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APPENDIX ONE.

To work out slip vector for three simultaneously opening veins.

Summary

Measured
- strike and dip of planes of pyramids
- apparent thicknesses of veins
- strike and dip of plane of outcrop
- lengths of each vein.

First assuming the base is horizontal and this is the plane we have measured in.
1) Work out height of larger pyramid.
2) Work out lengths of base of smaller pyramid.
3) Using 2) work out height of smaller pyramid.
4) Subtract 2) from 1) to give the height difference of the two pyramids. This is the vertical component of slip.
5) Working in the plane of the horizontal base, make a co ordinate system with ‘x’ axis parallel to one vein and origin in one corner of the larger pyramid. Project apex of larger pyramid into plane and calculate its co ordinates.
6) Keeping the same axes, project the apex of the smaller pyramid into the horizontal base plane. Work out its co ordinates.
7) Within the base plane, join together the two projected apices. This line is the horizontal component of slip. Work out its length by subtracting ordinates and abscissae, then find inner angle v and using tangent. (Using Pythagoras becomes very complicated).
8) Bearing = O’Z-v
(O’Z is parallel to the x-axis, which is parallel to one of the veins).
9) Using vertical and horizontal components of slip work out length and plunge of slip vector.
Step one: height of large pyramid.

In plane C
α  known
β  known
γ  known
Length C known.

But Sine rule has \( \frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c} \) where

Therefore in plane C
Length \( a = \frac{c \sin \alpha}{\sin \gamma} \) (known)
Length \( b = \frac{c \sin \beta}{\sin \gamma} \) (known)

O is the projection of the apex onto the base. Therefore planes P and Q are vertical—one containing the intersection line a and one containing intersection line b. They may therefore be plotted on the stereonet and angles δ and θ measured.

In plane P, \( h = \sin \delta, \quad h = \frac{b \sin \delta = c \sin \beta \cdot \sin \delta}{\sin \gamma} \) (known).
In plane Q, \( h = \sin \theta, \quad h = a \sin \theta = c \frac{\sin \alpha}{\sin \gamma} \) (known).

Both these equations should give the same answer for \( h \).

Also in plane P, \( x = \cos \delta \quad x = b \cos \delta = c \frac{\sin \beta}{\sin \gamma} \cos \delta \) (known).

And in plane Q, \( y = \cos \theta \quad y = a \cos \theta = c \frac{\sin \alpha}{\sin \gamma} \cos \theta \) (known)

Step two: working out lengths of base of smaller pyramid.

Length \( c' = c - k - l \)

Magnifying corner of base.

\[
\sin \mu = \frac{t_1}{n} \\
\sin \varepsilon = \frac{t_2}{n} \\
n = \frac{t_3}{\sin \mu} = \frac{t_2}{\sin \varepsilon} \\
* \quad t_3 = \frac{\sin \mu}{t_2} \sin \varepsilon
\]
But $\mu + \varepsilon = A = \text{difference in strike of two planes.}$

So $\mu = A - \varepsilon$

* $\varepsilon = A - \mu$

Using formulae marked *

$$t_2 = \frac{\sin \mu}{\sin (A-\mu)}$$

Let $t_3 = T$

$$T = \frac{\sin \mu}{\sin (A-\mu)}$$

But $\sin(A - \mu) = \sin A \cdot \cos \mu - \cos A \cdot \sin \mu$

So $T = \frac{\sin \mu}{\sin A \cdot \cos \mu - \cos A \cdot \sin \mu}$

$T (\sin A \cdot \cos \mu - \cos A \cdot \sin \mu) = \sin \mu$

$(T \sin A) \cdot \cos \mu - (T \cos A) \cdot \sin \mu = \sin \mu$

$(T \sin A) \cdot \cos \mu = (1 + T \cos A) \cdot \sin \mu$

$$\frac{T \sin A}{1 + T \cos A} = \frac{\sin \mu}{\cos \mu} = \tan \mu$$

Again using the formulae marked ‘*’

$$t_3 = \frac{\sin \mu}{\sin \varepsilon}$$

But $\mu = (A - \varepsilon)$

$$t_3 = \frac{\sin (A - \varepsilon)}{\sin \varepsilon}$$

Again let $t_3 = T$ and also substituting for $\sin(A - \varepsilon)$

$$T = \frac{\sin A \cdot \cos \varepsilon}{\sin \varepsilon} - \cos A \cdot \sin \varepsilon$$

$T \sin \varepsilon = \sin A \cdot \cos \varepsilon - \cos A \sin \varepsilon$
\[(T + \cos A) \sin e = (\sin A) \cos e\]

\[
\frac{\sin e}{\cos e} = \frac{\sin A}{T + \cos A} = \tan e
\]

T and A are both known.

