*Visual clutter on maps is a familiar experience but its precise nature is only poorly understood. Clutter was investigated in an experiment using a 1:50 000 geological map. Twelve representative map reading tasks were used to compare map reading performance on maps which differed only in their topographic base. The aim was to assess the effect of removing topographic symbols which are of only minor importance to the map reader. This reduction in visual clutter significantly improved performance on a number of the questions. Some evidence was obtained to support the hypothesis that line symbols clutter other line symbols, and point symbols clutter other point symbols, but there is little effect between the two. In practical terms the removal of minor point symbols and type led to larger improvements than the removal of minor line symbols, even though more of the latter were deleted. The relevance of the experiment to other geological maps, and to maps in general, is discussed.*

# An Investigation of Visual Clutter in the Topographic Base of a Geological Map

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## INTRODUCTION

Visual clutter is an easily experienced phenomenon but much less easy to define. Symbols on a cluttered map are difficult to read because of the presence of other symbols. This is not just because some symbols obliterate others by being superimposed on them: clutter seems to operate between symbols which are physically separate. It might be argued that cartographers are quite capable of judging the effects of clutter without any help from psychologists. But there is some evidence that our intuitions about clutter do not always agree with the way it affects map reading performance. Compare the two displays in *Figure 1*. Most people would agree there is more clutter in the left-hand display, but when students were asked to search for names on these kinds of display, they were slower on the right-hand condition (Noyes, 1980). Clearly, the interfering effect depends not only on the amount of clutter but the form it takes.

A possible approach to understanding clutter is suggested by some work on lateral masking reviewed by Woodworth and Schlosberg (1954, p. 104): a letter is easier to recognise in peripheral vision when it stands alone than when flanked by other letters. However, Hammond (1980) has shown that this effect is probably specific to letters and numerals; altogether different effects occur with other symbols. Therefore it would seem that lateral masking is not particularly helpful for a general understanding of visual clutter.

Merriam (1971) has suggested that clutter on maps may be related to the shimmering effects observed in repeated patterns of black and white lines, such as those used in *Op Art*, but the necessary conditions for this phenomenon—high contrast and repetition—are rarely found on a map. Wingert (1975) has seen clutter on maps in terms of spatial frequency, and has argued that it is the high frequency components which cause clutter. The implications of this idea are rather odd. Any sharp boundary between black and white will generate high spatial frequencies and so a blurring of all such boundaries would reduce the high frequency component which, according to Wingert, would reduce the clutter and lead to a better map. The implication seems to be that a smudgy, out of focus map would be easier to use than a well printed one.

Perhaps a more satisfactory approach is from experiments on visual search. It is likely that the more symbols that are present on a map, the longer it will take to find any particular symbol. Using eye movement recording, Williams (1967) was able to show that most eye fixations made while searching fall on objects which are the same colour as the search target. It follows that in search tasks, clutter comes largely from symbols of similar colour. Williams also showed that the size of symbols affected search in a similar way to colour, but less strongly.

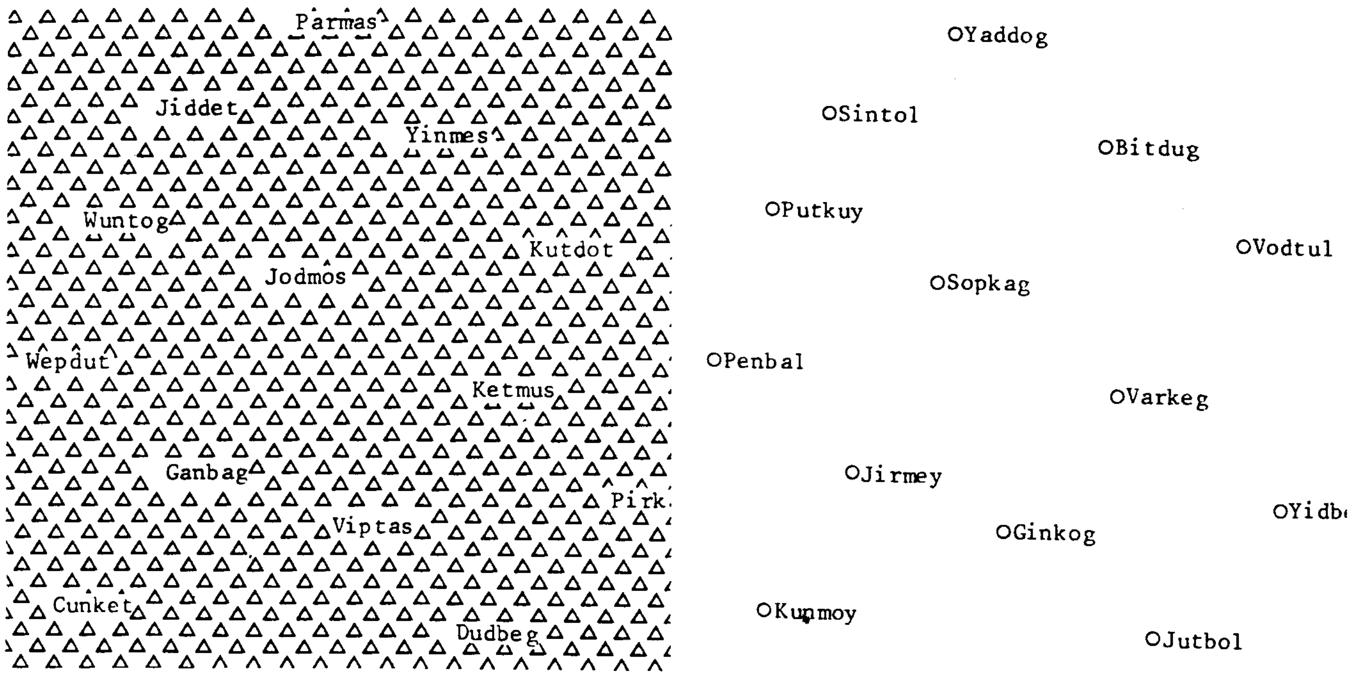



*Figure 1.* Which is the more cluttered display? Noyes (1981) found that searching for names was slower on the right-hand condition.

The idea that visual clutter occurs mostly between symbols which are similar in their size and colour is also supported by research on immediate visual memory (Von Wright, 1968). Knowledge of the colour or the size of target letters in a display can very rapidly increase the probability they will be retrieved from immediate visual memory, but only simple physical clues such as size and colour will do this.

