Determining earthquake recurrence intervals from trench logs: a multi-faceted, thought-provoking exercise for students at all levels

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Abstract

Trench logs of the San Andreas Fault at Pallett Creek, California are the data base for a lab or homework assignment that teaches about relative dating, radiometric dating, fault recurrence intervals and the reasons for uncertainty in predicting geologic phenomena. Students are given a trench log that includes several fault strands and dated stratigraphic horizons. They estimate the times of faulting based on bracketing ages of faulted and unfaulted strata. They compile a table with the faulting events from the trench log and additional events recognized in nearby trenches, then calculate maximum, minimum and average earthquake recurrence intervals for the San Andreas Fault in this area. They conclude by making their own prediction for the timing of the next earthquake. While basically an exercise in determining relative ages of geologic horizons and events, this assignment includes radiometric dates, recurrence intervals, and an obvious societal significance that has been well received by students.

With minor modifications, this exercise has been used successfully with elementary school students through university undergraduate geology majors. Less experienced students can work in groups, with each group determining the age of a single fault strand; combining the results from different groups and calculating recurrence intervals can then be done as a class activity. University students in an introductory geology course for non-majors can add their data from the trench log to an existing table with other faulting events already provided. The exercise can be made more challenging for advanced students by using logs from several different trenches, requiring students to design the table themselves, and giving students the uncertainties for the radiometric dates rather than simple ages for the strata. Most students - at all levels - are initially frustrated by their inability to determine an exact date of faulting from the available data. They gain a new appreciation for the task of the geoscientist who attempts to relate geologic phenomena to the human, rather than geologic, time scale.

The Assignment- Student Handout

The details of fault activity at any given location are determined from trenching studies. Trenches dug across the fault expose the sedimentary layers nearest the ground surface (therefore, the youngest layers). By mapping fault offsets of individual layers, geologists can determine the amount of fault slip for each event, and estimate the magnitude of the associated earthquakes. By dating any carbonaceous material in the layers (using ^{14}C), they can calculate the frequency of faulting events. This frequency is usually expressed as recurrence interval, i.e., the interval of time between faulting events.

Data for the following problem are from a landmark study at Pallett Creek, California, by Kerry Sieh, published in the Journal of Geophysical Research. The San Andreas fault forms the boundary between the Mojave Desert, to the northeast, and the San Gabriel Mountains, to the southwest. The Pallett Creek trenching site is along this boundary. The marsh sediments deposited where Pallett Creek emerges from the San Gabriel Mountains and enters the Mojave Desert preserve a detailed record of faulting history.

The following trench log, from Sieh's trench 1 (or 5, 10, or 11), shows several closely spaced strands of the fault, designated by letters, which have moved at different times. All of these strands probably merge at a fairly shallow depth, but their distribution in this trench (particularly the separation of the different strands near the ground surface) makes this an ideal place to unravel the movement history along this part of the San Andreas Fault. The stratigraphic horizons which contained datable material are numbered on the trench log, and the results of ^{14}C dating are shown in the following table. The ages of the layers are presented as the calendar date of deposition, not as "years before present" which is commonly used by geologists.

In addition, it is known from historical records that the most recent earthquake along this part of the fault was in 1857.

WHAT TO DO FOR THIS HOMEWORK ASSIGNMENT:

1. For each lettered strand of the fault, determine both the youngest layer it offsets and the oldest layer that is deposited across the top of it without being offset. These two dates bracket the most recent motion on that strand of the fault. Use these data to fill in the data table (attached). List the faulting events in chronological order, with most recent events at the top. From studying other trenches and exposures at Pallett Creek, Sieh concluded that there were several faulting events in addition to the ones you see in trench 1 (or 5, 10, or 11). These are already listed, in the correct order, on the data table.

Once you have filled in the dates that bracket each faulting event, make your best estimate of exactly when (between those dates) the faulting actually occurred, and put that date in the correct column on the table.

