

CHAPTER 8

Contour Lines

The contour is the most important element in the cartographic representation of the terrain and the only one which determines relief forms geometrically. It is also the basis for other types of representation.

The following should be expected of a good contour image: a survey accuracy which is appropriate to the scale of the map and the accuracy of drawing and a contour interval appropriate to map scale and the landforms present, and especially at smaller scales, a correct degree of contour generalization. The whole image should be easy to read. Scale, accuracy in surveying, contour interval and contour generalization should be very closely interrelated. For the necessity for accuracy in surveying see Chapter 2. This chapter will deal with the questions of the geometric and graphic depiction of elevation and depth contours.

A. Concepts and terminology

Definition: Contour lines are lines on the map depicting the metric locations of points on the earth's surface at the same elevation above sea level.

Landforms can be imagined as being sliced by horizontal planes, the lines of intersection of these with the land surface, or their more simplified outlines in a map, being known as *contours*, or *isohypses*. These designations apply in particular to lines *above a base datum*. Corresponding lines lying below this datum are called *depth contours* or *isobaths*. The corresponding terms in French are 'courbe de niveau', in Italian 'curva di livello'. In German there are numerous terms, e.g.: Höhenkurve, Höhenlinie, Horizontalkurve, Niveaulinie, Schichtlinie, all meaning the same thing.

In cartographic considerations, the curvature of the earth can normally be disregarded.

Zones of contours rather than single contour lines are depicted on maps. Consequently, the level horizontal planes are assumed to be separated from each other by an equal amount. The constant vertical distance between two consecutive contours, i.e. their height difference, is called *the contour interval*.

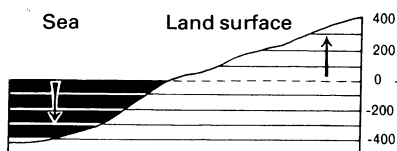


Figure 51. Elevation and depth layers.

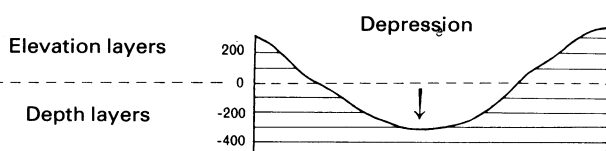


Figure 52. Depth layers in a depression (land surface below sea level).

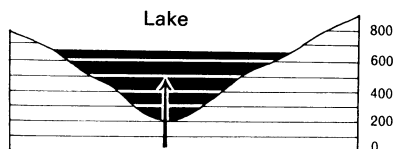


Figure 53. Uniform elevation layers above sea level on land and in a lake basin.

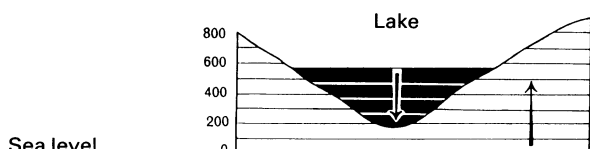


Figure 54. Exception. Elevation layers above sea level on land. Depth layers below mean lake level in basin.

The *base datum* or *datum height* referred to in the numbering of contours is, almost invariably, *sea level* (Figures 51–53). See also Chapter 6, Section 4.

There are *exceptions* of course, occasionally exemplified in special maps of lakes. An example of this is the “Bodenseekarte” (Map of Lake Constance) 1:50,000, published by the Vollzugcommission für Erstellung einer Bodenseekarte (Executive Commission for the Production of a Bodensee Map) under the Authority of the 5 States of Baden, Bavaria, Austria, Switzerland and Württemberg. It was produced by the Eidg. Topographische Bureau in Berne, in 1895. Engraving and printing was done by the Topogr. Anstalt Gebr. Kümmerly, Bern. In this map, a mean lake surface level was taken as the base datum for a system of bathymetric contours for use in the lake basin, while the surrounding land was represented, as usual, by contours above sea level (Figure 54).

The definition in “Lexikon der Vermessungskunde” (312) that bathymetric contours are contour lines under water, is wrong. It makes no difference whether the land being represented by contours lies under water or not. The contour lines in lake basins are also contours when they lie above sea level and are numbered from this base upward. Conversely, the designation ‘depth contour’ can apply to land surfaces below sea level, or depressions as they are called (Figures 52 and 53).

Coast and lake shorelines or stretches of beach are *examples of natural contour lines*. Artificial rice paddy terraces in Southern China are reminiscent of contour systems (Figure 115), as well as furrows cut horizontally into the ground. Normally, however, contours are not visible in the landscape. As explained in Chapter 5, Section 9, contour lines on a map are *abstract* or *conventional* lines. Altogether they form, as it were, an *elevation scale blanket* which overlies the cartographic terrain relief. They show height, position, the shape, the direction, and the inclination of any part of the surface.

B. The vertical intervals between contour lines

1. Simple equal-interval systems

At the outset, we will consider simple systems of equal contour intervals. A good selection of contour interval is very important. The choice is often difficult to make, however, since it depends not only on scale and line thickness, but even more especially on the type of terrain. The 'type', however, is very varied within most map areas. One tries to design the map on the basis of either a very strongly dominating type of terrain or to the steepest slopes which must be represented.

In general the smallest possible contour interval is selected as this leads to a more accurate and more richly detailed reproduction of the shape and a more three-dimensional image. On the other hand, the smaller the contour interval, the more crowded and difficult the map is to read (*Figures 57 and 58*). Thus it is necessary to weigh the advantages and disadvantages carefully against one another. The *contour interval values* should be simple numbers, easily added and easily divisible. They should also produce simple numerical values when grouped in fours or fives (index contours) or when halved or quartered, etc. (intermediate contours).

We can approach the question of the most suitable contour interval from two directions: either by calculation, where certain limits of slope angles and line thicknesses are assumed; or derived empirically, that is, by using experience from practical cartography. Let us first examine the calculation approach.

The relationships in *mountain areas* will be considered first, but leaving out precipitous rock areas for the moment. If steep rock areas were to be considered, suitable intervals would not be found. Steep rocks require special treatment, to which we will return in Chapter 11.

The *smallest possible* contour interval is sought. This is dependent on:

1. the map scale $\frac{1}{M}$
2. the steepest slope to be represented by the contours. Its inclination = α° .
3. the minimum, legible line thickness and the distance between lines which should be easily distinguishable with the unaided eye. A width of 1 millimeter on a map at the scale

$\frac{1}{M}$ corresponds, in reality, to a distance of $\frac{M}{1000}$ meters.

With a slope angle of α° , this distance represents a difference in elevation of

$$H = \frac{M}{1000} \cdot \tan \alpha \text{ meters.}$$

The greatest possible number of contours still remaining distinguishable or legible per 1 millimeter of horizontal interval is designated by k . Hence the smallest possible difference in height between contours amounts to

$$A = \frac{M \cdot \tan \alpha}{1000 \cdot k} \text{ meters}$$

To obtain A, we first make the following, reasonable assumptions for relationships in high mountain areas in maps: $\alpha = 45^\circ$; $k = 2$.

The assumption $\alpha = 45^\circ$ might perhaps appear somewhat extreme but there are very steep crag-free slopes whose inclination is as great as 45° – the walls of U-shaped valleys, for example, while the névé covered walls of cirques are even more precipitous.

Since the individual contours must be separated from each other by easily discernable distances, the assumption that $k = 2$ leads to line thicknesses of about 0.1 millimeters and to separation distances of about 0.4 millimeters. The resulting bands of lines are just legible to the normal human eye, even when contours are printed in brown and blue. It is very desirable in such cases to have the spaces considerably wider than the lines.

The assumptions $\alpha = 45^\circ$ and $k = 2$ yield a contour interval

$$A = \frac{M}{2000} \text{ meters.}$$

The corresponding values for the most common scales 1:1000 to 1:1,000,000 are given in Column 1 of the table on p. 115.

Let us now examine the empirical method. Column 2 of the table contains, for the same scales, the contour intervals which are often used in practice for maps of high mountains. It is obvious from the different values given that the choice, for many scales, is very difficult to make. For some scales it is barely possible to find a contour interval which is both graphically convenient and arithmetically simple. For this reason 1:50,000 scale maps of high mountains have four different contour intervals. As the Swiss “Siegfriedkarte” shows, a contour interval of 30 meters has worked out very well, from the graphic point of view, for alpine regions. However, this value is very inconvenient for rapid addition and does not provide convenient values for index contours and intermediate contours.* For 1:25,000 an interval of 10 meters leads to very closely spaced bands, while one of 20 meters leads to contour bands which are too spread out in many places. This also applies to 50 meter and 100 meter contour intervals at 1:200,000, and for 1:500,000 with intervals of 100 meters and 200 meters.

Several of the values from Column 2 are repeated in Column 3, and these are the ones which have proved to be most convenient from the graphic point of view. If we compare the values in Columns 1 and 2 with each other, the following comes to light: At the largest scales, 1:1000 to 1:10,000, the contour intervals used in practice (Column 2) are twice as large as the graphically smallest possible values of Column 1. In practice, one employs the values

$$A = \frac{M}{1000} \text{ meters.}$$

At the medium scales, 1:20,000 to 1:200,000, A varies with decreasing scale from

$$\frac{M}{1000} \text{ to } \frac{M}{3000} \text{ meters.}$$

In general, therefore, theory and practice correspond here quite well.

* At the time of the earliest contour surveys in Switzerland, before 1840, elevations were measured in feet. For the 1:50,000 scale an interval of 100 feet was chosen. Simple conversion to meters then gave rise to the 30 meter contour interval.

Equal-interval systems (in meters)

	High mountains $\alpha_{\max} = 45^\circ$								
	smallest possible equal contour interval which can be drawn for $\alpha = 45^\circ$, $A = \frac{M}{2000}$	common equal contour intervals	very useful graphical and arithmetical equal contour intervals	ideal equal contour intervals $A = n \cdot \log n$, where $n = \sqrt{\frac{100}{M} + 1}$	recommended equal contour intervals, for normal contours	recommended equal contour intervals for intermediate contours	recommended equal contour intervals for mountains of medium height	recommended equal contour intervals for flat and undulating land	
Scales	1	2	3	4	5	6	7	8	Scales
1:1,000	0.5	1		1.5	1	0.5	0.5	0.25	1:1,000
1:2,000	1.0	2		2.7	2	1.0	1.0	0.5	1:2,000
1:5,000	2.5	5	5	5.7	5	2.5	2	1	1:5,000
1:10,000	5.0	10	10	10	10	5	5	2	1:10,000
1:20,000	10.0	10		17	20	10	10	2.5	1:20,000
1:25,000	12.5	10,20	20	19	20	10	10	2.5	1:25,000
1:50,000	25	20,25 30,40	30	29	20	10	(10)		1:50,000
					30	15	20	5	
1:100,000	50	50	50	47	50	25	25	(5)	1:100,000
								10	
1:200,000	100	50 100		75	100	50	50	10	1:200,000
1:250,000	125	100		85	100	50	50	10	1:250,000
								(20)	
1:500,000	250	100 200		130	200	100	100	20	1:500,000
1:1,000,000	500	200	200	200	200	100	100	20 (50)	1:1,000,000

At small scales, those smaller than 1:200,000, the most useful contour intervals are smaller than the theoretical ones, that is, smaller than the 'smallest possible'. They correspond approximately to the values

$$A = \frac{M}{3000} \text{ to } \frac{M}{5000} \text{ meters. We will return to this apparent contradiction.}$$

The normal useful contour interval is thus a non-linear function of the scale $\frac{1}{M}$. The relationship

$$\frac{1}{M} \text{ decreases with a decreasingly smaller scale from } \frac{1}{1000} \text{ to } \frac{1}{5000}.$$

It is quite easy to express this non-linear relationship between contour interval and scale in the form of a curve and to establish a *law for this 'ideal contour interval curve'*. This was first

undertaken by the Swiss topographer E. Leupin. He published a contour interval formula in 1934 (190).

As the Leupin formula is arithmetically very inconvenient and contained several additional weaknesses, it was replaced by the author in 1957 with the following formula (133):

$$A = n \cdot \log n \text{ meters, where } n = \sqrt{\frac{M}{100}} + 1$$

The basic elements used in establishing this formula were primarily the graphically most useful values found in Column 3 of the table page. Several values calculated on the basis of the formula are found in Column 4 of the table. We call them '*ideal intervals*'. Clearly, they agree almost exactly with the graphically most useful values of Column 3. In a way these ideal contour intervals are control values, which should not be departed from, in either the upward or downward directions, to any extent. The curve corresponding to this formula appears in *Figure 55*. It is similar to a parabola and has no convex inflexions.

This formula is derived for '*high mountain*' maps, but the only requirement is to multiply its contour interval values by a suitable reduction factor, less than 1, to obtain the corresponding ideal values for maps of all scales for *flatter regions*. We give this reduction factor the form $\tan \alpha_{\max}$. For high mountain maps we set $\alpha_{\max}$ at 45° . Thus its reduction factor amounts to 1, and its ideal contour interval values remain as they are given in Column 4 of the table. For maps of flatter regions, however, $\alpha_{\max}$ is less than 45° and thus the reduction factor $\tan \alpha_{\max}$ is smaller than 1. $\alpha_{\max}$ corresponds, approximately, to the angle of inclination of the steepest slopes which occur most frequently in the map areas under consideration. In this case the horizontal distance of the contour lines then corresponds exactly to that of the steepest (45°) slopes of the high mountain maps considered above. This comes directly from the equation:

$$\text{Horizontal distance of the contour lines } E = \frac{\text{contour interval } A}{\tan \alpha}$$

In the case just discussed, the following holds true for maps of mountain regions:

$$E_1 = \frac{A_1}{\tan 45^\circ} = A_1$$

and for maps of flatter areas:

$$E_2 = \frac{A_2}{\tan \alpha_{\max}}$$

Both horizontal distances E_1 and E_2 are the same when

$$\frac{A_2}{\tan \alpha_{\max}} = A_1 \text{ or } A_2 = A_1 \cdot \tan \alpha_{\max}$$

Thus we have, in the value $\tan \alpha_{\max}$, a simple and graphic '*terrain factor*' as the angle $\alpha_{\max}$ is a characteristic element of the surface and can be easily imagined and located. It is appreciated that even flat areas can have steeper hillsides here and there, but when they amount to only a small percentage of the surface, they are of no significance in the selection of contour interval.

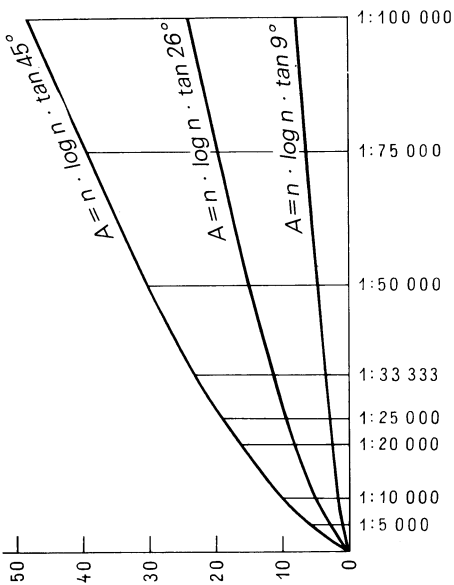
Figure 55. Ideal contour interval curves represent the relationship of contour interval A to map scale $\frac{1}{M}$ and to the terrain character. α is the slope angle of the steepest terrain occurring within extensive regions.

$$A = n \cdot \log n \cdot \tan \alpha \text{ meters, where } n = \sqrt{\frac{100}{M}} + 1, \text{ for}$$

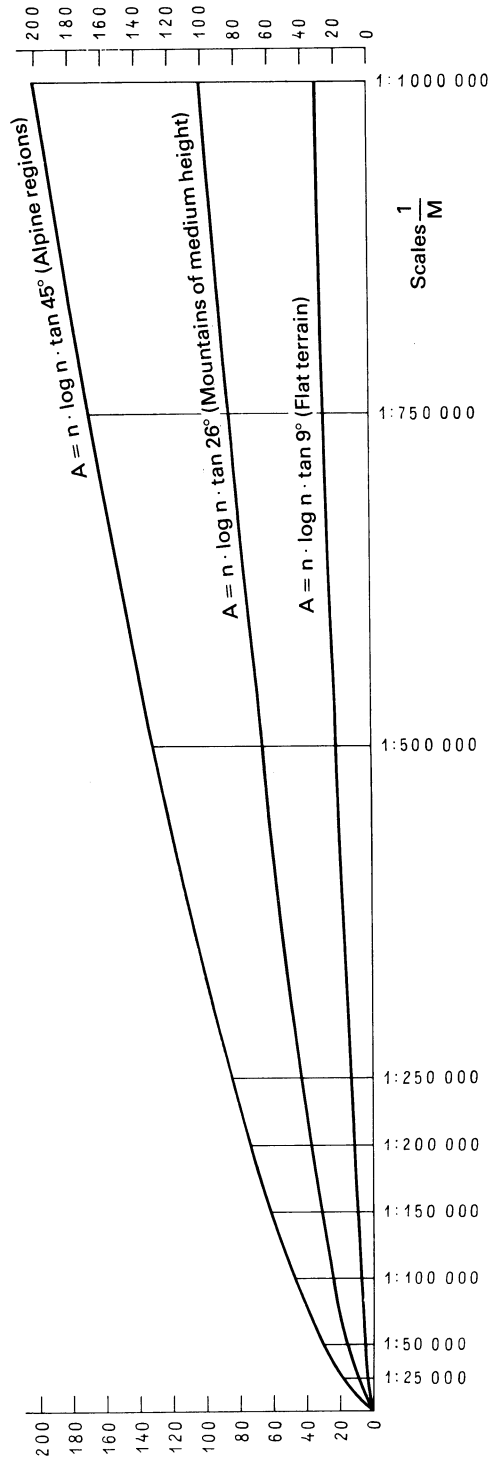
$\alpha = 45^\circ$ (High mountains, Alpine regions)

$\alpha = 26^\circ$ (Mountains of medium height)

$\alpha = 9^\circ$ (Flat and undulating land terrain)



A = Equal contour interval



A = Equal contour interval
(this is for the y axis of the graph, as above)

For mountains of medium height, such as those found in many places in France and Germany, a value of about 20° to 30° can be assumed for $\alpha_{\max}$. If we choose 26° , then our formula becomes

$$A = n \cdot \log n \tan 26^\circ = n \cdot \log n \cdot 0.5.$$

The ideal contour interval values are therefore half the value of those selected for an alpine area.

