Advanced Structural Geology, Fall 2022

Simple Deformation

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Just how deformed is this rock?

Or this one?

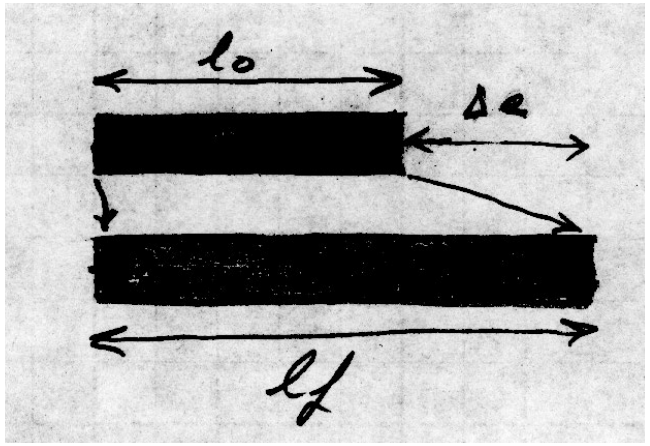
Summary of measures of deformation by changes in lengths of lines

Extension or elongation;

$e = (l_f - l_o)/l_o$ where lo = initial length and lf = final length

Stretch;

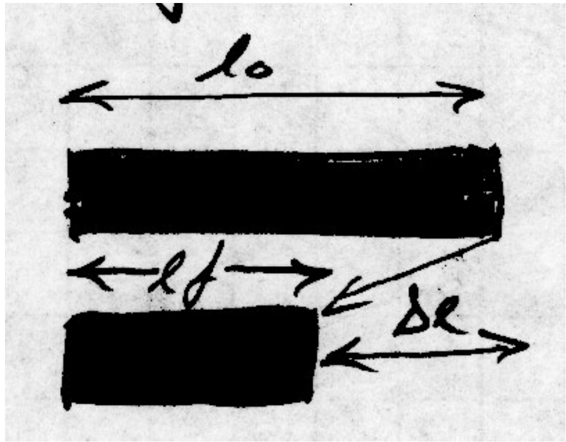
$S = l_f/l_o$ or $s = 1 + e$



"Extension"

$l_f > l_o$, so $e = >0/l_o > 0$

$S = l_f/l_o > 1$



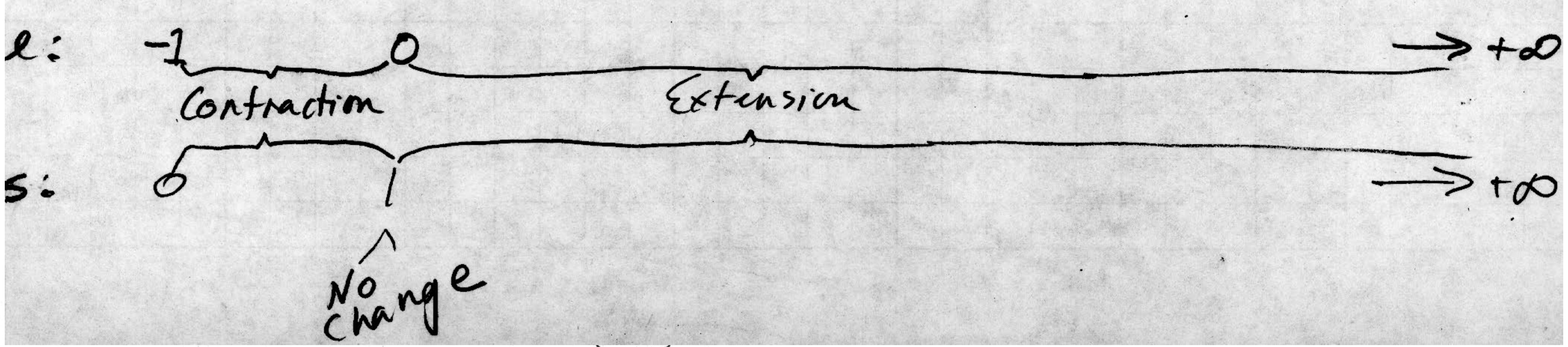
"Shortening", "Contraction", "Negative extension"

