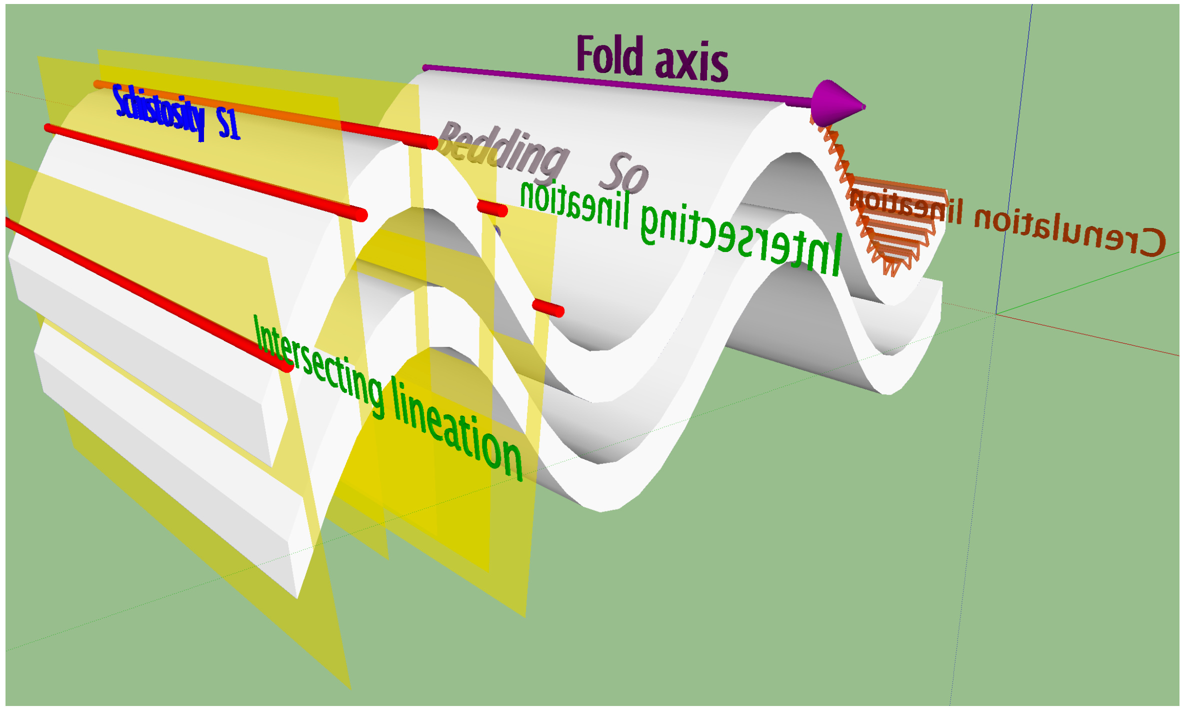
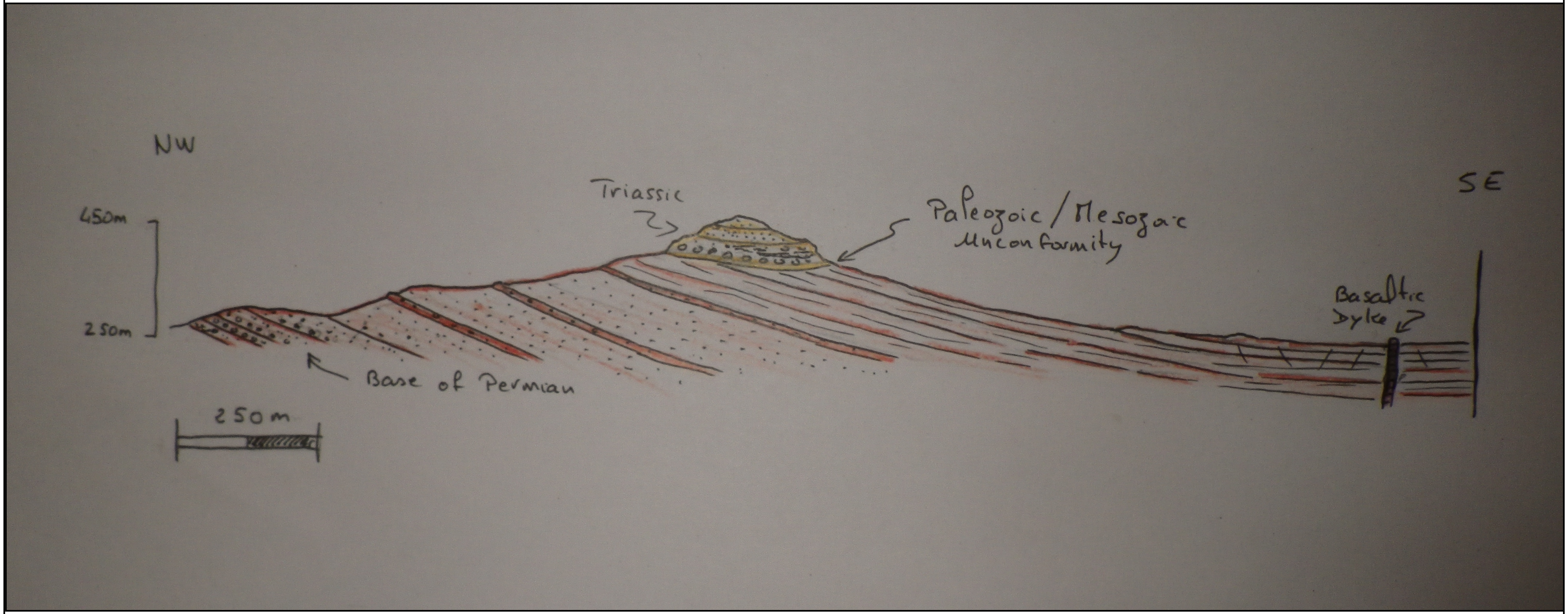
Interactive 3D Sketch*up*book



Patrice F. Rey

CHAPTER 1

Orientation of Planes & Lines



In a 3D space, a line can be oriented with respect to the geographic framework via the concepts of ***plunge*** and ***plunge direction***.

The ***plunge*** is the angle between an horizontal plane and the line of interest. The plunge is measured across a vertical plane, and it can vary from 0 (horizontal line) to 90º (vertical line).

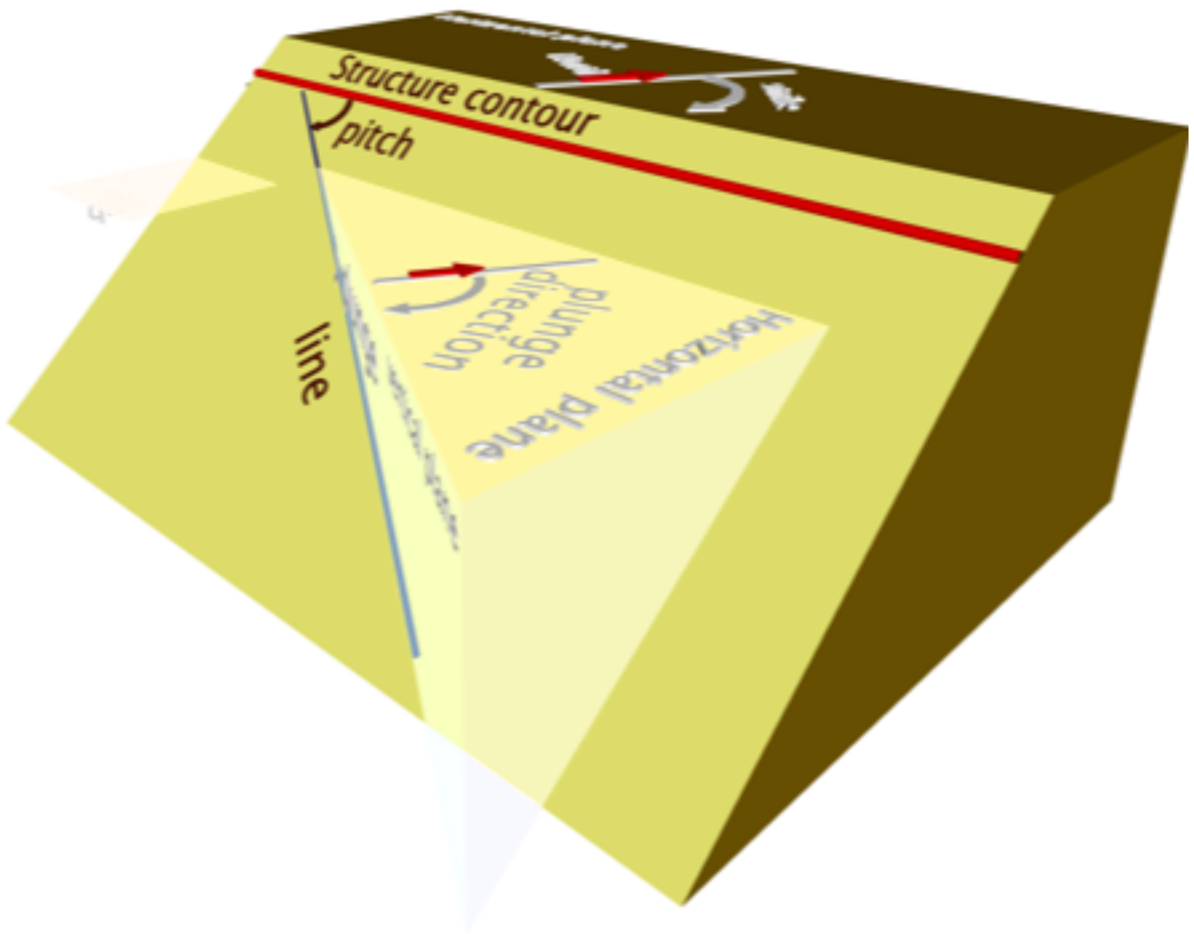
The ***plunge direction*** is the azimuth of the geographic direction towards which the line is plunging. It is given by a 3-digit number e.g. 022, it ranges from 000 (the line is plunging to the North), to 180 (the line is plunging to the South) and to 360.

