Slip-sliding away
How does monitoring fault creep help to forecast earthquakes?

Since the 1980s, scientists have used GPS (Ground Positioning System) satellite technology to accurately measure, with a precision of just a few millimetres, the slow creep along faults that eventually leads to their rupture and an earthquake. Fault creep is monitored using **repeated** surveys in which the precise position of fixed surface markers on either side of a fault zone are located by GPS and changes measured over time. There are three main types of survey; two involve very accurately measuring horizontal changes in the angles between markers on the ground or the distances between markers. The third (not covered here) measures vertical changes in elevation of the markers over time. Monitoring faults in this way gives an indication of the amount of strain building up over time in an attempt to help forecast earthquakes.

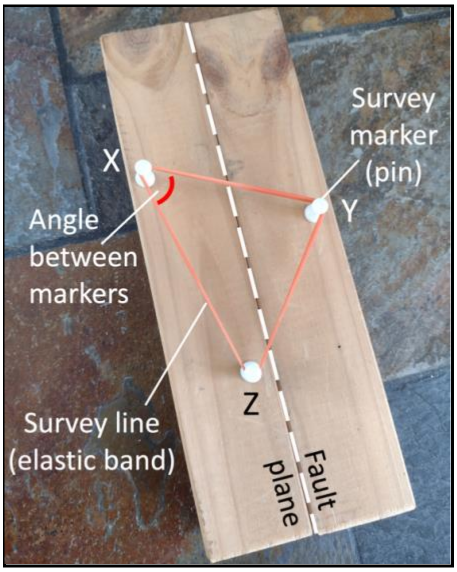

Fig 1. Simulating a monitoring survey (*Pete Loader*)

Simulating a monitoring survey

A simplified 3D simulation of a monitoring survey across a fault zone can be produced using two wooden (or other) blocks, three pins and an elastic band (Fig 1). The survey lines are represented by the sides of the elastic band stretched between three fixed survey markers (pins) on either side of the 'fault zone' between the blocks. Students might be encouraged to make their own models.

Relative displacement of the blocks results in changes to the distance measured between the fixed survey markers. This is recorded as a positive gain or negative loss in length of the survey lines between successive surveys. Survey line **X-Z** remains constant as it does not cross the fault. The amount of creep is also determined from the change in the angles between marker points (relative to the survey line **X-Z**).

Demonstrate that relative displacement will also occur even if both blocks are moved in the **same direction** but at **different rates**.

Presented with the simplified model, students are asked to:

- suggest what changes to the survey lines they can observe as the two blocks are moved **relative** to each other in either direction;
- record these changes as the blocks are moved one centimetre at a time relative to each other;
- use the data from their measurements to draw a line graph of changes in the length of the survey lines over time.

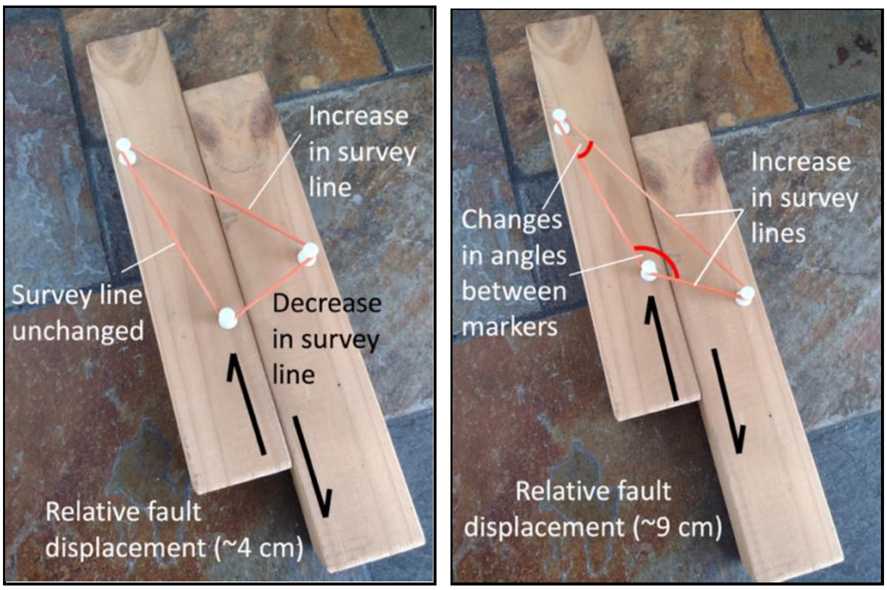

Fig 2a. Progressive slippage along the fault – note the change in angles and lengths of survey lines (*Pete Loader*)

Monitoring survey data across the San Andreas Fault system.

Following the simulation, students might be asked to analyse data from an actual monitoring survey across the San Andreas Fault system in central California during which time there were no significant earthquakes (Fig 3b). Here both the North American and Pacific plates are moving towards the NW but at different rates with the resulting **relative** displacement across the San Andreas fault shown in Fig 3a.

