 (Heights) - second booklet.  
 Question 6 (Long lines) - first booklet.  
 Question 6 (Long lines) - second booklet.

## Cluster 2.

- Question 2 (Short lines) - first booklet.  
 Question 2 (Short lines) - second booklet.  
 Question 3 (Profiles) - first booklet.

## Cluster 3.

- Question 5 (Sketch) - first booklet.  
 Question 5 (Sketch) - second booklet.

## Cluster 4.

- Question 7 (Route) - first booklet.  
 Question 7 (Route) - second booklet.  
 Question 8 (Model) - second three.

Number of Clusters	6	5	4	3	2
Error Variance	0.03	0.07	<u>0.16</u>	0.96	1.16

Cluster 1. Judgment of Absolute Height.

Question 4 (Heights) and Question 6 (Long lines) formed the first cluster. On both questions the two SYMAP maps were superior to the two SYMVU maps, but there was little difference between the SYMAP Contour and Layer maps.

Question 4 asked for height estimates and so was concerned with the judgment of absolute height. At first sight Question 6 is concerned with relative height: subjects were asked which of two points was higher. But when Question 6 is compared with Question 2 the results are entirely different. Question 2 also asked subjects to judge which of two points was higher, but here the points were much closer together. Question 6 required subjects to compare points which were often on opposite sides of the map, and the best strategy may have been to estimate the two separately and compare their numerical values. In this case, Question 6 is really about the judgment of absolute height. Therefore, it would appear that Cluster 1 contains two questions which measure the judgment of absolute height.

Cluster 2. Visualisation of the Landform.

Question 2 (Short lines and Question 3 (Profiles) formed the second cluster. The Layer maps produced the best performance and the Contour maps produced the worst, with the two SYMVU maps coming roughly in between. Question 2 asked for relative height judgments and Question 3 asked subjects to imagine the shape of profiles. The obvious common element here is that both questions require subjects to visualise the shape of the landform.

Clusters 3 and 4. Visualisation and Search.

Cluster 3 contains only Question 5 (Sketch), where subjects were asked to sketch the map from memory. This question is almost certainly biased in favour of the SYMAP maps because subjects were asked to use contour lines in their sketches. Without this bias, it is possible that Question 5 would have formed part of Cluster 4.

Cluster 4 contains Question 7 (Route) and the second three items of Question 8 (Model). On Question 7 subjects were asked to draw a route across the map from a verbal description and on Question 8 they matched areas of map to a plastic relief model. On these two questions the Layer maps are best, and there is little to choose between the other three types of map. This is also true of Question 5, except for the apparent superiority of the Contour maps over SYMVU maps.

Like the questions in Cluster 2, these all require subjects to visualise the shape of the landform. But the questions in Cluster 2 required subjects to visualise only small areas of the map, while the questions in Clusters 3 and 4 require the ability to visualise much larger areas. Question 5, for example, asks subjects to visualise the whole area of the map.

The act of visualising a large area of map is not a single action, but must depend on the ability to piece together information from different areas of the map. An important part of this task may be the ability to search for particular features of the map, for example, those which are prominent. Search is clearly important in Question 7 (Route), and may be equally important in Questions 5 and 8.

### Summary of Results

The questions have been divided into three groups: first those concerned with the judgment of absolute height, second, those which require visualisation, and third, those which require visualisation and search. The questions can certainly be classified in other ways, but this is offered as a plausible interpretation which is in good agreement with the classification of questions in two previous experiments (see Phillips, De Lucia and Skelton, 1975; Audley, Bickmore and Phillips, 1974). Figure 13 summarises the results for these three types of question.

