Geomorphological Analysis Tool based on the Generic Mapping Tools

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Abstract

This paper describes a new geomorphological analysis tool developed using the Generic Mapping Tools (GMT), a freeware mapping tool developed at Hawaii University. GMT is commonly used in the earth sciences, but less so by engineering geologists unfamiliar with computer programming. The new geomorphological analysis tool is based on GMT commands and is executed at the Windows command prompt. The tool is based on numerous complex parameters that can be entered into the calculations using a Microsoft Excel worksheet and without the need for any knowledge of computer programming. Various types of maps and diagrams can be generated with the tool, including maps representing contoured data, color gradations, topographic maps, cross-sections, slope maps, relief energy maps, drainage system maps, summit level maps, valley level maps, and stereographic projections of surface orientations.

Keywords: GMT, geomorphological analysis, DEM

1. Introduction

In recent years, digital elevation model (DEM) data, together with aerial laser surveys, have been widely used in geomorphological analysis. A variety of geographic information systems (GIS) software is available to analyze such data. In this paper, we describe an approach to topographical analysis based on The Generic Mapping Tools (GMT), open source mapping software developed by Wessel and Smith (1991). The software has no GUI (graphical user interface), and is operated using a series of command-line tools, or via a shell script.

The advantages of GMT are that it: (1) has strong grid manipulation functions; (2) is free; (3) can output to PostScript; and (4) runs in both the Windows and UNIX environments. The software is regularly upgraded and is stable, even on machines running Japanese versions of Windows (from GMT5 onwards).

GMT is used mainly in the research field. As GMT is a command-based software, it can be difficult to use for those unfamiliar with computer programming. Therefore, we have generated a series of command lines as an Excel spreadsheet (Fig. 1).

We describe here a new geomorphological analysis tool developed using GMT, with DEMs of 10 mesh and river data published by the Geospatial Information Authority of Japan (GSI). First, we describe the creation of some basic maps, and then of specific maps that require complicated grid computing.

2. Examples of Basic Maps

2.1 Shaded topographic map

A shaded topographic map (Fig. 2) is created by applying a color corresponding to the altitude of each

				↓ Check the increment by grdinfo command.							
File name	ytj10m	ytj10m.grd		gridincrement dx	5.38E-05	degree =	5.99	m	gridincrement dy	4.51E-05	degree =	5.02	m
longitude	133.3058611	133.3581389		W : H =	4.3	5.8	km					
latitude	33.46949444	33.51600278		max elevation	1000	m	grdmath ytj10m.grd median.grd SUB = tani.grd				
	133.332/33.49274861/	-R133.3058611/133.3581389/33.46949444/33.51600278									
Drainage map	ytj10m				↓ Copy and paste into the command window and execute.						
		Filter size (m)	50	median filter	grdfilter ytj10m.grd -Gmedian.grd -D2 -Fm0.05 -V					
		km	0.05	abstract valleys	grdmath ytj10m.grd median.grd SUB -0.025 GT = tani.grd					
				color pallet	makecpt -Cdrainage.cpt -T0/0.1/0.1 -Z > temp.cpt					
				project grid image	grdimage tani.grd -R133.3058611/133.3581389/33.46949444/33.51600278 -Jt133.332/33.49274861/306c -Ctemp.cpt -K -V > tani_50.eps				
				contour lines	grdcontour ytj10m.grd -Jt -L0/1000 -C50 -O -W0.05,red -K -V >> tani_50.eps				
				rivers from library	psxy r_Shikoku.xy -R -Jt -Wblue -O -K -V >> tani_50.eps				
				scale bar	psbasemap -R -Jt -Lfx10/1c/33.46949444/1k+l -B1mWeSn -O -K -V >> tani_50.eps				
				title	echo Map of Drainage Net (filter size = 50m) | pstext -R -Jt -F+cTL -Gwhite -O -V >> tani_50.eps				
				jpg file	ps2raster tani_50.eps -GC:\programs\gs\gs9.10\bin\gswin64c.exe -Tj -A -P -V				