Although these ideas go some way to understanding the operation of visual clutter, many practical questions remain unanswered. For example, on geological maps the base is usually printed in grey and some of the geology in black. Is this a large enough colour difference to prevent symbols in one colour cluttering the other? It is also not clear whether clutter is always mutual. For example, black symbols may clutter grey symbols, but not the reverse.

One striking physical difference in looking at a map is between line symbols and point symbols. If this distinction is like a difference in colour, we might expect the line symbols to clutter other line symbols, and the point symbols to clutter other point symbols, but there to be little interference between the two. This possibility is investigated in the experiment in the context of a geological map.

*Geological maps*

Geological maps are arguably the most complicated visual displays in common use. For example, the NERC Institute of Geological Sciences series of 1:50 000 and 1:63 360 geological maps usually have a *topographic base* printed in grey which contains almost all the information taken from the corresponding Ordnance Survey topographic map. Superimposed on this are areas of colour and texture denoting the types of rock and these are cased in continuous or broken black lines. A second network of black lines is sometimes present to distinguish the drift geology from the solid geology beneath it. In addition, the maps contain a large number of other geological symbols, for example, fault lines and dip arrows, and these are usually printed in black. The maps are complex both in the wide variety of symbols they use and in the density of information, although there is, of course, considerable variation from area to area.

If geological maps are packed full of information, the purposes to which they are put are equally complicated. Undergraduates studying geology are taught to visualise the shape of underground rock structures from the evidence provided by the map about rock structures on the surface. This involves not only the ability to decipher and interpret the map but a considerable skill in visualising three-dimensional structures, plus a certain amount of intelligent guesswork, as the clues on the surface are often open to varying interpretations.

Without doubt, geologists push cartography to its limits. They not only demand maps weighed down with information, but they demand a level of skill in map interpretation which is probably unequalled elsewhere. Clearly, geological maps are unrepresentative of other types of cartography, but because they take the problems of map design and map interpretation to extremes they may still help us understand and improve the design of simpler maps.

This paper reports an experiment which investigates the effect of the complexity of the topographic base on geologists' efficiency in reading a geological map. The aim is partly to make recommendations on ways in which 1:50 000 geological maps could be improved. But it is also hoped that by studying the effect of visual clutter in the context of geological maps it may be possible to formulate some principles which have wider implications for map design. The study focuses on the topographic base, rather than the geological information on the map.

*Uses and users of geological maps*

One of the biggest customers for United Kingdom 1:50 000 geological maps is the Open University and, in general, educational establishments form the largest group of purchasers. But as well as their role in teaching, the maps are put to a number of professional uses, for example, by civil engineers, mining geologists, town planners and archaeologists. A small informal survey was conducted to discover more about the uses of geological maps and the attitudes of users. The results of this are summarised in the Appendix. Almost everyone interviewed was in favour of simplifying the topographic base, but there was little agreement about how this should be done. Everyone agreed that the detail in built-up areas could be reduced and no one defended the inclusion of some names, for example, the names of farms, but almost every other type of feature was defended by somebody. Two major divisions of opinion concern the use of the map for location purposes, and the legibility of contour lines.

The map is used more often at a desk than in the field, but it is important that the geologist should be able to locate structures in the field. Does it follow that the topographic base should include landmarks which are of no geological interest, such as minor tracks or pylons, or should the user carry a separate topographic map for this kind of information?

The other major division of opinion concerns the contour lines which are often difficult to read on geological maps. Their importance is not so much in the field but for inferring underground geological structures. Those who teach geology generally argue for clearer contour lines to aid this difficult form of map interpretation. But others have argued that contour lines are of little practical importance and one professional geologist has suggested that they could be removed altogether.

Issues of this kind are clearly not the domain of psychologists, but where we can help is by providing information on whether the removal of one kind of information or another significantly improves the legibility of the map. This is the problem tackled in the experiment.

*Aims of the experiment*

The experiment compares five versions of a geological map which differ only in their topographic bases. By measuring map reading performance it is hoped to discover:

(1) The effect of reducing line symbols such as roads, boundaries and contours.

(2) The effect of reducing point symbols and type, such as buildings and place names.

(3) The value of an alternative design for the topographic base made by deleting information which the user survey has shown is seldom needed, and by making the contour lines more prominent. The deleted information includes some line symbols, some point symbols and some type.

The relationship between the five types of base map is shown in Table 1. The *full* map is the full topographic base as it appears on the published map. All the other types are simplifications of the *full* map, except that the *design* version makes the contour lines more prominent by printing them without a dot screen. The *line, point,* and *minimal* maps retain most of the base information needed by geologists, but they are intended as experimental manipulations rather than improved designs. However, the features on the *design* version were chosen carefully on the basis of information from the user survey, and this version is included as a design alternative to the *full* base. As it is an attempt to please everybody—both those who want to use geological maps for navigation in the field and those who want clearer contour lines—it differs from the *full* version less than the other maps.

TABLE 1

*The three comparisons made in the experiment between the five types of map*

| | | |
|---|---|---|
| DESIGN<br>An alternative design, with less symbols and clearer contours. | ←<br>(3) Old vs. new design<br>↓ | |
| | FULL<br>The base as used on the published geological maps. | LINE<br>The full base without selected point symbols and type. |
| ↑<br>(1) Effect of line symbols<br>↓ | POINT<br>The full base without selected line symbols. | MINIMAL<br>The full base without selected line and point symbols, and type. |
| | ← (2) Effect of point symbols and type. → | |

*Choice of questions*

Map design research has increased substantially in recent years (Board, 1979; Phillips, 1979) but there appears to be no previous experimental investigation of the legibility of geological maps. Taylor and Hopkin (1975) have investigated visual clutter in aeronautical charts using a task where locations are pinpointed from verbal descriptions of the topography, but this is not an appropriate task for geological maps.

The choice of appropriate questions for an experiment to compare map designs is a difficult matter and there is no standard procedure to follow. Clearly, questions should be representative of real map reading tasks, but there are so many ways in which geological maps can be used, the choice is wide and realism is certainly not the only consideration in choosing questions. Two equally important points are that the questions should measure performance and that they should be sensitive. Unless a question yields a score which reflects either the subject's speed, or accuracy, or some similar measure of performance, no reliable conclusions can be drawn. This is also true if a question is incapable of demonstrating statistically significant differences because variability in either the task itself or the map readers' skill swamps any difference between the maps. As well as these important considerations there are also practical limitations imposed by time and expense.

