Titre de l'invention / Title of invention

:3@773; :?

Automated Mobile Geotechnical Mapping

Field

physical environment. More specifically, this invention relates to apparatus and methods for measured characteristic, is the orientation of its joint sets, as this indicates the most likely planes of failure. A commonly used geological characterization of a discontinuity plane is its strike

and dip. These two quantities are the azimuth angle of the strike line of the plane (strike), and the angle relative to the plane whose normal is the gravity vector (dip) (see Fig. 1). Although an experienced field geologist or geotechnical engineer can sometimes qualitatively assess the

The apparatus may include an output device that produces an output including one or more of an axis map, a visual representation, and a data set. In one embodiment the output device may produce an output comprising a stereonet.

The MSP may comprise a handheld device, a robotic vehicle, an unmanned aerial vehicle, or a non-robotic vehicle. The sensors may comprise a range sensor (i.e., a device that

Another aspect relates to a method for generating an axis map of a physical environment [illegible] and a dashed line on the polar and equal area projections, respectively, and a plane with

Fig. 13A is a photograph of a rock face used to evaluate the embodiment of Fig. 12;

Fig. 13B is a stereonet corresponding to the rock face of Fig. 13A, produced by the embodiment of Fig. 12;

Fig. 14A is a photograph of another rock face used to evaluate the embodiment of Fig. 12; and

Fig. 14B is a stereonet corresponding to the rock face of Fig. 14A, produced by the

Stereonets

[illegible] plane is characterized by the azimuth angle of the strike

line of the plane (strike), and the angle relative to the plane whose normal is the gravity vector

(dip), as shown in Fig. 1. Although the strike is sometimes described by cardinal directions (e.g., $N30^{\circ}E$), this disclosure uses the azimuth angle, which is three-digit scalar measured clockwise from true North with the degree symbol omitted (e.g., $N30^{\circ}E = 030$). The dip is taken as the smallest angle from the horizontal, therefore it is always between 0° and 90°, and is also clusters of points in polar stereonets. From these clusters, the mean strike and dip of each set can be calculated (shown as a cross in each cluster). Note the uncertainty of each plane is not usually calculated; therefore, each plane is weighted equally in mean calculations.

Remote sensing has a number of advantages over hand measurements. A much larger number of planes can be measured with much less effort, including many that may be inaccessible by hand. Bias is reduced as the planes being measured are not manually selected (unless, of course, this is done during plane segmentation). As the operator does not need to interact directly with the rock face, it is generally much safer. However, there remains some disadvantages when using remote sensing, including:

- high cost of high-resolution 3D LiDAR;
- the size and weight of the sensor far exceeds that of traditional hand tools;

The MSP platform does not rely on any particular method of data collection, type of sensor, or type of vehicle for mobility. In general, an MSP has the capability to gather 3D point clouds of a rock face, and to measure its own motion (i.e., its change in orientation as it moves).

It is expected that MSP embodiments as described herein, which may employ axis [illegible]

[illegible]

those derived from hand measurements and stationary remote sensing, and therefore useful for the same types of quantitative analysis. It is noted that a direct comparison of hand-derived stereonets and MSP stereonets is not a measure of accuracy, as the hand-derived stereonets are [illegible]

[illegible]

Generating the Axis Map from the Optimized State

There are two major differences between axis mapping as described herein and

Axis mapping parameterizes rotations as both unit quaternions (global parameterization) and rotation vectors (local, vector-like parameterization). Fig. 4 is an illustration of a rotation vector $\boldsymbol{\theta}$. Geometrically, rotation vector space is a ball of radius π. The length of the rotation [illegible]

Fig. 6A is an illustration of the axis vector parameterizations. Axis vectors are one of the two parameterizations of axes used in axis mapping (the other being unit axes (Fig. 6B)). The

Associating Axes Observed at Different Orientations

The axes extracted from measurements by the 3D range sensor are all expressed in the coordinate frame of the sensor. To associate observations from different observations, the axes are first transformed to a common shared frame. Using the initial estimate of the sequence of orientations of the MSP, all the axis observations are transformed to the global coordinate frame. At this point, similar observations are clustered together and marked as observations of the same [illegible]

[illegible]

environment, and the directions of gravity and the Earth's magnetic field, such that each [illegible] observation is predicted based on the estimates of the orientations, and optimize an estimate of the orientations; and output a stereonet from the optimized orientation estimates.

Embodiments are further described by way of the following non-limiting Examples.

[illegible]

This example describes a generalized MSP including an algorithm that may be used to obtain an axis map (i.e., a list of dominant planar axes) in an environment, and generate a representative output, such as an axis map (e.g., a stereonet). Typically the environment is a rock face, although the embodiment may be applied to other environments. As noted above, the [illegible] is generated 30 by transforming the observed axes to the global coordinate frame using the

[illegible]

optimized orientation estimates.

Example 2

This example describes a more detailed embodiment based on the generalized

[illegible]

Axes of planar surfaces are extracted 40 from the point cloud measured by the range sensor. This involves first removing outliers in the point cloud, estimating the axis at each point in the point cloud, and then removing points whose axes are determined not to be part of a planar

surface. Similar axes are then clustered together 54 using, e.g., the DBSCAN algorithm (M.

Ester et al., "A density-based algorithm for discovering clusters in large spatial databases with

(a) rotations between consecutive orientations (from integrating the gyroscopes), (b) planar axes [illegible]

[illegible]

direction of gravity at each orientation (from normalizing the accelerometers), and (d) the direction of the Earth's magnetic field at each orientation (from normalizing the magnetometers) 58. Each observation is now associated with an orientation in the graph [illegible]

PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Aluminum tube
2	1	KinectOne

Claims

1. [illegible]

comprising:

4. The apparatus of claim 3, wherein the output device produces the stereonet by transforming the observed axes to a global coordinate frame using the optimized orientation

estimates.