For flat and undulating terrain, we set $\alpha_{\max}$ at 9° .

The curves corresponding to these values $\alpha_{\max} = 26^\circ$ and $= 9^\circ$ appear in *Figure 55*.

If a suitable selection is made for the maximum slope angle α , then the formula $A = n \cdot \log n \cdot \tan \alpha$ gives contour intervals which are well suited to all scales of maps of the area concerned and are in harmony with each other.

The significance of such formulae should not be overestimated however as their values correspond to ideal intervals. They are, as has just been emphasized, *control* or *reference values*. Differences in terrain, the assumptions, always somewhat arbitrary, of 'maximum' slope angle, and of line pattern required to meet visual standards and above all the frequent and unavoidable *upward or downward rounding of the A values to whole numbers* allow us to see only the approximate middle axes of interval ranges in the contour interval curves of *Figure 55*. The contour intervals which are used in maps of various scales for the same area should not vary too greatly from these midpoints.

Leading on from these considerations, the *recommended intervals* emerge. They also appear in the table on page 115 as follows:

in Column 5 for *high mountains*

in Column 7 for *mountains of medium height*

in Column 8 for *flat and undulating terrain*

Theoretically and practically these are the most favorable values. Column 6 gives the associated *intermediate contour values* (half the contour interval) for the standard values of Column 5.

It may have been noted that in Columns 5 to 8, two to three scales appear often with the same A values. This arises from the tendency to gravitate toward a simple integer. A more suitable adjustment to the various scales is made possible here by increasing or decreasing the number of intermediate contours.

Topographic maps, of *level areas and flat valley floors*, used for construction and land improvement purpose often have even smaller intervals than are given in Column 8 of the table. Thus we occasionally find

at 1:1000 an interval of 0.1 meter

at 1:2000 an interval of 0.2 meter

at 1:5000 an interval of 0.5 meter

at 1:10,000 an interval of 1.0 meter.

These values are close to our ideal contour intervals, if 4° is inserted for $\alpha_{\max}$.

Many maps contain a contour image that is much too dense. In converting maps of large scale to new, smaller editions, one is often unable to arrive at satisfactory degree of generalization. Many map makers are restricted by the geometry of their base map and are unable to transform it into a graphically clear, legible, simplified product. *In case of doubt, it is better to*

round off the interval value and, in level terrain, to introduce intermediate contours freely, rather than overload a whole map through a contour interval which is too small.

On natural sloping ground, the cross profile is normally more extended and constant, more of a 'straight line', than the contours of the same regions. This peculiarity of topography, which has been virtually ignored until now, permits a relatively large interval to be selected, rather larger than that necessary to bring out the smallest details of the terrain. For this reason it is quite unnecessary in most cases to selected the lowest perceivable limit. The fine detail drawing, the high density and overloading often found in maps go against the requirements of good perception and reduces legibility and the ability to obtain information.

We have, in the above, been seeking the best contour intervals, visually and graphically; we have compared them with the values occurring in practice, and represented the contour interval A as a function of the scale $\frac{1}{M}$ and of the maximum slope angle. In this we came to the rather unexpected conclusion that, as a rule, contour intervals are larger in large scale maps, and smaller in small scale maps, than the smallest possible size.

In the following pages we will investigate these conclusions in an effort to establish the causes which lead in one case to a coarsening of the contour system, and in the other to an over-refinement of it, and thus to a non-linear equation of the relationship between contour interval and scale.

The causes lie in the differences between the types of the object being represented. This in itself, the relief in nature, is of course always the same, but in a map we create in effect a model of the terrain reduced to the scale of the map. As already explained in Chapter 5, however, the various reductions change the character of the model completely. The models for small scales are much more complex, much more detailed in smaller areas, and differences in elevation with respect to the horizontal extent are much smaller than for a larger scale model. These variations are shown in *Figure 56* by drawings of the same area, in profile with a contour system, showing the same terrain enlarged by a factor of two.

The first profile, 1:10,000, shows a relatively simple, constant shape. Here the smallest possible intervals of 5 meters (left figure) would lead, in most places, only to an abundance of contours while the shape would neither be more detailed nor more easily grasped metrically than it would have been with contours of 10 meter intervals. The over-dense contour systems would clutter the map unnecessarily; they would often hold no rational relationship to the survey accuracy and would increase the production cost of the map. It would be meaningless to introduce the graphically and visually smallest possible interval

$$A = \frac{M}{2000}$$

into topographic maps of 1:1000 to 1:10,000 scale (on steep cliffs two contours per mm.). As pointed out above, however, maps of level areas, designed for special purposes, are exceptions to the rule.

The second profile shows the same terrain at a scale of 1:100,000. Here, in general, the shapes are already so finely articulated that it seems appropriate to use the theoretically obtained smallest possible interval,

$$A = \frac{M}{2000} = 50 \text{ meters,}$$

in its preparation.

Finally, the third profile is the same terrain at a scale of 1:1,000,000. In order to represent such a finely detailed and generally low and flattened relief, the contour interval must be selected to be smaller than the theoretically smallest possible limit. At first this sounds paradoxical.

Employment of the smallest possible contour interval,

$$A = \frac{M}{2000} = 500 \text{ meters,}$$

selected on the basis of steep cliffs occurring in the area, would not provide adequate representation of the flat regions of land, occurring so often in maps of this scale. The shape relationships would be lost and hence the contour interval is reduced. However, this leads to illegible or poor line distinction in steep terrain. To avoid this, these closely spaced lines are somewhat spread out. Individual lines are smoothed out and displaced, and in this way the steepest slopes are flattened to a certain degree to permit legible and distinguishable contours. A generalization such as this can scarcely be avoided in small scale maps, and one has to choose the lesser of two evils. In this case the lesser evil is probably the insignificant distortion of linework in small areas with steeper slopes rather than the extremely rigorous representation of the more common flatter land at this scale.

The horizontal bands of lines on the right hand side of *Figure 56* are contour systems for 45° slopes and give the 'recommended' intervals (from Column 5 of the table on page 115) for maps of 1:10,000, 1:100,000 and 1,000,000 (twice enlarged). From these figures one can appreciate the refinement of the contour network with an increasing map scale. This refinement follows the compression of the model according to the scale, but the sequence is not in proportion. Proportionality would give rise to a system ten times finer for 1:100,000 than for 1:10,000. The proportionality with respect to scale increase is avoided in the interests of the purpose of the map, the technique of production and the requirement for legibility.

Similar observations can be made for plan views of the terrain, and thus for images formed by contour lines. In large scale maps, the land forms are so simple and cover such large areas that, even with relatively large contour intervals, the relationship of forms and similarity of shapes in consecutive contours is retained. In many places in small scale maps, however, each contour twists and curves quite independently. In these cases a very detailed contour pattern is required to permit at least a partial grasp of the shape relationships.

The larger the scale, the more limited and hence the more uniform is the terrain to be represented. The selection of an appropriate contour interval is therefore relatively easy for some large scale maps such as 1:1000 to 1:10,000. With a decrease in scale, however, difficulties begin to appear. In any map or series of maps, the region to be represented may consist of high mountains, mountains of moderate altitude and hills all lying very close to one another. Even at the 1:25,000 scale one can appreciate the inadequacy of contours with one fixed interval to cater for such contrasting areas. If a satisfactory graphic result is to be obtained, then different intervals must be selected for alpine areas as distinct from flat and undulating regions. The inability of one contour interval to suit both becomes much more evident as the map scale is reduced, and as the areas to be included become more extended and contrasting in character.

The selection of contour interval for the 1:50,000 scale probably causes more trouble than any other. The ideal value for high mountains is about 30 meters, and theoretically the smallest possible contour interval is from 20 to 30 meters. The Swiss 1:50,000 'Siegfried

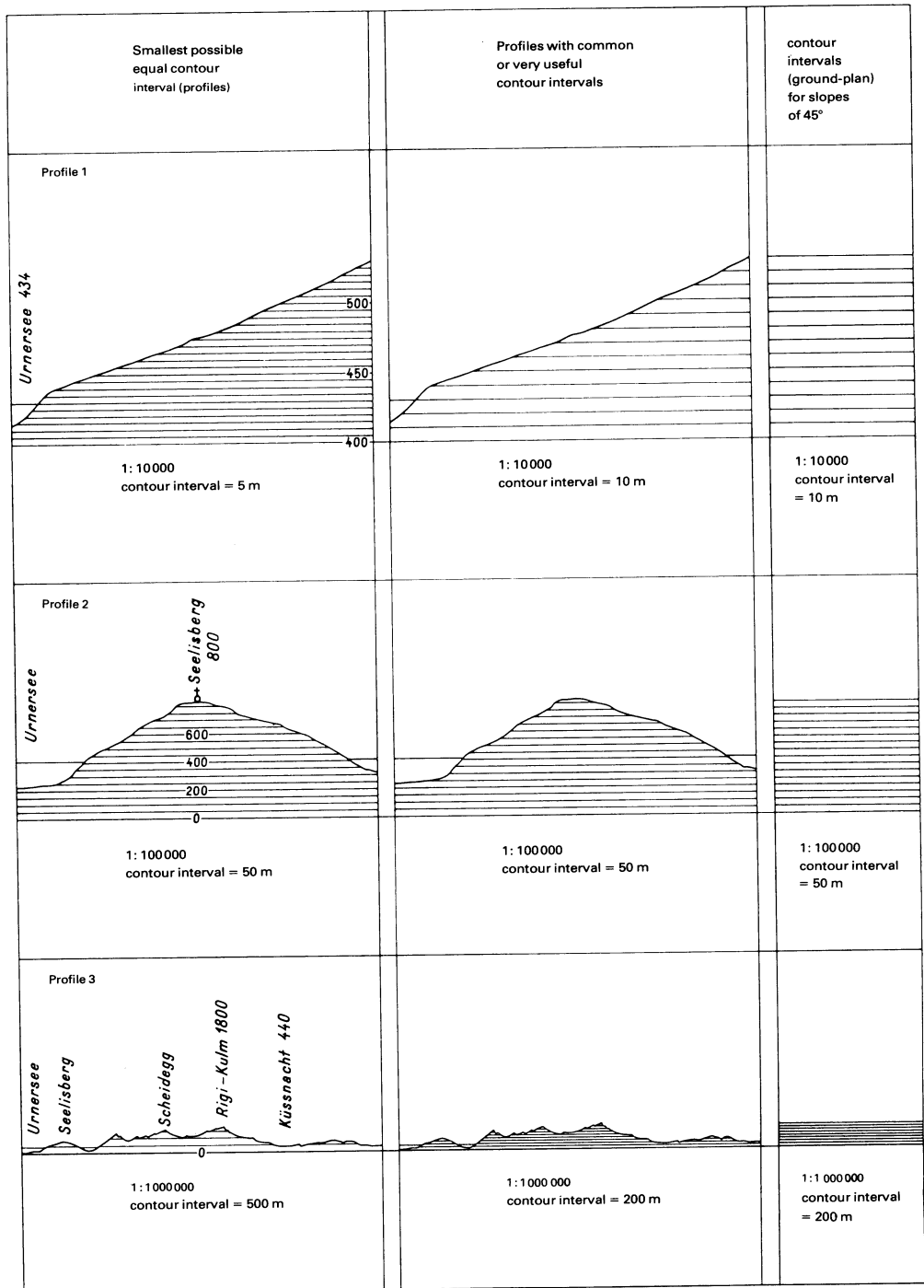


Figure 56. The variable character of the terrain model brought about by change in scale and the corresponding vertical intervals. All diagrams shown twice enlarged.

Atlas' has 30 meter contours. Graphically, this value has proved to be excellent for alpine areas, as has already been emphasized, but it leads to inconvenient numbers for intermediate contours, and also those contour lines which are numbered on the map. An interval of 25 meters would be as good graphically, but would be even less convenient for intermediate and index contours. Therefore, the 20 meter value, the lower limit, was selected for the new topographic map of Switzerland at 1:50,000, and its adoption was based on the following considerations: the value of 20 meters is very simple; it can provide intermediate contours at half intervals (successive dividing by two); it lends itself to the grouping of contours (in fives or tens) for index numbering; and it is also suitable for areas outside of the Alps.

The high accuracy of photogrammetric survey in high mountain areas has also been used as an argument in support of the use of a small contour interval. The sheets at 1:50,000 of the Swiss Alps which have now appeared indicate, however, that in high mountains the 20 meter contour interval really lies at the lowest level of visual perception. In many places, the use of the 20 meter interval requires the greatest possible sharpness and fineness of line to create legible images – and then only with clearly emphasized index contours. The crispness necessary is possible today by the use of scribing.

The selection of an interval for the 1:200,000 scale is also quite difficult. The ideal interval for high mountains is 75 meters, again rather an inconvenient value. The smallest possible value graphically is 100 meters, and this is obviously the most suitable value. A map at a scale of 1:200,000 always includes flat areas, however, and here one should add 50 meter intermediate contours liberally. Example: Ed. Imhof, Schweizerischer Mittelschul-atlas (*Swiss Secondary School Atlas*), editions 1962–1976, page 1, 'Central Switzerland'.

The unsuitability of a particular interval value for a landscape of contrasting relief shows up most obviously in maps of very small scale. In 1:500,000 scale maps, the 200 meter value is most suitable for high alpine areas, whereas in flat regions 100 meter contours are required. The same applies at the scale 1:1,000,000. Here the smallest possible interval, graphically, is only 400–500 meters for alpine areas. This is out of the question, however, for such a small map scale, since any expression of terrain relationships would be lost. In a situation like this a standard interval of 200 meters corresponding to the ideal value would be selected, and in addition, 100 meter intermediate contours would be employed freely for flat areas. But with a 200 meter interval, however, 5 contours plus 5 interval spaces would be compressed into one millimeter in high mountains and such a dense pattern of lines could no longer be deciphered. The lines must therefore be flattened at certain points and separated from each other. Extensive generalization deformations cannot be avoided.

In maps of even smaller scales, equal interval contour systems lose their value completely. Their place is taken by lines which merely indicate increasing stages of elevation, to be investigated in Chapter 13. But even for maps of large and medium scales, the inability to adapt the contour interval, no matter how well selected, to terrain which changes constantly has led to the development of combined interval systems. These are described below.

2. Combined interval systems

As has just been established, equal interval contours cannot easily reproduce contrasting relief. As a rule, a smallest possible contour interval is determined by steepness of slope but this often proves to be too large for flat and extremely complex terrain, and it does not permit an adequate appreciation of shape relationships and small details.