One type of question which often meets these demands is based on a simple and representative task which can be repeated a number of times in different parts of the map.

There is a definite time limit and the score is usually the number of correct responses which is a measure of both speed and accuracy. The time limit is set so that the average score is approximately equal to half the maximum score. A number of questions used in the experiment are based on this formula which is discussed more fully by Poulton (1965).

It might be thought that the geological map interpretation exercises used on university courses are a good basis for comparing map designs, but this is unlikely to be so. These exercises are designed to test the map readers and not the maps. Given that a satisfactory method could be devised for scoring an exercise, the score will reflect individual traits such as geological knowledge, map reading skill and spatial ability much more strongly than differences between map designs. Unless large numbers of people are tested, only the largest effects caused by differences between the maps will be detected.

Another difficulty is that this kind of exercise takes a long time. In general, a series of short tasks each yielding a score is preferable to one long task. With a series of short tasks it is much easier to discover the precise differences between map designs which affect performance.

These were the main considerations in choosing questions for the experiment.

Firstly, each question was based on a different task which is frequently carried out in reading geological maps. These tasks are often just one step in a complicated sequence necessary in interpreting the map.

Secondly, the questions were chosen to be sensitive, that is, capable of demonstrating statistically significant differences between the maps.

Thirdly, as the test maps differ only in their topographic bases, preference was given to questions about the topography, or the interaction between the topography and the geology.

Fourthly, because three dimensional interpretation is important for some geologists, a number of questions about relief are included.

Fifthly, a number of the questions measured speed of search. Search tasks are often a good way to evaluate maps because they test how clearly symbols stand out in peripheral vision. When symbols are hard to distinguish in peripheral vision this not only impairs search, but the whole problem of seeing a map as a unified structure.

## METHOD

### *Maps*

For the experiment, two small areas were taken from the drift edition of the 1:50 000 geological map of the Merthyr Tydfil region published by the NERC Institute of Geological Sciences. This covers an area of considerable geological complexity. The map is printed in eight ink colours including grey and black. Rock types on the surface are shown by about 20 colour codes. Other geological information is printed in black, most prominently, the fault lines and coal-crops. Topographic information such as roads, rivers, place names and contours is taken from the 1:50 000 Ordnance Survey map and printed in grey. The two areas chosen for the experiment are the *West* area, including Penderyn, grid reference SN 880-960 050-170, and the *East* area, including Merthyr Tydfil, grid reference SO 000-080 050-170.

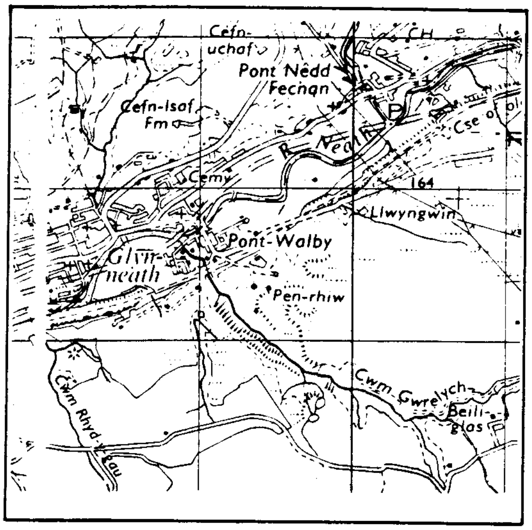
Five versions of the two areas were produced differing only in the topographic base; the geological information was held constant. The five versions are called *full, line, point, minimal* and *design*. Table 2 summarises the differences between them and they are illustrated in *Figure 2*. The *full* version has the standard topographic

TABLE 2

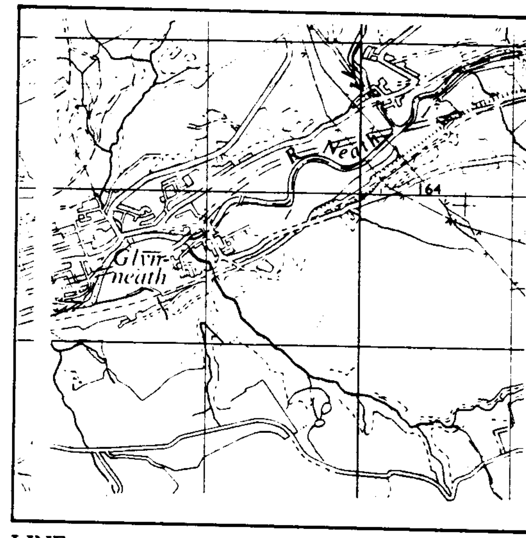
*This table lists the features which appear in each type of topographic base*

| | Contour lines | Water features | Grid | Roads, tracks etc. | Type (lettering and numerals) | Other features |
|---|---|---|---|---|---|---|
| Full | Every 15.3 m, screened | All present | Present | All roads, drives and tracks | All type printed in black or blue on the Ordnance Survey map | All other features printed in black on the Ordnance Survey map |
| Line | Every 15.3 m, screened | All present | Present | All roads, drives and tracks | Large place names,* type for water features and heights | All line symbols such as railways, boundaries, wood casing and pylons |
| Point | Every 30.5 m, screened | All present | Absent | All tarred roads but no drives, tracks, or minor roads in towns | All type printed in black or blue on the Ordnance Survey map | All point symbols such as rocks, buildings, rough grassland |
| Minimal | Every 30.5 m, screened | All present | Absent | All tarred roads but no drives, tracks, or minor roads in towns | Large place names,* type for water features, and heights | None |
| Design | Every 30.5 m, solid | All present | Present | All roads, drives and tracks | All type except small place names,* unless antiquities | Pylons, railways, and all point symbols except rough grassland |

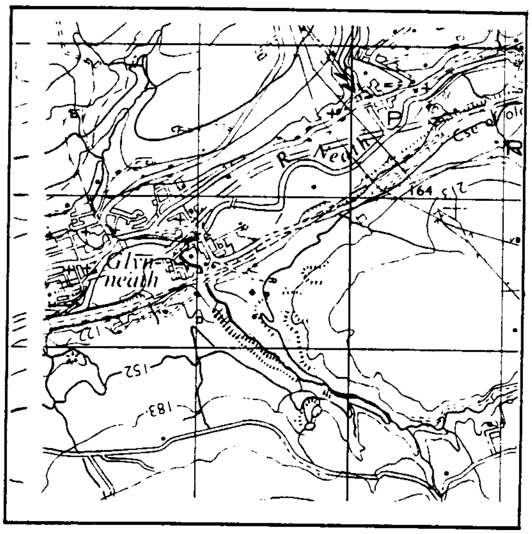
* Large names are set in 8 point type or larger.