Fig. 1 Example of a set of GMT commands in an Excel worksheet.

grid point, and assigning an intensity corresponding to the slope direction relative to the light source using the "grdimage" command. The color is taken from the GMT internal color palette, and the light source in GMT can be set up in two directions of which the greater directional derivative is used for shading. The light sources in Fig.. 2 were set in the west (270°) and north (0°), meaning the north–south and the east–west aspects of the terrain are emphasized. The map shows that mountain ranges, valleys, and narrow plains are oriented ENE–WSW or E–W (Fig. 2), although some valleys are oriented NNW–SSE and N–S.
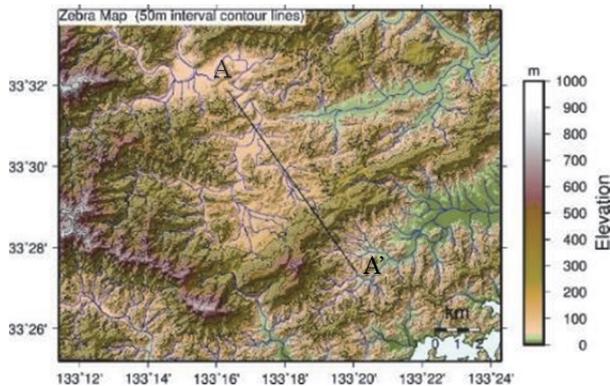

Fig. 2 Shaded topographic map. The line A–A' indicates the section line shown in Fig. 3.

2.2 Cross-section

A cross-section along line A–A' in Fig. 2 is drawn in Excel using the x–y dataset, which is obtained by projecting the elevation of the grid points that are within 10 m of the specified section line (Fig. 3). The command used was "project".

The cross-section shows that the southern slopes of the mountains at the southern edge of the basin are steeper than the northern slopes. The plain dips gently to the northwest.

Fig. 3 Cross-section along line A–A' in Fig. 2. Elevation data are from within 10 m of the section line, which is drawn 5 km to the northwest and southeast from the center of the map.

2.3 Slope map

A slope map is created by assigning colors to the slope angle at each grid point using the "grdimage" command; the slope angle is obtained using the "grdgradient" command (Fig. 4).

In addition to the 23 built-in color palette tables, users can create their own tables using the "makecpt"

command. Additional color palettes can be obtained from http://soliton.vm.bytemark.co.uk/pub/cpt-city /views/totp-cpt.html. Fig. 4 was generated using the color palette referred to by Young (1969).

In the southern part of Fig. 4, the slope gradient is steeper on the southern slopes (>30°) than on the northern slopes, where the gradient is commonly <18°. The distribution of flat ground (slope < 5°) forms like a grid pattern.
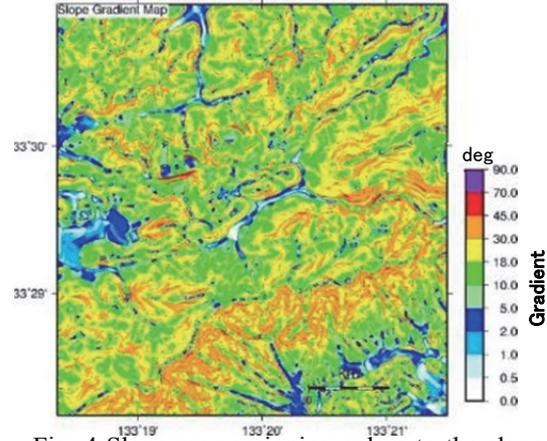

Fig. 4 Slope map assigning colors to the slope angle at each grid point.