$l_f < l_o$, so $e = <0/l_o < 0$

$S = l_f/l_o < 1$

But, when $l_f = 0$, $e = \frac{0 - l_o}{l_o} = \frac{-l_o}{l_o} = -1$

and $s = l_f/l_o = \frac{0}{l_o} = 0$



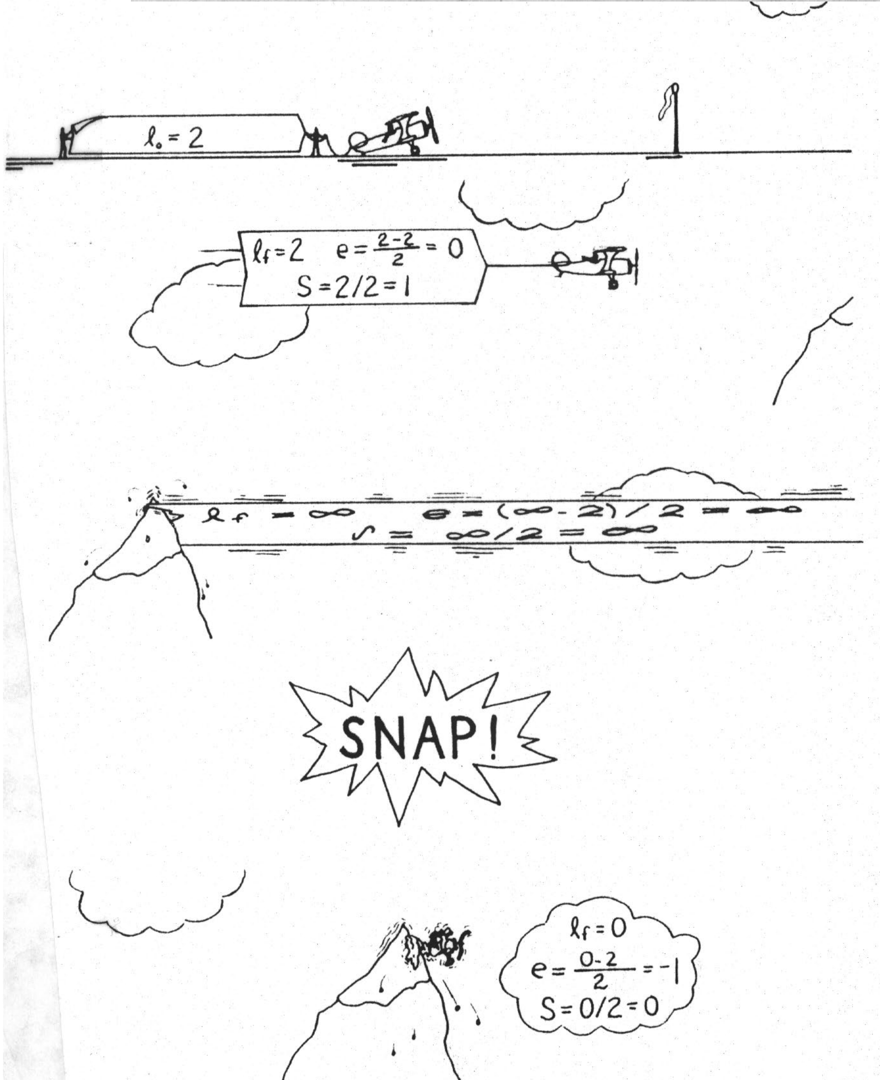
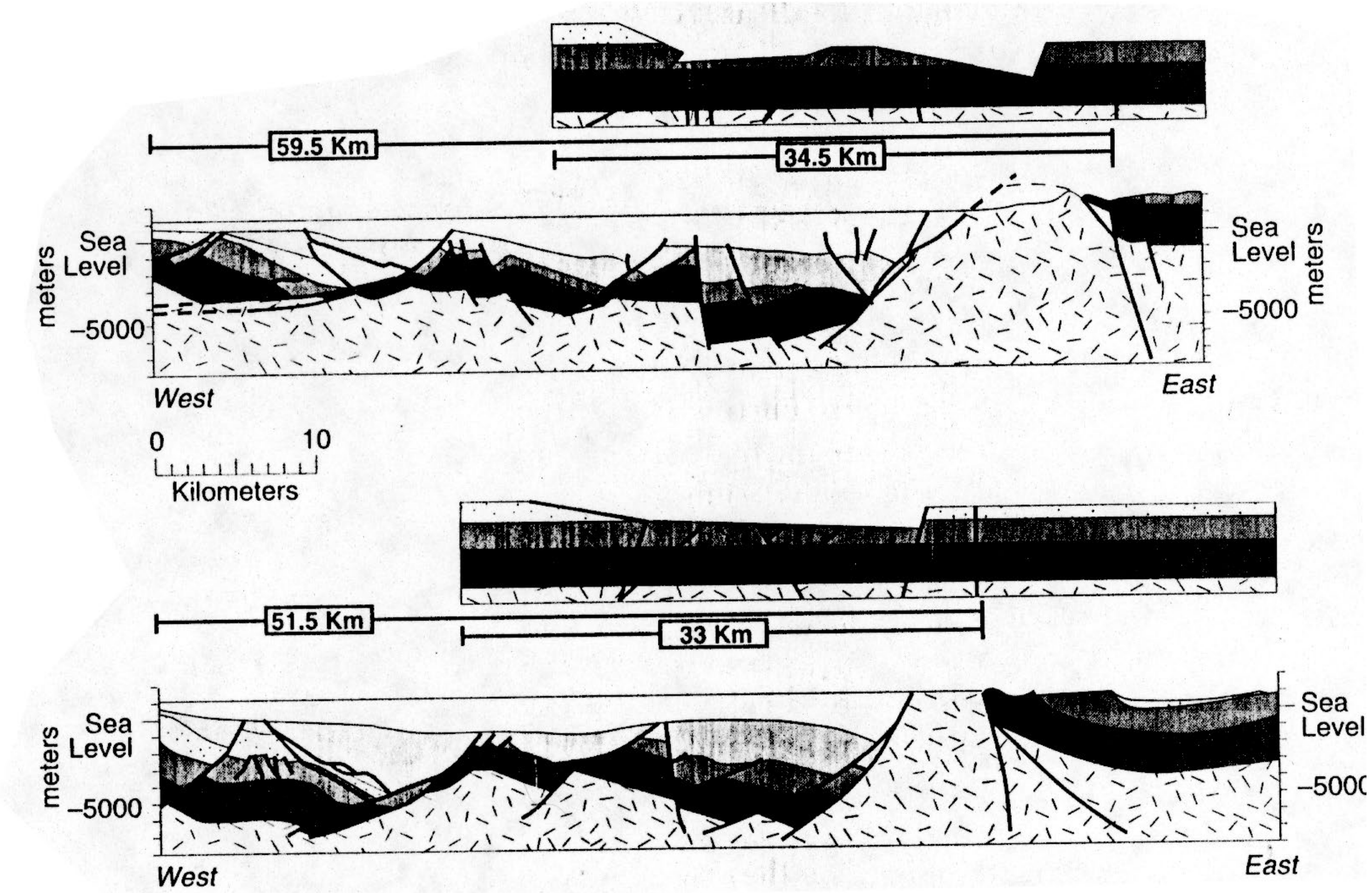


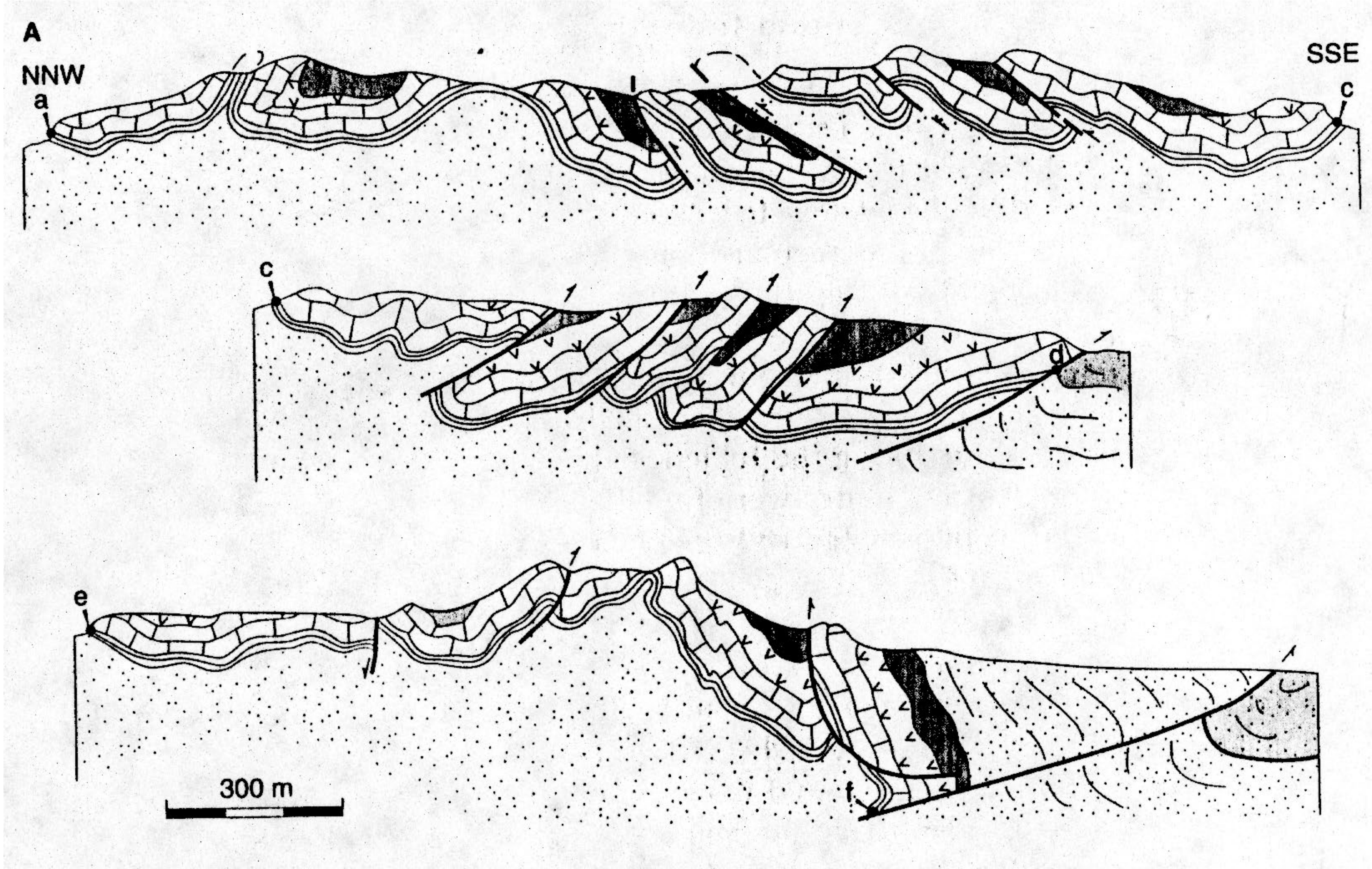
Figure 2.30 The ribbonlike banner that is neither stretched nor shortened has an *e* value of zero and an *S* value of 1.0. If the banner is stretched toward infinite length, both its *e* and *S* values approach infinity. If the banner is shortened toward zero, its *e* value approaches −1 and its *S* value approaches 0. On this particular flight, the airplane to which the banner is attached undergoes non–rigid deformation. (Artwork by R. W. Krantz.)