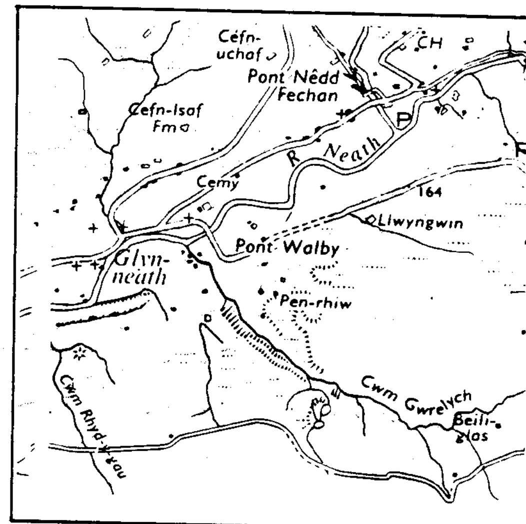

FULL

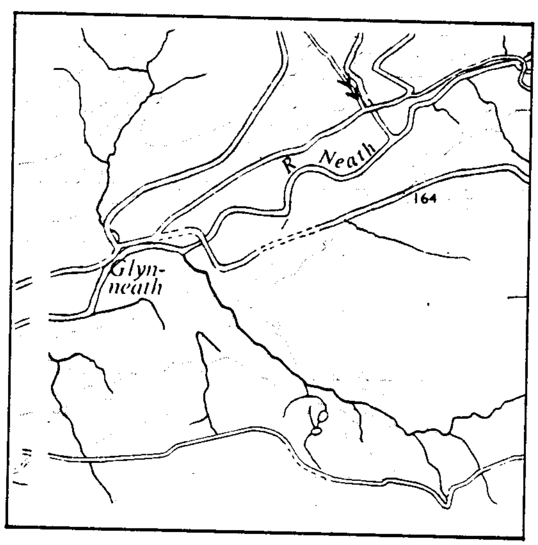

LINE


DESIGN


POINT


MINIMAL


*Figure 2.* Examples of the five types of topographic base. These were printed in grey and geological information was superimposed. (Reproduced from the 1975 Ordnance Survey 1:50 000 map with the permission of the Controller of Her Majesty's Stationery Office, Crown copyright reserved.)

base and so closely resembles the published map. The base is constructed from printing separations used in the Ordnance Survey 1:50 000 map. It includes all the information from this map which is usually printed in black, all the information usually printed in blue except for blue dot screens, and the contour lines. On geological maps this base is printed in grey and the contour lines have a dot screen.

The other versions of the experimental maps are all simplifications of the *full* version, made manually from film separations by duffing out unwanted detail and making good. In the *minimal* version, a large amount of the base information is deleted, but most features of geological importance, such as rivers, are retained. The line and point versions have bases which lie in complexity somewhere between the *full* and *minimal* versions. The *line* version retains all the line symbols such as pylons and boundaries, but many of the point symbols and names have been deleted. In contrast, the *point* version retains all the names and point symbols, including all the buildings, but many of the line symbols are removed. Although the *line*, *point* and *minimal* versions contain most of the information demanded by geologists, they are not intended to be design solutions for an improved geology map—they are an experimental manipulation. The *design* version is an attempt at a design solution; it has a simpler base than the *full* version but the information which has been deleted was carefully selected on the basis of the user survey. It also differs from all the other versions in that the contour lines are not screened but printed solid.

The legend for the maps was printed as a separate A4 sheet and was a slightly simplified version of the legend for the published map. Considerable care was taken to ensure correct colour matches between the legend and the maps. (The use of a separate legend for this kind of experiment is not recommended as even printers who specialise in maps are not used to working to the colour tolerances this requires.)

*Subjects and design*

Undergraduates studying geology at five English universities acted as subjects. They were 124 men and 21 women aged between 17 and 36 with a median age of 19. All had normal colour vision as defined by the Ishihara tests. Sixty-eight were first year students, 61 were from the second year, 11 were from the third year and five were postgraduate students. All had attended at least one course in geological map reading. Approximately equal numbers were assigned at random to the five kinds of map. Each individual used the same kind throughout the test, starting with 12 questions on one area, followed by 12 similar questions on the other area. Approximately half the subjects in each condition started with the East area and half with the West area.

*General procedure*

The subjects were tested in seven groups. Before starting they were briefed on the purpose of the tests and it was emphasised that each person should do as well as they possibly could on each question, even if he or she considered the map was a poor one. Each question was explained carefully and answered in a set time. The maps were assembled into booklets with a different copy of the map for each question. Blank pages were interleaved between the maps so that they were only visible when a question was actually being answered. Two versions of each question were constructed, one for each of the areas, and as far as possible, these were of similar difficulty. For some questions the maps were overprinted in purple—a colour chosen to stand out clearly from the other colours on the map. The legend was a loose sheet not bound into the booklets. Each person received three copies of this, two of which were used for question 3.

*Question 1—highest and lowest points*

The questions are numbered in the order they were attempted. Subjects were instructed to open the booklet and look carefully at the map for two minutes. During this period they were told to note whether the contour interval was 15.3 metres or 30.5 metres, for use in later questions. The first question followed this initial viewing. They were asked to find the highest and lowest points on the map, and mark these with two crosses. One minute was allowed for this and guessing was encouraged. Scores ranged from zero to two. On both areas any one of three similar maxima was counted as correct but only one minimum. A point was scored if the cross fell within a prescribed area (about 0.5 sq km) around the correct location.

*Question 2—finding spot heights*

Subjects were asked to circle as many spot heights as they could in half a minute. They were told to include all varieties of spot heights but not contour line labels. There were more than 20 spot heights in each area and the score was the number found.