2.4 Relief energy map

The relief energy map is compiled by calculating the maximum and minimum elevation within a circle of diameter 1 km centered on each grid point using the "grdfilter" command; the difference between the two elevations is mapped using a color scale. It is also possible to use a rectangular, rather than circular, window in the command. The boundary between areas with relief energy of <200 m, and mountainous areas with relief energy of >200 m, is well defined, showing that topographical classification by relief energy is possible in Fig. 5.
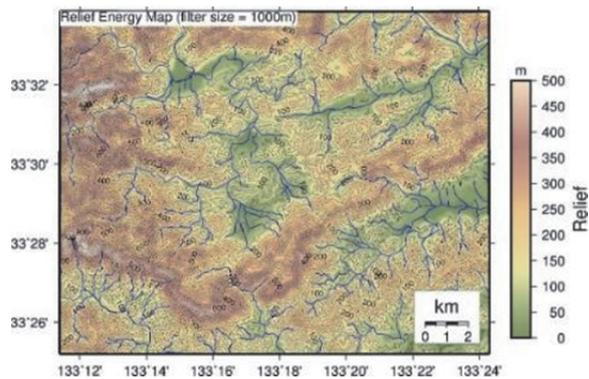

Fig. 5 Relief energy map based on the difference in maximum and minimum elevations within a 1 km circle at each grid point.

2.5 Aspect map

The aspect map is applied a color according to the direction of the slope inclination measured clockwise from north using the "grdgradient" command. This

map highlights the orientations of ridges and valleys, and curved and parallel ridges are clearly seen in Fig. 6.
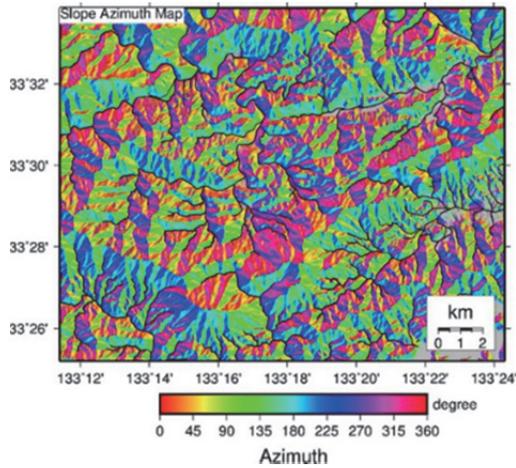

Fig. 6 Aspect map.
The direction of the slope inclination is measured clockwise from north

3. Examples of Applied Maps

3.1 Drainage system map

The extraction of drainage systems is possible by identifying pixels that are lower than a target pixel based on elevation differences. The conditions used for the extraction can be varied by obtaining the neighboring "average" elevation as well as by changing the diameter of the window. GMT allows the use of a simple average, or the mode and median, creating a weighted normal distribution using the "grdfilter" command. In general, the grid data uses the elevation values of a square, such as 3 × 3 or 5 × 5, and it is possible to specify the diameter (m) of the search window (filter) in GMT.

Fig. 7 is created by extracting the points for which the difference between the center and the median elevation of the window was negative. The drainage slope map is shown in Fig. 8, which clearly shows spatial differences in the density, the pattern of drainage system, and the relationship between channel order and gradient.
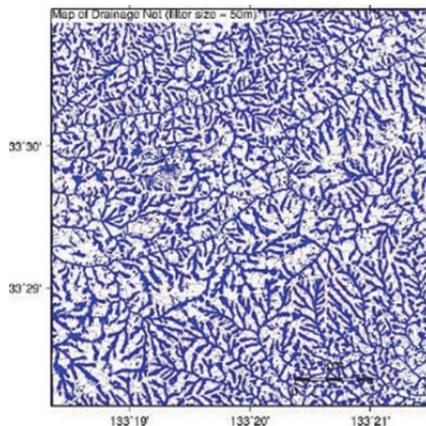

Fig. 7 Drainage system map.
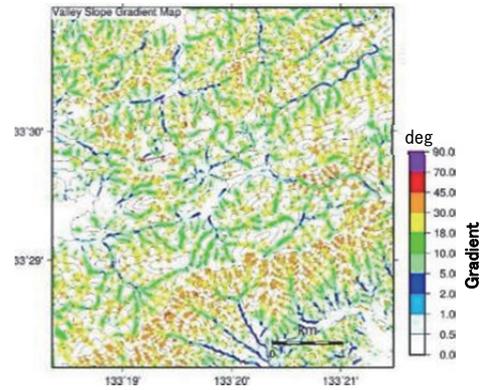Spatial differences in the density can be seen.