For example the line 78-223 is a line strongly plunging to the SW.

When a line is carried by a plane (e.g. striae on a fault plane), it can be oriented by its ***pitch*** and ***pitch direction***. The pitch is the acute angle (therefore varying from 0 to 90º) between a structural contour and the line of interest on the plane, the pitch direction is the geographic direction toward which the line of interest is plunging. The pitch direction is given as a geographic direction, e.g. SSW.

All interactive 3D models are made with ***Sketchup*** and are available at:
https://3dwarehouse.sketchup.com

Interactive 1.1 Plunge - Plunge Direction, and Pitch - Pitch Direction



In a 3D space, planar surfaces can be orientedwith respect to the geographic framework via the concepts of ***strike***, ***dip*** and ***dip direction***.

The ***strike*** of a planar surface is the ***azimuth*** of any ***structural contour*** on that surface. By definition it is the clockwise angle between the geographic North direction and a structural contour on the surface of interest. This angle, measured across an horizontal surface, is always given using a 3-digit number (e.g. 040) and can range from 000 to 360.

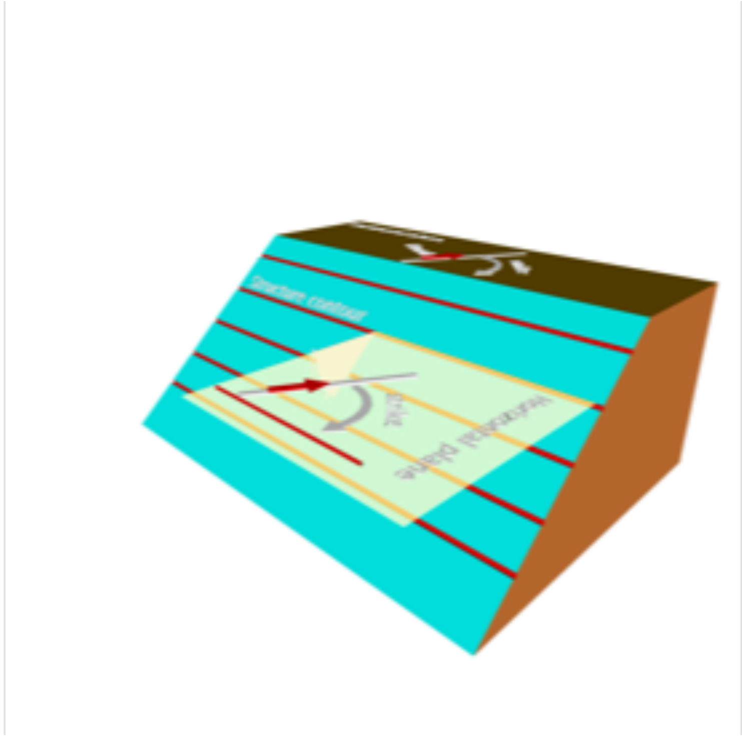
The ***dip*** is the angle between an horizontal plane and any line perpendicular to structural contours and lying within the plane of interest. The dip is measured along a vertical plane, and ranges from 0 (horizontal) to 90º (vertical).

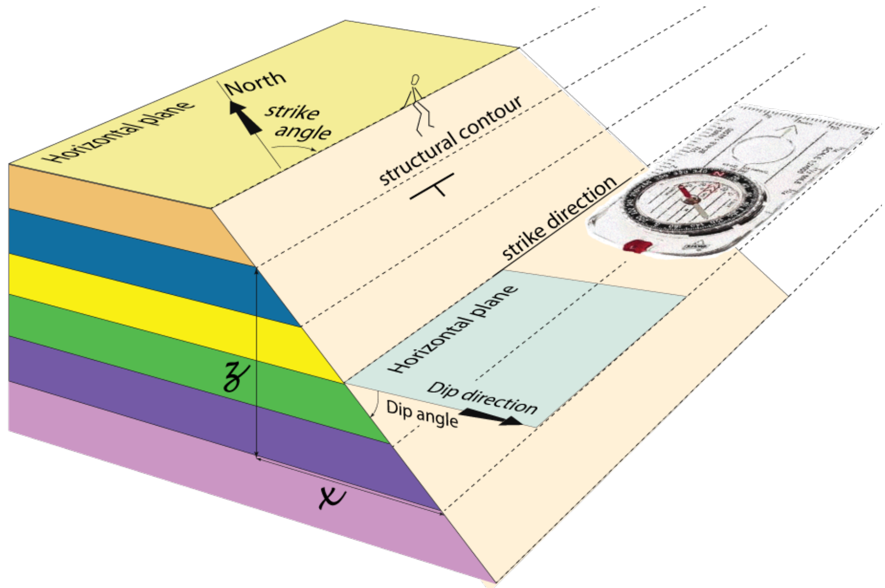
The ***dip direction*** is the geographic direction toward which the plane is dipping. It is given by a geographic coordinate, e.g. SSW.

For example, the plane 029-18SE is striking NE and gently dipping to the SE.

There are other way one can orient planar surface in a 3D space. For instance dip and dip direction is the minimum required to fully orient a planar surface (e.g. 18-119). However, this notation can be confused with the plunge and plunge direction of a line.

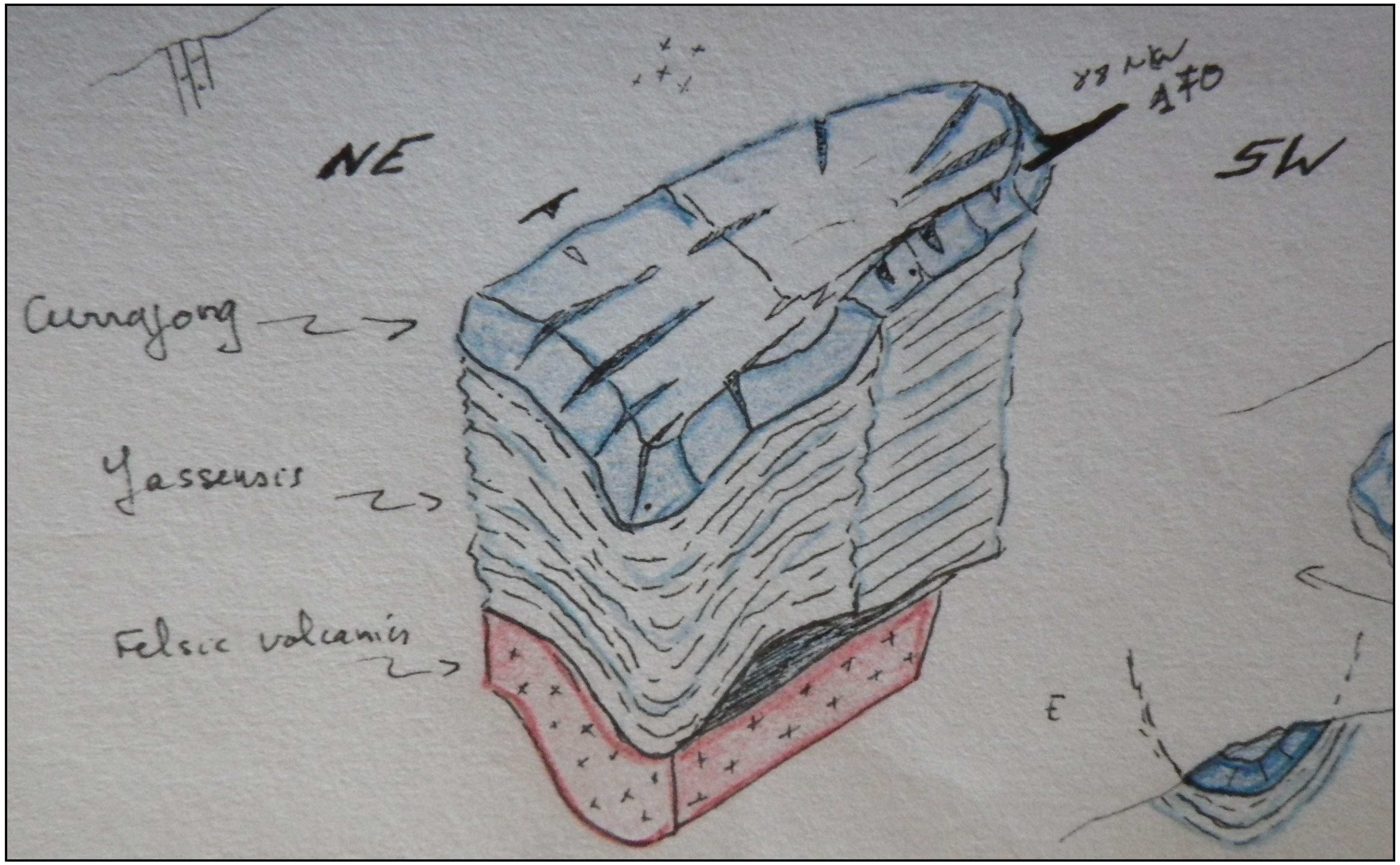
Interactive 1.2 Strike, dip and dip direction





CHAPTER 2

Folds & Folds Systems



Folds and folds systems (a fold system is a series of cogenetic folds) are oriented in space through their fold axes and axial surfaces, as these elements remain roughly parallel from one fold closure to the next.