**Lengths k and m.**

\[
t_2 = \tan \varepsilon \quad \text{and} \quad k = \frac{t_2}{\tan \varepsilon}
\]

\[
t_3 = \tan \mu \quad \text{and} \quad m = \frac{t_3}{\tan \mu}
\]

But \(\tan e = \frac{\sin A}{(T + \cos A)}\) and \(\tan \mu = \frac{T \sin A}{(1 + T \cos A)}\)

therefore

\[
k = t_2 \cdot \frac{(T + \cos A)}{(\sin A)} \quad \text{and} \quad m = t_3 \cdot \frac{(1 + T \sin A)}{(T \sin A)}
\]

Substituting for \(T = \frac{t_3}{t_2}\)

\[
k = \frac{t_3}{\sin A} + \frac{t_2 \cos A}{\sin A} \quad \text{and} \quad m = k + \left( \frac{t_3}{t_2} \cos A \right) \left( \frac{t_3}{t_2} \sin A \right)
\]

\[
k = \frac{t_3}{\sin A} + \frac{t_2}{\tan A} \quad \text{and} \quad m = \frac{t_2}{\sin A} + \frac{t_3 \cos A}{\sin A}
\]

\[
m = \frac{t_2}{\sin A} + \frac{t_3}{\tan A}
\]

Repeat this for all corners to base to give increments of shortening.
Pyramid base now looks like this:

Where lengths $c$, $d$ and $e$ are known,

Thicknesses $t_1$, $t_2$ and $t_3$ are known

Therefore $c'$, $d'$ and $e'$ can be calculated, and are therefore also known.
Step three: working out height of smaller pyramid.

\[
D' = \text{projection of apex of inner pyramid into horizontal plane}
\]

For outer pyramid it was shown that \( h = c \frac{\sin \alpha}{\sin \gamma} \cdot \sin \theta \)

Since the inner and outer pyramids are similar,

\[
h' = c' \frac{\sin \alpha}{\sin \gamma} \cdot \sin \theta
\]

But \( c' = c - \left( \frac{t_3 + t_2}{\sin A \tan A} \right) - \left( \frac{t_1 + t_2}{\sin B \tan B} \right) \)

therefore \( h' = \left( c - \left( \frac{t_3 + t_2}{\sin A \tan A} \right) - \left( \frac{t_1 + t_2}{\sin B \tan B} \right) \right) \frac{\sin \alpha}{\sin \gamma} \cdot \sin \theta \)
Step four: working out the height difference between the two pyramids.

Height difference = \( h - h' \)

\[
= c \frac{\sin \alpha \cdot \sin \theta}{\sin \gamma} - \left( c \cdot \frac{t_2}{\sin A \cdot \tan A} + \frac{t_1}{\sin B \cdot \tan B} \right) \frac{\sin \alpha \cdot \sin \theta}{\sin \gamma}
\]

\[
= \left( \frac{t_3}{\sin A \cdot \tan A} + \frac{t_2}{\sin B \cdot \tan B} \right) \frac{\sin \alpha \cdot \sin \theta}{\sin \gamma}
\]

Angle A = difference in strike of planes B and C (B' and C')
Angle B = difference in strike of planes A and C (A' and C')

\( t_1, t_2, t_3, A, B, \alpha, \theta, \gamma \) are all known, therefore the height difference of the two pyramids is known.
Step five: Location of the projection of the apex of the larger pyramid onto the horizontal base.

Already shown that

\[ a = \frac{c \sin\alpha}{\sin\gamma} \]
\[ b = \frac{c \sin\beta}{\sin\gamma} \]

In plane Q,

\[ \frac{y}{a} = \cos\theta \]
\[ y = a \cos\theta = \frac{c \sin\alpha \cdot \cos\theta}{\sin\gamma} \quad \text{(known)} \]

In plane P,

\[ x = \cos\delta \]
\[ x = b \cos\delta = \frac{c \sin\beta \cdot \cos\delta}{\sin\gamma} \quad \text{(known)} \]

Plan of base of large pyramid. (Horizontal plane).

Set up co-ordinate system with abscissa parallel to C, ordinate perpendicular to abscissa and origin at the corner of sides C and B of the pyramid.
\[ \cos \lambda = \text{abscissa} \quad \sin \lambda = \text{ordinate} \]

\[ x \cdot \cos \lambda = \text{abscissa} \quad x \cdot \sin \lambda = \text{ordinate} \]

Therefore co-ordinates of the projection of apex are \((x \cos \lambda, x \sin \lambda)\)

But \(x = \frac{c \sin \beta \cdot \cos \delta}{\sin \gamma}\)

Therefore the co-ordinates of the point O are \(\left(\frac{c \sin \beta \cdot \cos \delta \cdot \cos \lambda}{\sin \gamma}, \frac{c \sin \beta \cdot \cos \delta \cdot \sin \lambda}{\sin \gamma}\right)\)
Step six: location of projection of apex of smaller pyramid onto horizontal base of pyramids.