In 1923 and 1924, this led the '*Eidgenössische Landestopographie*' (Swiss Topographic Department) to investigate *combined* or *mixed interval* systems, based on German maps.*

By logically following the thought processes which underlay these investigations, a solution has been which is demonstrated by an example from an alpine map, at 1:25,000 (*Figure 59*).

A main contour system of 40 meter interval is emphasized and shown without breaks. Wherever the terrain begins to flatten out, and hence where the contour spacing starts to increase, finer intermediate contours of 20 meter intervals are inserted. In still more level terrain, fine, dashed 10 meter contours are inserted, and finally 5 meter contours are dotted in. In this fashion the widest variations are possible. Such an interspersing of different contour systems provides the following advantages:

Nowhere do confusing difficult groups of lines appear. Even on the steepest cliff, the contour image remains open. At no point do contours lie so far apart that shape relationships are lost: flat regions and small features in the landscape are well depicted. Relatively speaking the maximum metric framework is provided by the minimum of contour lines.

In spite of these advantages, however, such intermixed contour systems are not generally recommended. They are too difficult to read and not sufficiently obvious. All parts of the terrain, whether flat or steep, appear to be equally covered with contour lines in such maps, and any suggestion of shape, produced by the grouping and spacing of these contours, is lost. Topographic maps are not made for experts in special fields, but rather for the general user. The normal contour image itself puts quite a high demand on the comprehension ability of many map users. The continuous change of contour interval and the multiplicity of line symbols, however, would make the grasp of land forms unbearably difficult, the problem not being eased by the addition of symbols for ground cover, names etc. which form a normal part of the cartographic image. What is more, this process tends to over-emphasize individual contours – and leads to unsuitable, impractical index values for contours. *Nice theories do not help us to solve cartographic problems if, in their application, they ruin the image, destroy the overall impression and make legibility more difficult.*

3. Intermediate contours

Intermediate contours also conform to the combined contour interval system. While the author may not hold to the principles of the mixed systems described above, this does not mean that he is opposed to intermediate contours in reasonable numbers. Quite the contrary. *There should be a much more common and systematic use of intermediate contours.* They should not, as often happens, be introduced simply where and when it seems fit, in a thoughtless and unplanned manner, but they should be used in special circumstances.

Views are varied as to whether intermediate contours should be limited to half-interval subdivisions, or whether, depending on local circumstances, two to five intermediate con-

* They were designed by W. Schuele (287) as 'flexible intervals'. This nomenclature is not very apt as such a geometric, graphical problem has nothing to do with flexibility, so it will not be used here. More accurate would be the other commonly used term 'variable interval', although this expression suffers from an inherent contradiction. Vertical interval (or equidistance, as it is called in Switzerland) means equal separation, and variable or flexible distances cannot be 'equidistant'.

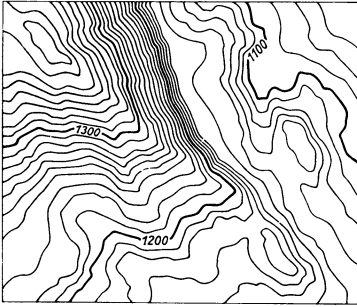


Figure 57. Uniform contour interval, 10 meters, no intermediate contours, numbered contours 100 meters.

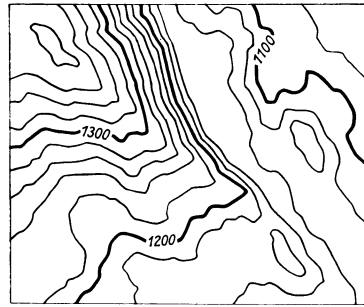


Figure 58. Uniform contour interval, 20 meters, no intermediate contours, numbered contours 200 meters.

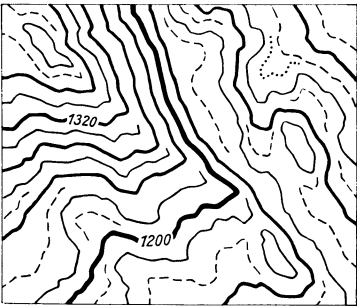


Figure 59. Normal contours 40 meters, local intermediate contours 20 meters, local intermediate contours 10 meters, local intermediate contours 5 meters, numbered contours 200 meters.

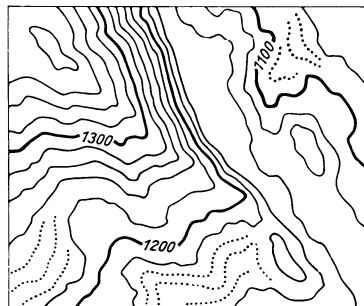


Figure 60. As in Figure 58, but with groups of 5 meter intermediate contours.

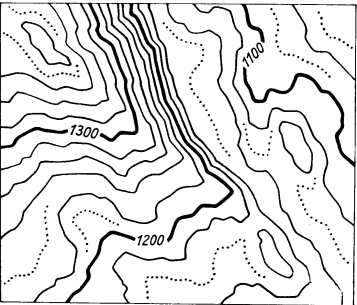


Figure 61. As in Figure 58, but with local 10 meter intermediate contours.

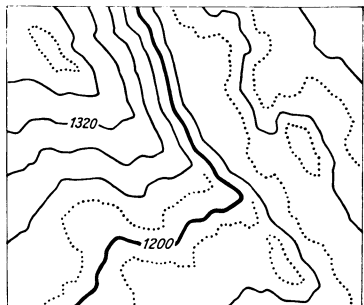


Figure 62. Normal contour interval 40 meters, local intermediate contours 20 meters, numbered contours 200 meters.

Figures 57–62. Various contour interval systems at 1:25,000 scale. Figures 57–58, simple contour interval systems. Figures 59–60, combined contour interval systems. Figures 61–62, intermediate contours of half the contour interval.

tours should be introduced. E. Leupin, an experienced topographer, supported the point of view that: ‘One should not hesitate to introduce up to five intermediate contours if this is necessary’ (190).

This may apply to large scale maps, which are intended primarily for technical purposes (construction, land utilization) and will be used by technicians and engineers. For topographic maps which are for general use, however, the local insertion of numerous intermediate contours should be avoided, or at most only carried out in very flat land. Local groups of contours (*Figure 60*) disturb the clarity and homogeneity of the standard contour system. Provided a good choice has been made for the normal interval, intermediate contours are not required in topographic maps, except for local areas where sections of intermediate contours, at half the contour interval, are sufficient (*Figures 61 and 62*).

Sections of intermediate contours half way between the main contours are recommended in the following three cases:

1. In very flat terrain to provide a sense of area relationships. The entries in the following *table* may provide standard guides.

Values for insertion of intermediate contours for constant slopes

Scale	Equal contour interval	Slope angle	Horizontal distances between normal contours	Horizontal distances between normal contour and intermediate contour
1: 5,000	5 meter	5%	20 millimeter	10 millimeter
1: 10,000	10 meter	5%	20 millimeter	10 millimeter
1: 25,000	20 meter	5%	16 millimeter	8 millimeter
1: 25,000	10 meter	2.5%	16 millimeter	8 millimeter
1: 50,000	30 meter	5%	12 millimeter	6 millimeter
1: 50,000	20 meter	3.3%	12 millimeter	6 millimeter
1:100,000	50 meter	5%	10 millimeter	5 millimeter
1:200,000	100 meter	5%	10 millimeter	5 millimeter
1:500,000	200 meter	5%	8 millimeter	4 millimeter

Half-interval intermediate contours are recommended when the slope angle is smaller and the horizontal distance between normal contours is greater than the values shown below.

With the relatively large horizontal distances given in this table, clustering and shading effects do not occur, so that no disturbances of the impression of form arise from intermediate contours. With steeper slopes, intermediate contours would interfere with the impression of shape, without adding anything of metric value (*Figures 63 and 64*).

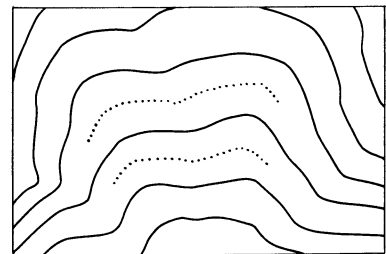


Figure 63. Intermediate contours unnecessary.

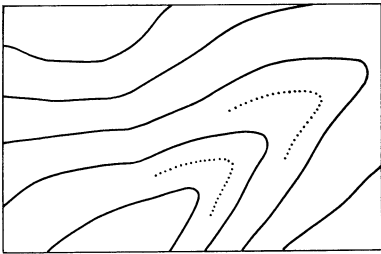


Figure 64. Intermediate contours unnecessary.

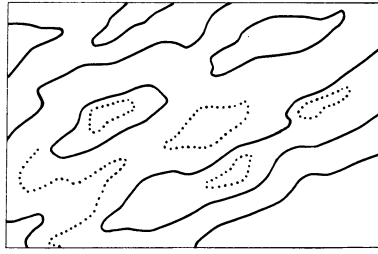
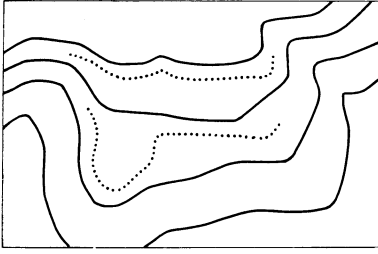


Figure 65. Intermediate contours required. Figure 66. Intermediate contours required.

Figures 63–66. Where are intermediate contours required and where are they unnecessary?

The data in the table refer to straight, constant slopes, where the intermediate contours run approximately halfway between two normal contours.

2. Intermediate contours are particularly valuable in giving more precise location to the edges of level regions and terraces and in terrain with very complex profiles, for instance where they run within the zone bounded by the first or last third of the strip between two normal contours. These lines should be extended in each direction to the points where they lie, once again, in about the middle of the strip (*Figure 65*). If the contour sections are too short it can lead to a cluttered map image.

3. Intermediate contours are an excellent means of emphasizing more clearly the geomorphological character of areas with small hillocks. They are inserted to bring out and indicate more precisely rises in the ground, knolls, hollows, saddles, and more generally to add richness of detail to regions which are not steep, such as land slip deposits, moraine sides, areas of *roche moutonnée*, dunes etc. (*Figure 66*).

It is recommended that intermediate contours be drawn as extremely fine, short dashed or dotted lines, so that they are subdued in contrast to normal contours and thus add as little disturbance as possible to the impression of slopes. Fine lines can be drawn easily and quickly with the aid of scribing, although series of dots cause more work.

Finally, and with some emphasis, the following is established: *Intermediate contours well-selected and correctly applied provide a map whose contour image has the metric advantages of a smaller interval, while the disadvantages of the low adaptability of equal interval contours to varying types of terrain is significantly reduced.*

C. Generalization of contours

All generalization in cartography is designed to make an image more easy to read by applying intellectual and graphic simplification. An image which has been reduced in size by photography, for example, may faithfully retain its detail but may have become illegible. To accomplish this improvement in clarity, details may have to be combined, deleted, emphasized and transformed.

Should contours be generalized or not? Some say they should, others say no. “Why should one survey accurately, if later the accuracy is to be destroyed by generalization?” This argument is used by the same people who accept that the plans of built-up areas and many other things can only be shown in generalized form in small scale maps. However, there are

no contour representations existing at small scales which are not generalized. None can exist. The questions here revolve around “How?” and begin with “Starting at what scale?”.

Although the same problems are of continuing concern in the generalization of contours, the causes and extent of distortion in large scale maps (1:10,000 and larger), medium scale (about 1:20,000 to 1:100,000), and small scale (smaller than 1:100,000) vary a good deal. In the interests of clearer presentation, this separation into scales will be followed here.

1. Maps at scales of 1:5000 and larger

In ground plans of 1:500 to 1:5000, contours are certainly seldom either intentionally or consciously generalized. Nevertheless, the lines deviate considerably from the true shape, since, at such scales, the contours are not usually surveyed with such accuracy and drawn with such precision as is technically and graphically possible.

Example 1:

Figure 67 depicts a stretch of road in very flat terrain, at a scale of 1:500 with a contour which wanders through the fields and crosses the road. It is surveyed with extreme accuracy (by local levelling, with points surveyed to an accuracy of 1 decimeter (0.1 meter), and to 0.2 mm accuracy on the plan). The contour follows all the irregularities of the uneven surface.

A contour such as this can be surveyed and plotted, but this would be pointless and uneconomical, since it would only confuse the overall image. A change in the level or an error in height measurement of only one or two centimeters would completely change the path of a line, and furthermore, such a precise contour would only have to be considered if the interval were reduced beyond any reasonable requirement.

Figure 68 shows a more rational presentation of the same contour; its simplified form satisfying all requirements. To satisfy the intended purpose and cost factors, the interval selected in such maps is never so small and the survey accuracy so great that the depicted line provides the finest extremes of detail possible. Apart from special requirements, all surveys at these large scales lead to contours which, in comparison to the actual forms, are already simplified. On very flat terrain, the location of any contour is uncertain, within particular limits as explained in Chapter 2, and small simplifications of form do not lead to a significant loss of accuracy, although they do add to the usefulness and legibility of the maps.

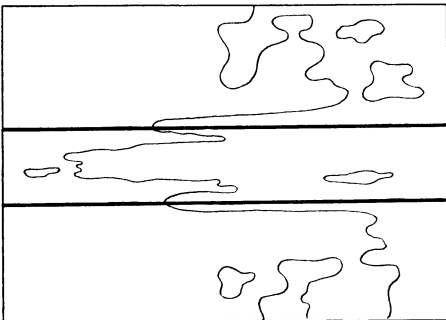


Figure 67. A precise contour crosses a road on flat terrain.

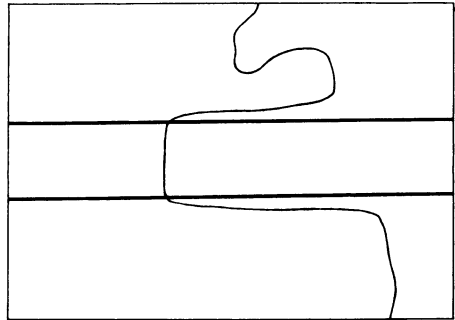


Figure 68. The same contour with normal and adequate accuracy.

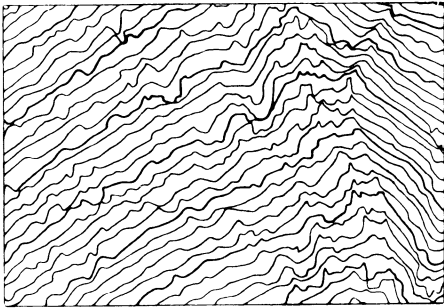


Figure 69. Precise contours of an alpine scree area. Scale 1:2,000, contour interval 2 meters.

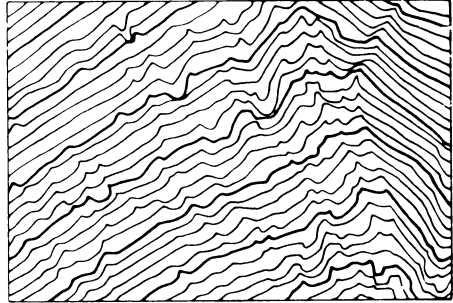


Figure 70. The same area with generalized contours.

Example 2:

Figure 69 shows the contours of an alpine scree slope at a scale of 1:2000 with an interval of 2 meters, and, in this particular instance, as accurately surveyed and plotted as would be possible at this scale. The incidental zig-zagging of the lines leads, as it were, around every large rock, while other blocks, just as large, are not picked out by the pattern of contour lines. On scree slopes such as these, however, the individual rocks are of no interest to us and the image is unnecessarily confused.

Figure 70 shows the same area covered by a more typical survey and using the same interval but where the surface forms can be recognized more easily.

2. Maps at scales of 1:10,000 to 1:100,000

At these scales, contours which have been well surveyed by plane table do not normally require generalized simplification by the cartographer. The point of the topographer's pencil automatically produces an adequate simplification.

Things are sometimes rather different with photogrammetric surveys. Photogrammetric contours often follow the smallest details of the terrain, their exact graphic reproduction leading here and there to jagged, uneven lines and sometimes to the interweaving of lines in steep ground. In such cases, the lines should be gently flattened and separated. Not every meaningless, small incidental movement occurring in one single contour is worth retaining.

Example 3 (Figures 71–74) illustrates such a situation.