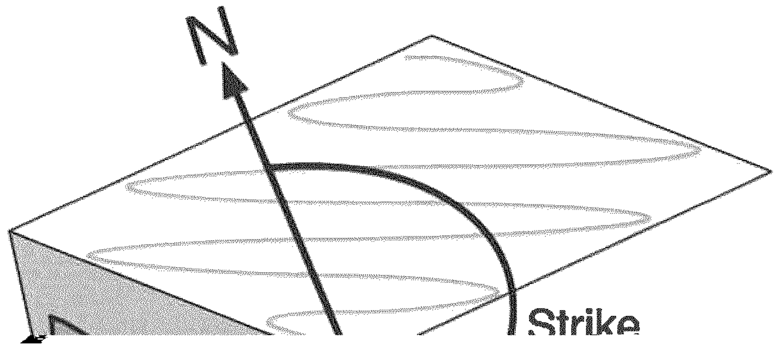
[illegible]

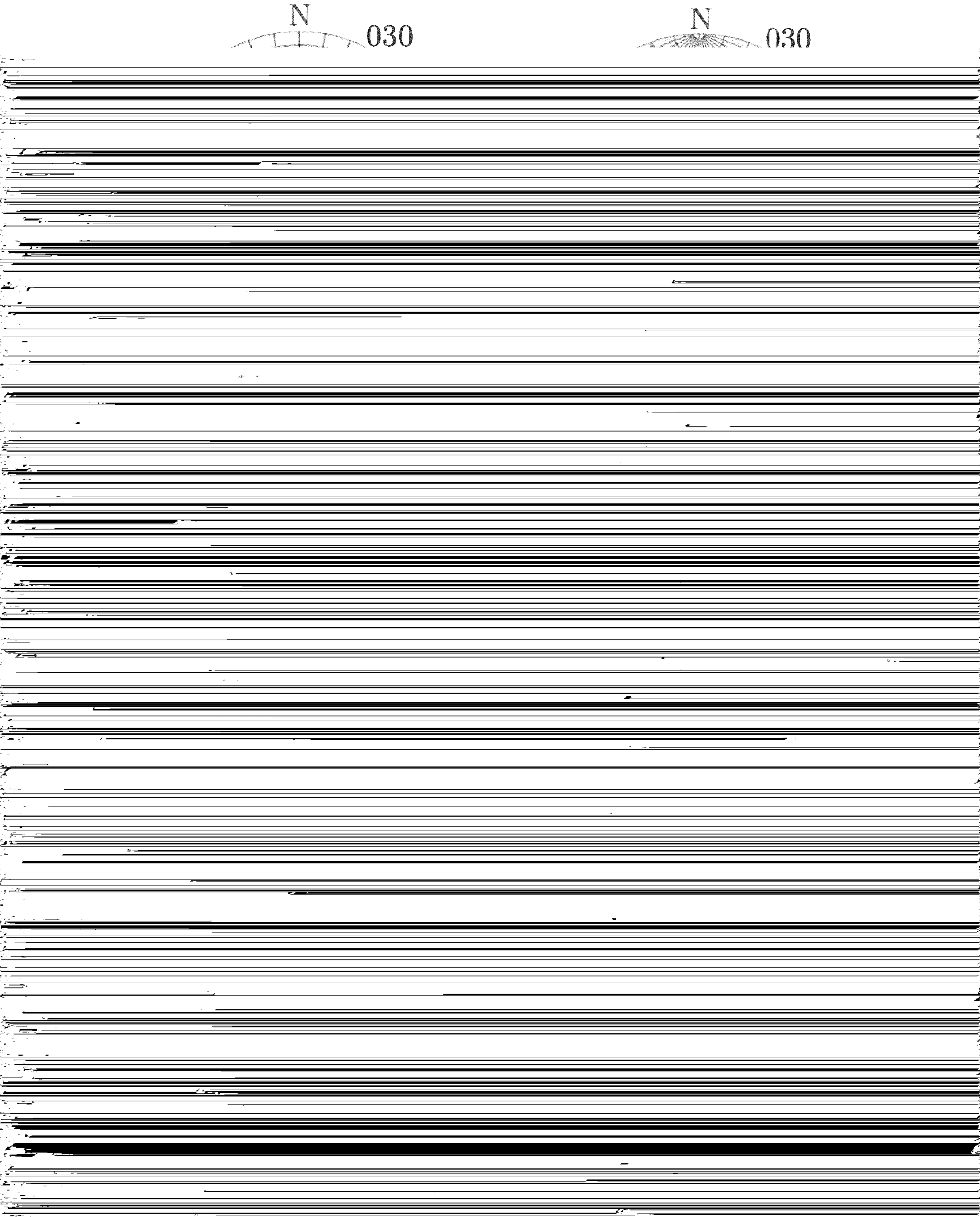
(iii) minimizing uncertainty in the observations of axes that define orientations of the planar