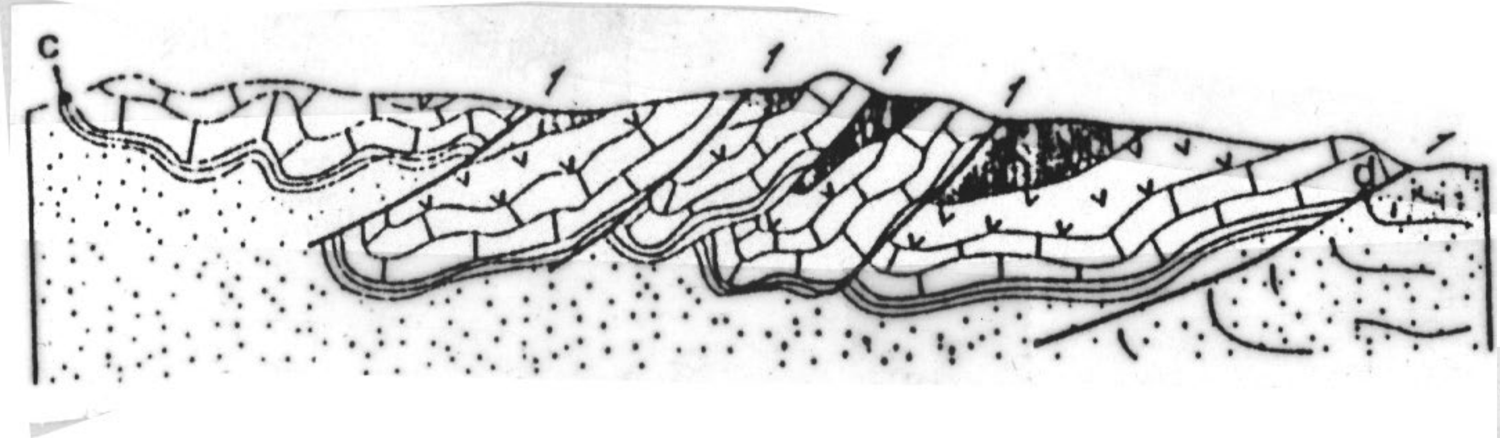
Change in length of region because of faulting

$e = (l_f - l_o)/l_o = (59.5 - 34.5)/34.5 = 25/34.5 = 0.72$
$s = l_f/l_o = 59.5/34.5 = 1+e = 1.72$

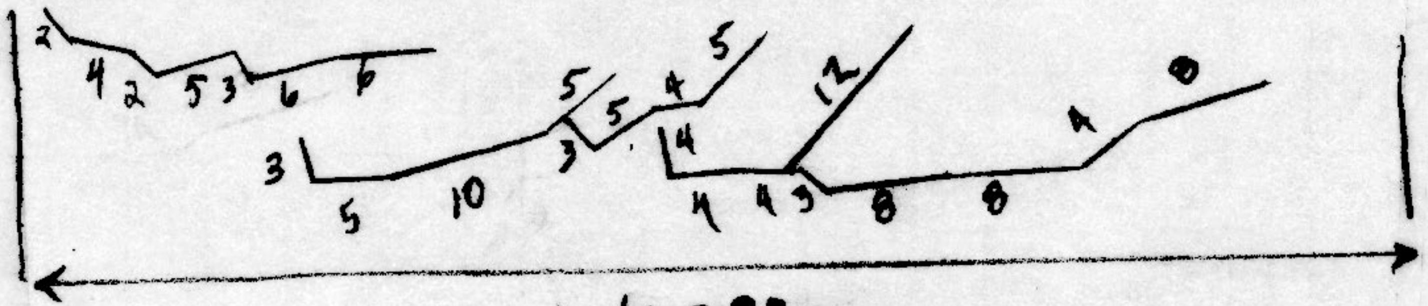


Is e <0 or >0?





Line segments approximating the basal sedimentary layer above
lengths in mm



$l_f = 89$ mm

l_0 = Sum of individual segment lengths = 123 mm

$$e = \frac{l_f - l_0}{l_0} = \frac{89-123}{123} = \frac{-34}{123} = \boxed{-0{,}276}$$ No units

Stretched belemnite

This fossil, discovered in folded rocks in the western Alps by Albert Heim in the nineteenth century (Milnes, 1979), was stretched into an array of rigid shell fragments of approximately equal size. Spaces that developed during deformation were simultaneously filled by calcite. The original length (l_0) of the belemnite fossil can be determined by measuring and summing the widths of the individual shell fragments. The final length (l_f) of the belemnite is simply the total length of the fossil in its present state, including the calcite filling.