Co-ordinates of \( O' \) (projection of apex of SMALLER pyramid onto its base) for same axes as larger pyramid are:

\[
\left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} + v, \frac{t_2}{\tan A} + (t_2 + w) \right)
\]

But \( v = x' \cos \lambda \) and \( w = x' \sin \lambda \).

Therefore the co-ordinates are

\[
\left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} + x' \cos \lambda, (t_2 + x' \sin \lambda) \right)
\]

But \( x' = c' \cdot \frac{\sin \beta \cdot \cos \delta}{\sin \gamma} \)

where \( c' = c - \frac{t_3}{\sin A} + \frac{t_2}{\tan A} - \frac{t_1}{\sin B} + \frac{t_2}{\tan B} \)

therefore \( x' = c - \left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} \right) - \left( \frac{t_1}{\sin B} + \frac{t_2}{\tan B} \right) \cdot \frac{\sin \beta \cdot \cos \delta}{\sin \gamma} \)

so the co-ordinates of the projection of the apex of the smaller pyramid are:
\[ \text{Abscissa} \]
\[ \frac{t_3}{\sin A} + \frac{t_2}{\tan A} + \left( c - \frac{t_3}{\sin A} + \frac{t_2}{\tan A} \right) \left( \frac{t_1}{\sin B} + \frac{t_2}{\tan B} \right) \frac{\sin \beta \cdot \cos \delta \cdot \cos \lambda}{\sin \gamma} \]

\[ \text{Ordinate} \]
\[ t_2 + \left( c - \frac{t_3}{\sin A} + \frac{t_2}{\tan A} \right) \left( \frac{t_1}{\sin B} + \frac{t_2}{\tan B} \right) \frac{\sin \beta \cdot \cos \delta \cdot \cos \lambda}{\sin \gamma} \]
Step seven: working with horizontal component of slip vector.

Plan view of pyramid bases.

O = projection of apex of large pyramid onto base.

O' = projection of apex of small pyramid onto base.

Magnifying.

Length of OZ = abscissa O' - abscissa O

\[
= \frac{t_1}{\sin A} + \frac{t_2}{\tan A} + \left( c \left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} \right) - \left( \frac{t_1}{\sin B} + \frac{t_2}{\tan B} \right) \right) \frac{\sin B \cdot \cos \delta \cdot \cos \lambda}{\sin \gamma}
\]

To simplify let \( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} + \frac{t_1}{\sin B} + \frac{t_2}{\tan B} = \Gamma \)

and \( \frac{\sin B \cdot \cos \delta \cdot \cos \lambda}{\sin \gamma} = \Lambda \)

Therefore length of \( OZ \) = \( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} + (c - \Gamma) \Lambda - c \Lambda = \frac{t_3}{\sin A} + \frac{t_2}{\sin A} - \Gamma \Lambda \)
Length of $O'Z = \text{ordinate } O' - \text{ordinate } O$

$$= t_2 + \left( c \left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} \right) - \left( \frac{t_1}{\sin B} + \frac{t_2}{\tan B} \right) \right) \sin \beta \cdot \cos \delta \cdot \cos \lambda - c \sin \beta \cdot \cos \delta \cdot \sin \lambda \over \sin \gamma$$

Again, simplifying by defining

$$\frac{t_3}{\sin A} + \frac{t_2}{\tan A} + \frac{t_1}{\sin B} + \frac{t_2}{\tan B} = \Gamma$$

and

$$\frac{\sin \beta \cdot \cos \delta \cdot \cos \lambda}{\sin \gamma} = \Lambda$$

Length of $O'Z$

$$= t_2 + (c - \Gamma).\Lambda - c\Lambda$$

$$= t_2 - \Gamma \Lambda$$

Step eight: bearing of slip vector.

$$\tan \nu = \frac{O'Z}{OZ}$$

$$= \frac{(t_3 - \Gamma \Lambda)}{\left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} - \Gamma \Lambda \right)}$$

Bearing of slip vector = bearing of x-axis - $\nu$

= strike of vein c - $\nu$

Therefore bearing of slip vector = strike (vein c) - $\tan^{-1} \frac{(t_3 - \Gamma \Lambda)}{\left( \frac{t_3}{\sin A} + \frac{t_2}{\tan A} - \Gamma \Lambda \right)}$
Step nine: length of the slip vector.