The fold B axis (or simply fold axis) is parallel to the fold hinge. Fold B axes connect points of maximum curvature on a given fold hinge.

Axial surfaces are defined by the successive fold B axes lying of different folded surfaces, folded about the same fold closure (see sketch on the right).

The sketch on the right shows an antiform and a synform fold closures. The red lines are B axes along various surfaces folded about the antiform closure. The grey plane passes through all the B axes. This grey surface is the axial surface of the antiform fold closure. One can guess that the fold axes and the axial surface of the synform closure are parallel to those of the antiform closure.

Folds can be described in many different ways. The simplest scheme is based on the dip angle of the axial planar surface, or the plunge of the fold B axis.

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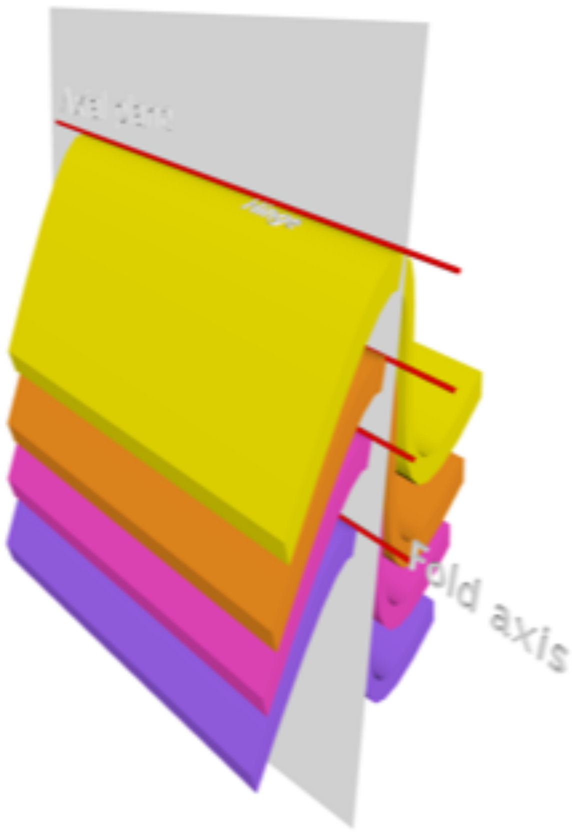
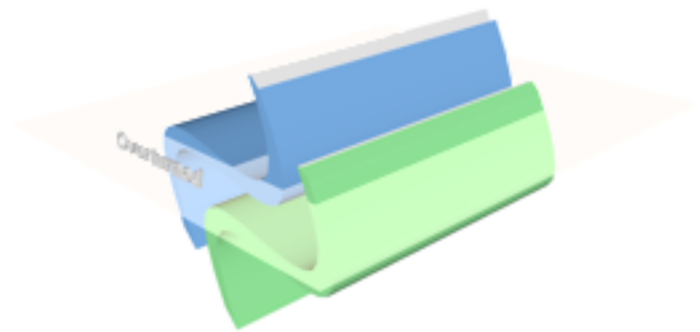
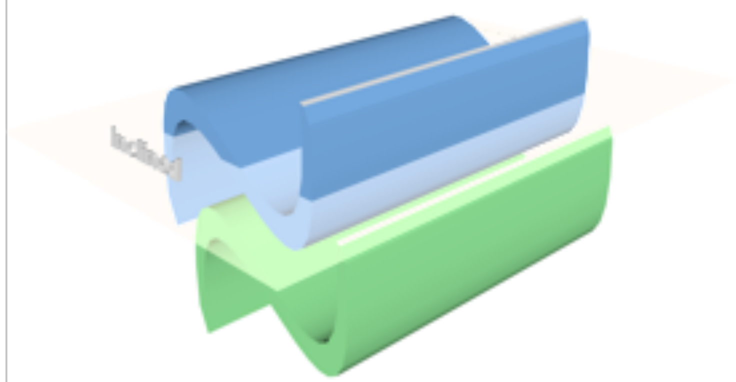
Interactive 2.1 Fold elements



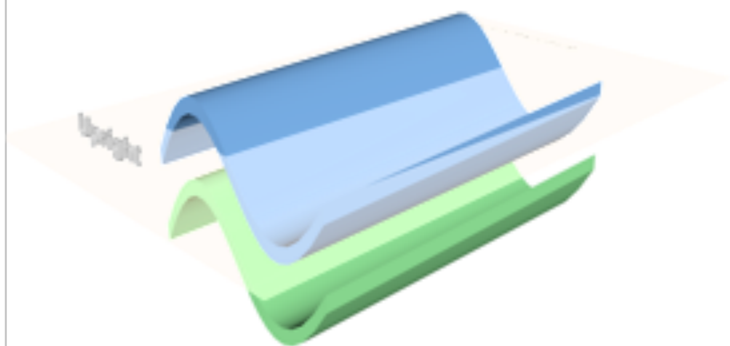
Interactive 2.2 Overturned folds



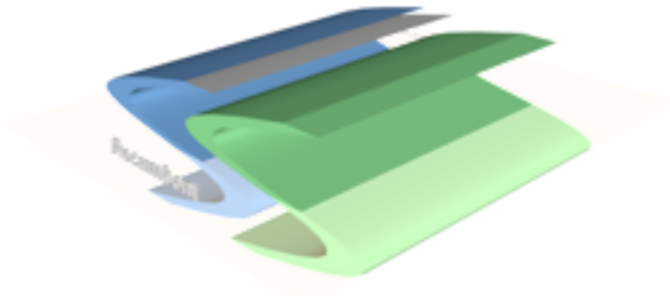
Interactive 2.4 Inclined folds



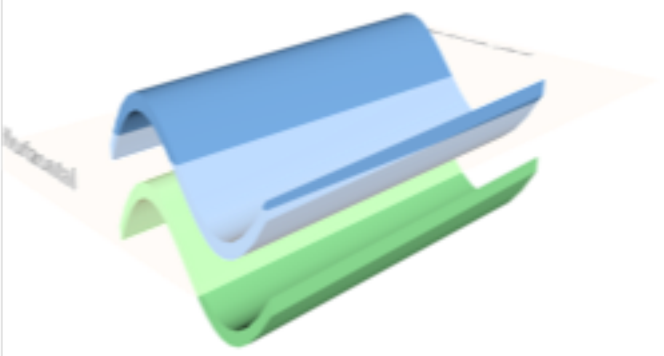
Interactive 2.3 Upright folds ...