Figure 71: Base map 1:5000, contour interval 5 meters. A steep, gullied slope.

Figure 72: The same map with edge lines added.

Figure 73: The same area converted to a map with scale of 1:50,000 and a 20 meter contour interval. The figure has been photographically converted back to the base map scale of 1:5000 thus retaining the fidelity of form. A magnified image such as this allows easy identification of any graphic deformations which have occurred. The positions of lines on the map at the 1:5000 scale were arranged so that they were virtually the same as on the original, the line thicknesses corresponding to that of the map at 1:50,000, but shown 10 times wider. The deficiencies mentioned above come clearly into view.

Figure 74 shows the generalized image. The lines have been smoothed here and there, opened up and separated. Small, isolated indentations have been eliminated but those which

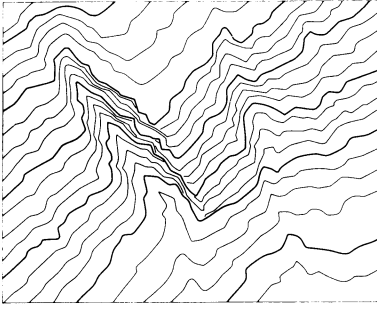


Figure 71. Steep slope Scale 1 : 5,000, contour interval 5 meters.

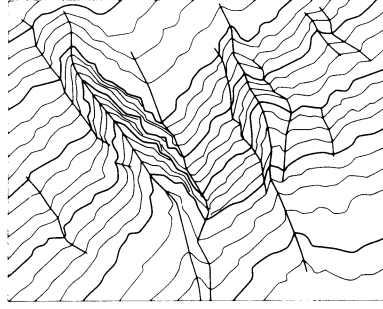


Figure 72. The same map with edge lines.

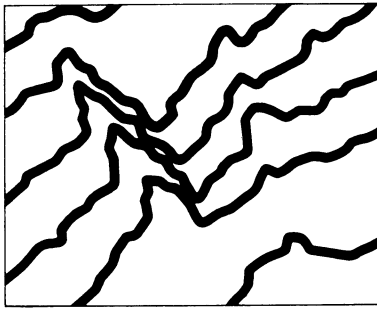


Figure 73. The same map converted to a scale of 1 : 50,000, contour interval 20 meters. Inadequate generalization. Figure 10 times enlarged.

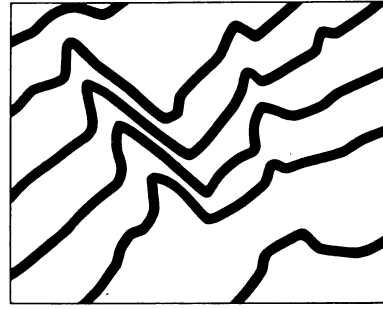


Figure 74. The same map scale 1 : 50,000, better generalization. Figure 10 times enlarged.

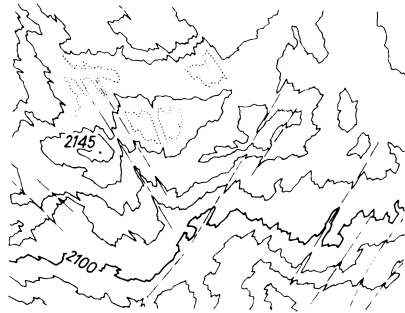


Figure 75. Contours of a limestone formation (karren area). Scale 1 : 10,000, contour interval 10 meters.

are encompassed by several contours have been retained. Care was also taken to retain, in the generalized contour image, lengthy ridges which cross several contours.

However, such simplifications to lines on steep slopes are only required in exceptional circumstances in the medium-scale group. Often, the line details are characteristic of a certain type of terrain and as such they should be retained, if possible. Examples of this latter type are contours on glacial tongues and certain types of limestone pavements (karren fields) (Figure 75). These limestone formations are referred to in Chapter 11, Section B, 6.

3. Maps at scales smaller than 1:100,000

These maps are normally produced by conversion from maps of larger scales. Contour intervals are larger, as a rule, than in the basic maps, e.g.: of each five contours on the basic map, four will be eliminated and in this way some of the small modulations of the surface disappear. The remaining lines bring out numerous small details which, on a faithful reduction, would be barely legible and would often no longer fit with neighboring contours. With decreasing scale, the thickness of lines increases with respect to the bends and twists of these lines so that many small details are finally absorbed into the line itself.

In circumstances such as this, generalization is unavoidable to maintain clarity. At scales smaller than 1:100,000, the simplification of the lines extends more or less over the whole map image and not only in particular places.

The type and extent of such generalization are shown in *Figure 76, 1–6* (Landscape on the upper Rhine River in the neighborhood of Flims, Graubünden Canton, Switzerland).

Figure 76, 1: Base map: 1:50,000 with a contour interval of 20 meters.

Figure 76, 2: Map 1:100,000. Contour interval 50 meters.

Contours are slightly generalized here and there. Shown twice enlarged.

Figure 76, 3: Map, 1:200,000. Contour interval 100 meters. The image is four times enlarged. An example of poor generalization. The contours are unnecessarily rounded, so that the terrain character is lost (young, steep, sharp erosion gullies separate the older, flatter terrain surfaces which are covered in places with scree). Some contours follow prominences in the terrain but other neighboring contours, which should also follow them, do not.

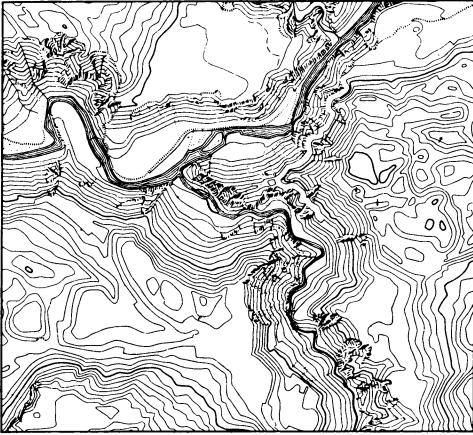
Figure 76, 4: The same map at a scale of 1:200,000 with a 100 meter interval, also four times enlarged. Better generalization. Distinct edges, which cross several contours, are retained as far as possible. (Map makers should not conclude from this example that all bands of contours in the world should be sharply angled.)

Figure 76, 5: Map, 1:500,000, contour interval 200 meters. The illustration is ten times enlarged. Again an example of poor, stylized generalization. Here, too, the contours are too uniformly rounded and hence the shape differences between older and newer surfaces are even less in evidence.

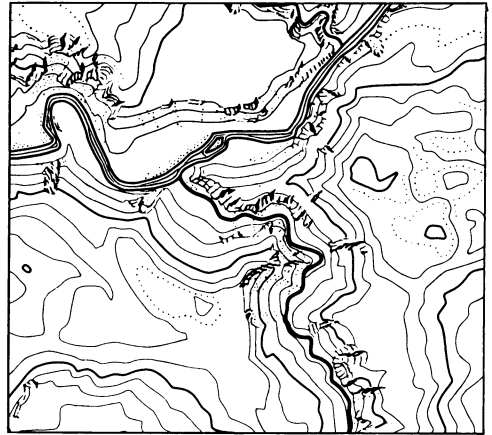
Figure 76, 6: The same map at a scale of 1:500,000 with a 200 meter contour interval, also ten times enlarged. A better generalization despite the same extent of simplification as in *Figure 76, 5*, with several typical characteristics retained.

In general, the following conclusions can be reached: the smaller the scale, the more the contours are deformed. The relief forms in nature are replaced more and more, as the scale decreases, by simpler, less sophisticated forms but, unfortunately, their shapes are often left to the discretion or the style of a draftsman. Many maps are still found to have all shapes rounded down. Rounded, wave-like contours were once considered as correct and attractive; all earlier textbooks on surveying, on topography and on cartography showing flowing, rounded lines exclusively in their illustrations. Good topographers have long since recognized the unreality of this situation, but it took photogrammetrically surveyed maps to open the eyes of some of the 'blind'. Many cartographers went to the opposite extreme and replaced all contour curves with corners. This is just as incorrect.

To generalize well, to enable the simplified, reduced form to present the correct character, requires frequent and careful observations of the landscape and intensive study of exact contour maps rich in detail. As already emphasized, a geomorphological training will help the cartographer to develop an eye for characteristic form. The relief of the earth's surface is



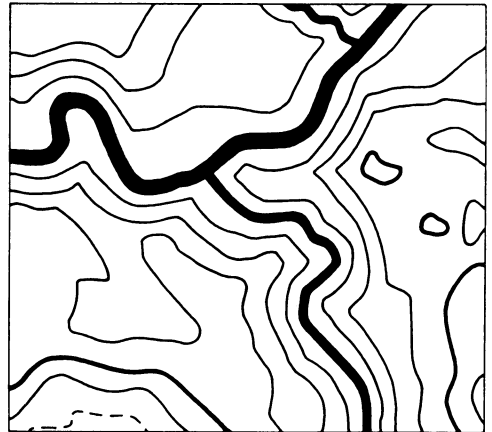
1. Scale of 1:50,000, contour interval 20 meters, base map for Examples 2–6.



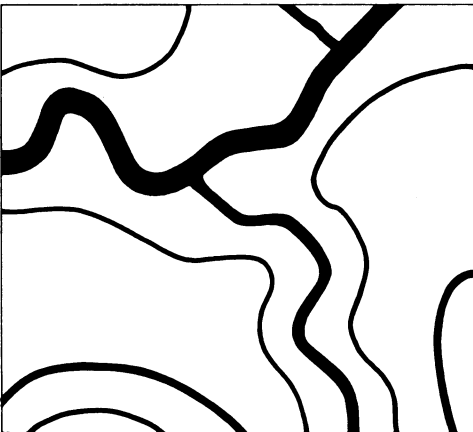
2. Scale 1:100,000, contour interval 50 meters. Enlarged to 1:50,000.



3. Scale of 1:200,000, contour interval 100 meters, poor generalization. Enlarged to 1:50,000.



4. Scale 1:200,000, contour interval 100 meters, good generalization. Enlarged to 1:50,000.



5. Scale 1:500,000, contour interval 200 meters, poor generalization. Enlarged to 1:50,000.



6. Scale 1:500,000, contour interval 200 meters, good generalization. Enlarged to 1:50,000.

Figure 76. Generalization of contours at various scales.

composed of innumerable combinations of geomorphological features. This relief is often large and clearly defined but often it may be quite broken up, hilly, rounded and jagged. Nevertheless, wherever the land has been heaved up and water flows, many-branched eroding streams, borders of valleys and depressions, and terrace edges provide the skeletal framework for the draftsman, and this holds, more or less, true for small features as for large.

The following eight rules attempt to summarize the doctrine of *contour line generalization for small scales*:

1. One must never overlook the fact that *surfaces* are being depicted with contours. A single line says very little. One line does not define a surface. Everything comes back, eventually, to the formation of the system of lines, that is, the surface. One should not, therefore, draw a single line without considering the lines on either side of it and for each small section of any area one should create the complete line system belonging to it.

2. Small details which are not reflected in closely neighboring contours should be smoothed out. The direction of the individual line should be considered with respect to the contour interval. Only on flat ground and in the case of especially characteristic hilly or hummocky areas (karst formations, glacial tongues, dunes, scree slopes, etc.) should single lines take their own course.

3. Except in special cases (cliffs, clints in karren areas) neighboring contours should never touch. Not only must the single line be brought under control, but the whole line system as well. This should be introduced from one place to the next by the careful adjustment of neighboring contours.

4. On the whole, generalized contours should not look like gently smoothed wavy lines, neither should they appear jagged and crooked overall.

5. Before commencing any generalization of contour lines, one should transfer all significant sharply defined terrain crests or breaks of slope to the manuscript as drawing guides, so that these will receive due consideration when the contours are drawn.

6. If a small double wave form cuts across several contours on the generalized map, it should be treated as a whole. That is: it should be either retained in all the contours or left out. Even if the contours do not lie close to one another, so that the interdependence of form is not clearly apparent, it would be wrong to include the curves in one line and overlook them in the neighboring line (112).

7. Prominent parts of the terrain should be retained as far as possible, since they determine to a significant extent the aspects, profiles, the appearance of mass inland features. Enclosed basins on the other hand are scarcely visible at a distance in the landscape. Basically, however, a hollow form is just as meaningful and just as much a subject for portrayal as an upstanding prominent form. The depiction of a hollow shape is often only possible if it is broadened at the expense of smaller features lying on either side. The larger negative form is more worthy of retention than the smaller positive form. Streams, railway lines and roads often follow gorges, cuttings, etc. The former are always widened considerably in small scale maps, however, and they also force apart the valley and defile walls, which enclose them, as shown in *Figures 217–219*.

8. In generalization, the lines should be basically as unchanged as possible from their large scale original positions, and only altered as much as is required for the legibility and clarity of the map and by the compatibility of the map elements.

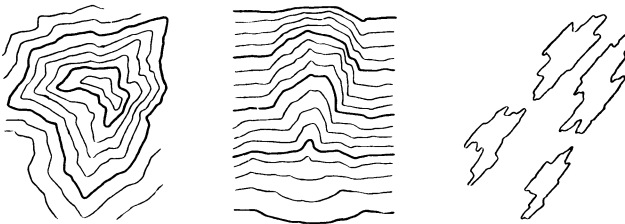
Inaccurate, incompetent drawing should never be excused on the grounds that it is presumed generalization. One should also guard against uncertain or misunderstood geomorphological speculations.

Several further *examples* may serve to illustrate what has been discussed above.

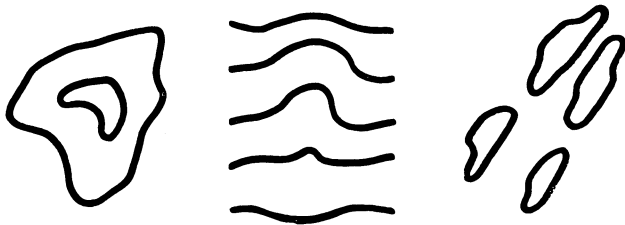
Figures 77, 80 and 83 illustrate various terrain features from maps at 1:25,000 scale, employing precise, not generalized, contours with a 25 meter interval. These features are a sharp ridged, pyramid-shaped mountain peak; the gully formed by a mountain torrent, with a *débris* fan; and several rounded ridges of a parallel and steeply bedded limestone surface.

Figures 78, 81 and 84 show the same sections magnified ten times from maps at one tenth of the scale, i.e. 1:250,000, and with a contour interval of 100 meters. Here the contours are poorly generalized, being unnecessarily rounded. Characteristic traits, such as the crests of the pyramid, the sharp edges of the gully, the apex of the *débris* fan and the parallel, angled ribs of the limestone formations, are all gone.

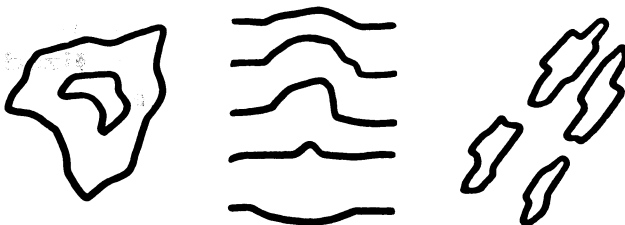
Figures 79, 82 and 85 again show these areas at the same scale, 1:250,000, magnified ten times as before, but the contours here, although just as simple graphically, are generalized more effectively. The main ridges of the mountain peak appear as ridges, the erosion gully is sharply cut into the slope, the extent of the associated *débris* fan being brought out by slight inflections in the contours. Intersecting lines associated with older and younger parts of the surface appear as geomorphological ridges or crests. Usually they also follow a geometrical



Figures 77, 80, 83. Basic maps, scale 1:25,000, contour interval 25 meters. Contours overall are not generalized.



Figures 78, 81, 84. Scale 1:250,000, contour interval 100 meters. Contours poorly generalized. All examples enlarged 10 times.



Figures 79, 82, 85. The same contours better generalized. All examples enlarged 10 times.

pattern, which should be retained in the generalized image as far as is possible. In *Figure 85*, the lines are parallel and extended in the direction of the trend of the rock layers; the lines lying at an angle to them bend sharply. Characteristic features such as these should not be completely removed even under extreme generalization.

Finally, the *relationship between contour generalization and the remaining content of the map* is discussed.

If the contours are presented in detail it would be senseless and out of place to oversimplify the stream network, the communications pattern, the built-up areas, etc. The opposite would be just as wrong, as every part of the image should be compatible in its graphical presentation and degree of generalization.