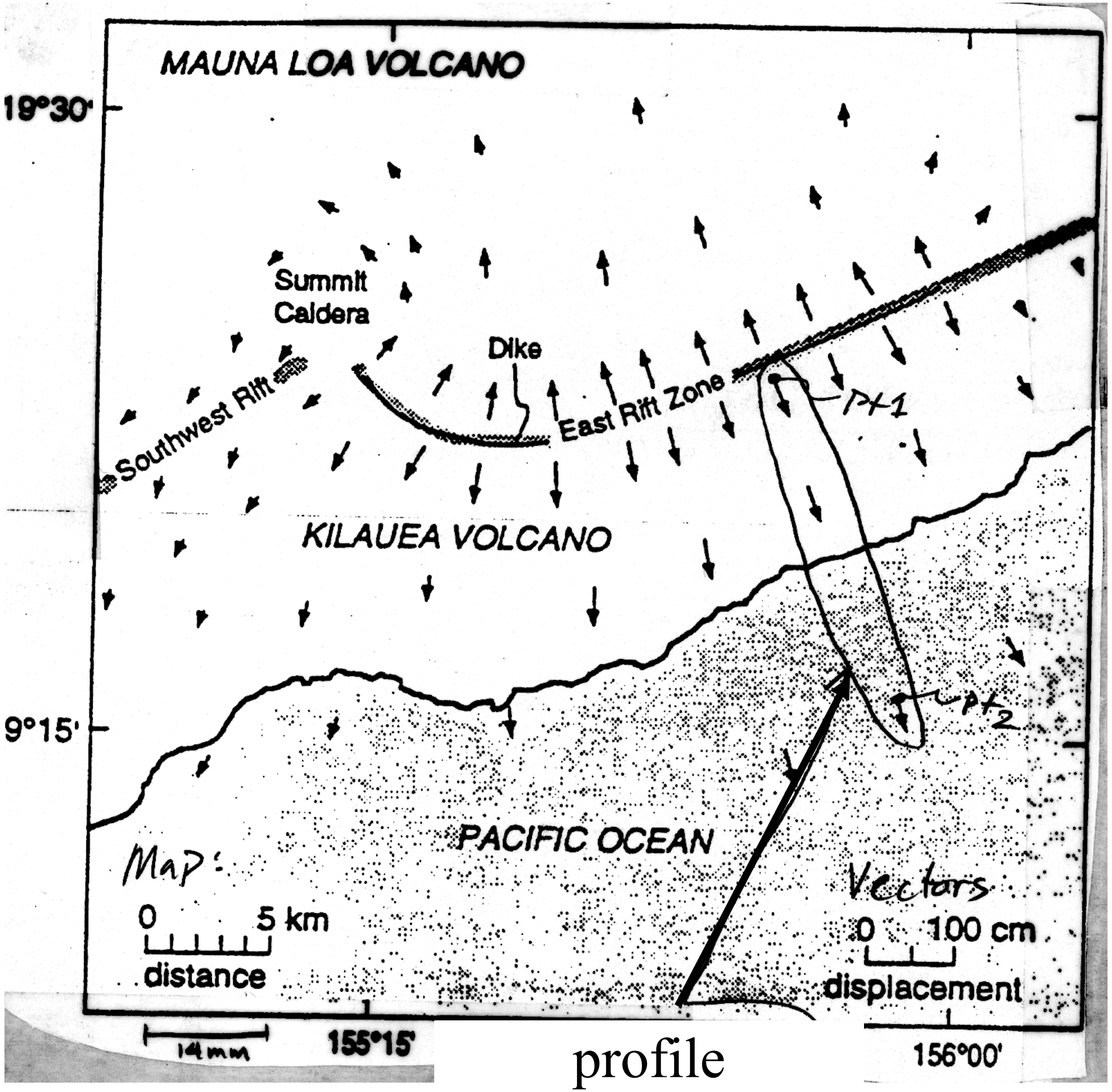
$l_o = 82$ mm, $l_f = 185$ mm

$e = ?$

$s = ?$

Deformation and displacement gradients

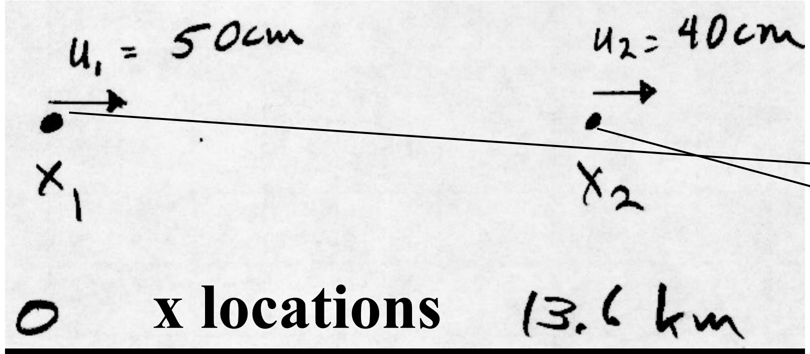
Displacement vectors caused by dike inflation at Kilauea



profile

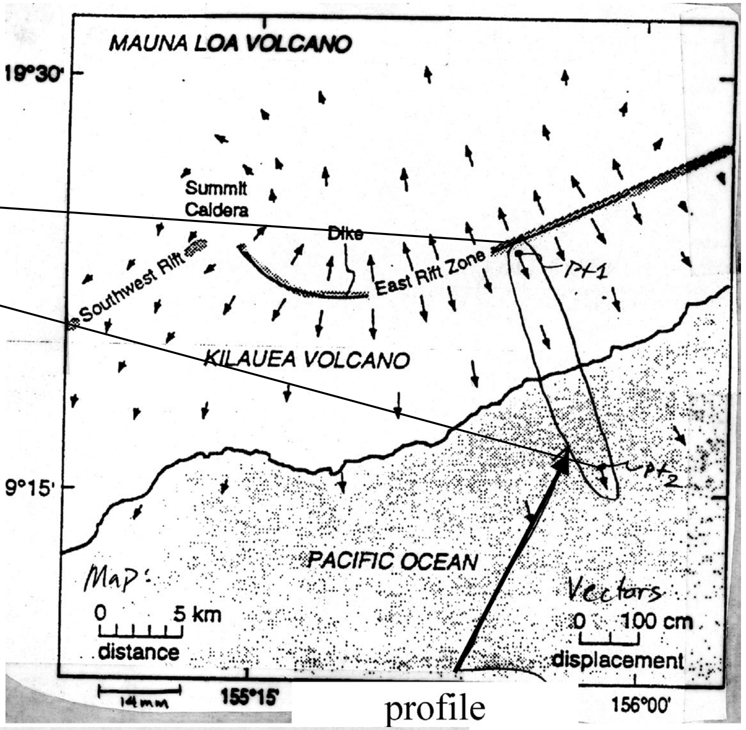
Consider a profile from point 1 to point 2:

u is velocity. x and u are positively increasing to the right



$$e = \frac{l_f - l_0}{l_0}$$

$$= \left[\frac{[(x_2+u_2)-(x_1+u_1)]-(x_2-x_1)}{(x_2-x_1)}\right]$$



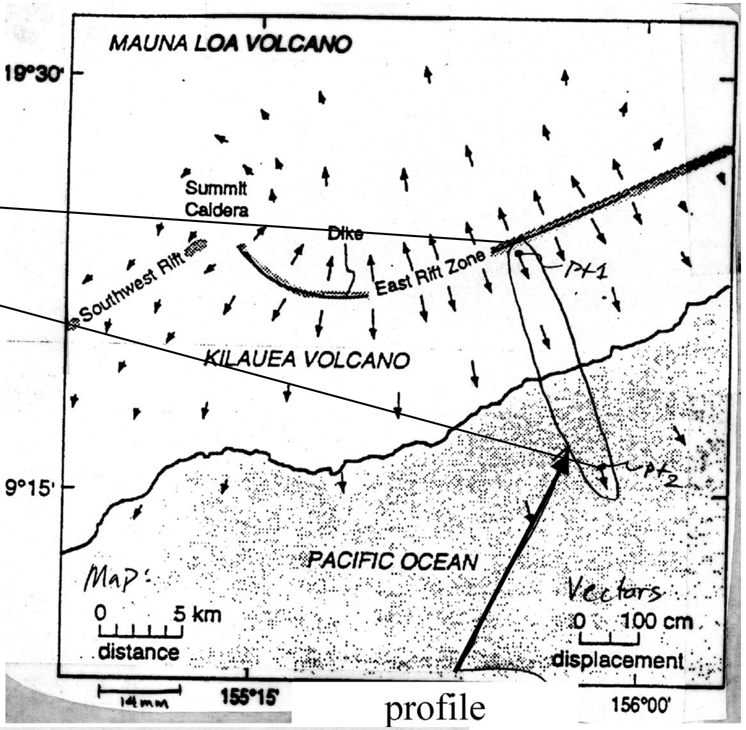
$$\frac{\Delta u}{\Delta x} = \frac{u_2 - u_1}{x_2 - x_1}$$