*Question 3—rock identification*

This question tested speed and accuracy in identifying rock types with the help of the legend. The map was overprinted with 12 circles labelled *A* to *L*. Each circle enclosed the code which identified a particular type of rock. Subjects were asked to work in alphabetical order and match each code and the colour on which it lay with the legend where they wrote the letter. The question was a simple one on which speed was encouraged and no interpretation of the map was needed. The time limit was 45 seconds and the score was the number of correct responses. The question made use of both solid and drift rock types.

*Question 4—contour location*

Subjects were asked to trace along any 305 metre contour lines they could find on the map: this is one of the contour heights shown with a bolder line. Both areas included one especially long length of 305 metre line and, to help subjects start, the two points where this intersected the edge of the map were clearly marked. Speed was encouraged and exact tracing of the lines was not required. One minute was allowed and one point was scored for each 25 mm section of 305 metre line started or completed.

*Question 5—height estimation*

For this question maps were overprinted with the same 12 circles used in question 3. Subjects were asked to estimate the height at the centre of each circle to the nearest 5 metres. The items could be tackled in any order and the time limit was two minutes. One point was scored for each answer falling between plus or minus 15 metres of the corect answer.

*Question 6—finding alluvium*
Subjects were asked to find areas of alluvium on the map and draw around them. When two separate areas lay close together they were asked to draw around them separately, but otherwise drawing accuracy was not required. The time limit was half a minute. One point was scored for each area circled, except for a number of large areas which received two points.

*Question 7—river location*
The maps were overprinted with a diagonal line joining two opposite corners. Subjects were asked to search for rivers and streams which crossed this line and to mark each one with an arrow to indicate the direction of flow. The time limit was one minute and one point was scored for each river correctly marked.

*Question 8—relative height*
The maps were overprinted with 12 20 mm lines and subjects were asked to circle the higher end of each line. The time limit was 30 seconds and one point was scored for each correct answer.

*Question 9—wave symbol*
Many of the drift areas of the map are coded with a wave symbol (~). Subjects were asked to circle as many of these as possible, including the symbol in combination with letters, numerals or other symbols. The time limit was 30 seconds and one point was scored for each one found.

*Question 10—true or false?*
Subjects had four minutes to decide whether ten statements about the map were true or false. For both areas, six of the statements related to both geological and topographic information, three statements were related to geological information only, and one statement was related to topographic information only. Examples of these three are respectively: (1) Limestone (d3) never occurs below 305 m on this map, (2) In this region there are two main directions of faults running roughly at right angles to each other, and (3) The main rivers shown on the map are flowing in a northerly direction. Subjects were told not to guess but to leave a blank when they were uncertain. One point was scored for each correct answer.

*Question 11—rock heights*
A list of six types of rock was provided and subjects were asked to mark on the map the highest and the lowest points where each type occurred on the surface. Three minutes was allowed and a cross was counted as correct if it fell within a circle of radius 200 m around the correct point. In a few cases, one of two correct answers were allowed.

*Question 12—small scale map*
For this question the test booklet included a second map on the opposite page to the geological map. This was a 1:100 000 topographic map printed in black only which included the whole of both the East and West areas. Subjects had one and a half minutes to draw a rectangle on this second map to show the area covered by the geology map. The scale difference was explained and both maps were marked with the scale and a legend showing miles and kilometres. Neither map had grid numbers. When a side of the rectangle was drawn within 5 mm of its correct position two points were scored, and one point if it was within 10 mm. Points from the four sides were added up giving a maximum score of eight.

## RESULTS

A few subjects failed to follow the instructions on some of the questions and so their responses could not be analysed. An average of 6.3 scores was lost in this way on each question.

Table 3 shows the grand mean for each question on the first and second attempts, and the means for the five types of map expressed as deviations from the grand mean. Error rates are shown where these are informative. There were hardly any errors on questions 2, 6 and 9, and as most subjects completed questions 1 and 12, on these the error rate is implicit in the grand mean.

A separate analysis of variance was carried out for the first and second attempts at each question. There were significant differences between the scores from the East and West areas on a number of questions, but only on question 4 was there a statistically significant interaction between the area and type of map. In this case separate analyses of variance were carried out for the East and West areas. The East area showed larger differences between the five types of map, but the pattern of results in the two areas was otherwise similar.

Planned comparisons were made between (1) the *full* and *line* maps versus the *point* and *minimal* maps to assess the effect of reducing the number of line symbols, (2) the *full* and *point* maps versus the *line* and *minimal* maps to assess the effect of reducing point symbols and type, and (3) the *full* versus the *design* maps to compare old and new designs. These comparisons are illustrated graphically in Table 1. It should be noted that the third comparison is not independent of the other two. The statistical significance of these comparisons together with their values is shown in Table 3.

Neither the subject's age nor sex significantly affected performance on any of the questions, but geological experience did. As a crude measure of experience, a scale was constructed where 1 = first year student, 2 = second year student, 3 = third year student and 4 = postgraduate student, with one point being added if an individual had passed A-level geology. This scale correlated positively ($p < .05$) with performance on questions 3, 6, 8, 9 and 10. The largest correlation coefficient ($r = 0.31$) was with question 3 (rock identification).

The results of 72 statistical significance tests are reported in Table 3 and there is a danger that some may have reached the significance level by chance. To meet this objection the data were reanalysed in a more conservative way. Scores from the first and second attempts were pooled to reduce the number of tests to 36, and the $p < .01$ two tail level of significance was adopted. With this analysis, on the first comparison only question 4 is significant, on the second comparison questions 2, 8 and 10 are significant, and on the third comparison questions 4 and 7 are significant. With the exception of the second comparison on question 4, these are the same planned comparisons which are significant on one or both attempts in the analysis reported in Table 3.

## DISCUSSION

Reducing visual clutter improves map reading performance. Of the 12 statistically significant differences from the planned comparisons, all but two indicated better performance with the simpler maps.

A reduction in point symbols and type affected the largest number of questions significantly. There was a 31 *per cent* improvement in finding spot heights, an 11 *per cent* improvement in contour location, a 15 *per cent* improvement on the relative height question and an 11 *per cent* improvement on the 'true or false?' question. (These are percentages of the grand mean, combining scores from the first and second attempts.)

A reduction in line symbols produced a statistically significant effect on only one question, although the difference was a large one: contour location improved by 45 *per cent.* The same question produced the only significant improvement (26 *per cent*) when the *design* condition is compared with the *full* map, but this comparison showed one significant effect in the opposite direction: river location was worse by 22 *per cent* on the *design* map. This result may be unrelated to the reduction in clutter because on the *design* map the contour lines are unscreened and so are similar to the symbol for rivers. It may be this confusion which caused the poor performance.