As already mentioned in connection with one of the examples, the simplified and widened lines for streams, roads, railways, etc. necessitate corresponding *accommodation and local adjustment* of contours in small scale maps. These points will be considered again in Chapter 14.

The *extent* of contour generalization depends considerably on the *degree of generalization of the remaining content of the map*, and hence on the purpose of the map and on the character which one wishes to impart to the map as a whole. In this way, for example, a *wall-map* corresponds in its content and degree of generalization approximately to a normal map at a scale $2\frac{1}{2}$ to 4 times smaller.

D. Relationships between survey accuracy and generalization

As has been shown in Chapter 2, the mean positional errors of map contours can be obtained from the deviations of map contours from more accurately surveyed control contours, or from the height errors of individual points determined by control measurements, and these errors can be represented in the form of band-like zones.

In the same way *displacement bands* can be constructed for *displacement arising from generalization*. This is shown in *Figures 86, 87 and 88*.

Figure 86: The fine line represents an accurately positioned, ungeneralized contour line drawn along a sharp deep gully in the terrain, at a scale of 1:5000. If converted accurately to the 1:100,000 scale, the line would follow the course shown (20 times enlarged) by the shaded band. As a result of the relative width of the line, very narrow spaces occur between contours in places, and sections of line run together.

Figure 87 shows the same ungeneralized contour as a continuous line at the 1:5000 scale. The shaded band, however, now corresponds to a generalized contour at 1:100,000, again twenty times enlarged. The path of the line in the gully has been opened up and the broken line indicates the middle course of this contour band.

Figure 88: This shows the ungeneralized contour, at the 1:5000 scale, and the middle line of the generalized contour, just discussed, enlarged 20 times from 1:100,000. The shaded area between these two lines is the *displacement zone of the generalized contour*. The width of the zone at each point shows the extent of contour displacement. In an open region, not too steep nor too flat, the zone narrows to zero as displacements are not required when generalizing points like this. In the narrow gully, however, the zone is wide, as this is where the generalized contour is likely to be displaced.

A comparison of the mean error zones in survey with the displacement zones of generalization, both reduced to the same scale, illustrates where the survey errors are predominant and generalization errors secondary, and vice-versa.

Both zones become broader: the survey error zone, primarily in very flat terrain (see Figure 19), and the generalization displacement zone in narrow gullies, on sharp crests, on steep terracing, in rough and dissected terrain and occasionally in very flat terrain as well.

Figures 89 and 90 give an example, at 1:100,000 five times enlarged. On the left are the zones of survey errors, on the right the zones of displacement caused by generalization.

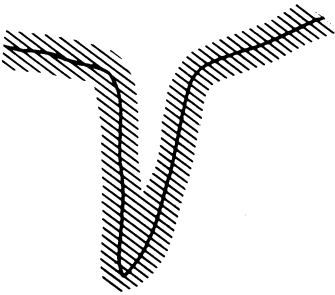


Figure 86. The fine continuous line = the accurate location of a contour at scale 1:5,000. The shaded band = the same contour at scale 1:100,000, but not generalized. Enlarged 20 times.

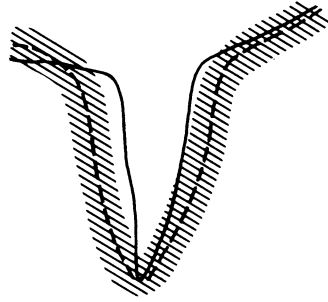


Figure 87. The fine continuous line = the accurate location of the contour as in Figure 86. The shaded band = the same contour at scale 1:100,000, but generalized, that is, shown somewhat spread out of the very narrow gully. Enlarged 20 times. Dashed line = center line of band.

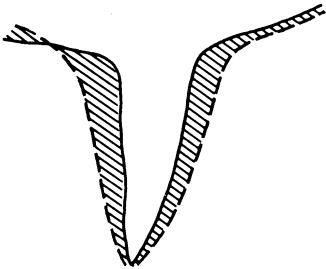


Figure 88. Fine continuous line as in figures 86 and 87. Dashed line as in 87. Shaded band = displacement of the generalized contour.

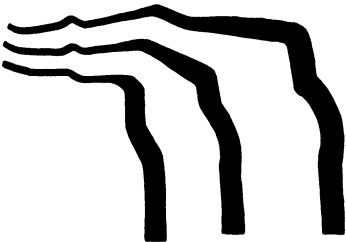


Figure 89. Zones of survey errors, scale 1:100,000, enlarged five times.

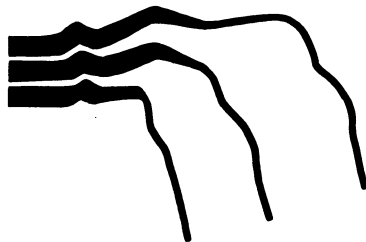


Figure 90. Bands of displacement caused by generalization, scale 1:100,000, enlarged 5 times.

At large scales, the generalization displacement zones are of somewhat lesser magnitude as a rule than the survey error zones. In other words, possible generalization displacements are so small that they are covered by the survey inaccuracies.

At small scales, the opposite is true. Survey errors are hidden by the reduction in scale, but the displacements from generalization increase.

The point of cross-over, where the increases of both error bands are equal, may be at about 1:100,000. This applies to good modern surveys. In old, inaccurate surveys, this limit is found at considerably smaller scales. In many older maps at 1:200,000, the inaccurate location of a section of a contour line should be attributed to survey errors, and not to displacements caused by generalization. Indeed, for all *rocky regions*, which are not considered here, the cross-over point would be at about 1:10,000 or even larger scales.

E. Relationships between contour structure and contour interval

In previous sections, attention was repeatedly drawn to these relationships. Here several additional remarks will be made, to develop these ideas.

The structure: the coarser or finer curving or twisting of individual contours, can be caused by

- *the nature of the relief itself* (rocky areas are more rugged than the terrain without rocks).
- *the scale* (at a small scale the relief has a more detailed structure than at large scales).
- *survey accuracy* (exact surveys such as photogrammetric surveys yield more richly detailed contours than inaccurate surveys).
- *generalization* (generalized contours are poorer in form than are ungeneralized contours).

Contour structure, whether it is attributed to one or several of the above factors, should have meaningful relationships to *contour interval*. With a large interval, many small shapes are missed by the open network of contours – they are not picked up. A large contour interval, therefore, is, in a sense, similar in effect to an inaccurate survey or extensive generalization. A small contour interval, however, is advisably in very detailed relief, surveyed with great accuracy, and with no generalized treatment of lines.

Wilhelm Schüle (1871–1931), former chief cartographer of the Eidgenössische Landes-topographie (Swiss Topographical Institute), had mentioned these relationships as early as 1929. He wrote (287): “The contour line system (the contours and their interval value) must be so created that an interval harmony binds the system and the individual contours together to form an image with an equal, but well-balanced, capability of expression. No harmony exists when the single contour is less expressive than the system, when it is poorly formed, stiff, rigid, parallel, equally spaced, as though drawn on a smooth, regular, mathematically formed object in such a way that the same form could have been just as easily represented with a more open interval. Harmony is lost in just the same way at the other extreme: where one line is drawn in great detail and intricacy, expressing much more than the general system is capable of doing, and in such a way that the rest of the contours are unable, because of the large interval, to show the sequence of shapes suggested by this

one contour. The single contour may be able to bring out more than the system can contain. Between these two cases lies the harmonious case, where system and contours are so mutually attuned to each other that their capabilities of expression are equal." The three cases are illustrated in *Figures 91, 92 and 93*.

Figure 91: Contours are poorly formed. The interval is unnecessarily small.

Figure 92: Contours are very detailed in formation. Interval is very great.

Figure 93: Contour forms and interval are in harmony. Examples of the first type are often found in older topographic maps as the consequence of a lack of survey precision.

Many recent photogrammetric contour maps contain examples of the second type, especially at very large scales.

Good, harmoniously balanced contour images are contained in some sheets of the *Eidg. Topographischen Atlas* (Swiss Topographic Atlas) 1:50,000 (the "Siegfried Karte"), surveyed by plane table between 1880 and 1900, and also more recently in the sheets of the *Landeskarte der Schweiz*, at 1:25,000 and 1:50,000.

The contour lines must show the land forms in their *relationship* to one another. Groups of contours must bring out the shapes of the land in their correct relationships to one another. Wide parallel curves are just as meaningless as contours with intricate crenulations which are not echoed in the neighboring contours. The intricate detailing of individual contours is of no value when there are wide intervals on either side without suitable adjacent contours to complete the picture. For this reason the contour map should not show incidental detailed forms, but it should present a *uniform overall treatment of the terrain which is fully interrelated*.

But once again, no rule exists without exceptions, and in this case the exceptions are quite numerous.

As already mentioned, exceptions are formed by karren regions (limestone pavements), since these rocky wastelands are characterized in maps by the very complexity of their lines.

Contours in *flat terrain*, also provide exceptions since they lie so far apart that interrelationships of form are often no longer recognizable. It would be meaningless to carry out extensive generalization here.

Exceptions are also formed by most contours in very *small scale* maps. Despite extensive generalization, landforms always show very small details relative to the size of the contour intervals. Even using the smallest possible interval, the contours are often incapable of showing relationships in the terrain.

These findings indicate certain *deficiencies* or *weaknesses* in the technique of representation and the *limits of the usefulness* of contour lines. We will return to these questions below.

F. Graphic conventions and forms

1. Index contours

To facilitate the counting of contours and to provide for a rapid appreciation of the location of elevations in an area, it is usual to emphasize every fifth or every tenth contour as an index contour by strengthening the line, or by making it a broken line and annotating it. The five-line system is to be recommended in preference to the ten-line method, since, with the latter, large portions of maps in flat and hilly terrain would receive no index contours.

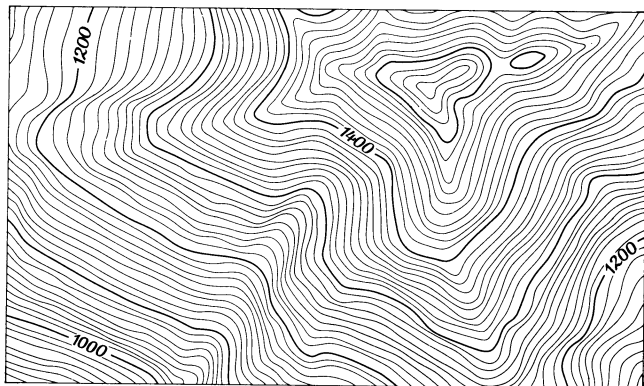


Figure 91. Contour interval of normal contours = 10 meters. With respect to the contour interval, the contour lines are too poor in form and smoothed out too greatly.

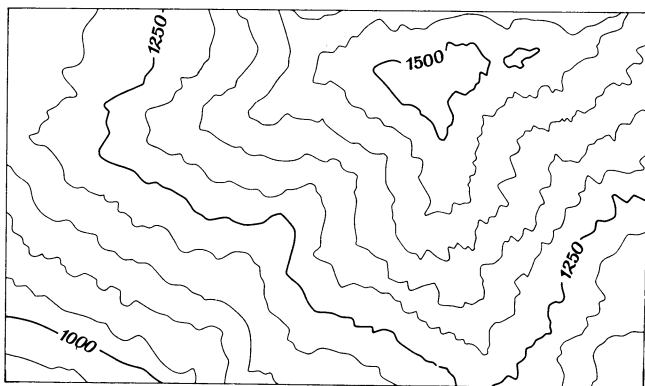


Figure 92. Contour interval of normal contours = 50 meters. The contours show too much detail, too much activity relative to the very large interval.

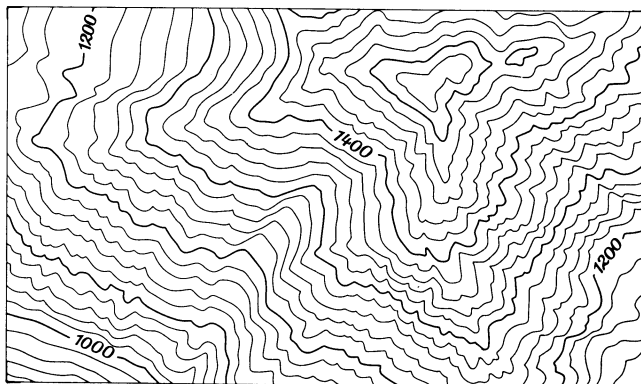


Figure 93. Contour interval of normal contours = 20 meters. The detailed form of the contours and the contour interval are in good harmony with each other.

Figures 91–93. Contours at scale 1:25,000.

Strong emphasis of the index contours makes a general appreciation of the map easier, but it may also disturb the continuity of the impression of shape and tends to present the terrain as a series of stepped elevations. In selecting line strengths, therefore, it is necessary to choose carefully between advantages and disadvantages. In the past, the broken line was preferred; today it is the continuous line, slightly emphasized.

The height figures in index contours are set along the axis in small breaks in the lines, but not above or below the lines. They are plotted and printed in the same color as the lines to which they refer, thus assuring that their exact position is clear. They should be distributed over the contour image in such a way that at no point does a disturbing collection of numbers build up, so that for very section of the terrain a number is available and easily located nearby. Their final positions are normally established after the map image, including ground cover and names, has been completed. In this way their coincidence with symbols or with textual material can be avoided. 'Ladders' of numbers, occasionally encountered, have disturbing effects induced by the columnar stacking of values and are not effective in performing their function.

In some countries it is common practice to orientate the contour numbers (since these are not spot heights) to show down-sloping directions (*Figure 96*). In case of doubt, therefore, the direction of slope should be expressed. However, the resulting inversion of some numbers can be quite disturbing as lettering should be upright where possible. For this reason, in Switzerland it is normal to orientate these numbers as shown in *Figure 97*.

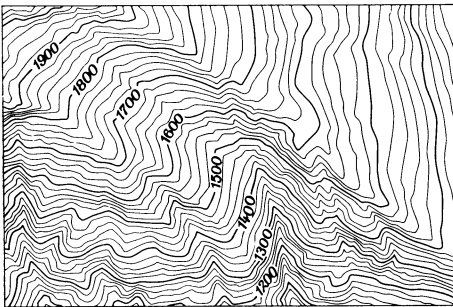


Figure 94. Poor arrangement of contour height numbers.

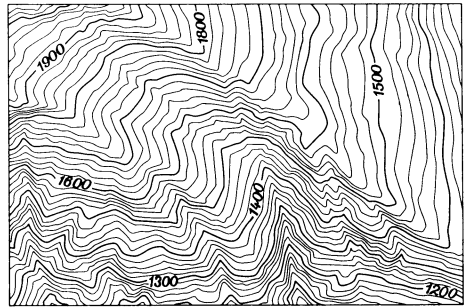


Figure 95. Good arrangement of contour height numbers.

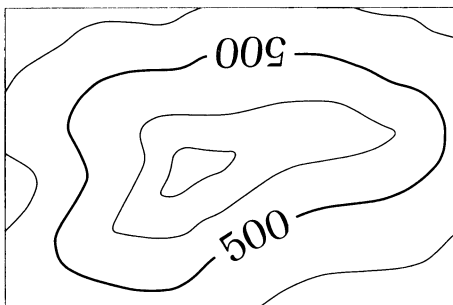


Figure 96. Numbers oriented to direction of slope.

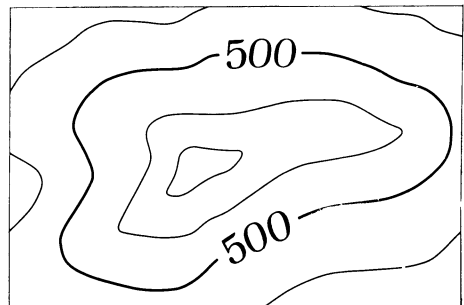


Figure 97. Numbers with upright orientation.

2. Intermediate contours

The meaning and use of intermediate contours were discussed in Section B of this chapter. Subsequent sections should be referred to for information on line thickening and graphic forms.

Intermediate contours should be subdued by using thinner lines and should disturb the network of normal contours as little as possible. They should be drawn or engraved as lines made up of short, fine dashes or dots.

3. Uncertain contour lines

In maps of inadequately surveyed areas, the topographic surveyed contour image may be very incomplete. To provide form relationships, contours may be drawn in over these areas, their positions estimated or located simply by guesswork. Such sections should be shown as dashed or dotted lines, and attention should be drawn to the unreliable character of these contours in the map legend.