Consider a profile from point 1 to point 2:

u is velocity. x and u are positively increasing to the right

$u_1 = 50\,cm$ → at x_1 $u_2 = 40\,cm$ → at x_2

0 **x locations** 13.6 km



$$e = \frac{l_f - l_0}{l_0}$$

$$= \left[\frac{[(x_2 + u_2) - (x_1 + u_1)] - (x_2 - x_1)}{(x_2 - x_1)}\right]$$

$$= \left[\frac{[(13600m + 0.4m) - (0 + 0.5m)] - (13600m - 0)}{13600 - 0}\right]$$

$$= \frac{[13600.4m - 0.5m] - 13600\,m}{13600}$$

$$= \frac{13579.9m - 13600m}{13600\,m} = -$$

$$= \frac{-0.1\,m}{13600\,m} = -7.4 \times 10^{-6}$$

No units

$$\frac{\Delta u}{\Delta x} = \frac{u_2 - u_1}{x_2 - x_1}$$

$$\frac{0.4m - 0.5m}{13600m - 0m} = \frac{-0.1\,m}{13600m}$$

Same result

Deformation rates

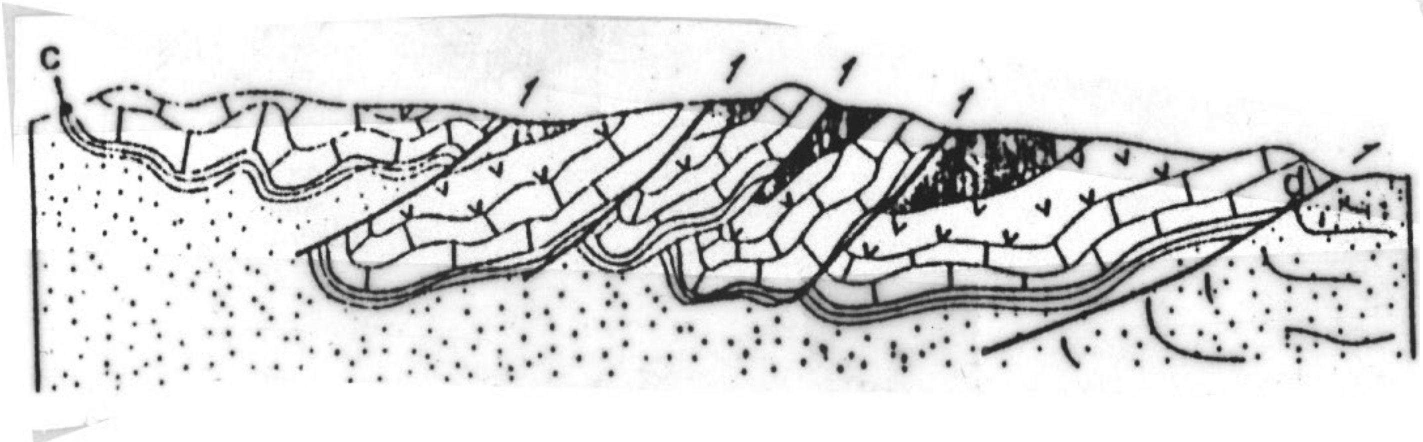
If we take the Kilauea example as a representative geologic deformation rate (and it is), how long would it take to build a structure like that shown below?

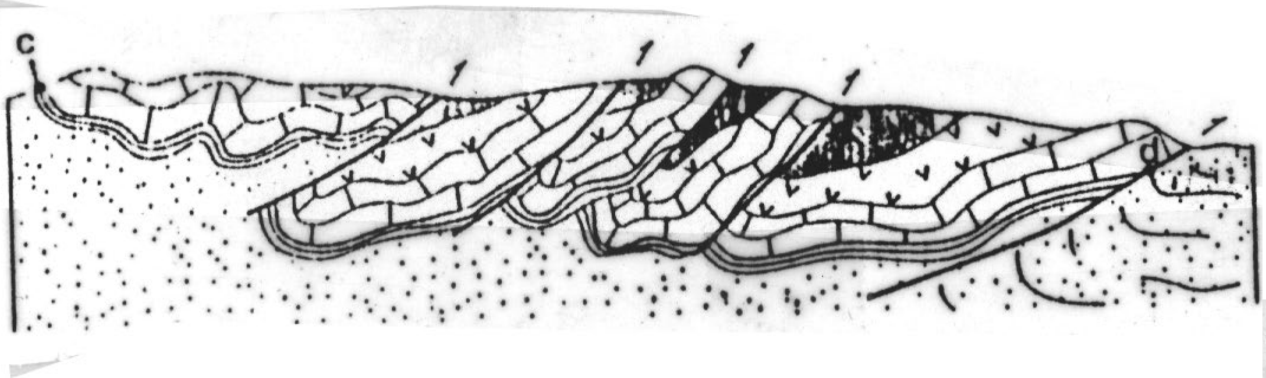
For Kilauea, we got $-7.4 \times 10^{-6} = e$ over 20yrs

to the contraction rate, $\dot{e} = \frac{-7.4 \times 10^{-6}}{20\,yr} = -3.7 \times 10^{-7}\ yr^{-1}$

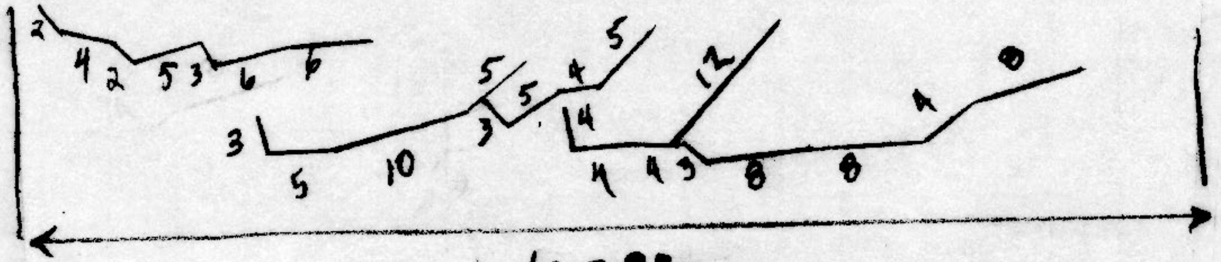
$-3.7 \times 10^{-7} \frac{1}{yr} \cdot \frac{1yr}{365days} \cdot \frac{1day}{24hrs} \cdot \frac{1hr}{60min} \cdot \frac{1min}{60sec} =$