Visual clutter seems to operate between symbols of a similar colour, and it was predicted that clutter from line symbols and point symbols may also operate independently. The results offer some support for this hypothesis. A reduction in line symbols produced the greatest effect on question 4 which was concerned with contour lines, and a reduction of point symbols and type produced the greatest effect on question 2 which involved searching for spot heights. As far as this goes, it seems that like clutters like; although this is probably a simplification.

It is interesting that although question 2 (spot heights) and question 9 (wave symbol) were very similar tasks, only performance on question 2 was significantly improved by a reduction in point symbols. The spot heights and wave symbols were of similar size but the important difference may be that the spot heights were, like the rest of the base, printed in grey while the wave symbol, being geological information, was printed in black. The colour difference may have been enough to prevent the wave symbols being affected by changes in the base.

Deleting information in the base improves the legibility of the information which remains, but would the loss of this information affect other uses of the map? Clearly the user in the field will lose some landmarks, but apart from this the loss is probably small in practical terms. Of considerable importance for field use is question 12 which tests the ease with which the geological map can be matched to another map at a different scale. But this task appears to be unaffected by the deletion of either large numbers of roads or place

TABLE 3

*The mean scores for each question on the first (a) and second (b) attempt. Means for the five types of map,* full *(F),* line *(L),* point *(P),* minimal *(M) and* design *(D), are expressed as deviations from the grand mean. The planned comparisons show the effect on the scores of (1) deleting line symbols, (2) deleting point symbols and type, and (3) differences between the* design *and* full *versions. A positive number indicates that the maps with less symbols had the better performance.*

| Question | | Range | Grand mean (errors in parenthesis) | F | Means (as deviations from the grand mean) L | P | M | D | Planned comparisons (1) Lines | (2) Points | (3) Designs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Highest and lowest | a | 0–2 | 1.0 | 0.1 | −0.1 | 0.1 | −0.1 | 0.0 | 0.1 | −0.4 | −0.1 |
| | b | 0–2 | 1.4 | 0.1 | 0.0 | 0.0 | −0.1 | 0.0 | −0.1 | −0.2 | −0.1 |
| 2 Spot heights | a | 1–13 | 4.9 | −0.5 | 0.1 | −0.5 | 1.3 | −0.5 | 1.1 | 2.5† | 0.1 |
| | b | 1–15 | 5.7 | −1.0 | 0.6 | −0.7 | 1.7 | −0.9 | 1.4 | 4.0‡ | 0.1 |
| 3 Rock identification | a | 2–12 | 7.9(0.2) | 0.2 | −0.1 | −0.5 | 0.2 | 0.1 | −0.4 | 0.4 | −0.1 |
| | b | 4–12 | 9.7(0.2) | 0.3 | −0.2 | −0.3 | 0.2 | 0.0 | −0.1 | −0.1 | −0.3 |
| 4 Contour location | a | 1–25 | 11.9(0.9) | −2.1 | −3.1 | 1.7 | 3.3 | 0.0 | 10.1‡ | 0.7 | 2.1 |
| | b | 2–31 | 15.0(1.1) | −4.6 | −2.7 | 1.6 | 5.0 | 0.1 | 13.9‡ | 5.3* | 4.7† |
| 5 Height estimation | a | 0–8 | 3.5(1.6) | −0.5 | 0.5 | 0.1 | 0.1 | −0.3 | 0.2 | 1.1 | 0.2 |
| | b | 0–9 | 4.3(2.1) | −0.5 | 0.0 | −0.1 | 0.2 | 0.2 | 0.7 | 0.7 | 0.7 |
| 6 Finding alluvium | a | 1–14 | 7.6 | −0.4 | 0.0 | 0.1 | 0.7 | −0.6 | 1.2 | 0.9 | −0.3 |
| | b | 2–18 | 8.4 | −0.6 | 0.5 | 0.0 | 0.5 | −0.6 | 0.6 | 1.6 | −0.1 |
| 7 River location | a | 0–7 | 4.0(0.2+) | 0.3 | −0.1 | −0.1 | 0.4 | −0.5 | −0.1 | −0.1 | −0.9* |
| | b | 0–8 | 4.1(0.2+) | 0.7 | −0.1 | −0.1 | 0.0 | −0.4 | −0.5 | −0.6 | −1.1* |
| 8 Relative height | a | 0–11 | 5.6(1.2) | 0.2 | 0.5 | −1.0 | 0.6 | −0.2 | −1.0 | 1.8* | −0.4 |
| | b | 1–10 | 6.0(1.3) | −0.5 | 0.2 | −0.6 | 0.5 | 0.3 | 0.2 | 1.7* | 0.7 |
| 9 Wave symbol | a | 1–15 | 7.1 | −0.5 | 0.9 | 0.4 | −0.1 | −0.8 | −0.1 | 0.9 | −0.3 |
| | b | 1–16 | 8.2 | 0.0 | 0.6 | −0.4 | −0.1 | −0.2 | −1.0 | 0.9 | −0.1 |
| 10 True or false? | a | 1–9 | 6.1(1.5) | −0.3 | −0.1 | −0.6 | 0.6 | 0.2 | 0.3 | 1.4* | 0.5 |
| | b | 1–10 | 6.7(1.8) | −0.3 | 0.2 | −0.5 | 0.5 | 0.0 | 0.0 | 1.5* | 0.3 |
| 11 Rock heights | a | 0–9 | 3.1(3.0) | 0.2 | −0.4 | 0.5 | 0.1 | −0.3 | 0.7 | −1.0 | −0.6 |
| | b | 0–9 | 3.9(4.4) | −0.4 | −0.2 | −0.1 | 0.4 | 0.3 | 0.9 | 0.6 | 0.6 |
| 12 Small scale map | a | 2–8 | 5.3 | −0.1 | −0.2 | −0.2 | −0.1 | 0.6 | 0.0 | −0.1 | 0.6 |
| | b | 1–8 | 5.5 | 0.0 | 0.0 | −0.5 | 0.0 | 0.6 | −0.2 | 0.5 | 0.6 |

+ Errors on direction of flow.