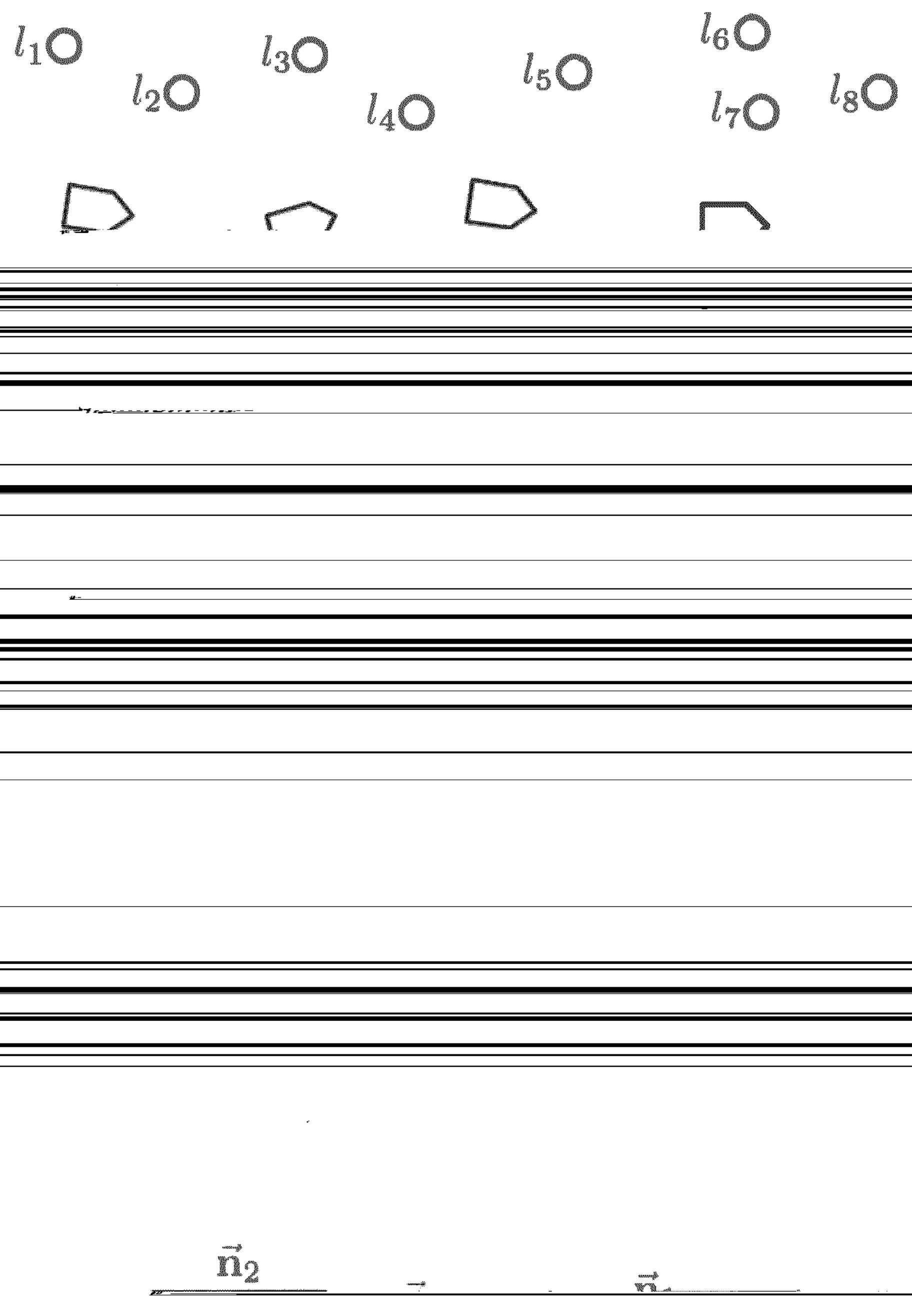
surfaces and in the estimates of the MSP orientations by linking the estimates of the MSP orientations, the clustered observations of axes that define orientations of the planar surfaces, and

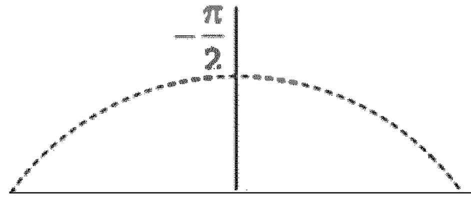
20. The method of claim 19, wherein the range sensor comprises a scanning laser rangefinder, LiDAR, time of flight (ToF) camera, stereo camera system, or other range sensing device.

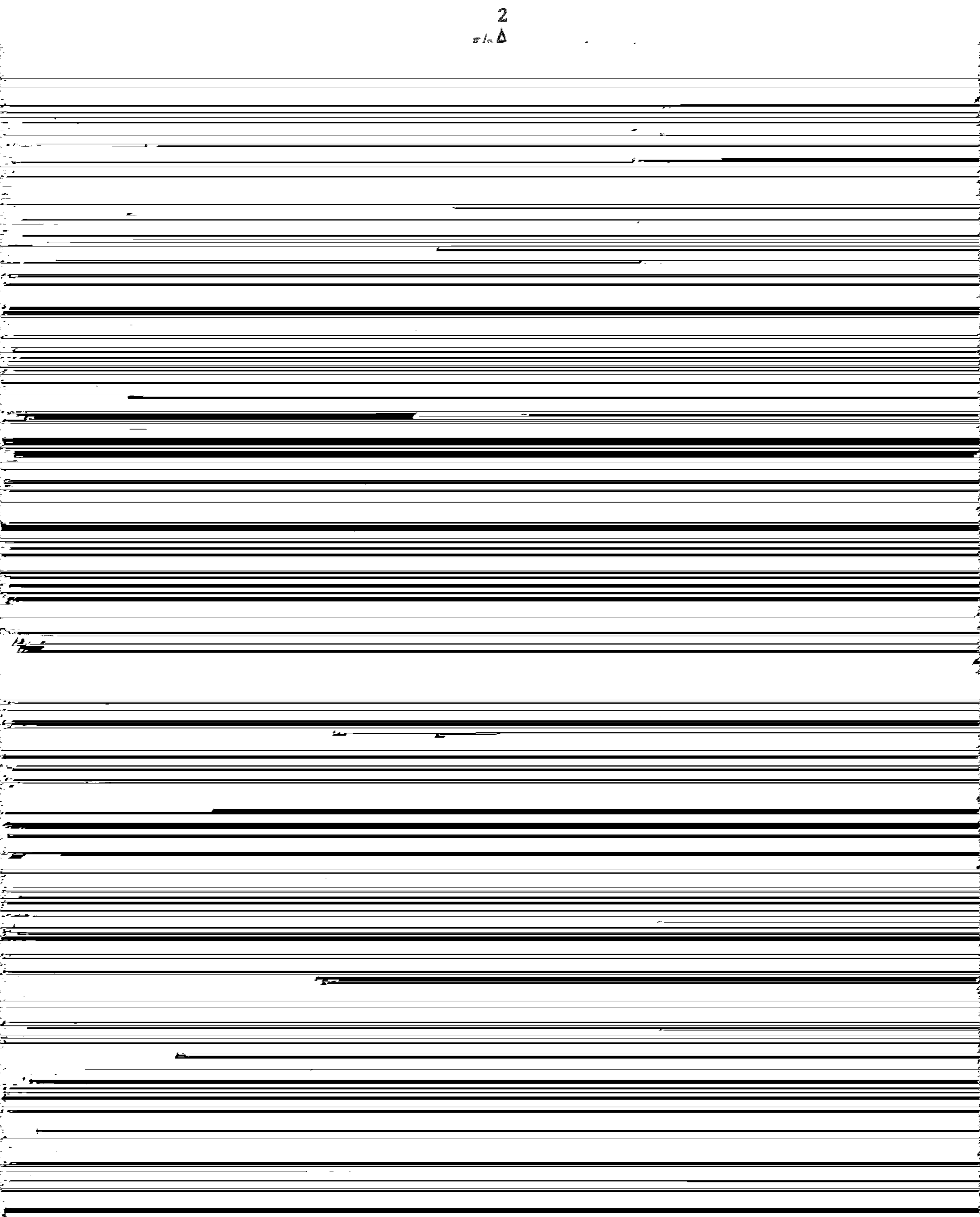
21. The method of claim 12, wherein the physical environment comprises a rock face.