Determine the time interval between events, and use this to fill in the "recurrence interval" column of the table.

Include the completed table in your report.

2. Using all of the data in your table, answer the following questions:
How many faulting events are documented at Pallett Creek?
What is the shortest time interval between events? What is the longest?
What is the average recurrence interval for faulting in this area?

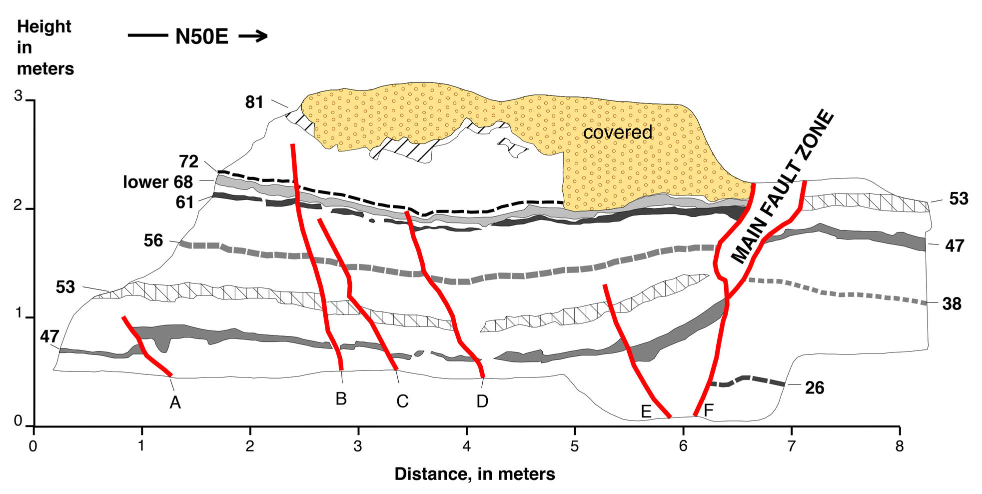
3. Assuming that the data from Pallett Creek are representative of the present slip rate along the San Andreas, and that they can be extrapolated to predict future activity along this part of the fault, interpret your data to answer the following questions.
Given that the last slip event on this part of the fault was in 1857, what does the geologic record here predict will be the time range in which the next big event will occur?
If the next event occurs at the average recurrence interval, when will it occur?
[NOTE: Include your answers in your report. It is NOT necessary to write the answers here. Should these answers be included in the "Data" or "Interpretation" portion of the report?]

Please turn in:
1) A one-page, typed report, using the same outline as your lab reports.
2) The data on which your report is based, i.e., trench log, data table.

Overview

These four examples, developed for use in different semesters, are from four of the trenches at Pallett Creek (Sieh, 1978). The students are given the trench log and a list of the dated horizons in that trench; from these, they fill out a table to estimate the timing for each of the fault splays exposed in the trench. Not all faulting events (or dated stratigraphic horizons) occur in each trench, however, so the additional faulting events are already filled out in each table. The students can then calculate maximum, minimum and average recurrence intervals based on all faulting events recorded at Pallett Creek.