*Analysis of Variance.* ‡ = $p < .001$, † = $p < .01$, * = $p < .05$, all two tail.

Analyses of variance were also carried out on the combined scores from the first and second attempts. For details see the text.

names. (95 *per cent* confidence limits for the three planned comparisons on question 12 are: (1) −11 *per cent* to 5 *per cent*, (2) −7 *per cent* to 10 *per cent*, and (3) −1 *per cent* to 25 *per cent*.)

*Implications for a better base map*

The *design* map was not very successful, perhaps because relatively little information was taken out. The experiment of printing the contour lines on the *design* map without a screen appeared to increase their confusion with river symbols (question 7). The question of contour line legibility is discussed in more detail below.

The planned comparison which gave best results was the deletion of selected type and point symbols. This significantly improved performance on four questions while the removal of selected line symbols produced a significant improvement on only one. Common sense might predict the opposite as an examination of *Figure 2* apparently shows more clutter in the *line* map than the *point* map. Clearly, our intuitions about visual clutter are not always a good guide.

The removal of selected type and point symbols would be a relatively inexpensive change to make in the production of geological maps. It would make the maps easier to read and there is unlikely to be any serious effect on field use as all roads, tracks, railways, rivers and pylons remain as landmarks. Clearly, there are problems in implementing these changes on a series of maps where the density information changes from area to area. It would be necessary to devise workable rules to set upper limits on the density of type and point symbols.

*Relief and contour lines*

If a reader of a geological map wants to build up a picture of the shape of the strata beneath the surface he must first visualise the relief, that is the shape of the landform on the surface. Relief is also useful in the field both in providing landmarks, and in suggesting sites where rock structures may be viewed. Because relief plays an important role on geological maps it was the subject of a number of questions. Two questions (2 and 4) probed the legibility of the symbols used to show relief. Neither of these required any interpretation of the map, but several other questions did test interpretation including 1, 5, 8 and 11. Phillips, DeLucia and Skelton (1975) and Phillips and Noyes (1978) have discussed the different forms relief interpretation can take and the tasks used here appear to be fairly representative.

The poor legibility of contour lines is a frequent criticism of geological maps (*e.g.* Linton, 1948). When contours first appeared on United Kingdom geological maps they had distinctive line patterns such as alternating dots and dashes. These were the symbols used on the corresponding Ordnance Survey topographic map, but when the Ordnance Survey adopted an unbroken line for contours, there was a danger that on the monochrome base of a geological map, the contours could be confused with other line symbols, and so the contours were printed with a dot screen. An examination of any modern sheet shows that the screen is successful in differentiating contours from, for example, rivers, but it often appears to make the contours themselves very difficult to see.

In this experiment, the *design* maps had contour lines printed without a screen. We hoped that the distinctive shape of contour lines would be enough to prevent their confusion with other symbols but the results of question 7 suggest that we were wrong. It appears that unscreened contours make it harder to interpret the rivers. Our other manipulation was much more successful. The removal of some line symbols from the map including half of the contours themselves produced a substantial improvement on the contour tracing task. It is likely that the benefit comes mostly from the reduction in the number of contour lines, and this might be considered as a method of improving the base, although its value is probably limited to areas with many steep slopes. There are other ways in which contour lines might be improved, for example, by printing them in a different colour from the rest of the base, or by using a more distinctive line symbol such as the *dot and dash* symbol used on early maps. However, these possibilities are outside the scope of this investigation.

The other main source of relief information is spot heights. These were easier to find on maps where point symbols and type had been reduced (question 2). This also made it easier to answer questions about relative height (question 8) which might suggest that subjects used spot heights more than contour lines to answer this question. On the Ordnance Survey map from which the base is taken, spot heights are rather sparse and there may be a case for increasing their number on geological maps. However, it is likely that a general improvement in contour lines would reduce the importance of spot heights.

*Attitudes to map design*

There are a number of fundamentally different approaches to producing maps. Some cartographers regard the map as a kind of data store into which information should be tidily packed. Others regard a good map as like a work of art where the spectator is delightfully surprised that so much detail could be put into so small a space. Both of these points of view argue for filling maps with information until they are on the brink of illegibility. In contrast, the functional view of map design is that maps should do their jobs well. They should help the map reader, whether expert or novice, to use maps quickly, efficiently and with the minimum of error.

In works of art, obscurity is sometimes defensible where it is desirable that images should only slowly unfold themselves to the spectator, but no similar argument can apply to a map. The data store approach is perhaps valid for certain types of map, for example geological maps at a larger scale than those studied here. But when a map is used as a work of reference rather than an archive, the foremost consideration is that it should be easy to read.

One British road map published in the 1930s boasted on its cover 'three-fourths of usual details being purposely omitted'. But it is rare for cartographers to acknowledge that the deletion of information can improve a map. This experiment demonstrates that the removal of quite small amounts of information from geological maps can substantially improve their legibility.

## CONCLUSIONS

A less cluttered map is easier to read. Removing information from the topographic base of a geological map increased performance on a number of representative map reading questions. There is some evidence that visual clutter operates in a fairly specific way. It is likely that symbols only have a cluttering effect on other symbols of the same colour, that line symbols mostly clutter other line symbols, and that point symbols clutter other point symbols. However, our understanding of the way visual clutter operates is far from complete.

The design of legible geological maps is a subject of considerable complexity. The experiment reported here has investigated only the topographic base; many interesting questions are posed by the design of symbols for the geology which have not been touched on here. Some caution is needed in generalising the results reported here to other geological maps and it should be noted that the map used is not representative of all IGS 1:50 000 maps. However, it should be remembered that the phenomenon of visual clutter exists in the head rather than on the map: maps appear cluttered because the brain has only a limited capacity to process visual information. Clutter is a signal that the system is becoming overloaded. It seems likely that different types of map depicting very different types of data may overload the visual system in a similar way.

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Those marked have been sent reprints.

REFERENCES

Board, C. (1979) Maps in the mind's eye: maps on paper and maps in the mind, *Progress in Human Geography*, 3, 434–441.

Hammond, E. J. (1980) The tachistoscopic serial position function: evidence for letter-specific processing strategies. Paper presented to the Experimental Psychology Society, University College London.

Linton, D. L. (1948) The ideal geological map, *Advancement of Science*, 5, 141–149.

Merriam, M. (1971) Eye noise and map design, *Cartographica Monograph*, 2, 22–28.