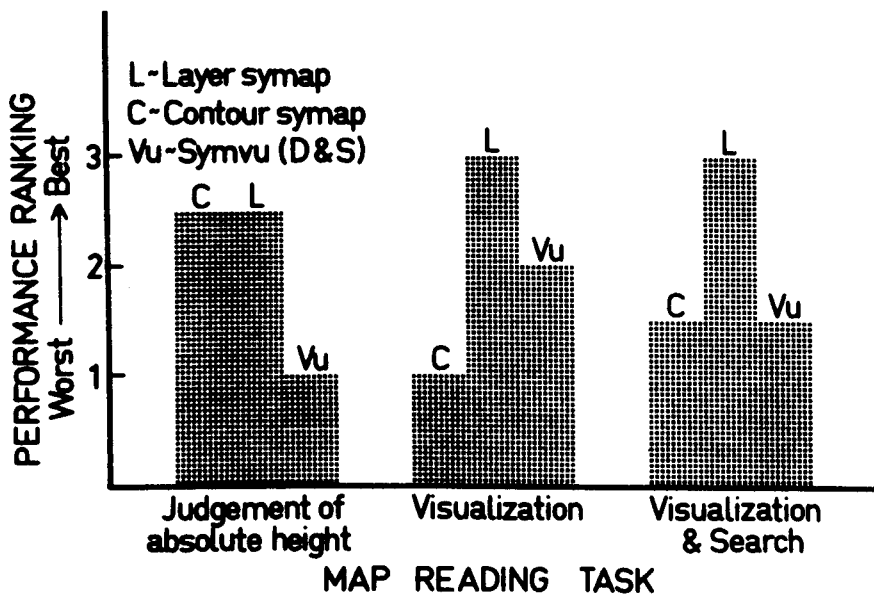


Fig. 13

This histogram summarises the results of the experiment.

### Conclusions

Performance on the SYMVU maps was consistently worse than that on the Layer maps. It is possible that other types of question would show SYMVU in a better light. However, our questions were selected with care and we are confident they are reasonably representative. It could be argued that the subjects were more familiar with Layer maps than with the SYMVU maps, and that performance on SYMVU might improve with practice. But a comparison of scores on the first and second booklets does not support this.

It seems that despite the immediate visual impact of SYMVU maps, it is difficult to extract information from them. When looking at them, it is common to think that one can see the relief in great detail, but any attempt to interrogate this detail shows that it is illusory.

Considering the results as a whole, the Layer version of SYMAP is strongly recommended. Its main limitation is the difficulty of superimposing other information legibly. When this is a problem, the Contour map is a possible alternative.

Another important consideration is that SYMAP is a much easier computer program to run than SYMVU.

How do these computer produced maps compare with conventional maps? In terms of subjects' speed and accuracy, the Layer maps are at least as good as the conventional layer tint maps studied in a previous experiment. But this is not a fair comparison because of the far greater detail which can be shown on a conventional map. Even when SYMAP and SYMVU maps are photographically reduced, as in this experiment, their scale must be about three times as large as conventional maps to show information of the same detail.

#### NOTES

1. Figures 5 to 12 place the four types of map along the abscissae of graphs. We have been criticised for doing this and told that only interval information should be shown in this way. But there are several precedents for our type of presentation (e.g. personality test scores) and we feel it is much clearer than the alternative of using histograms. The reader is invited to sketch our results as histograms. The comparison of results between booklets and between types of question becomes much more difficult than with the graphs. Surprisingly, our critics have not been mathematicians or statisticians, but cartographers and designers who, we believe, should know better.

2. This paper has developed from a talk given to a joint meeting of the Society of University Cartographers and the British Cartographic Society held at the Open University in November 1977. Its preparation forms part of the United Kingdom Social Science Research Council project HR2917/1 awarded to Professor R. J. Audley and Dr. R. J. Phillips. We gratefully acknowledge the Council's financial support.

3. Since writing this paper, Christopher Worth of the London School of Economics has pointed out a possible source of error in question 4 (Heights). Both SYMVU maps have been smoothed by the computer program. This has the effect of flattening the higher regions of the map, but there is no corresponding change in the height scale. If subjects measured heights by a direct comparison with the scale, there would be a tendency to underestimate. An examination of the distribution of answers showed slightly more errors of underestimation than overestimation.

The question was re-analysed to discover the maximum effect this could have. Treating the Square and Diamond maps separately, a number of 'correct answers' were tested for each of the ten items on question 4. These ranged between the original answer and a value 20 per cent lower to allow for smoothing. The answer which gave the highest score was chosen in each case. In this way it could be shown that the largest possible increase in the score for the Square maps is 12.8 per cent and for the Diamond maps, 12.9 per cent. It is clear that this would not substantially alter the results presented in Figure 8.

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#### ERRATA

These errors appeared in the journal but have been corrected in this reprint.

1. Page 18. First sentence 'Procedure' should end "one subject per cell."
2. Page 19. 'Question 3. Profiles.' The third sentence should end "decision."
3. Page 20. Last sentence of the fourth paragraph should read "For example, S L D C indicates that the square maps did not differ significantly from the layer maps, and the diamond maps did not differ significantly from the contour maps, but all other pairs did differ significantly from each other."
4. Page 25. The title of the first reference should begin "Legibility criteria."