Fig. 8 Drainage slope map. The relationship between channel order and gradient can be seen.

3.2 Summit level map

We describe the summit level maps generated using the valley filling method and the grid method.

(1) Valley filling method

A summit level map (Fig. 9) can be generated by filling the valleys, which leaves the ridges highlighted. In this method, the ridges are extracted using a median filter as follows.

(a) Subtract the elevation of each point from the median.
(b) Set the points where the elevation difference is greater than the value set in advance (2 m here) to 1, and the others to 0, to leave only prominent ridges.
(c) Taking the product of this and the DEM elevation, elevation becomes zero except for ridges.
(d) Make a data grid using the "ridge.grd" command by setting those points with an elevation of zero as no data (NaN).

This procedure generates the following GMT commands:

grdmath median.grd dem.grd SUB 2 GT dem.grd MUL 0 NAN = ridge.grd   (1)

Here, median.grd and dem.grd are the grid data files for the median and DEM, respectively. The calculations taking the difference (SUB) or product (MUL) are in the "grdmath" command. Thus, implementing these GMT commands uses a reverse Polish notation.

(e) Finally, interpolate between the areas with no data, such as around valleys. There are two interpolation methods available in GMT, which use either the average values of the peripheral or the smoothing function. We used the latter method, and the "surface" command.

Three parameters must be specified in the above

procedure: the median filter diameter, the altitude difference from (b), and the parameters from the interpolation function in (e).

The river system is also shown in Fig. 9. In places, the course of the river cuts the slope of the rising gradient (uphill), and river capture or stream movement may occur at these points.
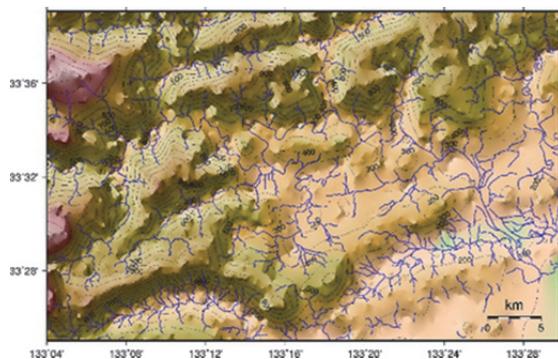

Fig. 9 Shaded summit level map generated using the valley filling method. The map is created by filling valleys between high ridges more than 2 m higher than the median elevation. The diameter of the filter is 100 m.

(2) The grid method

Summit level maps (Fig. 10) based on the grid method are created by interpolating between the highest points in the rectangle, separated at regular intervals. The procedure is as follows.

    (a) Cut out the predetermined rectangle using the "grdcut" command and obtain the coordinates and elevation of the highest point in the rectangle with the "grdinfo" command.

    (b) Move the partition to the next rectangle and repeat the procedure in (a) in a whole area.

    (c) Interpolate between the points obtained from the above procedures.

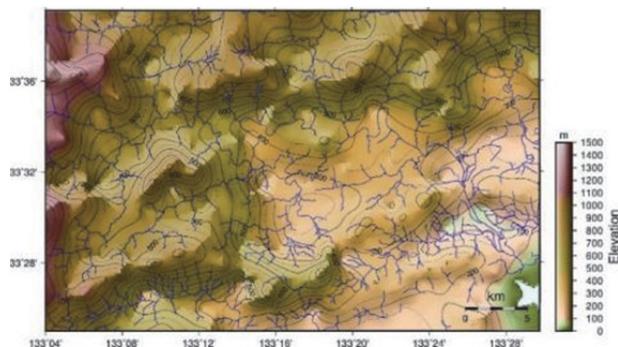As the process in (b) is repeated within a predetermined area, it can be performed using an Excel macro.