$-1.2 \times 10^{-14}\ sec^{-1}$





Line segments approximating the basal sedimentary layer above
lengths in mm



$l_f = 89\text{mm}$

l_0 = Sum of individual segment lengths = 123 mm

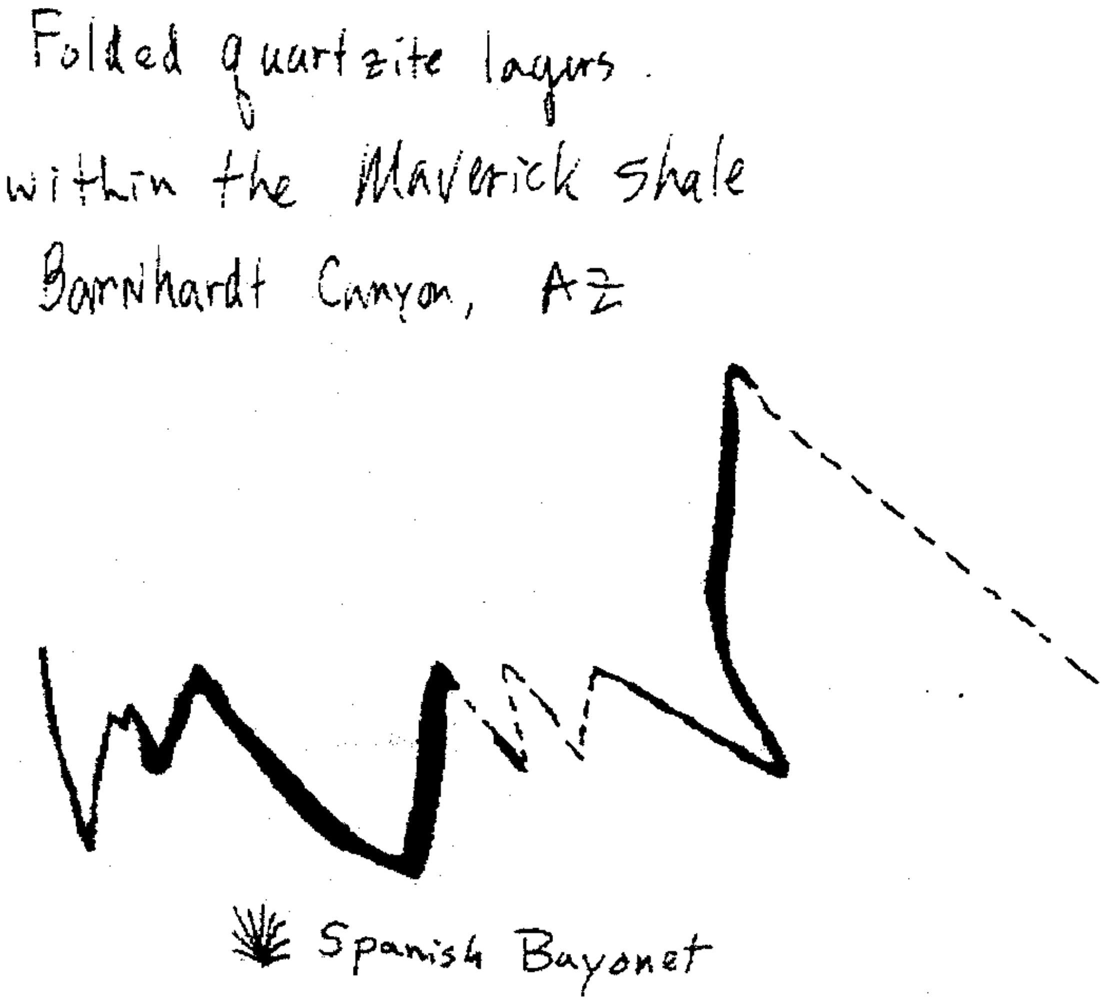
$$e = \frac{l_f - l_0}{l_0} = \frac{89-123}{123} = \frac{-34}{123} = \boxed{-0.276} \quad \text{No units}$$

We want time, so we divide e (extension) by $\dot{e}$ (extension rate):

$$\frac{-0.276}{-3.7\times10^{-7}\,yr^{-1}} =$$ **7.5×10^{5} yr**

750,000 yrs!


Folds!

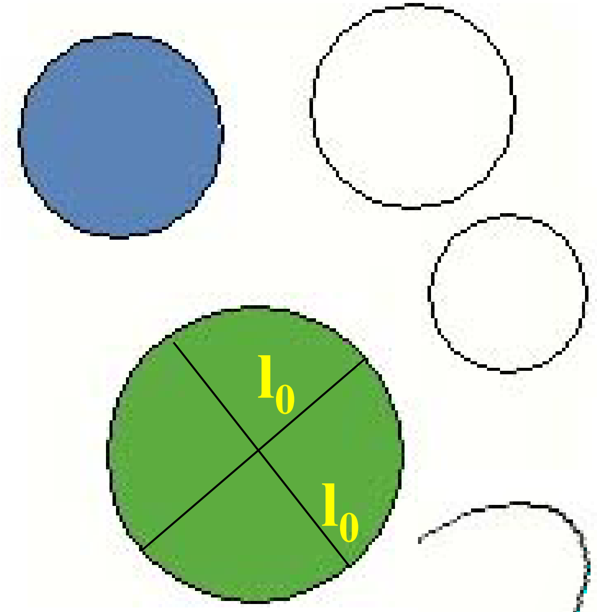


Determine the magnitude of shortening (e) of this bed assuming that it was originally planar

If a reasonable shortening rate is –1 x 10^{-7}/yr, how long would it take to make these folds?

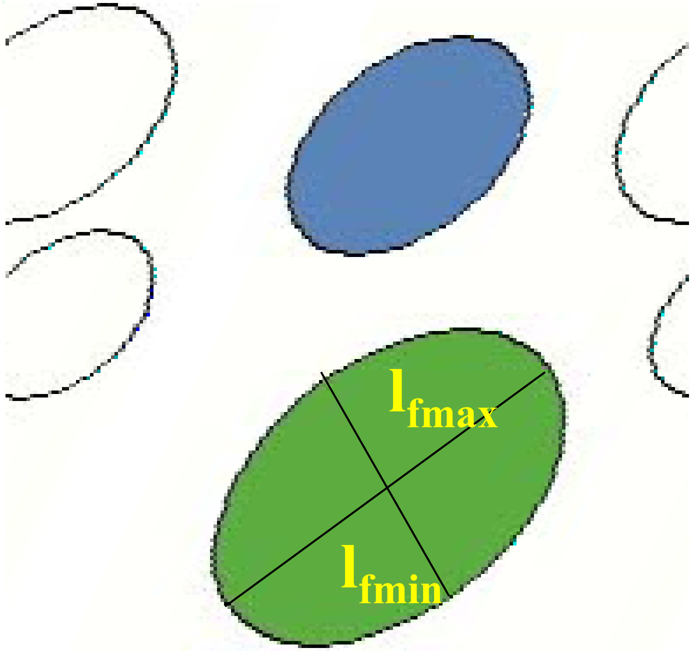
Moving from 1 to 2 to 3 dimensional deformation

- E and s as we have defined them in the last two lectures are 1 dimensional (measured along l_f).
- In a deformed material; however, we can define the minimum and maximum stretches and they will be perpendicular