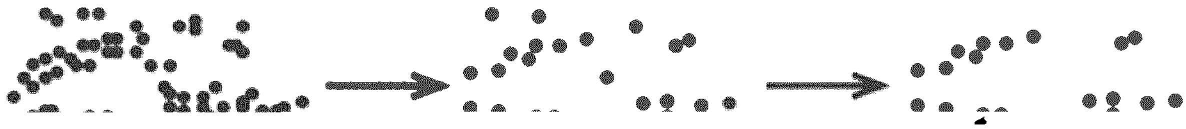

N
Strike

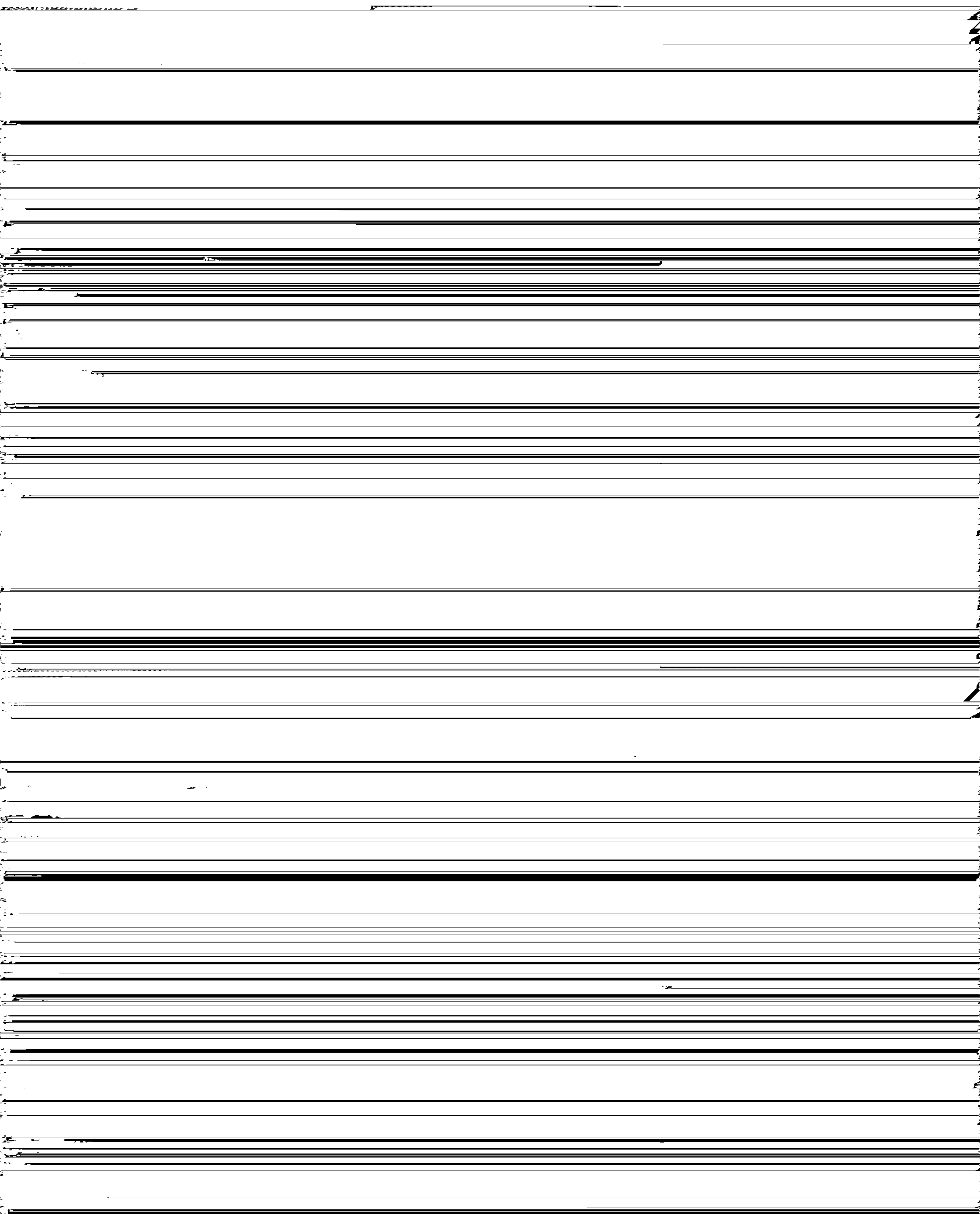

N
030
N
030

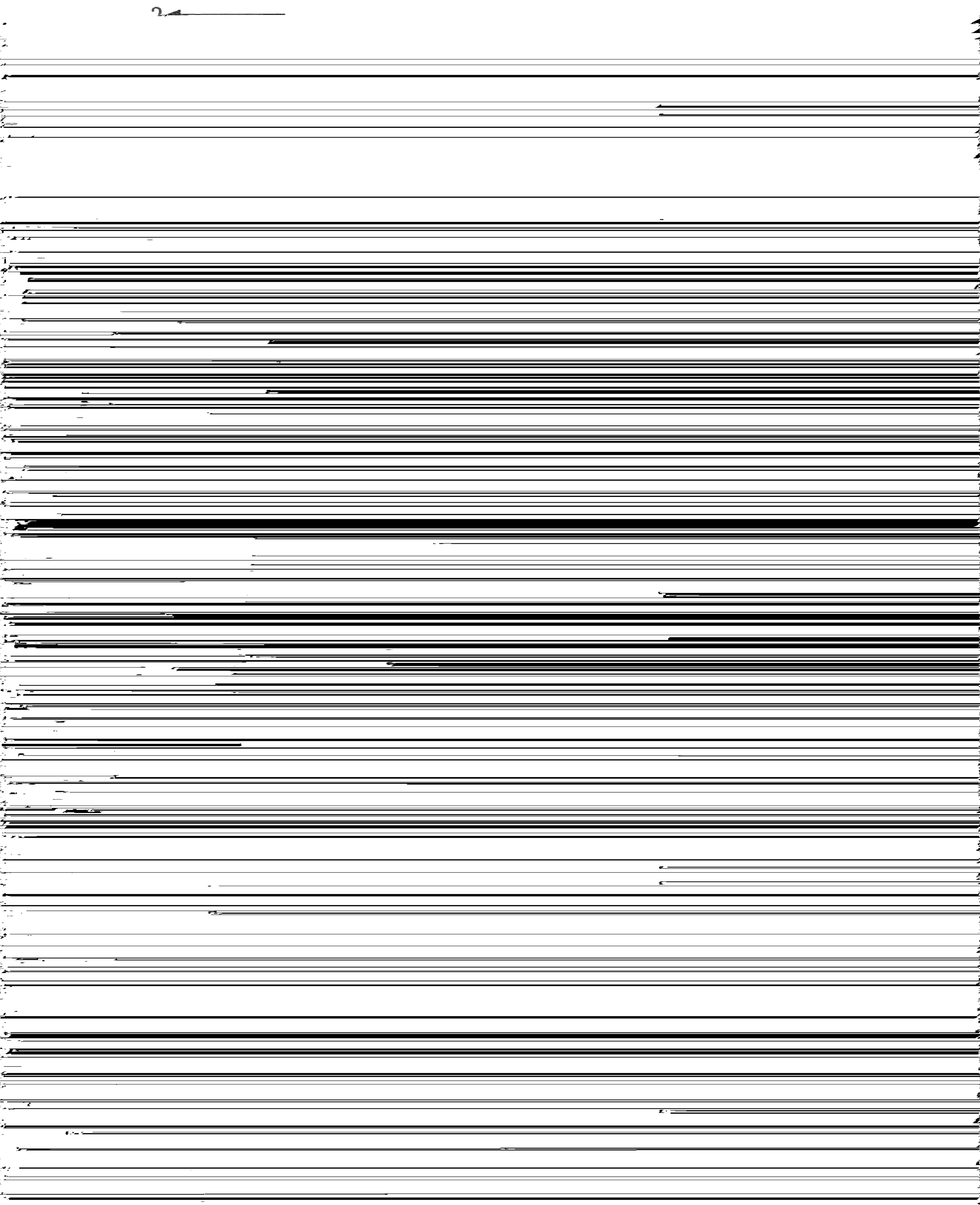

l_1
l_2
l_3