Fig. 10 Shaded summit level map created using the grid method on a 2 km grid.

3.3 Valley level map

The valley level map (Fig. 11) is generated by removing the ridges. Fig.. 11 shows a map that is created using the grid method to interpolate between the lowest elevation points in each grid. Almost all of the ridges have disappeared in the southeastern section, which is in contrast to the other areas. The valley level map is useful to infer groundwater system.
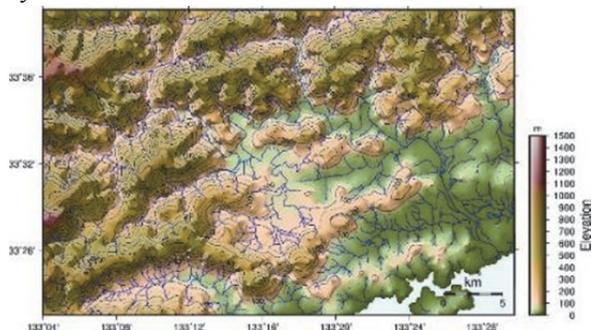

Fig. 11 Valley level map created using the grid method on a 500 m grid.

3.4 Extraction of nick line and ridge shape

There is little difference between the median elevation and nick point elevation when the filter is applied to a single slope (Fig. 12). The elevation frequency distribution in the window, in the case of the slope, does not become a unimodal distribution, such as the normal distribution, and this also differs from the unbalanced single-peak distribution. This point is the cause of the difference between the mean and the median.

If the slope is convex upward (Fig. 12, left), the elevation of the window center is higher than the average, but the center point is lower than the average in the case of a convex downward slope (Fig. 12, right). However, the difference between the median value and the window center point elevation of the slope is not evident in the figure.
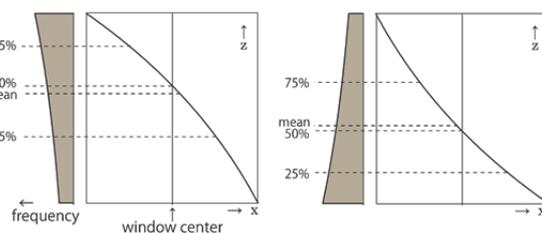

Fig. 12 Frequency distribution of elevation within a window on the slope. The elevation and horizontal distance in the window are indicated by z and x, respectively. The average is shown as the mean, and the median as the cumulative frequency of 50% of the multiple elevation data in the window.

If elevation increases (or decreases) monotonically with horizontal distance in a

two-dimensional cross-section, regardless of the shape of the cross-section, the elevation of the center point equals the median. This may be explained as follows. As shown in Fig. 13 (left), window width in the two-dimensional cross-section is the distance between the equidistant points from the center. The cumulative value of the altitude of all points in the window equals to the cumulative value of each altitude from the lowest to the highest elevation (Fig.13, right). When considered as a continuous distribution with a sufficient number of points, the cumulative number of points is equal to the horizontal distance.
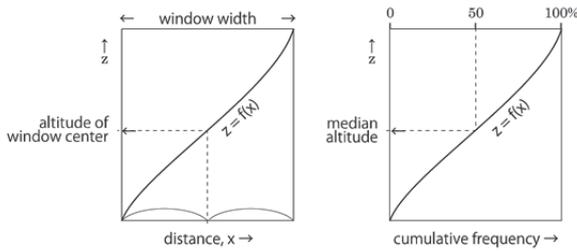

Fig. 13 Topographic section (left) and cumulative curve of elevation (right). The slope indicates that the median elevation is equal to the window center elevation (see text for details).