Noyes, L. (1981) The positioning of type on maps: the effect of surrounding material on word recognition time, *Human Factors*, 22, 353–360.

Phillips, R. J., De Lucia, A. and Skelton, N. (1975) Some objective tests of the legibility of relief maps, *Cartographic Journal*, 12, 39–46.

Phillips, R. J. and Noyes, L. (1978) An objective comparison of relief maps produced with the SYMAP and SYMVU programs, *Bulletin of the Society of University Cartographers*, 12, 12–35.

Phillips, R. J. (1979) Making maps easy to read—a summary of research, pp. 165–174 *in* P. A. Kolers, M. E. Wrolstad and H. Bouma (eds.), *Processing of Visible Language 1* (New York: Plenum Publishing Co.).

Poulton, E. C. (1965) On increasing the sensitivity of measures of performance, *Ergonomics*, 8, 69–76.

Taylor, R. M. and Hopkin, V. D. (1975) Effects of density of cartographic information on marking verbally described pinpoints on a map. RAF Institute of Aviation Medicine medical report no. 546.

Von Wright, J. M. (1968) Selection in visual immediate memory, *Quarterly Journal of Experimental Psychology*, 20, 62–68.

Williams, L. G. (1967) The effects of target specification on objects fixated during visual search, *Acta Psychologica*, 27, 355–360.

Wingert, E. A. (1975) Applications of optical processing to the communication of cartographic data. Paper read at the ICA International Symposium on Cartographic Communication, Royal Society, London.

Woodworth, R. S. and Schlosberg, H. (1954) *Experimental Psychology* (3rd ed., London: Methuen).

# Appendix

## A SMALL SURVEY OF USERS

Ten professional users of 1:50 000 and 1:63 360 geological maps were asked for their views on legibility and for possible improvements. The users included lecturers in geology, consultant geophysicists, a geochemist, a vulcanologist, a town planner and an archaeologist. Informal interviews revealed a broad range of opinions with consensus on rather few points. It should be emphasised that these are a summary of the views of a small number of users and they may not be entirely representative.

The maps were used more often at a desk than in the field, where a larger scale map was preferred by the majority. The general opinion was that a single map should contain information for both applications, although one geologist said he would prefer two maps, one for field and one for desk use.

There was an almost unanimous opinion that the map was too cluttered and that some simplification was required, but it was less easy to find suggestions as to how this should be done. Most seemed anxious that the parts important to them should not be removed and they were doubtful as to what parts of the maps could be simplified without affecting usage in some sphere. For example mining geologists needed more information about the solid geology, whereas civil engineers were more interested in the drift. In the field, roads and tracks were of importance, while in the laboratory great stress was laid on contours.

Some people always took a topographic map into the field and were therefore more amenable to a reduction of the base, but others considered the use of two maps impracticable. Another suggestion was for printing a very simple map with overlays for different applications, but this had the disadvantage of cost and impracticality.

*Topographic base*
The majority were for some reduction or simplification of the base. Natural features were generally considered important as they related to the geology, for example, it was thought that all rivers should be included as they often afford sites for studying the geology. Contours elicited the most comment. They were generally thought to be important, especially for three-dimensional interpretation, but were sometimes found to be too faint. However, some people wanted more of them, while others said less were desirable.

It was with human features that most suggestions were made for simplification. On roads and tracks there was a wide variety of opinions, from the inclusion of only main roads on the one hand, to every detailed track on the other, as this information is helpful when approaching geological sites. The general opinion was that towns were much too complex and that built-up areas should be either shaded or outlined. The siting and naming of individual buildings in towns was considered unnecessary. It was thought there is a good case for including both used and disused railway lines as cuttings offer an excellent opportunity for studying the geology.

A frequent opinion was that too many names clutter up the map and some need to be removed. One user thought that those names that were included should be printed in black rather than grey, to make them more legible. Only one person considered minor features such as farms were important, as he used them for location purposes, but he did not advocate naming them. The grid was considered essential by most, but one person made a case for its removal.

*Geology*
There was less criticism in this respect and it was mostly related to individual use, and therefore not so widely applicable.

Colour caused by far the most comment. Concerning the various codes, some thought the British system best, but cases were also put forward for other codings. Colouring was generally considered poor. Among many suggestions, one user thought that the thin washes used in early geological maps were much clearer than the modern colours. The colouring of fault lines was thought by some to be useful in distinguishing them from other features—red being preferable to blue for this purpose.

One geologist made a plea for marking areas where the geology could be clearly seen, for example in river valleys. Rock outcrops are marked on most maps and some modern geology maps show an asterisk for areas of special geological interest, but this does not cover all sites.

Point symbols, such as boreholes, were all considered useful. On the subject of the legend, one user thought that its siting on both sides of the map causes difficulty, especially when teaching geological map reading.

# Map Curators' Conference

Conservation, storage and recording were the three main themes treated by the European Map Curators' Group during its biennial conference at centres in England and Wales from 20th to 24th September 1982. The itinery was devised to show representative map repositories in the United Kingdom. It began with a whole-day visit to the Ordnance Survey in Southampton to study the production and storage of maps. The following day was spent at Cardiff visiting the National Museum of Wales, which has a large collection of geological maps, and the Glamorgan Record Office, which includes many maps among the archives which it keeps for the three new counties of Glamorgan. At Fonmon Castle in the Vale of Glamorgan the Group saw a private library including old maps and globes, as well as a special exhibition of the earliest local maps, arranged by the Glamorgan Archive Service. The party then went to Duffryn House a few miles away for a reception by the Chairman of South Glamorgan County Council. The third day was spent at Aberystwyth, where members' papers were read at the College of Librarianship Wales (which was responsible for the administration of the conference). There was a visit to the National Library of Wales, which holds a large collection of maps deposited under the Copyright Act; there they were received by the President of the Library at an exhibition of Estate Maps of Wales. The fourth day included a visit to the Bodleian Library at Oxford, another Copyright deposit library. The Conference was held under the Chairmanship of Mr Donald Moore, Keeper of Prints, Drawings and Maps at the National Library of Wales. The Secretary was Mlle. Monique Pelletier, Conservateur des Cartes et Plans, Bibliothèque Nationale, Paris. At the business meeting new officers were elected for 1983–84: Mlle. Pelletier as Chairman and Mrs Sarah Tyacke of the Map Library, The British Library, as Secretary.