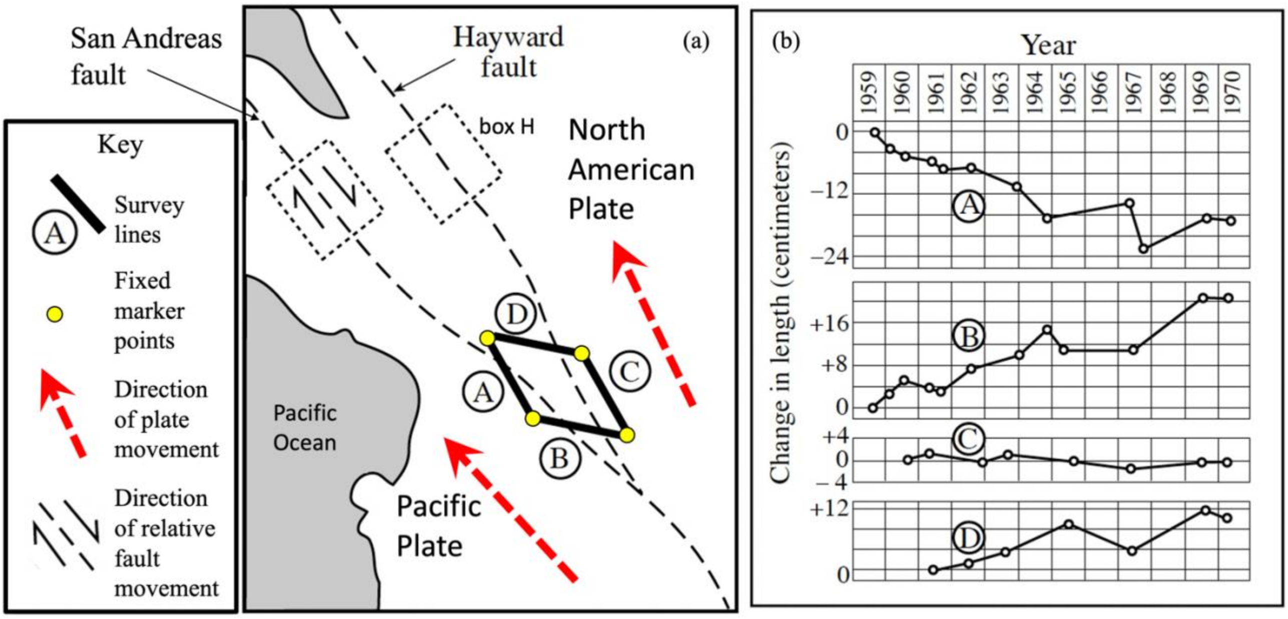

Fig 3 (a) Survey lines across the San Andreas fault system – central California, (b) Changes in the length of survey lines (1959 – 1970)

Students are asked to:

- calculate the average rate of change in the length of the survey line (**A**) between 1959 – 1970;
- describe the main difference in changes to the lengths of survey lines (**A**) and (**B**) over time;
- explain the difference in the average rate of change in the length of survey line (**B**) compared to that of (**C**);
- use the survey data to draw in the direction of **relative** fault displacement on either side of the Haywood Fault in **box H**;
- suggest which plate (Pacific or North American) is moving NW at the faster rate;
- explain how monitoring surveys might be used to forecast an impending earthquake in this area.

The back up

Title: Slip-sliding away

Subtitle: How does monitoring fault creep help to forecast earthquakes?

Topic: A simulation and case study of a monitoring survey used to monitor the slow creep along fault planes that leads to the build-up of strain prior to its release in an earthquake.

Age range of pupils: 16 – 18 years

Time needed to complete activity: 20 minutes

Pupil learning outcomes: Pupils can:

- identify the quantitative methods used to measure fault creep over time;
- explain the difference between relative displacement across a fault and the actual direction of plate movement;
- identify that displacement across fault planes (creep) does not always result in rupture but can be used to measure the build-up of strain prior to an earthquake;
- interpret and mathematically manipulate spatial data given in maps and graphs.

Context:
The simulation demonstrates that permanent markers on the Earth's surface, fixed by GPS, can show measurable changes in angular bearing and distances from each other as ground deformation causes faults to slowly creep.

In the San Andreas system, the length of survey line **(A)** decreased over time (calculated to be approximately 2 cm/yr.) as the distance between markers shortened, whilst survey line **(B)** was stretched and increased in length. Survey line **(C)** remained more or less constant as it does not cross the fault.

When reference is made to survey line **(D)** the overall increase in the length suggests the survey line is being stretched. This shows the relative displacement across the Haywood Fault is to the **right**, similar to the San Andreas Fault, and contrary to the direction of plate movement. When compared with survey lines (**A**) and (**B**) it is evident that the Pacific plate is moving NW at a **faster rate** than the American plate.

Note:
- The angular bearings between markers will have also changed over time but this is not recorded in these data.

Following up the activity:
Ask students to research:
- when this area last experienced an earthquake;
- seismic gaps;
- elastic rebound theory.

Underlying principles:
- When tectonic stresses cause stretching or shortening of the ground surface, survey lines crossing a fault zone will be shortened or lengthened over time and the angles between fixed markers will change.
- Constant monitoring of these changes will identify the strain locked in a fault zone as fault blocks creep past each other without causing an earthquake.
- These data can be used to monitor sudden changes in creep rates which may help in forecasting an earthquake.

Thinking skill development:
Analysing the graphs establishes a pattern of extension or shortening of the survey lines. The direction of relative displacement along the Haywood fault is contrary to the direction of movement of the North American plate causing cognitive conflict. Explaining and discussing the results of the surveys involves metacognition. Applying data from the model to the real world involves bridging.

Resource list:
- two wooden (or other) blocks
- three pins/nails
- one elastic band
- San Andreas monitoring data

Useful links:
https://www.earthlearningidea.com/PDF/359_Mars_plate_margins.pdf

Source: Activity devised and written by Pete Loader of the ELI Team based on an idea in 'Teaching Earth Sciences', Vol. 30 No. 3 2005. San Andreas data - after Bolt (Earthquakes 1993). Photos by Pete Loader