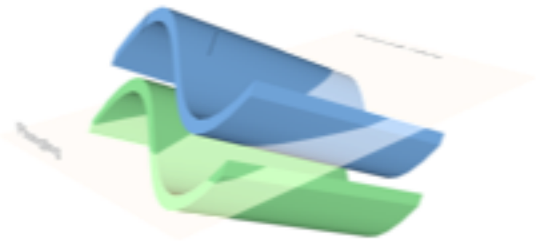
Interactive 2.5 Recumbent folds



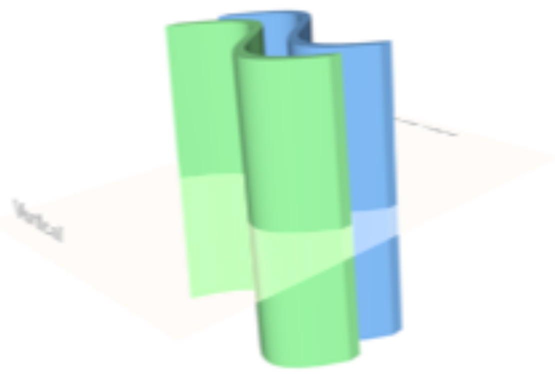
Interactive 2.6 Horizontal folds



Interactive 2.8 Plunging folds

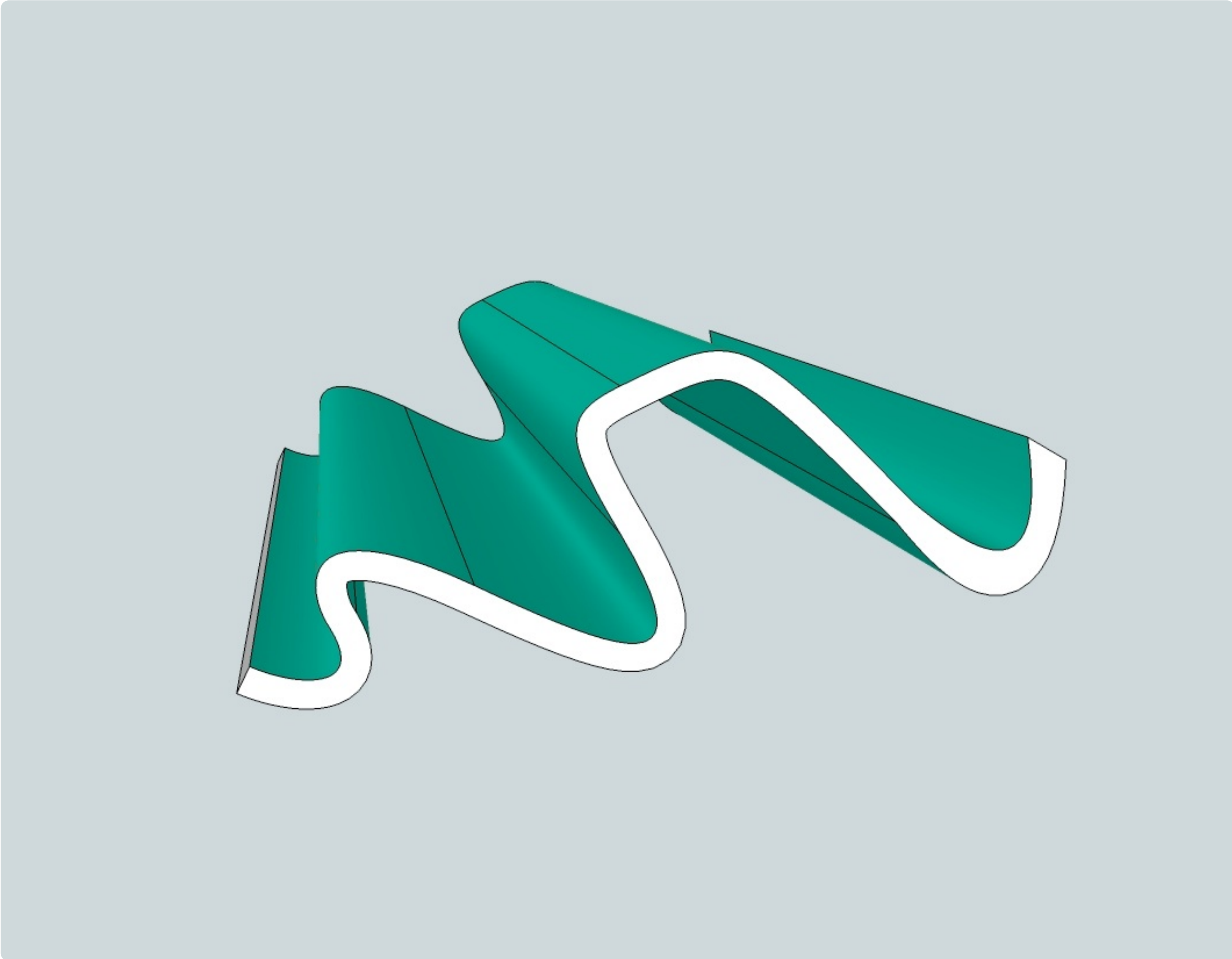


Interactive 2.7 Vertical folds



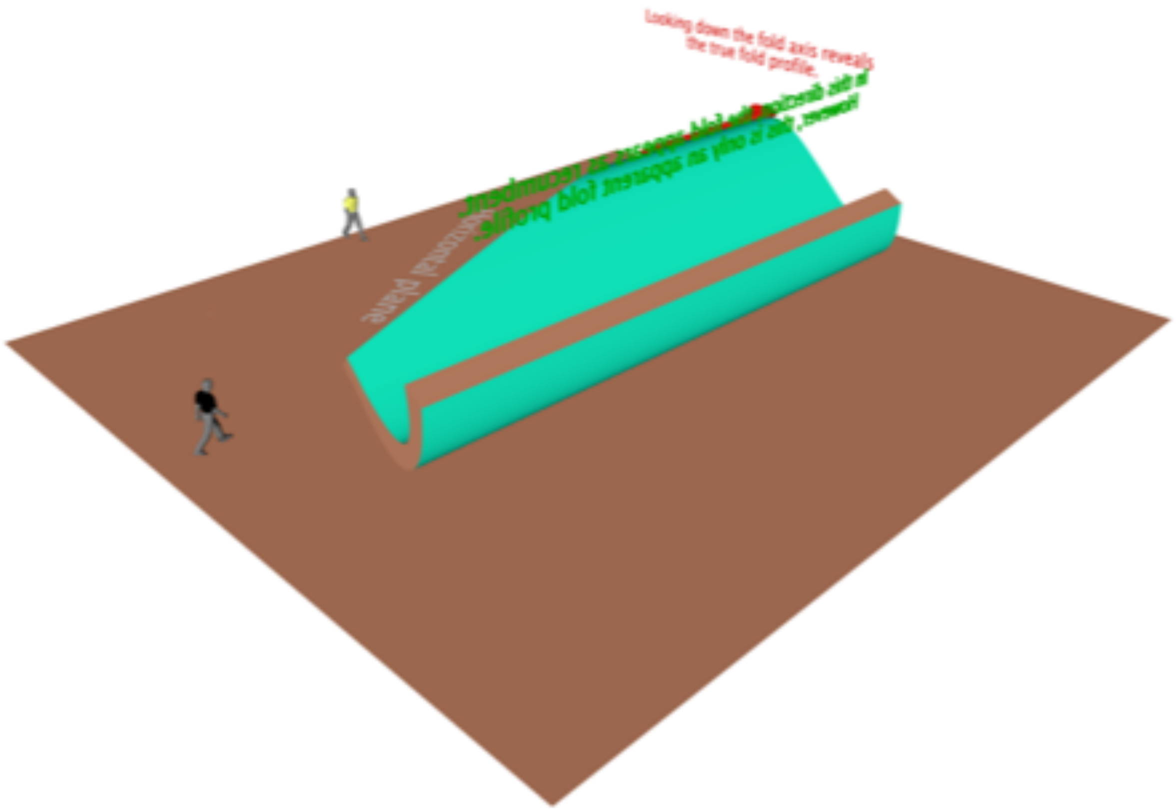
Interactive 2.9 Reclined folds

Gallery 2.1 A misleading 2D section across a fold

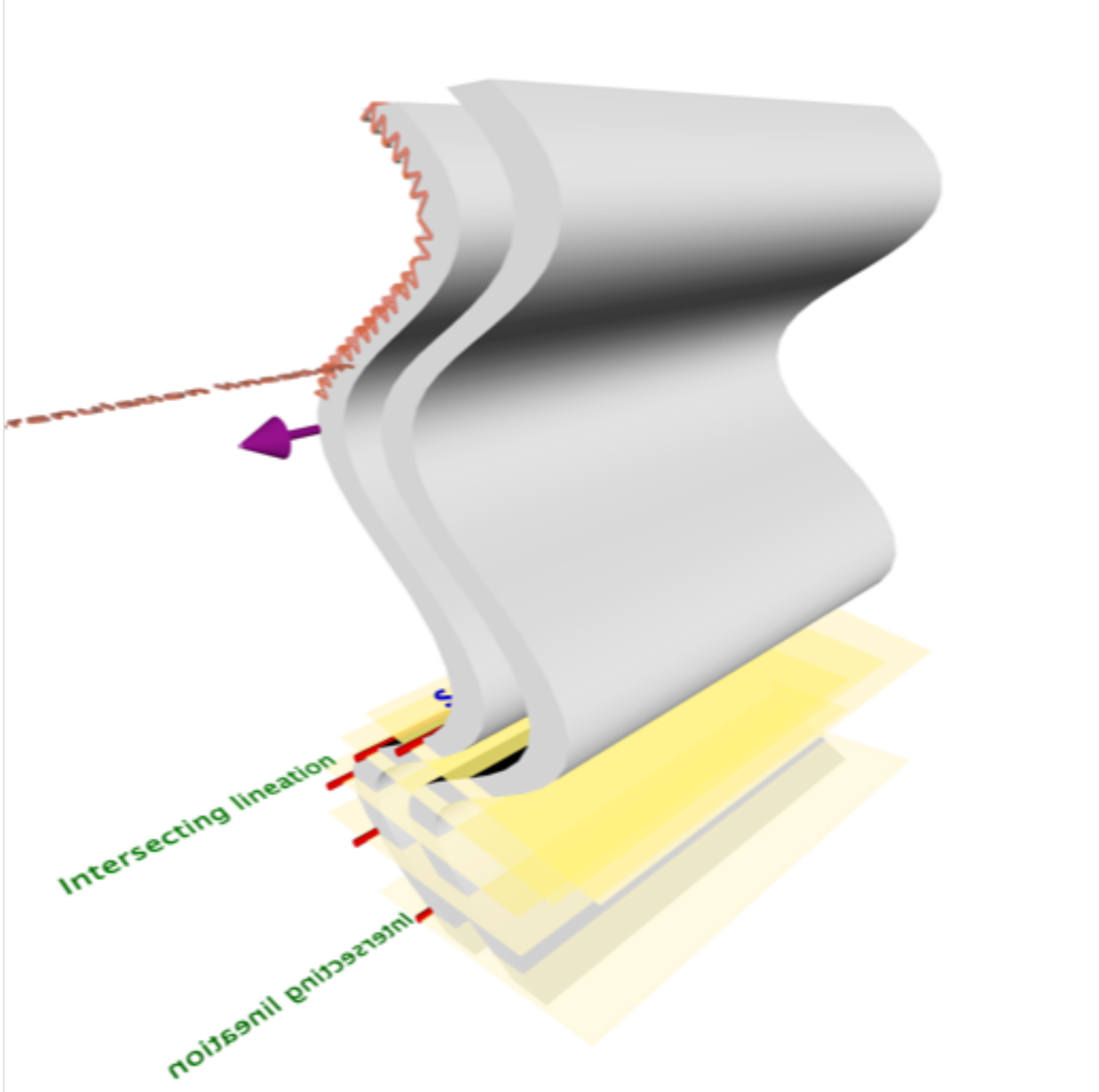


A section perpendicular to the fold axis reveals an overturned fold, it reveals the true fold profile.