4. Additional aids to orientation

Isolated, closed contours in flat terrain do not always permit the recognition of slope directions (*Figure 98*). The contour picture in such cases is often expanded to include *spot heights* (*Figure 101*), *plus and minus signs* (*Figure 99*), or small *down-pointing arrows* and *down-slope symbols* (*Figures 100 and 101*). Variations in the width of sections of the contour lines derived from the technique of three-dimensional shading, discussed in section H, or shadow tones themselves (Chapter 9), remove all possible doubt.

5. Contour colors

By varying the colors of contours the cartographer can improve the effectiveness and detailed content of the map. Colors of contours can be modified according to the *nature of the ground*, the *elevation*, or the *position of that area of the terrain with respect to oblique*

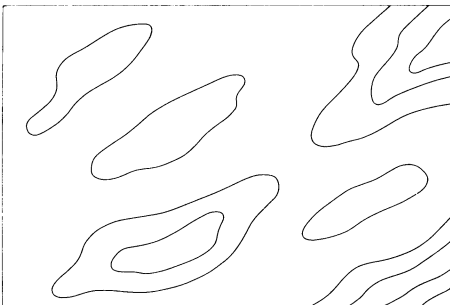


Figure 98. Indeterminate slope direction.

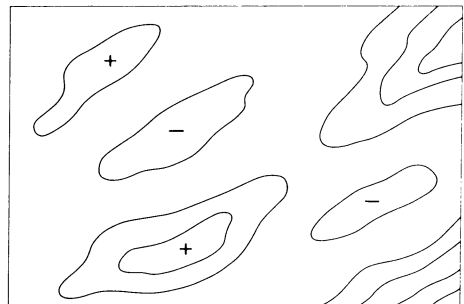


Figure 99. Hills and depressions are identified by the plus and minus signs.

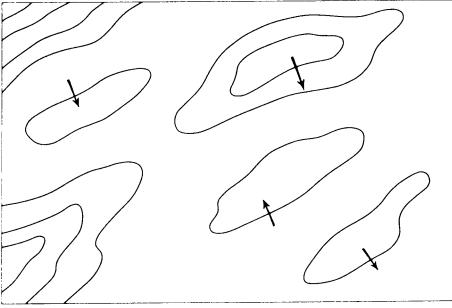


Figure 100. Slope arrows bring out hills and depressions.

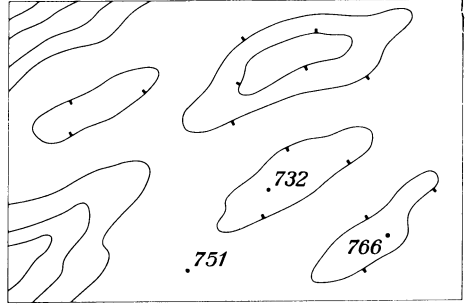


Figure 101. Down-slope indicators and spot heights indicate hills and depressions.

lighting. These have all been tried many times but, in general, contours are only modified in color to distinguish between types of ground. All three possibilities are discussed below.

a) Differentiation of contour color according to the type of ground (see *Plates 3, 4, and 12*). Here the contour gives not only the form of the relief but, through colors, an indication of the *material forming the land surface, thus revealing the character of the terrain*. The power of expression in the color of the contours is naturally very limited in flat terrain as a result of the large distances between contours. One, therefore, should always limit oneself to the simplest differentiations.

Contours on glaciers, together with the stream network, are often printed in blue, while all other contours are black, dark brown or grey. This causes glacial areas to appear very prominent to the eye. In such cases, contours on lake floors may also be printed in blue.

In topographic maps of large and medium scales we normally find a differentiation of contours in *three* colors, as follows:

black for rock, stone and gravelly ground

blue for permanent snow and glacier surfaces, and occasionally for contours under water

brown for earth-covered ground (usually vegetation).

Color differentiation such as this is particularly successful in maps of alpine areas, where the density of contours allows for a distinct differentiation of rock and scree areas, permanent snow slopes, and vegetation-covered regions. The technique is also useful in the following way.

Black is the most readily and commonly available printing color. It is the color given to 'culture', i.e. built-up areas, communications, etc. Rock and scree areas are usually free of such elements, so that black contours used here would not be disturbed by anything else. Sometimes a dark brown is used to replace the black.

Blue, the color of water, is also used to symbolize snow and ice.

The *third color*, for contours on earth-covered ground, should be selected to contrast as boldly as possible with black and blue. Yellow would satisfy these requirements but it contrasts too weakly with white paper. Red would also be suitable, but red contours have too jarring an effect; what is more, red should always be used sparingly, and kept to emphasize special symbols. This leads us to select a strong *reddish-brown* of good printing

quality. Maps often contain contours which are too broad, pale and yellowish-brown giving a washed-out, smudged impression. Strong, fine lines always produce much clearer results.

Earth-covered ground carries, at least in European climates, a covering of green vegetation. It would therefore appear fitting to express it in a map by *green contours*. The green color produced by a fine, dense contour pattern does give quite an authentic impression of nature. Maps have already appeared here and there with green contours. The author tried them out for the first time in 1918 on an unpublished map of the Glärnisch massif (Glarus Canton, Switzerland) 1:50,000. A number of years ago, the Eidgenössische Landestopographie also undertook tests of this type but the green of the contours is too similar to the blue of rivers and glacier contours. In general, therefore, brown is preferable for contours on earth-covered terrain. In certain cases, however, where maps are to be produced to look as close to reality as possible, green contours and a very rich blue for water would seem to the author to be worth considering.

The differentiation of ground surface types is often extended to various other colors in large scale maps or plans. Thus in the 'Übersichtsplan' of the Schweizerische Grundbuchvermessung (maps for the Swiss land-register) at 1:5000 and/or 1:10,000 scales, for example, contours for rock areas were gray (not a happy choice) while the scree contours and dot symbols were in black. The opposite, black for rock, grey for scree, were also tried. This color differentiation gave much better results and could certainly be recommended for richly detailed, multicolored plans. Recently in some maps the black of rock contours (as well as rock drawing) has been replaced by dark brown, blue-violet or violet-brown. In association with bluish-grey or grey-violet shading tones, this is more harmonious and less contrasting than the combination of black rock contours with the same shading tones.

Other colors have also been used. Many Austrian maps have red-brown contours for stony and rocky ground (generally located at high elevations) and grey contours for the rest of the terrain which is normally lower-lying. In order to create a wintry impression on the landscape of skiing maps, blue or blue-grey contours have been tried in Norway and Switzerland.

The possibilities of such color differentiation in contours are by no means exhausted. There is room for further experimentation, but the ineffectiveness of the differentiation in flat regions, because of wide distances between the contour lines, should never be ignored.

In maps at *scales smaller than 1:100,000*, it is recommended that one contour color only be used for glacier-free terrain since the fine detail in the form of the surface, and the very small areas of rock, scree and earth which would have to be differentiated, make considerable generalization necessary. Breaking up the contours into red-brown, black or sepia destroys the miniature shapes in the small scale map.

Economic and technical considerations would also favor a moderation in the color differentiation of contours described above. Each new color places the highest requirements on the accuracy of map reproduction. If the various colors do not fit to within fractions of a millimeter in printing, a distorted contour image results. What is more, the smaller the scale and the finer the structure of land forms, the more does color differentiation disturb the three-dimensional effects. Even at the largest scales, some caution should be exercised. Too intricate detailing in stony ground and in vegetation-covered ground leads, in alpine terrain, to numerous points of contact between different colored lines, and hence to a considerable increase in problems of fitting the areas together and of map revision work. Extensive *generalization* is necessary for these reasons also.

b) Variations of contour color according to elevation layer. In maps employing layer tints, the land is varied in color with increasing elevation. Attempts have been made to achieve corresponding effects using linear elements, by varying the colors of contours. In general, this is a waste of time, since contours often occur on maps at widely spaced intervals, and are quite unsuitable for this purpose. Also, it would be technically too complicated and expensive. Each group of lines, for a particular elevation, would require its own color and hence its own printing plate and its own printing step. As so many inks would be required, weak, poor printing colors such as yellow would have to be included.

There is, however, a *special case* in which a limited use of this principle appears justified. In maps of the Jordan River valley, all *contour lines* lying above sea level can be drawn in brown-red, while the *depression contours*, that is, the lines lying below sea level, are in blue-violet.

Thus, the depressions are more easily and quickly recognizable than in a map of the same area with uniformly colored contours. In this and similar cases, it is perfectly reasonable that a special peculiarity in the landscape should receive special treatment.

c) Variations of contour color according to illuminated and shaded sides. With the assumption of oblique light, the slopes of a terrain model facing the light source are bright, while those away from it are dark. Attempts have been made to imitate the three-dimensional effects by means of varying the colors of the contours. The lines on the illuminated slopes are thus printed in a warm yellow-brown or red-brown and those on the shaded slopes in a strong black-brown.

However, this is little more than an amusing game, too difficult for reproduction in maps and not achieving the anticipated effects. When treated in this way the terrain appears to be arranged in a series of steps. In flat regions an adequate effect is not achieved, but the main problem is that *the gradual transition from light to dark cannot be formed, as the color changes quickly and erratically*. For this reason the impression of shape is destroyed since *'shape lies in the transition'*. To add to the inadequacies of the image there are the technical difficulties of achieving satisfactory register between the variously colored lines.

6. Line weights, the form of broken lines

The weights of contour lines have a great influence on the effect of the image and on the legibility of a map. Today's technical processes (scribing, drawing work at larger scales with special pens, for example, and subsequent photographic reduction) enable any desired line thickness to be maintained exactly. This is true for scribing and for original drawing. It is not always true for the lines in printed copies. Photo-transfer, copying processes and rapid press printing can change line thicknesses to a certain degree.

Before the production of a topographic map series, the line weights to be used must be carefully determined. They should suit the *scales*, the *general character of the map*, the *contour intervals*, the *nature of the terrain* and the *colors of the lines* themselves. Simple, large scale plans not only accommodate, but require, bolder lines than do more heavily detailed small scale maps. Dense contour patterns resulting either from small contour intervals, or especially steep slopes, make it necessary to have very fine lines. In some cases it is best to adjust the *thickness of the line to the slope of the land*, so that densely grouped contour lines are drawn finer than those which wander indeterminately through flat, open country. Varying of line strength in this way, to suit slope angle, makes line work more difficult and slows it down, but leads often to a much clearer map image.

Line weight and line color should be harmonized with one another. Black line patterns darken an area about three times as much as would a similar zone of brown contours. The dark blue of glacier contours lies between black and brown in the scale of lightness. The unequal tonal values of various line colors can be reduced by the selection of relatively darker blue, brown and gray tones, but this also leads to a reduction in the ability to differentiate between them. In order to balance out the differences in tone value, the black lines are often drawn somewhat finer than the dark blue lines while brown and gray lines require the greatest line thickness. These differences in line weights are recommended in the interest of maintaining the greatest possible homogeneity of impression from the lines and the least possible interference with the three-dimensional form of slopes.

Line weights must also be carefully balanced for *index contours* and for *intermediate contours*. If the index contours are too bold, the terrain appears as a series of steps. If they are too fine, they do not perform their assigned function. Intermediate contours, however, should always be as unobtrusive as possible.

The following table contains suitable weights for contour lines. From these one can select variations for various scales and colors, but they should not be regarded as standardized; they should simply act as a guide. For *wall maps* of corresponding scales, a line weight two to three times larger should be selected.

Table of Line Weights of Contours, Figures in Millimeters

	Index Contours continuous lines			Normal Contours continuous lines			Intermediate Contours broken lines		
Scale	black	dark blue	brown or gray	black	dark blue	brown or gray	black	dark blue	brown or gray
1:1000 and 1:2000	0.25	0.30	0.35	0.15	0.18	0.20	0.10	0.13	0.15
1:5000 and 1:10,000	0.20	0.25	0.30	0.10	0.15	0.18	0.07	0.09	0.10
1:25,000	0.12–0.18	0.14–0.20	0.18–0.24	0.07–0.10	0.08–0.12	0.10–0.15	0.05	0.06	0.08
1:50,000	0.10–0.15	0.12–0.18	0.15–0.20	0.05–0.08	0.06–0.10	0.07–0.12	0.03	0.04	0.05
1:100,000 and smaller	0.08–0.10	0.10–0.13	0.12–0.15	0.05–0.08	0.06–0.10	0.06–0.10	0.03	0.04	0.05

The expressiveness of broken or dashed lines is influenced by the relationships between
the *weight of the dashed line* (a)
the *length of the dash* (b)
the *interval between the dashes* (c)

Lines with long dashes and short spaces can barely be differentiated from continuous lines. Wide spaces, however, destroy the continuity of the line and usually indicate hurried work. The proportions a:b:c: = 1:(8–12):(4–6) appear most useful.

The relationship of a dot diameter ‘a’ to the interval ‘c’ must be considered in dotted lines. The relationship a:c of about 1:(1–1.5) is useful in this context.

G. Clarity of contours and the untenable theory of vertical lighting

As pointed out at the beginning, the contour is an abstract graphic aid since it does not normally appear on surfaces in nature. In spite of this, patterns of contours can, under favorable conditions, produce an acceptable picture of the shapes of the surfaces of slopes. However, it is quite unrealistic to try to express by a mathematical formula the degree of 'vividness of impression' produced by a particular method of terrain representation, as Walter Geisler tried to do in 1925.

This term 'vividness of impression' or clarity providing for the easiest possible visual grasp of shapes, is the result of the combined manipulation of graphic effects, visual experiences and subconscious memory concepts. The clarity of a contour system was attributed by many authors to its *darkening effects*. This is more closely examined below.

The steeper the slope and the denser the zone of lines, the greater is the darkening effect on the paper surface. The principle of representation '*the steeper, the darker*', was commonly and incorrectly labelled '*vertical illumination*', under which one imagined a darkening or shading gradation, derived from assuming light rays falling perpendicularly from above onto the terrain.

But the actual darkening of areas illuminated in this way is extremely complex in nature. It is dependent, for example, on surface texture (the smoothness or roughness of the surfaces, etc.) and on the direction from which it is viewed. Up to the present the following theoretical assumptions have been employed as a rough approximation in cartography:

If parallel light rays strike a white relief surface from directly above, only the following takes place: Horizontal surfaces receive full illumination, their degree of lightness being $H_0 = 1$. However, an equally large but tilted area whose angle of slope $= \alpha$ receives only the amount of light which corresponds to its cross-section. Its degree of lightness $H \propto$ thus amounts to $H_0 \cdot \cos \alpha$. A vertical surface receives no light; it appears completely black. If one designates the proportion of black per unit of surface area as the degree of darkening S , $S = H_0 - H \propto = 1 - \cos \alpha$ results. This relationship of degree of darkening S to the slope angle α is expressed by curve 1 in *Figure 102*.

In this calculation, the cartographic theorists presumed the effects of vertical illumination to be a visual reality. Such effects, however, do not exist in reality. Only in a vacuum could such a terrain model be experimentally illuminated by parallel light rays falling vertically from above. Our visual experiences, are formed in our daily environment, and hence in an air-filled space. Here, the effects of so-called 'vertical' illumination would be weakened by the diffusion of light to a point of almost complete uselessness. The relationship $S = 1/2 (1 - \cos \alpha)$ has been established for this condition in an almost completely arbitrary way. It is shown in *Figure 102* as curve 2.

The darkening caused by zones of contours, however, conforms in no way to the theoretical gradations of curves 1 and 2. They increase only very slowly up to a slope angle of about 60° , as curves 3 and 4 in *Figure 102* show, then at that point set in strongly on extremely steep slopes.

These observations apply to white paper and black lines. The degree of darkening '1' means that the paper is completely obscured by black. A shading value of 0.1 represents the relationship black to white, as 0.1 to 0.9, etc. In contour zones, the darkening depends upon

the relationship: scale to contour interval, on the line weight and on the angle of slope. The diagram in *Figure 102* shows that complete darkening (total cover of the paper surface with lines) is already achieved on slopes of about 75° to 85° from vertical illumination. In gentler terrain, the contours lie so far apart that the darkening effect produced is negligible in comparison with the rest of the map.

As we have seen, the darkening effect of zones of brown lines is only about one third as great as that of black lines, and hence appears quite insignificant in most parts of the map.

What is commonly known in cartography as vertical illumination is nothing more than a conventional abstract gradation of tones according to some simple principle such as 'the steeper, the darker'. The contour system is not a suitable means of producing such gradations. If it were, it would not be possible to represent each individual relief feature without the break-up and destruction of the three-dimensional effect through the varying tonal capacities of contour colors – brown, black, gray and blue.