a) Length of horizontal component of slip.

\[ \sin \alpha = \frac{O'Z}{O'O} \]

\[ O'O = \frac{O'Z}{\sin \alpha} \text{ = horizontal component of slip.} \]

\[ O'O = \frac{t_2 - \Gamma \alpha}{\sin \left( \tan^{-1} \left( \frac{t_2 - \Gamma \alpha}{t_2 + \Gamma \alpha} \right) \right)} \]

b) Plunge of slip vector.

\[ \tan \Phi = \frac{A_P P_L}{A_S P_L} \]

\[ \Phi = \text{plunge of slip vector} \]
\[ A_{1PL} = \left( \frac{t_3 + t_2}{\tan \theta} \right) + \left( \frac{t_1 + t_2}{\tan \beta} \right) \frac{\sin \alpha \cdot \sin \theta}{\sin \gamma} \]

\[ A_{2PL} = \frac{t_2 - \Gamma \Lambda}{\sin \tan^{-1}\left( \frac{t_3 + t_2}{\sin \alpha \tan \Gamma} \right)} \]

Therefore \[ \Phi = \tan^{-1}\left( \frac{\frac{\Gamma \sin \alpha \cdot \sin \theta}{\sin \gamma} \cdot \sin \left( \tan^{-1}\left( \frac{t_3 + t_2}{\sin \alpha \tan \Gamma} \right) \right)}{t_2 - \Gamma \Lambda} \right) \]

Plunge of slip vector, \[ \Phi = \tan^{-1}\left( \frac{\frac{\Gamma \sin \alpha \cdot \sin \theta}{\sin \gamma} \cdot \sin \left( \tan^{-1}\left( \frac{t_3 + t_2}{\sin \alpha \tan \Gamma} \right) \right)}{t_2 - \Gamma \Lambda} \right) \]

c) Length of slip vector.

\[ \sin \Phi = \frac{A_{1PL}}{A_{1AS}} \]

\[ A_{1AS} = \frac{A_{1PL}}{\sin \Phi} = \text{Length of slip vector} \]
Length of slip vector = \[ \frac{\Gamma \sin \alpha \cdot \sin \Theta}{\sin \gamma \cdot \sin (\gamma \cdot \Gamma \sin \alpha \cdot \sin \Theta \cdot \sin (\gamma \cdot \tan^{-1}\frac{(t_2 - \Gamma \Lambda)}{t_2 - \Gamma \Lambda}) + \frac{t_1 + t_2}{\sin \Theta \cdot \tan \Theta})} \]
Summary

Vertical component of slip = $\Gamma \sin \alpha \cdot \sin \theta \over \sin \gamma$

Horizontal component of slip = $\frac{t_2 - \Gamma \Lambda}{\sin \left(\frac{\tan^{-1}\left(\frac{t_2 - \Gamma \Lambda}{\sin \Lambda \tan \Lambda}\right)}{\frac{t_3 + t_2 - \Gamma \Lambda}{\sin \Lambda \tan \Lambda}}\right)}$

Bearing of slip vector = strike (vein c) - $\tan^{-1}\left(\frac{t_2 - \Gamma \Lambda}{\frac{t_3 + t_2 - \Gamma \Lambda}{\sin \Lambda \tan \Lambda}}\right)$

Plunge of slip vector = $\tan^{-1}\left(\frac{\Gamma \sin \alpha \cdot \sin \theta \cdot \sin \left(\frac{\tan^{-1}\left(\frac{t_2 - \Gamma \Lambda}{\frac{t_3 + t_2 - \Gamma \Lambda}{\sin \Lambda \tan \Lambda}}\right)}{t_2 - \Gamma \Lambda}\right)}{\frac{\sin \gamma}{\sin \gamma}}\right)$

Length of slip vector = $\frac{\Gamma \sin \alpha \cdot \sin \theta}{\sin \gamma}$

where $\Gamma = \frac{t_3 + t_2 + t_1 + t_2}{\sin \Lambda \tan \Lambda \sin \beta \tan \beta \over \sin \gamma}$ and $\sin \beta \cdot \cos \delta \cdot \cos \lambda = \Lambda$
b) Thicknesses of veins.

Line \( t' \) is within the outcrop plane and is perpendicular to the intersection of plane C with the outcrop. The plunge of \( t' \) is \( \chi \)

\( t' = \text{apparent thickness in outcrop plane.} \)
\( t = \text{apparent vein thickness in horizontal plane.} \)

\[
\sin \chi = \frac{t'}{t}
\]

\( t' \cdot \sin \chi = t \)

May substitute for thicknesses in previous equations.
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