Interactive 2.10 Apparent vs true fold profile

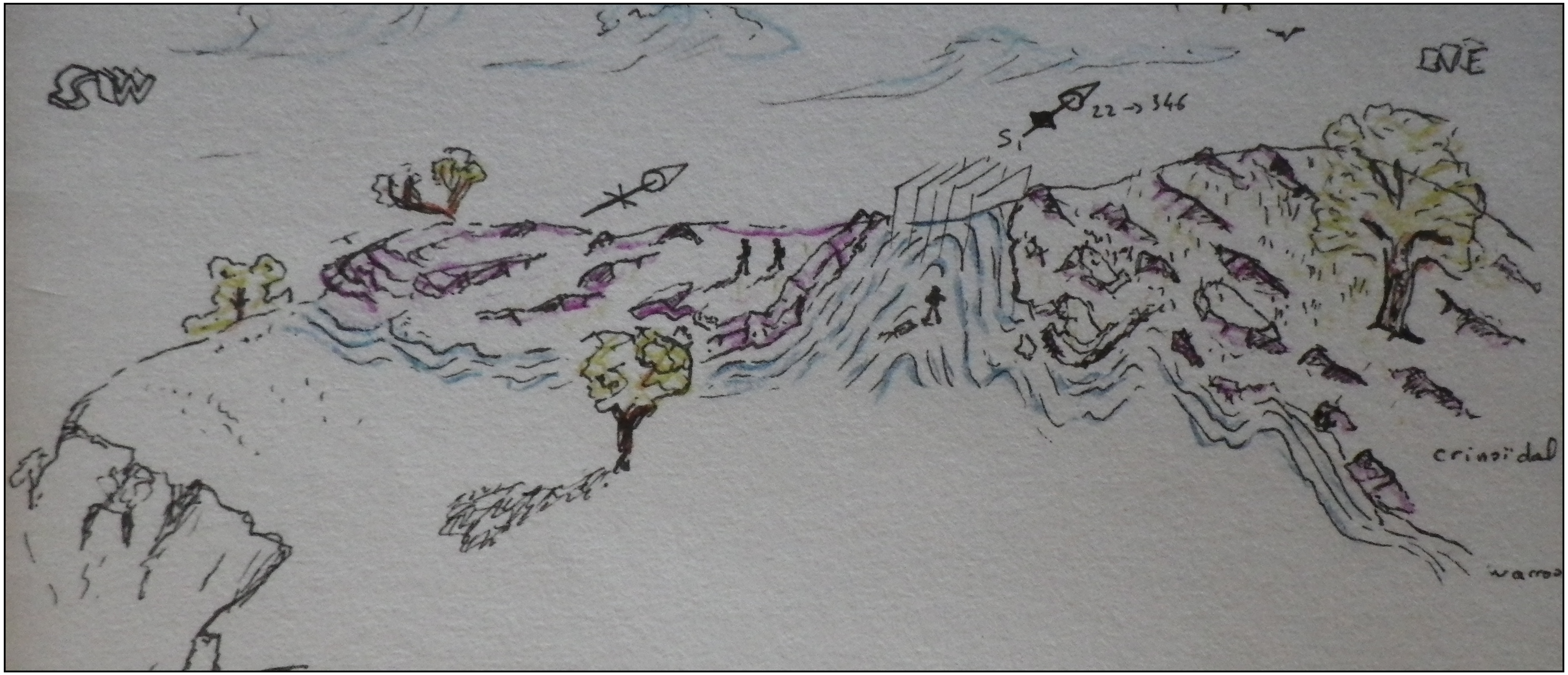


Interactive 2.11 Fold related lineations



CHAPTER 3

Faults



Different fault styles develop depending on the tectonic regime responsible for their formation. There are three contrasting tectonic regimes:

- Contraction: involves horizontal convergence andshortening
- Extension: involves horizontal divergence and lengthening
- Transcurrent: involves horizontal shearing

Dip slip reverse faults (or simply reverse faults) dominantly form during contractional tectonic regime. Reserve faults accommodate shortening, and result in the local duplication of part of the stratigraphy.

Dip slip normal faults (or simply normal faults) dominantly form during extensional tectonic regime. Normal faults accommodate lengthening, and result in the local removal of part of the stratigraphy.

Strike slip transcurrent faults (or simply strike slip faults) dominantly form during transcurrent tectonic regime. Transcurrent faults do not involve shortening or lengthening, nor do they impact of the stratigraphy.

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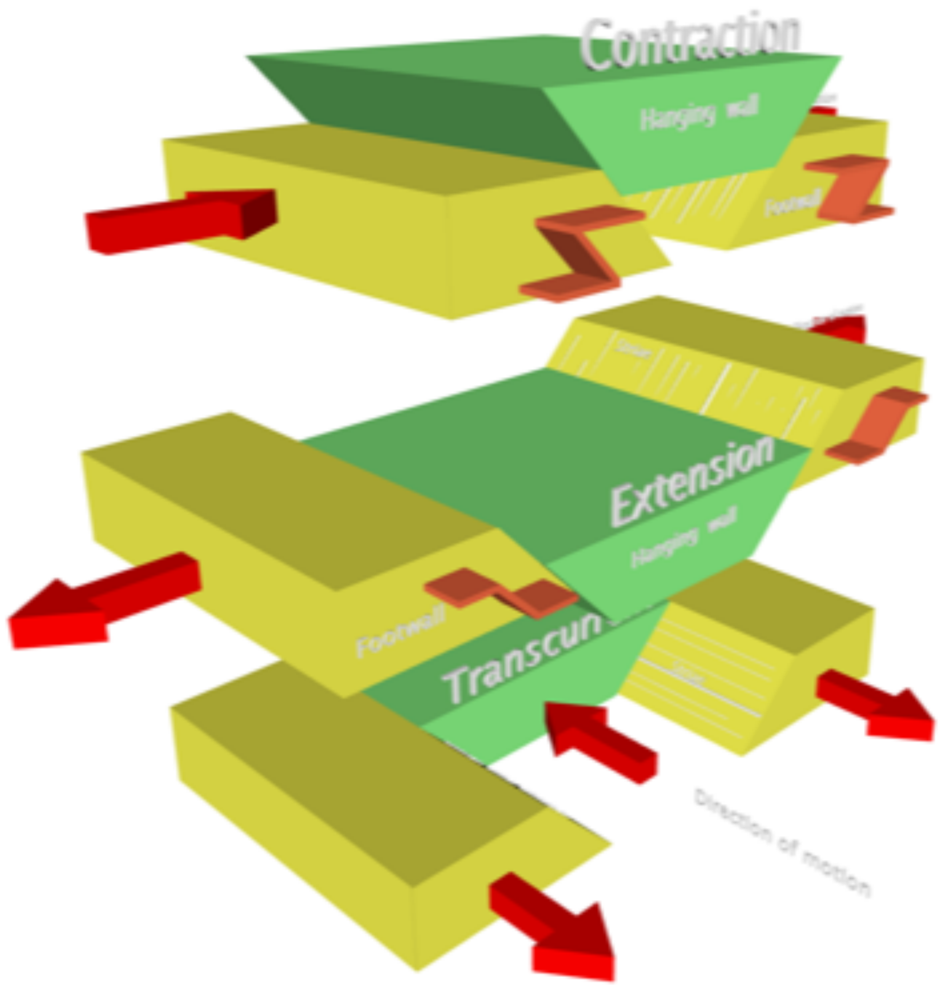
Interactive 3.1 Fault blocks and tectonic regimes

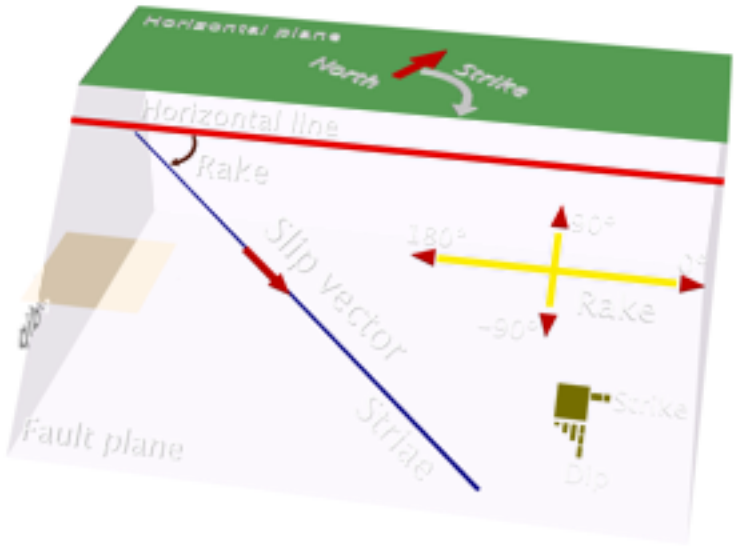


Fault data including the strike, dip and direction of the fault plane, the plunge and plunge direction of the striae, and the relative sense of motion can be processed to recover the orientation of the state of stress at the origin of the faulting.