Therefore, the median value of the altitude distribution is the altitude where the cumulative number of the points is 50% of the frequency distribution, equals to the distance is 50% from the window edge. This point is the center point of the window. In other words, the elevation of the center point of the window is at the median altitude. This holds regardless of the shape of the slope. The slope may be any shape if the altitude increases (or decreases) monotonically; moreover, the relationship of the median and the window center is independent of the gradient of the slope.

The median of the elevation distribution on any slope is equal to the elevation of the window center point. Furthermore, because the difference between the median elevation of surrounding points and the elevation of each point is always zero, in principle a nick point cannot be extracted by difference. However, in practice, because the slope including the y-direction forms a curved surface in the three-dimensional terrain, a slight difference does occur.

On the other hand, when a window is large, both ridge and valley may be included in the window. The median value is lower than the elevation of the window center on the ridge but higher in the valley.
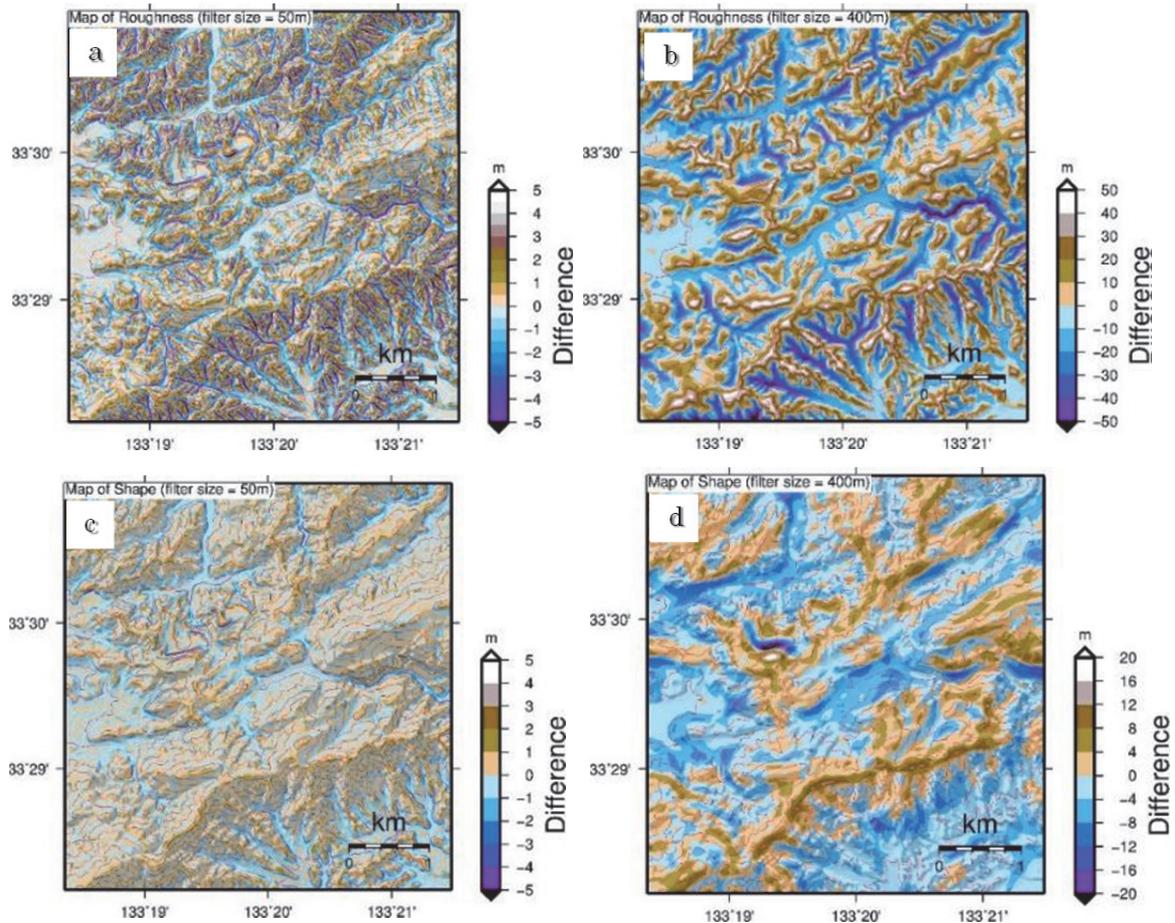

Fig. 14 Maps showing differences between the elevation of the window center and the mean elevation (a, b), and between the median and mean elevations (c, d). The diameters of the windows are 50 (a, c) and 400 m (b, d).