l_4
l_5
l_6
l_7
l_8
$\vec{n}_2$

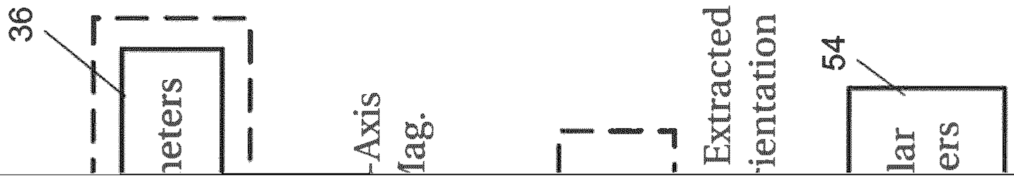

$-\frac{\pi}{2}$

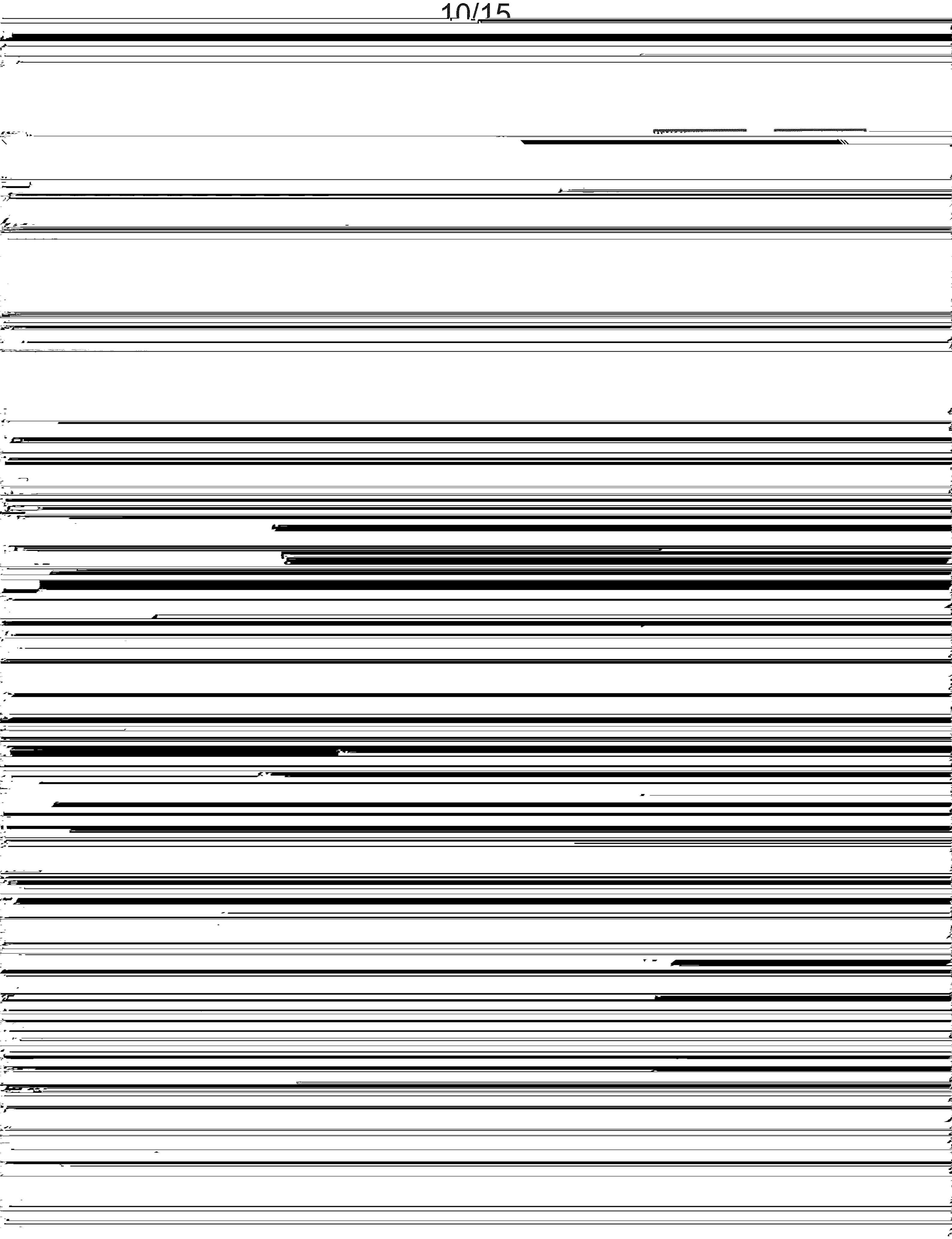

2