A visual phenomenon, which we will call the *form-line effect*, appears to be much more important. Objects which are made up of parallel layers of constant thickness display this internal structure as a series of lines which appear on the surface, or on a section cut through the object – not unlike the patterns of rings to be seen on the cross section of tree trunks. The smaller the angle between the inner layer and the outer surface, the more spread out are the lines on the surface. Familiar, accepted concepts such as these are unconsciously transferred to the contour line image on the map.

The effectiveness of contour lines is primarily dependent upon the way in which zones of close, parallel and consecutive lines reveal the form of the land. Increase in density in the lines is seen as an increase in slope, while reduced density suggests flattening-out. Zones of contours are only effective in bringing out form if they can be understood with ease. Their effectiveness is thus dependent upon the shape and expanse of the terrain area under observation, on the scale, on the contour interval, on the thickness and color of the lines and, above all, on the type and density of the remaining items in the map. This effectiveness is only brought out with adequate slope, and usually only locally for small parts of the map, seldom for the whole sheet. What is more, it is seen differently by different people. People with special observational abilities and those who have learned to use maps can see form and shape in certain patterns of contour lines which would be no more than a confused jumble of lines to poor observers. Visual efficiency and utility, however, are not always concurrent properties. Very dense zones of lines are normally good for demonstrating form, but the individual lines are often difficult to distinguish and count.

The question arising from this is to what extent may the horizontal distance between two consecutive contours be increased without jeopardizing the shading effect. It is not easy to give an answer to this old question, since many other factors play their part. Zones of thick lines drawn on fairly empty maps at scales of 1:1000 – 1:10,000 can be seen as part of a system even if the lines are two or more centimeters apart in places. However, in densely packed small scale maps with extremely complex forms it takes only a few millimeters of horizontal separation of contours to destroy the coherent hatching effects. *The table in Section B.3* (intermediate contours) may give some hints on the evaluation of such questions. The horizontal distances given between normal and intermediate contours might correspond to about the largest values which should be considered. At larger separation distances, the contours appear as individual lines without suggesting hatching effects. Long, straight lines can withstand greater horizontal separations without losing their shading effects than can complex twisting lines.

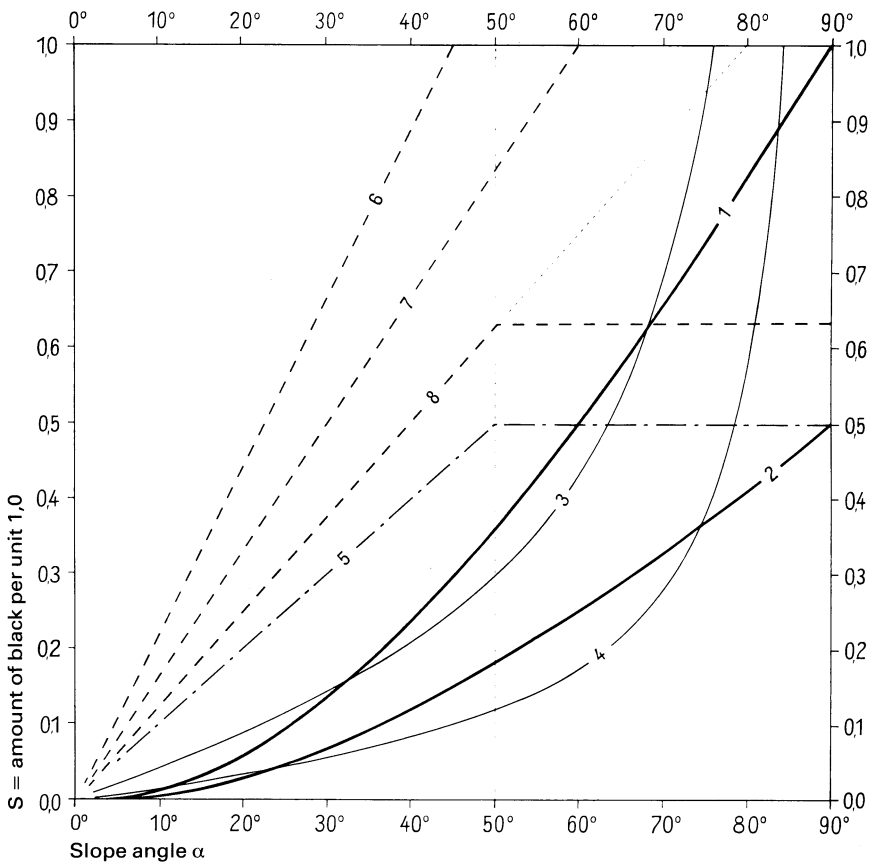


Figure 102. Diagram of surface darkening. 1 = with theoretical vertical illumination; $S = 1 - \cos \alpha$. 2 with diffused vertical illumination; $S = \frac{1}{2} (1 - \cos \alpha)$. 3 = area darkened by contours. Scale: 1 : 50,000, contour interval 20 meters, line width = 0.1 mm., line color is black, 4 = area darkening by contours. Scale 1 : 10,000, contour interval 10 meters, line width = 0.1 mm., line color is black. 5 = area darkening by grey slope shading; very variable and uncertain. 6 = area darkening by black hachuring after Lehmann in a map of Saxony, scale 1 : 50,000. 7 = area darkening by black hachuring after Müffling in a map, scale 1 : 50,000. 8 = area shading by black hachuring in the Österreichischen Spezialkarte scale 1 : 75,000, older form.

The capability of any cartographic relief representations including contours to bring out shape and height effectively is both relative and imprecise. Of course, one will recognize the terrain to be steeper in one place and flatter in another, but actual values for differences in elevation are found only from the contour numbers and intervals, while slope angles are derived from construction of a drawing or by calculation. This means that they can be obtained only when scale and contour interval are known. The uncertainty of the visual impression goes so far that many an unannotated map image can as easily be taken for a negative form as for a positive form. Such inversion of a relief seldom however occurs in practice since it is prevented not only by printed contour values, but also by associations with the form of streams, etc. If the same map is used often, such as the 1 : 50,000 with a 20 meter interval, experience will facilitate the spontaneous recognition of the approximate inclination of the area from the density of contours.

In conclusion, the following peculiarity of contours should be borne in mind. The terrain is not structured by zones of contours in a ‘natural’ sense. Erosion and deposition always work in the direction of greatest slope. Along with the edge line, the line of slope is a characteristic producer of the naturalistic image of the terrain. Generally, horizontal lines are not common to the natural landscape. They mar the characteristic expression of shape and they run like lattice work across the terrain ridges and seldom allow these to achieve enough prominence. Horizontal shading therefore models the form of the terrain in too soft, too rounded and too indefinite a manner. Unfortunately, this fault is still often exaggerated by the draftsman as a matter of style. It becomes even more prominent, the coarser the line ‘lattice’ is in relation to the relief features, or, in other words, the smaller the scale or the more complex the form in nature. The coarser the line mesh, the less likely it is that a form will reappear in the neighboring contours.

For all these reasons, the effectiveness of contour line zones decreases with a decrease in scale.

H. Variations of line weight, and three-dimensionally shaded contours

As contours produce such a poor visual impression of relief, attempts began many years ago to improve their expressiveness. This does not mean supplementing the contours by other techniques – to be considered later – but rather it means varying the contours themselves, in weight and color. Once again line weight will be given most emphasis in this section, although it has been discussed above, in Sections F. 5 and 6.



Figure 103. Contours increasing in thickness with increasing elevation. Großglockner, scale 1:100,000. From: Franz Keil, orthographic physical map of Großglockner and its environs, *Petermann's Geographische Mitteilungen*, Gotha, Justus Perthes, 1860, Plate 4.

1. Increasing the line weight as elevation increases

Figure 103 shows an example of this type, a portion of a map of the Grossglockner, 1:100,000, prepared by Franz Keil, which appeared in “*Petermann’s Geographische Mitteilungen*” edited by Justus Perthes, Gotha, 1860. The technique was not adopted since its disadvantages are all too evident.

Variations of line color with elevation is not a very suitable technique, as has already been determined.

2. Three-dimensional line strengthening without area tones

(*Figures 105, 106, 107*)

One begins with the concept of a layered or stepped model which is illuminated from the top left. Vertical walls are not visible when viewed from above. The ‘steps’ away from the light cast a shadow on those directly below. The width of this shadow depends on the height of the step, the angle of the light, and above all, on the horizontal angle between the vertical face of the step and the light rays. This angle and hence the width of the shadow cast, change from place to place (*Figure 107*). The width of the contour corresponds to the width of this changing shadow; it decreases as the contour bends toward the direction of the light source.

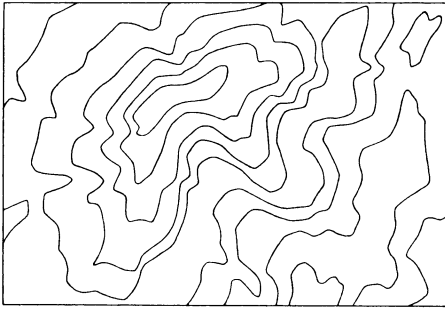


Figure 104. Contours without the emphasis of three-dimensional shading.

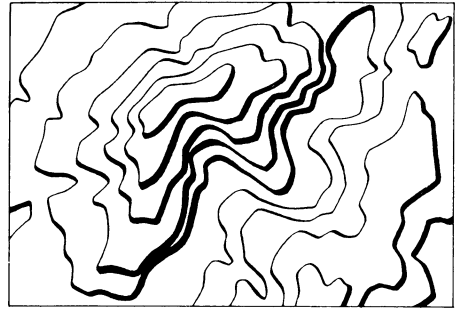


Figure 105. The same contours with thickening of lines on shaded slopes.

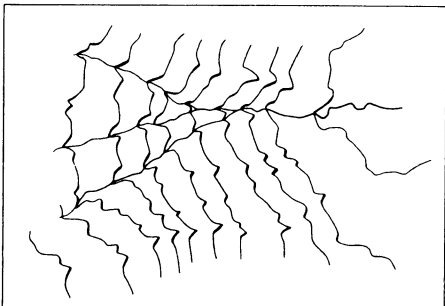


Figure 106. Slight local thickening of contours of very small terrain details.

Figures 104 and 105 show the same contour image without and with such variations. Under the right conditions of position and form, contours treated in this way can produce quite an effective impression of three dimensions. This method is often applied in graphic art generally but is especially useful in map design for bringing out the solid appearance of objects (letters, symbols, buildings, areas) in the simplest way.

These 'shaded contours' have various obvious *deficiencies* however: good three-dimensional effects are limited to favorably positioned and well defined regions of the terrain which are neither too steep nor too flat. The illuminated slopes especially are at a disadvantage. *Figure 107* shows that the entire semi-circle facing the light lacks any shadow effects. Without half-toning the flat surfaces, no visual balance can exist between light and shadow slopes. On flat, shaded slopes, where the lines become more widely spaced, the terrain appears to be too distinctly layered. Broad shadow lines on steep slopes are particularly poor since they often appear to coalesce at these points, as can be seen in *Figure 105*. Fine contours of constant line weight combined with hill shading tones produce a much better effect. However, the technique can be very useful in some cases, in the production of single color line drawings for book illustration.

The three-dimensionally shaded contour is already well established. It was used as early as 1865 in alpine excursion maps at 1:50,000 by the Schweizer Alpen Club (Swiss Alpine Club). Despite this, every few years it is rediscovered here and there and praised as a cartographic novelty.

3. Local increases of line weight

The objections just mentioned do not apply to the following process – which is a variation of the last. The application of slight increases of line thickness is limited to the shadow side of very small, very sharp landforms (young moraine ridges, small, sharp ravines, screes, dunes, etc.). There is no intention in this case to bring out the three-dimensional form of the whole contour image, as was attempted with the previous method. The clarity and vividness of topographic maps are increased by accentuating, very slightly, all the sudden changes in contour direction. These techniques of thickening contours to give a three-dimensional effect, however, are recommended for frequent systematic but economical use. Examples appear in *Figure 106*.

4. Differentiation of the color of contours according to whether slopes are illuminated or shaded

In Section F. 5. c) above, we have already discussed this technique, effective in many cases, but still too complicated from the reproduction point of view.

5. Three-dimensionally shaded contours with flat area tones

The obliquely illuminated model of contour layers is fundamental to this method, as before, but in this case the light/dark effects are much more authentic. Oblique light produces a medium tone on horizontal flat surfaces, and to create this impression the map is given a

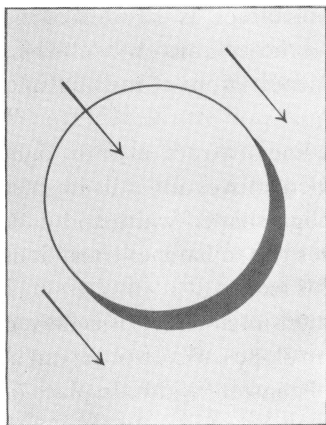


Figure 107. Shaded contour without area toning. Arrows = direction of light.

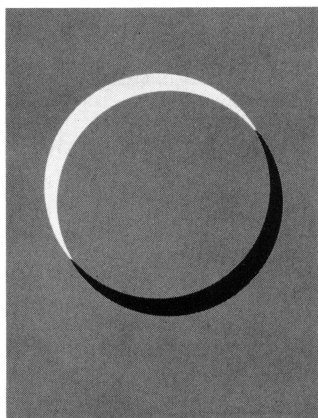


Figure 108. Parallel displacement of contours. Light and shadow areas filled in.

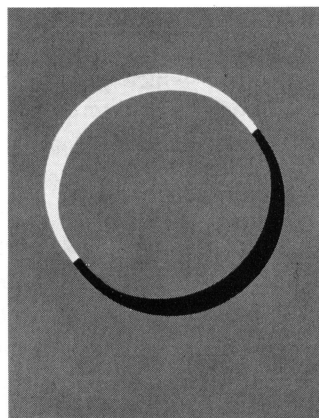


Figure 109. As in Figure 108. The transition point of the light and shadow strengthened.

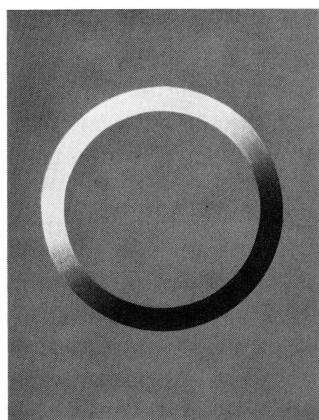


Figure 110. An obliquely illuminated model. The risers of the step-like layers are uniform slopes.

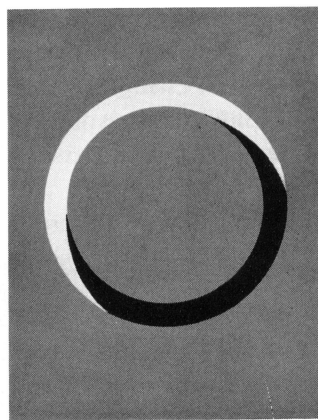


Figure 111. As in Figure 110, but with the light/dark transition simplified.

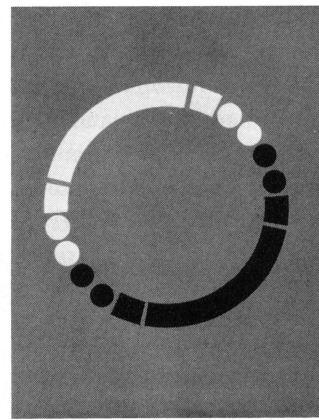


Figure 112. As in Figure 110, but with the light/dark transitions dotted black and white (Pauliny).

Figures 107–112. Three-dimensionally shaded contours. Construction principles.

corresponding gray tone. The contours being drawn in white on illuminated slopes, while those in shadow are dark. However, several different principles are employed in different maps to produce the graphic image. These are explained in *Figures 108–112*.

First method (Figure 108): Each contour is drawn twice, but one line is displaced by an amount equal to the maximum shadow width or illuminated width. The maximum width of the cast shadow lies in the direction of the light source. The spaces between the lines are then made white or black and are made to come to a point where it changes from light to dark. If this operation is carried out on each contour the overall effect of black and white lines gives quite a strong impression of three dimensions. In this technique the widths of the bands are varied by rendering, as thin lines, the points of transition from light to dark, where the light is tangential to the band. The technique is a practical, simple, but approximate,

approach and not an exact reproduction of the natural illumination effect, as the walls of the steps lying on the light side shaded sides would not be seen on the assumed model when viewed from above. The light and dark bands can be seen as concentrations of the light and shade to be found on sloping parts of the land.