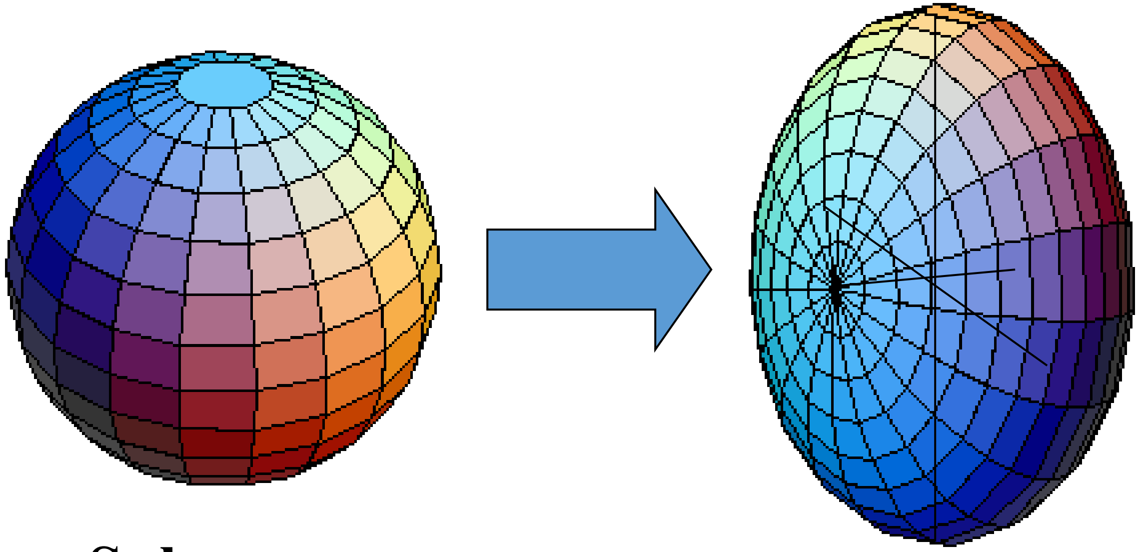


$s_{min}=l_{fmin}/l_0$

$S_{max}=l_{fmax}/l_0$



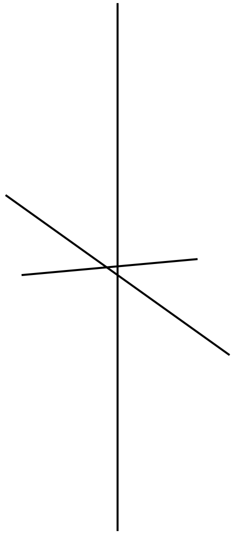
Principal stretches

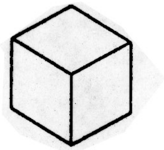


Sphere

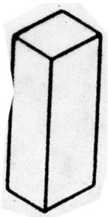
Ellipsoid

In 3D, S_1 is max, S_3 is min, and S_2 is intermediate





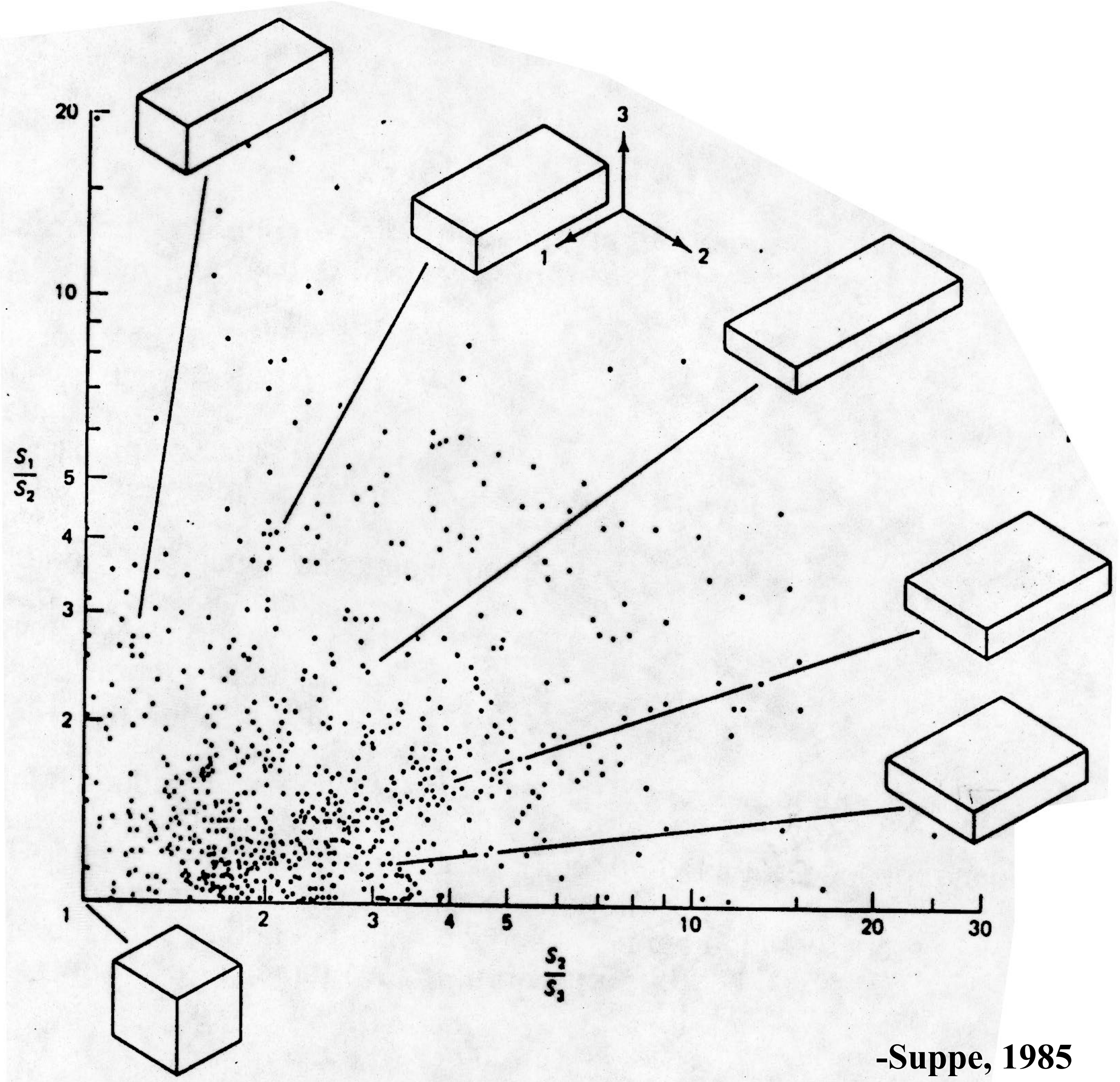
Cube



Prism

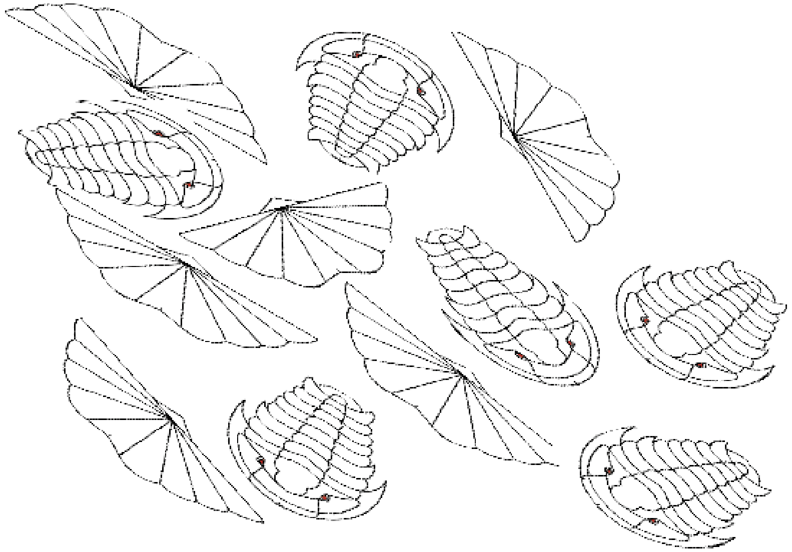
Measured stretch ratios in rocks from around the world

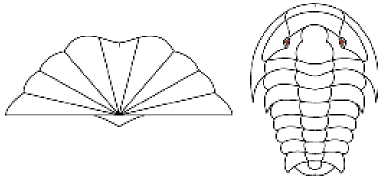
"Constriction"