In this case (i.e., a large window), the relationships are almost the same with the differences calculated using the simple average and the window center point. By using the characteristics of both, it is possible to extract only nick lines.

As the elevation difference between the average and the window center point (Fig. 14a, b) is simply used to indicate whether higher or lower than the ambient points, ridges and valleys are highlighted as well as undulations on the slopes. In contrast, elevation differences between the window center point and the median tend to extract only ridges and valleys without showing the unevenness of the slopes. Therefore, taking the difference between the average elevation and the median (Fig. 14c, d), a number of ridges and valleys are excluded and this results in enhancement of the undulations on the slope.

By exploiting these differences, features such as nick lines and failure terrains are easier to extract. Furthermore, as shown in Fig. 15, the relationship between the average and median differs depending on the shapes of the ridges and valleys. This relationship can also be helpful in the evaluation of shape, and can be used by changing the window size to match to the scale of the topography of interest.
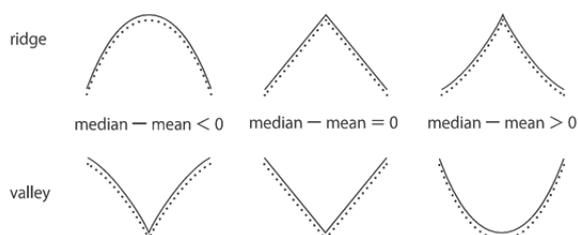

Fig. 15 Comparison of differences between the median and mean along various types of ridges and valleys.

3.5 Stereo projections

A number of projections are available in GMT, and it is possible to create a stereo projection by plotting the dip and strike of the ground surface in a Lambert equal-area projection (Fig. 16a). Comparing stereo projections of discontinuities, such as bedding lanes and joints in the terrain, helps to highlight the relationship between geological structure and topography. As the dip and strike data can be stored in a text file, it is also possible to export the data to other programs for constructing stereo projections (e.g., Grohman et. al., 2010, Fig. 16b).
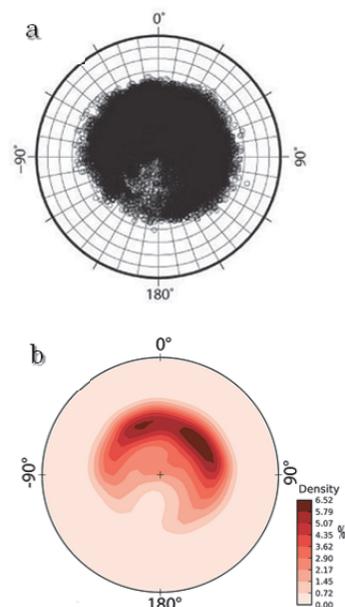

Fig. 16 Equal area projection of poles to the ground surface (a) and contour diagram of the pole data (b) plotted in the lower hemisphere. The contour diagram was made using Open Stereo (Grohman et al., 2010). The sample size is 22,650 data points.

4. Conclusions

GMT offers flexible and powerful grid computing functions and could become a useful geomorpholo-gical analysis tool. In addition to the basic drawings typically used in geomorphological analysis, it is also possible to create various other figures for specific purposes such as elucidation of river capture and evaluation of ridges' shapes. To allow users unfamiliar with computer programing to create command sets, we developed a new tool that is executable at the Windows command prompt. This tool is based on numerous complex parameters that are entered into the calculations using a Microsoft Excel worksheet, and requires no previous experience in computer programming. As GMT has no graphical user interface, a new application incorporating a GUI would be desirable in the future.

References

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