There is always more than one way to record the orientation of planes and lines. The sketch on the right documents and explains the concept of ***rake***. This concept is relevant to the orientation of striae along a fault plane. The rake is similar to the pitch, but unlike the pitch angle which can only vary from 0 to 90º, the rake can take values from 0 to +180º (positive values indicating a reverse fault component), and 0 to -180º (negative values indicating a normal fault component).

The concept of rake uses the "***right hand rule***" where the thumb aligns with the strike of the fault plane, and the fingers point down dip. Along the fault plane, the thumb points toward 0º. The rake of the slip vector (i.e. the striae) increases up to 180º for reverse fault (anticlockwise rotation), and decreases down to -180º for normal fault (clockwise rotation).

Interactive 3.2 Fault slip data: The concept of rake



CHAPTER 4

Stress Ellipsoid

The stress ellipsoid represents the state of stress acting on a physical point.

Rocks deform only when submitted to an anisotropic state of stress. If the state of stress is isotropic (i.e. same stresses from all directions), no deformation is possible regardless of the magnitude of the stress.

Like any ellipsoids, the stress ellipsoid is characterized by 3 principal orthogonal axes. These are called σ_1, σ_2 and σ_3, and by convention the principal stress axes are such that:

$$\sigma_1 \geq \sigma_2 \geq \sigma_3$$

Different families of ellipsoids can be defined:

- Prolate (axial compression) stress ellipsoid: $\sigma_1 > \sigma_2 = \sigma_3$
- Oblate (axial extension) stress ellipsoid $\sigma_1 = \sigma_2 > \sigma_3$
- Hydrostatic (isotropic) stress ellipsoid $\sigma_1 = \sigma_2 = \sigma_3$

The mean stress is σ_{mean} =($\sigma_1 \geq \sigma_2 \geq \sigma_3$)/3 and the principal deviatoric stresses are:

$$\sigma_{1'} = \sigma_1 - \sigma_{mean}$$
$$\sigma_{2'} = \sigma_2 - \sigma_{mean}$$
$$\sigma_{3'} = \sigma_3 - \sigma_{mean}$$

It is the deviatoric stress that causes rock to deform.

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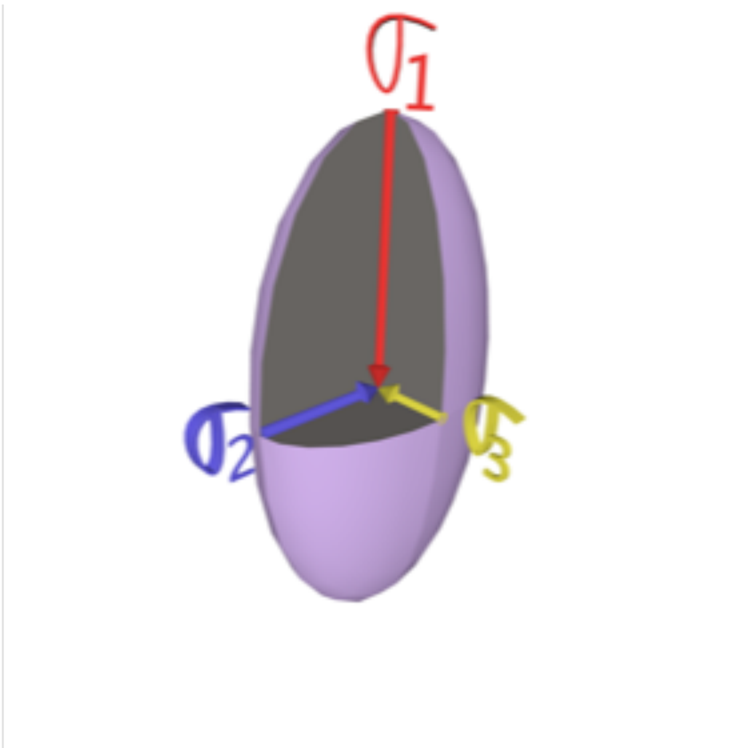
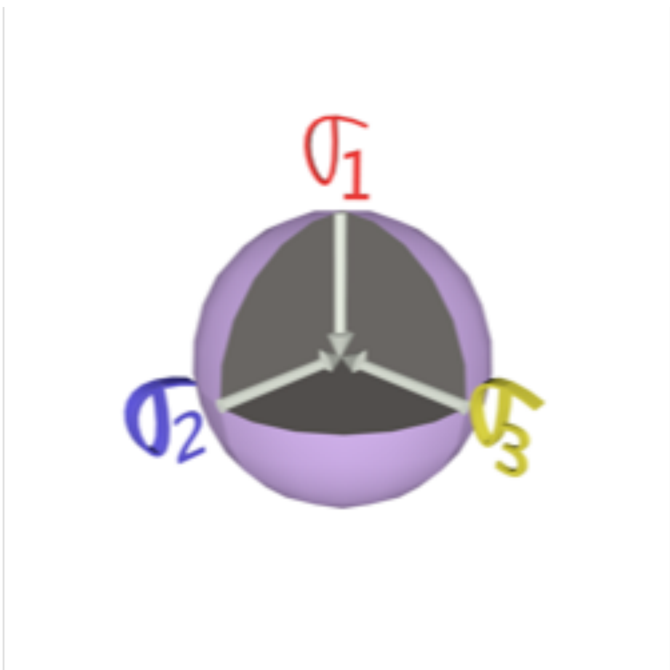
Interactive 4.1 Stress Ellipsoid



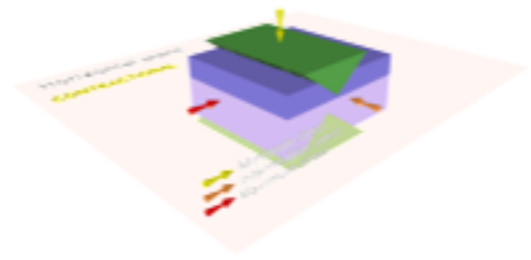
Interactive 4.2 Isotropic stress



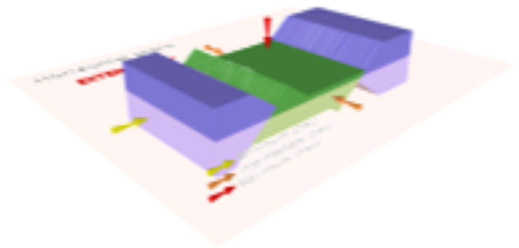
At, or very close to the Earth's surface, one of the principal stress axes is always vertical (i.e. perpendicular to a gravitational equipotential surface). The three tectonic regimes (i.e. contractional, extensional and transcurrent) are defined by which of the principal stress axes is vertical.

- Contractional tectonic regime: σ_3 is vertical.
- Extensional tectonic regime: σ_1 is vertical.
- Transcurrent tectonic regime: σ_2 is vertical.

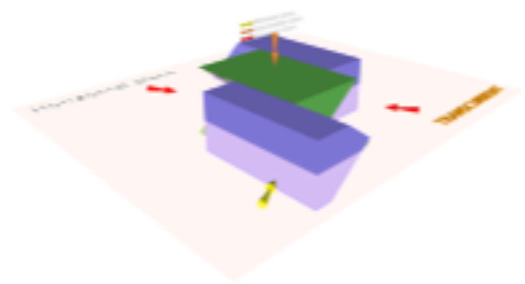
Interactive 4.4 Contractional Tectonic Regime