Second method (Figure 109): If contours are shifted along the line of direction of the light source, then the light/dark transition point is abrupt, as described above, and thus impairs clarity and continuity. To help overcome this difficulty, the wedge-shaped white and dark lines are reinforced to a certain extent, but this improvement gives rise to harsher transitions from light to shadow. *Figures 113 and 114* were constructed in this manner.

Third method (Figure 110): A small improvement in three-dimensional effects is achieved by assuming the risers of the step-like layers to be steep, uniform slopes. When observed in plan view these sloping steps are seen as contour lines or bands of constant width. In place of the sharp transitions of the 'displaced line' technique, the limiting lines of any contour layer are always two concentric circles – as in *Figure 110*.

On the light sides, these bands receive light tones (white), with dark tones on the shaded sides. In between, however, gradual transitions take place giving tonal values in some places which can scarcely be distinguished from the gray tone of the flat areas. The three-dimensional impression produced in this way is considerably closer to the model but this advantage is achieved at the expense of the more difficult graphic representation and distortions of the format transition from light to dark.

Fourth method (Figure 111): This form of representation is derived from the third form described above, and is used to simplify the drawing and, at the same time, to clarify the image. The transitional tones are replaced by wedge shapes tapering down from the completely light and completely dark bands.

Fifth method (Figure 112): This depiction also corresponds to the third form described above. The gradual transition from light to dark is accomplished by breaking the line into small components like a string of pearls. Since these dots are so small it is a very complicated process to draw.

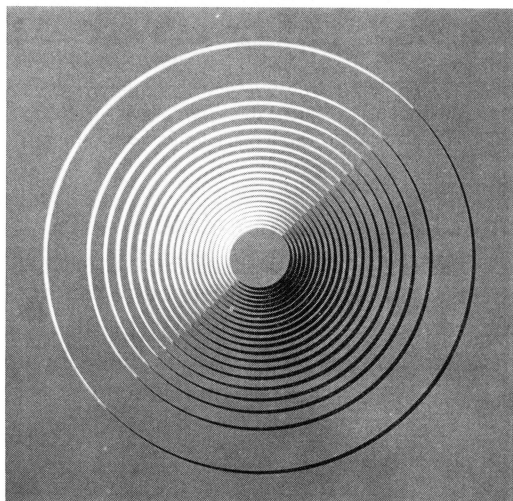


Figure 113. A circular cone with increase in gradient as height increases, represented by the method of *Figure 109* by Kitiro Tanaka.

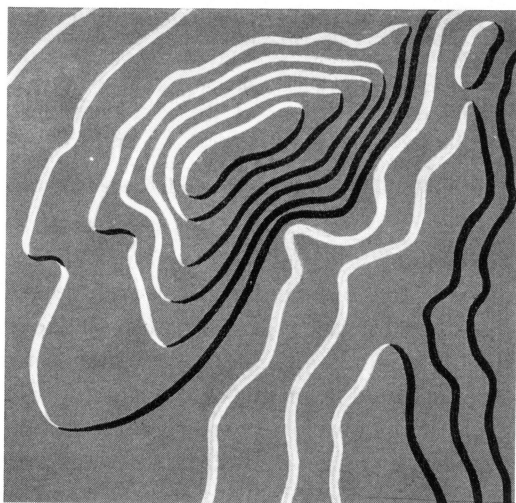


Figure 114. Similar representation of terrain forms.

Even these three-dimensionally shaded contours with tones on flat areas, and applied in all the variations discussed, are by no means recent inventions. A depiction of this type was produced as early as 1870 by the *Topographische Anstalt Wurster, Randegger und Cie* in Winterthur, *Karte von Konstanz und Umgebung* (Map of Constance and its environs), at 1:25,000. In the 1885 volume of the technical publication, 'Der Civilingenieur,' an article appeared entitled 'Über Reliefs und Relief-Photogramme' (On Relief and Relief Photograms) by C. Köpcke of Dresden. The relief-photogram of Königstein, scale 1:50,000, prepared by the "topographische Bureau" of the *Königliche Generalstab von Sachsen* (Topographic Bureau of the Royal Saxon General Staff) and included in the article, corresponds to the process shown (the third method), but was produced by photography of a layered model. Best known are the attempts by J.J. Pauliny in 1898. He produced, in the "*k.u.k. Militärgeographischen Institut, Wien*" (Royal and Imperial Military Institute in Vienna) a map of 'Schneeberg, Raxalpe, and Semmering' at 1:375,000, using the fifth method described above (*Figure 112*). Since then still more maps of this type have been produced. In 1951, the process was adopted by Kitiro Tanaka in Tokyo. He constructed a map of a Japanese volcanic landscape, which represents a classic example of its type. A portion of this map is reproduced in *Figure 116*. Tanaka expanded the extremely simple principles of construction along mathematical and geometrical lines to an extent which was probably unnecessary (301 and 302). Since then the process has been called the *Tanaka method*. Another interesting attempt of this type was undertaken by the Institut für Angewandte Geodäsie (Institute for Applied Geodesy) in Frankfurt am Main in 1954, whereby wooded areas received a green tone, while the remaining areas received a violet (!) basic tone. The process has also been used for maps of the sea floor and, finally, the



Figure 115. Contours inature. Rice paddy terraces 150 km south of Kunmig, South China (photo: Ed. Imhof).

corresponding general topographic map in the planning atlas of Schleswig-Holstein should not go without mention.

However, these methods have not provided the answer to the impossible, the band-like elevation and depth contours being generally too inaccurate metrically. The unnatural impression of steps comes out more clearly than it would with only a slight emphasis on the shadow-side contours, the transitions from the light to the dark contours appear hard or abrupt, or they even lose legibility. These light contours will stand out clearly only if the area tone is made very dark, but dark area tones and fine light contours are not compatible with the rest of the map content. These shortcomings also influence the quality of the three-dimensional effect achieved through the assumption of parallel oblique light, but the latter leads us directly into the next chapter.

Finally, reference must be made to the graphic problems. The preparation of this type of map is simple but very time-space consuming, and it should be done at a very large scale in order to achieve satisfactory precision. We have been looking at very interesting experiments, special examples, but not techniques which are to be recommended for general application.

I. The employment of contours for elevations and depressions

The contour line is the only graphic element which both geometrically delineates the terrain and also expresses its overall physical appearance. It is also the most common method of representing the results of topographic survey. Good or bad, it is the form of terrain representation employed or referred to by geodesist and topographer, planner, civil engineer, agriculturist and those involved in many aspects of research in geography and the natural sciences. It is, therefore, a method employed whenever it is possible.

Along with their advantages, however, contours do suffer from certain weaknesses which limit their application. The web-like, often extremely complex structure of fine lines in the contour net does not have sufficient ability to express the overall appearance of the landscape image. Good, clear impressions may often be achieved for small local areas, but this may not extend to the map as a whole.

The low adaptability of the contour line in regions of contrasting relief is a disadvantage. Any selected interval in any one map may lead to too open a line structure for some areas, and too close a structure in others. This disadvantage increases sharply at smaller scales, but may already be found in terrain with small detailed features and a highly dissected surface, and finally with very steep landforms at large scales. Steep rocky regions and certain small features are never rendered correctly in shape or in overall appearance by contours alone. These problems will be considered again in Chapters 11 and 12.

In the following section, *the applicability and suitability of contours for various scales are considered.*

Scales of 1 : 10,000 and larger: Here, the forms to be depicted are usually large in area and uniform. Apart from level areas and mountainous regions, uniform zones of similarly shaped lines are produced. The ability of contours to provide quantitative information about the landscape is taken for granted and in most areas contour maps at large scales provide a more than adequate impression of overall patterns of landforms, and contour lines can be read with ease. The main reason for this highly desirable situation is the very low density of

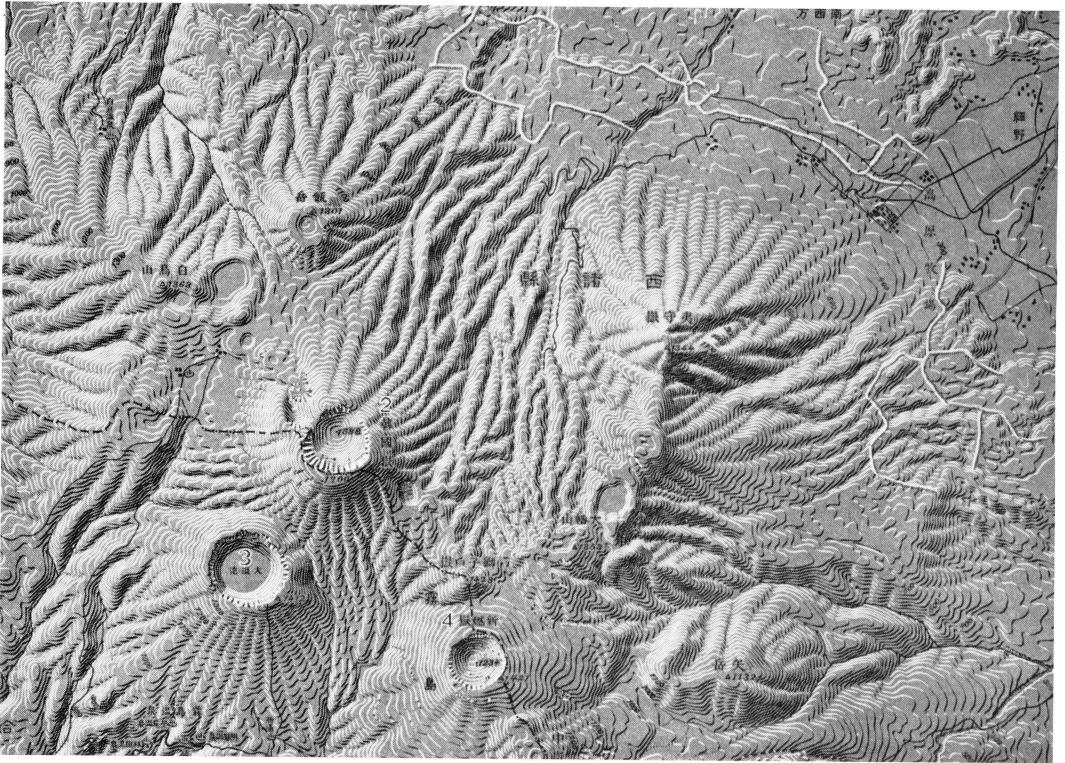


Figure 116. Three-dimensionally shaded contours. Example of the so-called “relief contour method” of Kitiro Tanaka. The image is that of a volcanic landscape in Japan. Scale 1:100,000, contour interval 20 meters.

symbol content, apart from the relief, existing over the map – symbols which would normally interfere with the topography and confuse the map reader. On the other hand, contour intervals are large in comparison to the scales. Therefore in flat areas, the contours lie far apart from each other and appear only as single lines, giving geometrical information, but are not part of an overall image. The impression of form is weak. But, as large scale plans are normally used for technical purposes, the provision of geometric information is more important than the presentation of form.

Medium scales of 1:20,000 to 1:100,000: Here the relief forms may still cover large areas and are simple; contour intervals are small relative to the detail of the terrain. As a result, the systems of contour lines on mountain slopes bring out the forms with great effect. However, as features still extend over large areas and the map has a denser cover of additional symbols, etc., this impairs the ease with which one can comprehend the forms of these broader regions. Individual forms, when considered separately, can still be appreciated easily and their shapes are simple to grasp. However, the scarcity of contours makes it more difficult to represent flat areas, ravines and ridge-covered landscapes. Conditions are more favorable for table-lands, where flat and steep terrain are in strong contrast, and also for high mountains, where shading of rocky zones and the blue contours on glaciers produce a crisp effect. The addition of shading tones can have a dramatic effect in contour maps of medium scales, and this effect improves as the scale is reduced. The primary purposes of medium scale maps are to give location and orientation within the terrain. This places great demands on the clear depiction of the shapes of the landscape on the map.

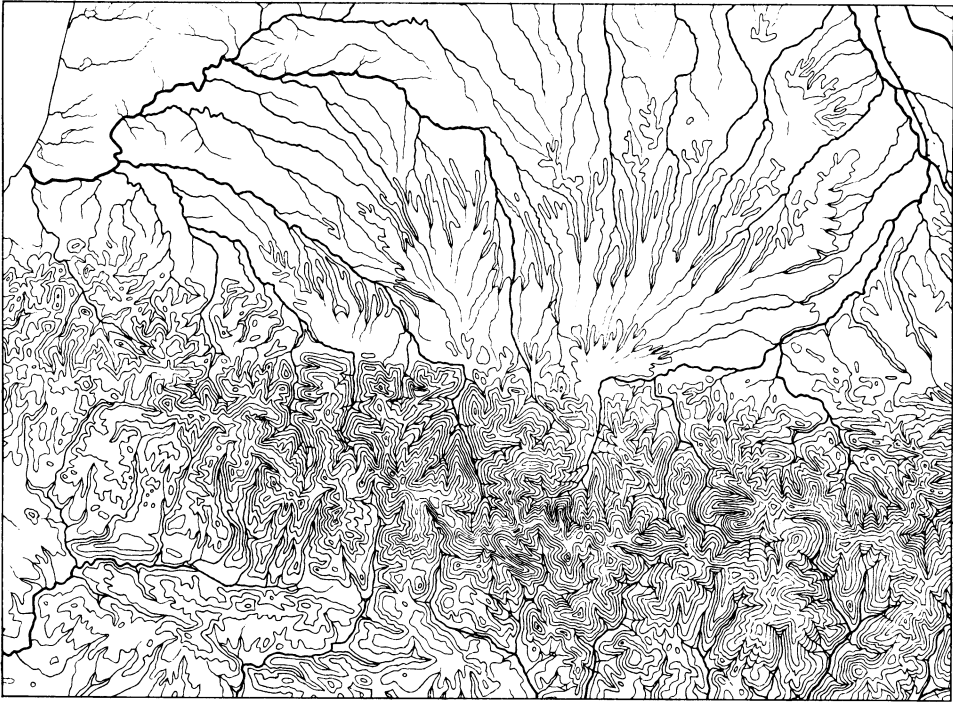


Figure 117. The inadequacy of contours with equal vertical intervals in small scale maps. Western Pyrenees and Gascony, 1:2,000,000, contour interval 200 meters.

There are exceptions here as well. If the maps are to serve as a basis for the recording of special information (geology, vegetation, land use, etc.) then contours without shading tones are preferred.

Scales of 1:100,000 to 1:1,000,000: In this group the above statements apply to an even greater extent. At 1:500,000, layer tints and relief shading are the dominating elements and the contours are employed merely as a structural foundation for the shading, although it is still best to keep them in the map. Exceptions may be made from this normal pattern, to suit special purpose maps. For example, a road map at scale 1:200,000 or 1:500,000 requires no contours.

Scales smaller than 1:1,000,000: Relief here is extremely intricate and flat if viewed as a whole. Even the smallest possible contour interval measured against the small details of shape is too large and the contour pattern too coarse. Zones of sub-parallel lines are found only in isolated areas on high mountain slopes. In general and in flat lands in particular, each contour follows its own individual, tortuous course which may often be difficult to trace. Contour patterns become complicated, illegible confusions of lines. They do not seem to form coherent images in any region, extensive or localized. They can give little information on the actual heights of the land as their patterns are too open in flat areas and too generalized in mountains. Techniques which are more suitable and visually effective should be used in place of contours in small scale maps such as these.

Figure 117 brings out, very clearly, the unsuitability of contours for small scale maps. It shows the middle Pyrenees and Gascony by means of contours with a 200 meter interval at a scale of 1:2,000,000. Despite extreme simplification, the mountain ranges appear as form-

less confusions of lines. In the flat land adjacent to the mountains, however, the relationship between terrain forms is quite inadequate. The appearance or non-appearance of a particular feature in any location in the map may be quite accidental, as it depends on its height and whether or not this height is intersected by a contour line.

References: 3, 20, 32, 33, 65, 66, 68, 69, 71, 82, 93, 94, 95, 112, 114, 115, 129, 130, 133, 134, 138, 171, 186, 190, 221, 223, 224, 242, 244, 245, 267, 287, 288, 294, 301, 302, 303, 312, 314, 332.