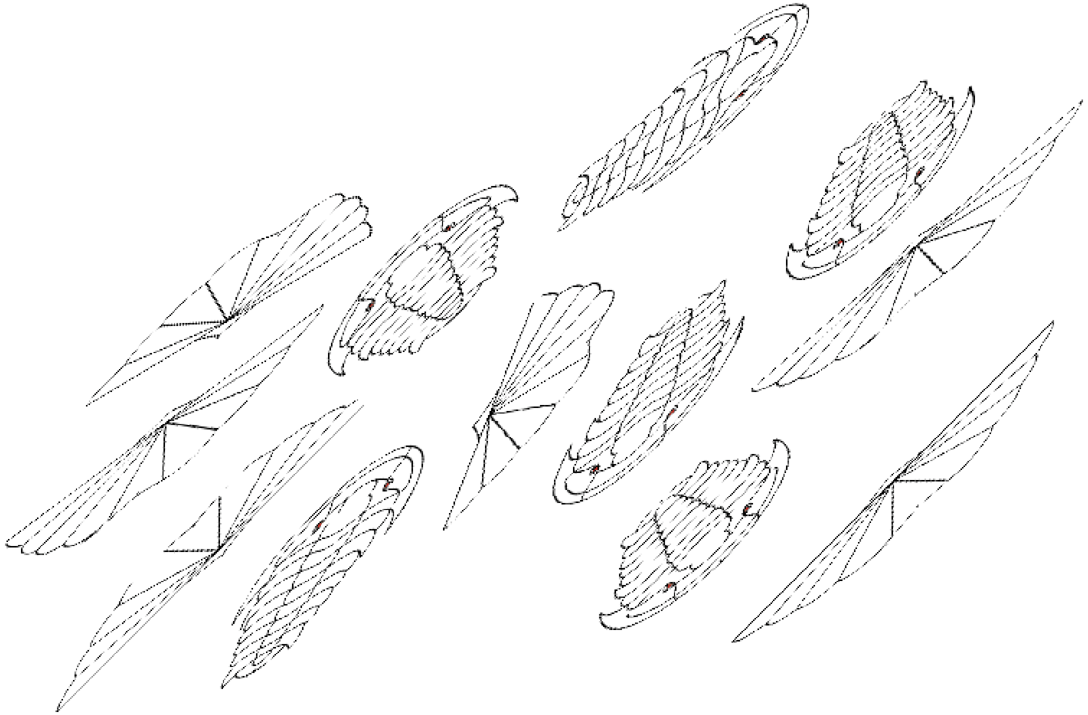
"Flattening"
More common

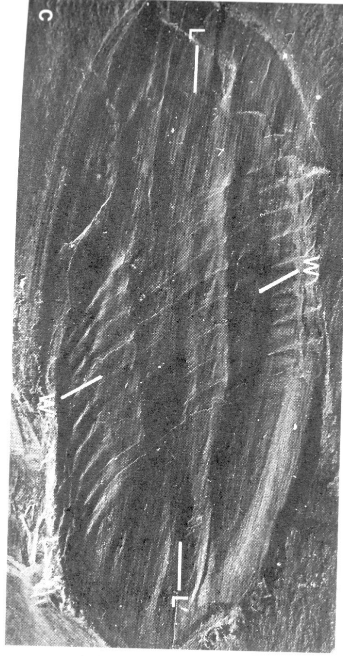
-Suppe, 1985





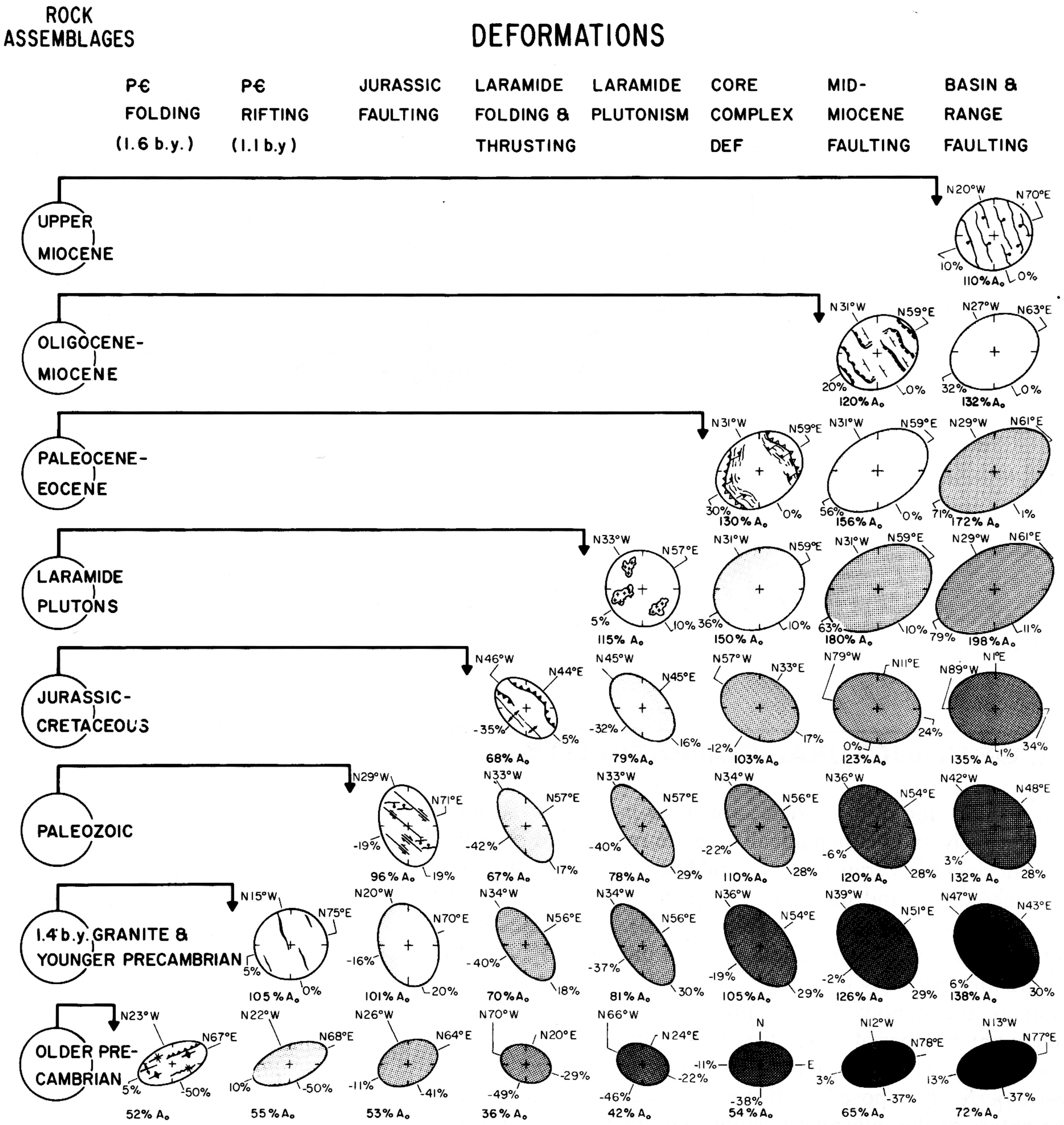
Draw the stretch ellipse for each





Deformed trilobites do exist!

Progressive strain



History of regional deformation in southern Arizona