Interactive 4.3 Extensional Tectonic Regime

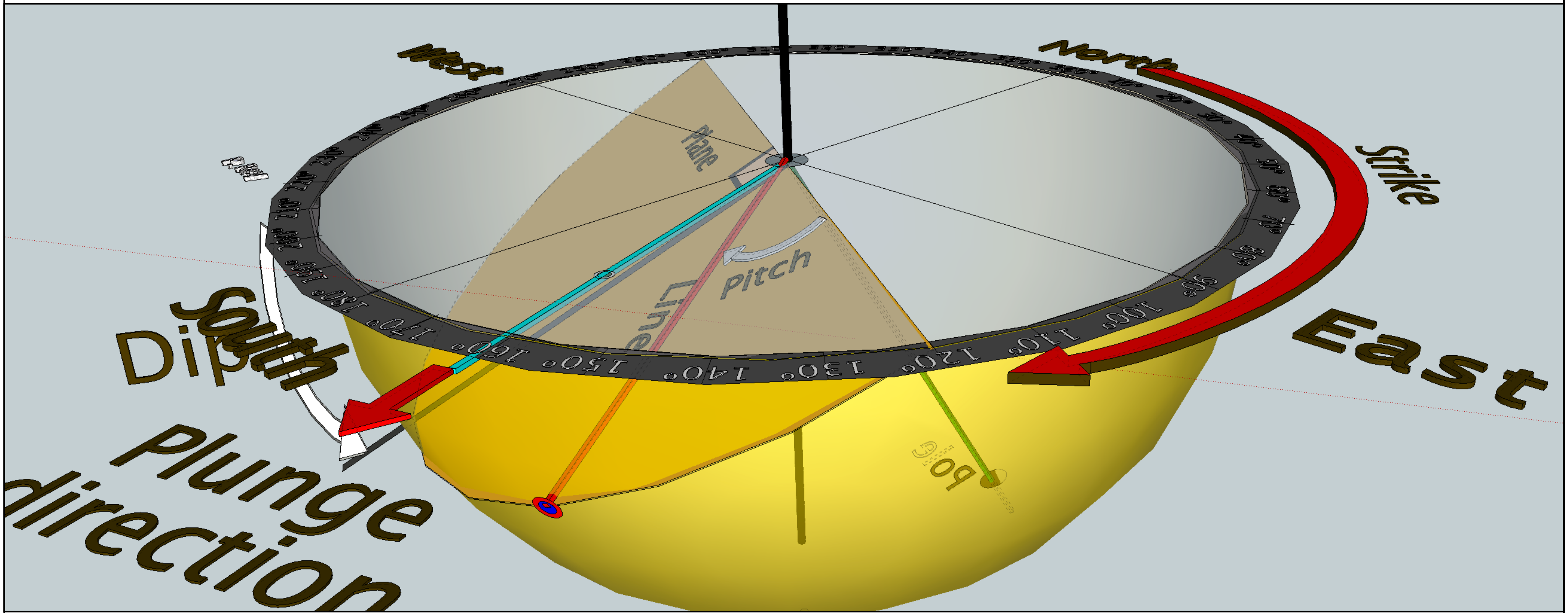


Interactive 4.5 Transcurrent Tectonic Regime



CHAPTER 5

Stereonet



There are multiple ways to project the surface of a sphere onto a 2D plane, one of them is the stereographic projection. In the stereographic projection, any point P at the surface of a sphere is represented by a unique point P' onto the equatorial plane of the sphere.

One form of stereographic projection uses the *apex* of the sphere as pole of projection. A straight line joining the pole of projection to a point P a the surface of the lower hemisphere intersects the equatorial plane at a point P'. P' is the stereographic projection of P. The same procedure can be applied for the projection of the upper hemisphere using the sphere's *antapex* as projection pole.

The stereographic projection conserves angular relationships between lines and planes. It is at the origin of the Wulff stereonet canvas.

The Wulff stereonet canvas is an abacus representing the equatorial plane of the sphere. On this abacus, the curved lines joining the north and the south poles of the stereonet canvas, are called *great circles*. They represent the stereographic projection of north-south striking planar surfaces passing through the center of sphere. These planes have varying dip angles, with 2° dip increment. A second set of lines, running across the canvas and called *small circles*, joints lines of equal pitch on great circles.

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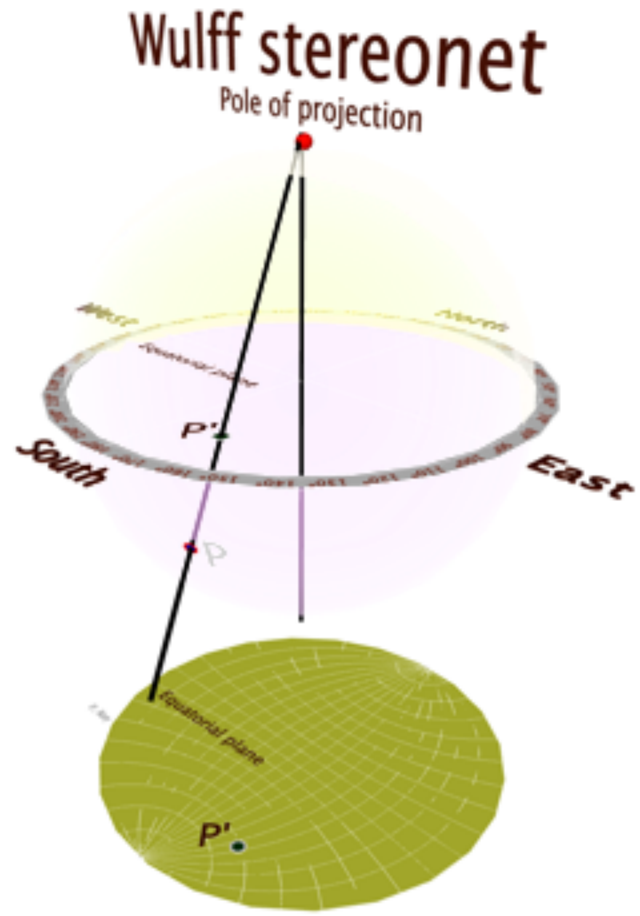
Interactive 5.1 Wulff stereonet: Equal angle

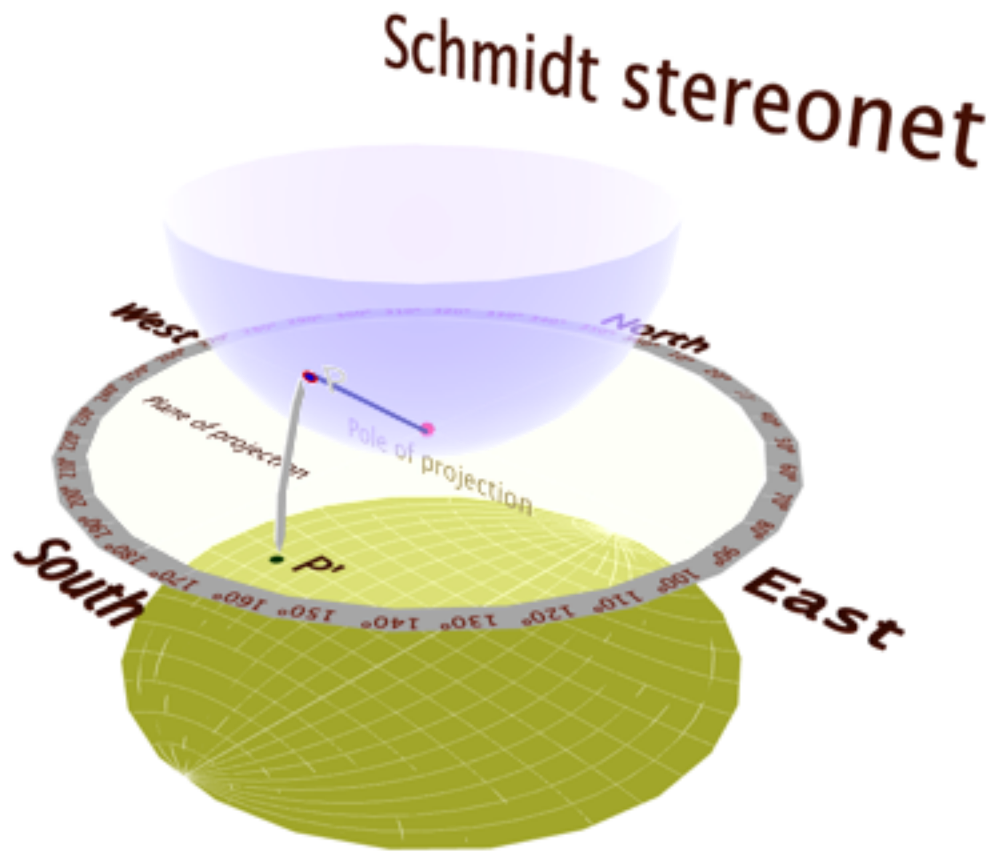


Another type of stereographic projection uses the antapex of the sphere as pole of projection, and the 2D plane tangent to the sphere's antapex as plane of projection.

P', the stereographic projection of a point P lying of the surface of the lower hemisphere, lies on the basal plane where the straight line connecting the pole of projection to the point on interest P meets the plane of projection following a simple rotation of the line along a vertical plane.

This stereographic projection, also known as the Lambert azimuthal equal-area projection, conserves surface area. It is at the origin of the Schmidt stereonet canvas. The Schmidt canvas is used to perform statistical analyses on spatial distribution of planes and lines.

Interactive 5.2 Schmidt stereonet: Equal area

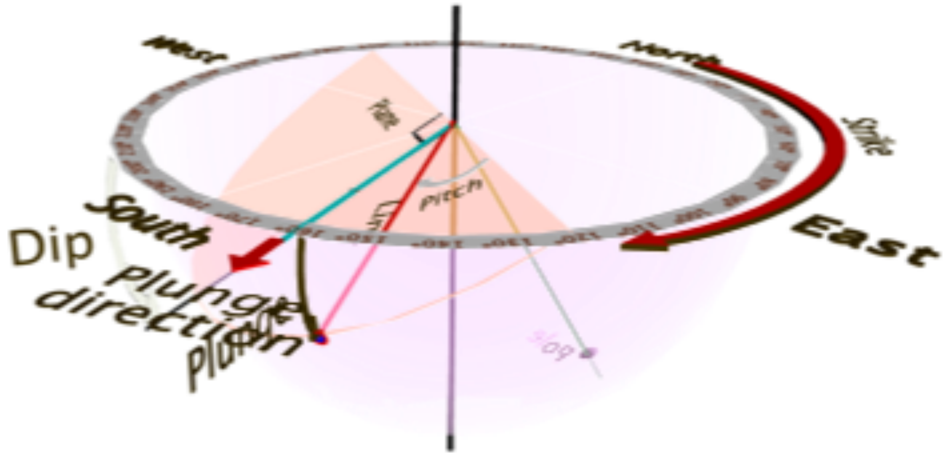


The attitude (i.e. orientation in space) of planar surfaces and straight lines can be represented using a lower hemisphere, and its equatorial plane which represents the ground surface.