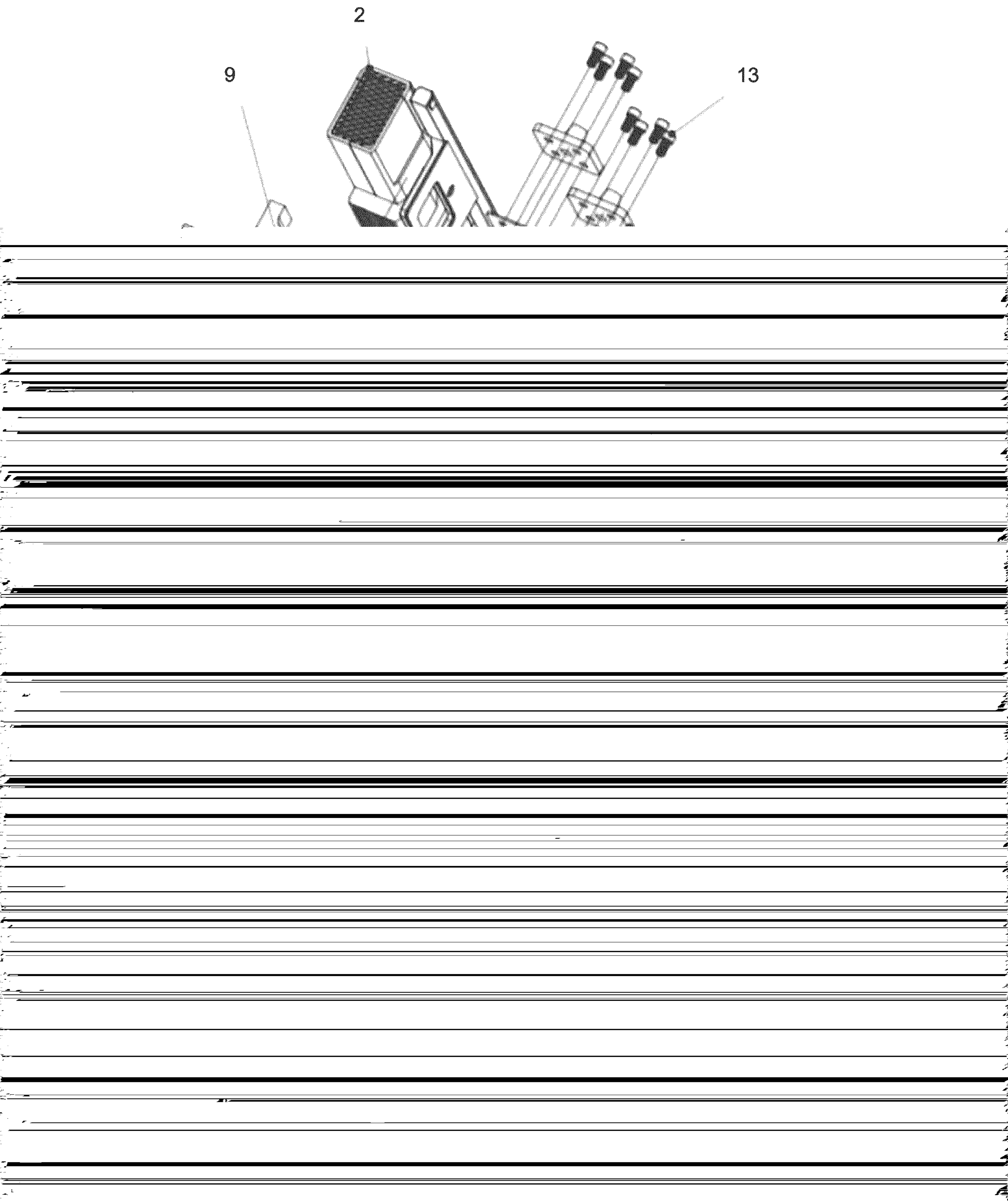


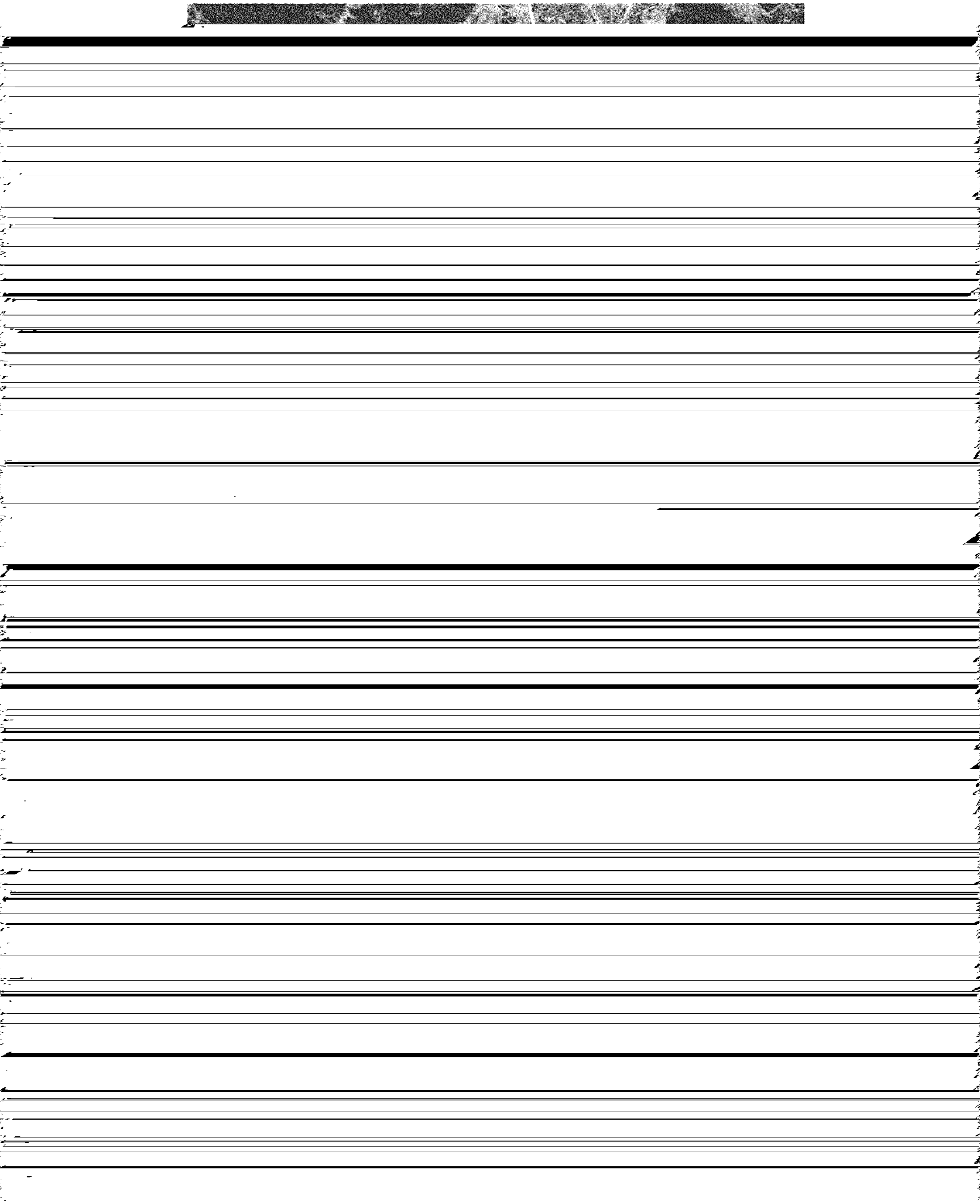


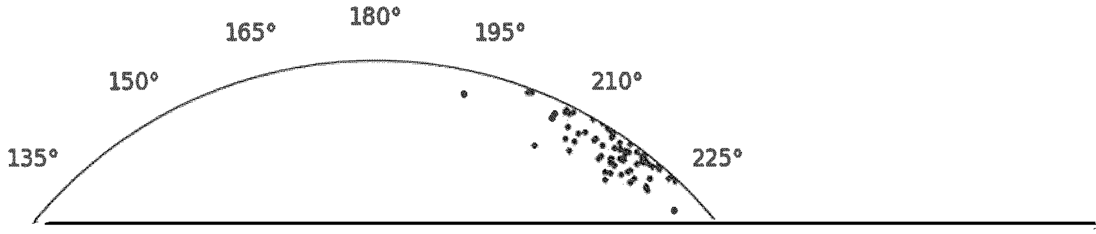


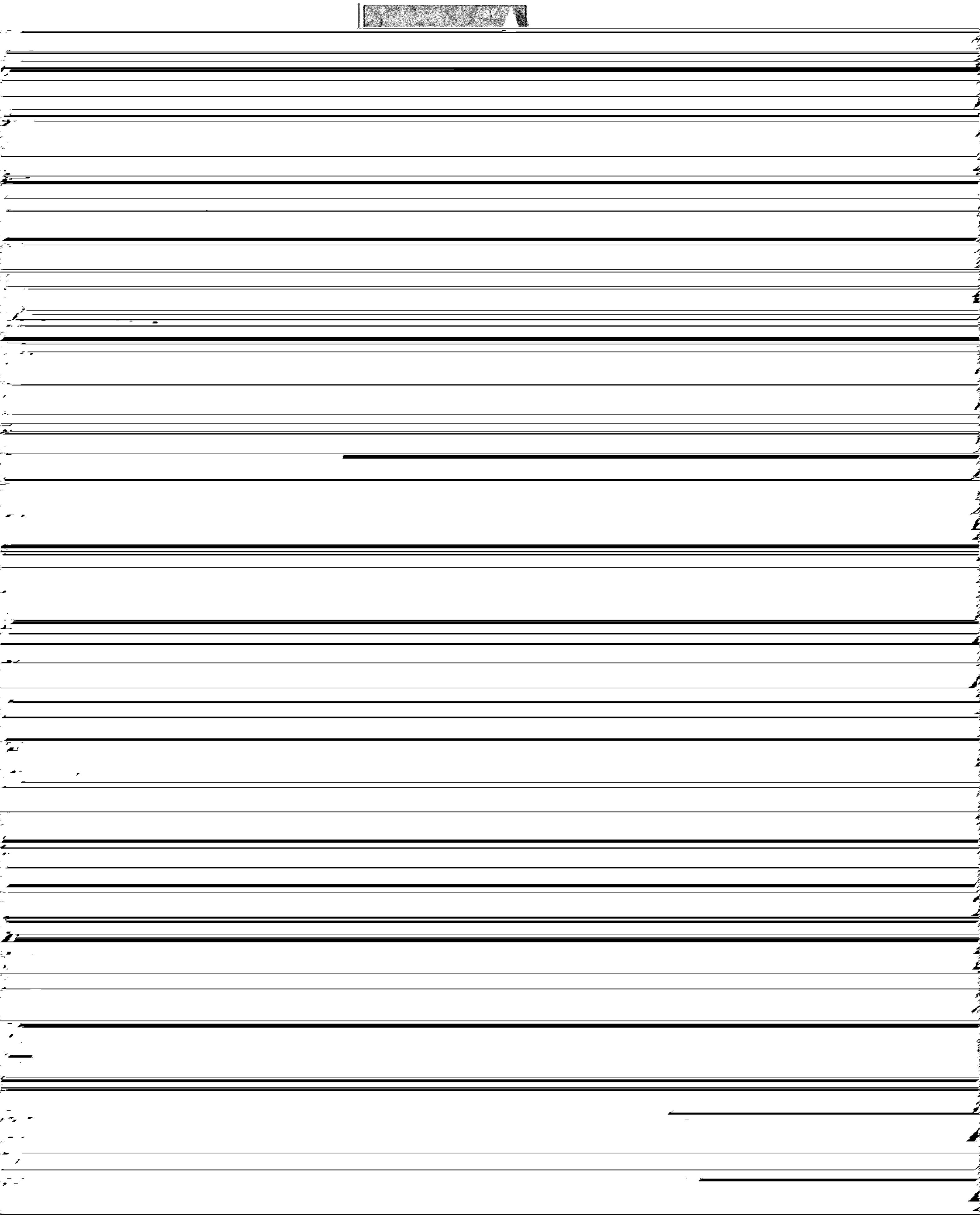

36
Extracted