These planar surfaces (e.g. bedding surfaces, faults, dike, sills, fold axial surfaces, etc) and straight lines (e.g. fold axes, striae on a fault plane, flute-casts on a bedding surface, etc.) intersect the surface of the lower hemisphere. Because the stereographic projection of these intersections onto the equatorial plane (equal angle projection) conserves angular relationships, one can analyse the angular relationships of these planes and lines directly on the stereonet canvas.

Stereonet canvas is a 3D protractors.

Interactive 5.3 Attitude in the stereonet



CHAPTER 6

Maps

The underground geology, simplified into a bunch of rock formations of similar properties, is often only partially exposed at the Earth's surface. The mapping of these rock formations and their contacts (stratigraphic contacts or structural contacts such as faults) is the job of field geologists. Geologists focus on mapping *formlines*, the lines of intersection between major geological contacts and the Earth's surface. What follow shows the relationship between structural contours, formlines, geological map and the 3D geology below the Earth's surface

Let's assume that, on the red circle close to the drill hole you have measured the attitude of the top surface of a geological formation. The strike-dip and dip direction for this formation is 160-30-W.

Assuming that this bedding is planar and of constant dip in the region, one can easily construct the intersection between this geological surface with the topographic surface. This intersection is called a *formline*. To construct this formline, construct the structural contour going through the red dot. This structural contour is by definition parallel to the strike direction of the plane, it is therefore making an angle of 160° clockwise from the geographic north.

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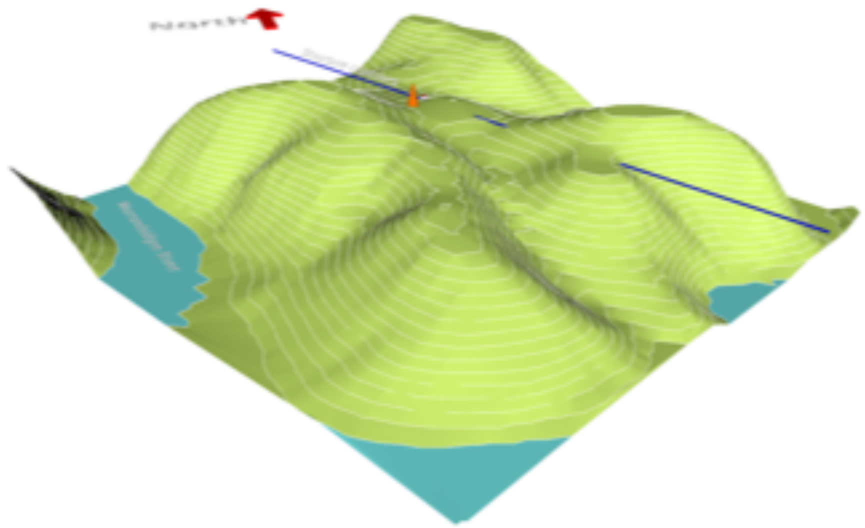
Interactive 6.1 Structure contours and form lines



Skechup tip: To extract topographic contours from a GoogleEarth terrain and import them into Sketchup, follow these instructions: http://www.gearthblog.com/blog/archives/2012/08/sketchup_tip_creating_3d_contour_li.html

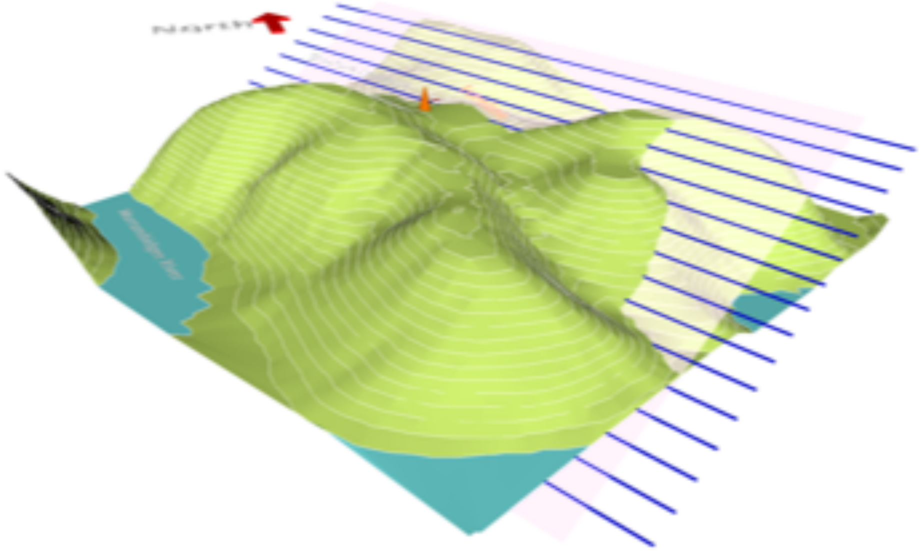
On a planar geological surface, structure contours (i.e. the intersections between the geological surface and horizontal surfaces of incrementally increasing elevation) are horizontal lines. Since we are dealing with a planar geological surface these structure contours are parallel to each others and straight. You may guess that on a curved geological surface, structure contours are curved horizontal lines.

From knowledge of the dip and dip direction of a geological surface, a bunch of equally spaced structural contours (blue lines) are constructed. From the dip angle one can derive the horizontal spacing of successive structure contours for a given difference in elevation. For instance for a 30º dip angle, the spacing between structure contours of elevation contrast (*dz*) of 20 m is ... ~40 m.

On the sketch on the right, the planar geological surface (transparent purple surface) is defined by these structural contours. The intersections between these structure contours and the topography lead to the formline.

Try to look at this 3D sketch straight down from above. You will see the sketch, and its various elements (topographic contours in white, structural contours in blue, and points of intersection between structural contours and topographic surface), from a “mapping” perspective.

Interactive 6.2 Structure contours and form lines



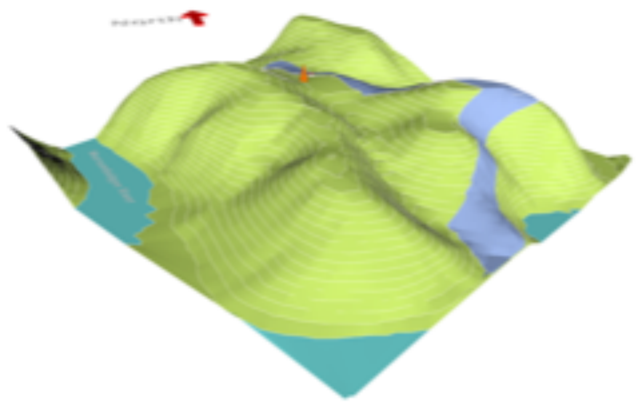
If one can locate the base of the rock formation at one location, then the formline of the base of the rock formation can be constructed and the rock formation (here in light blue) mapped. This is done by translating the set of structure contours until one of the structure contours passes through the outcrop where the base of the rock formation has been located.

Look the 3D sketch from various direction and appreciate how the trace of the rock formation (the blue band at the topographic surface) relates to the underground geology. What would the blue trace on the ground surface look like is the topography was perfectly horizontal and flat?

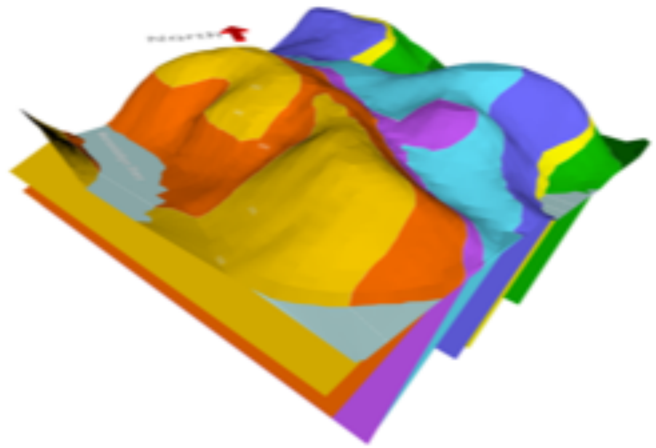
Repeating this procedure to a number of rock formations leads to the construction of a geological map.

The color pattern, visible on the geological map, reflects the intersection between the the underground geology and the topography. In other terms, if the topography changes the geological map will also change.

Interactive 6.3 Structure contours and form lines



Interactive 6.4 Structure contours and form lines



Untitled

Azimuth

Clockwise angle from geographic north to a direction in an horizontal plane.

Related Glossary Terms

Drag related terms here

Index Find Term

Structural contour

A structural contour is an horizontal line on a geological surface such as bedding, fault, foliation etc. This concept derives from the concept of *topographic contour* which represents an horizontal line on the topographic surface.

Related Glossary Terms

Drag related terms here

Index Find Term