54

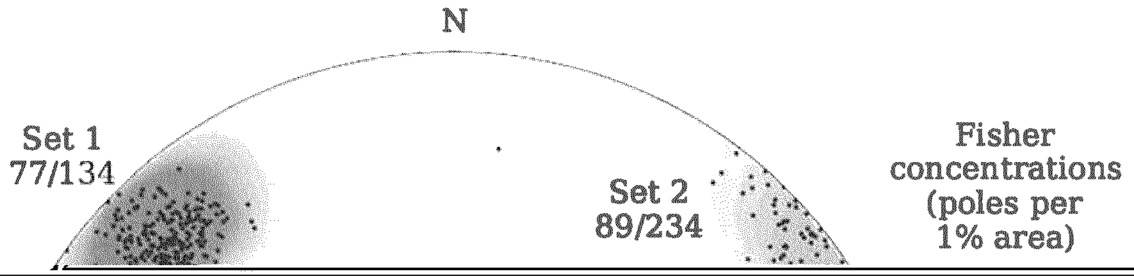



2
9
13



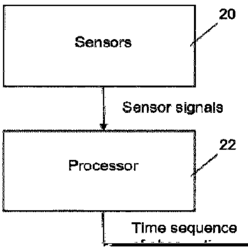

135°
150°
165°
180°
195°
210°
225°




N
Set 1
77/134
Set 2
89/234
Fisher
concentrations
(poles per
1% area)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau


Sensors
20
Sensor signals
Processor
22
Time sequence