Pallett Creek Trench 1



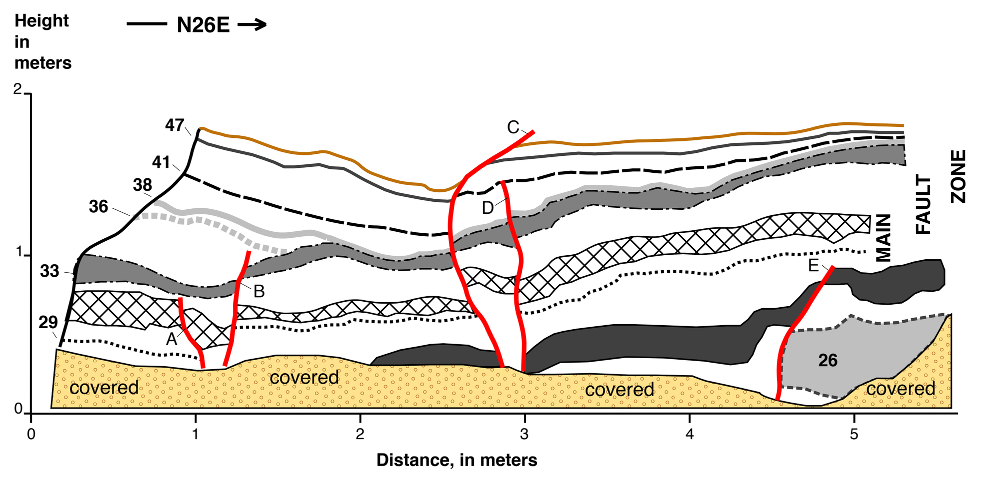
Sedimentary layers are labeled numerically, from oldest to youngest; not all are shown here
Faults are labeled alphabetically, from southwest to northeast

Layer #	Calendar date (A.D.) of deposition
81	1812
72	1480
lower 86	1410
61	1235
53	1050
47	955
38	800
26	680 (above top of bed)

Faulting events at Pallett Creek Trench 1

Fault strand	Youngest layer offset	Oldest layer not offset	Estimated time of faulting (calendar date)	Recurrence interval (in years)
F	ground surface		1857	
			1346	
			797	
			734	63
			671	more than 142
			pre-529	

Pallett Creek Trench 5



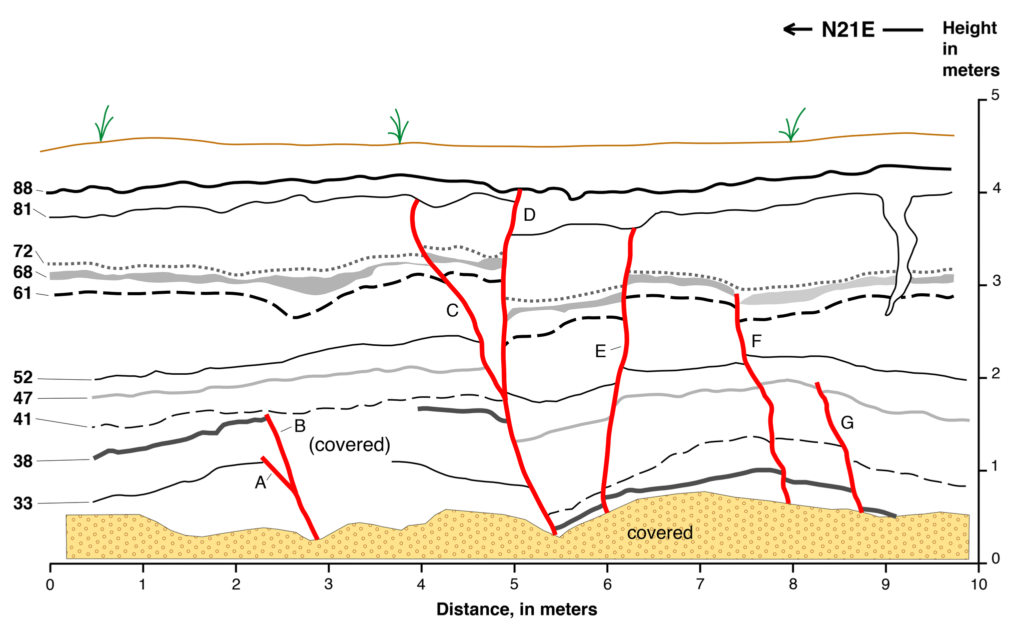
Sedimentary layers are labeled numerically, from oldest to youngest; not all are shown here
Faults are labeled alphabetically, from southwest to northeast

Layer #	Calendar date (A.D.) of deposition
47	955
41	~ 825
38	800
33	740
26	680 (above top of bed)

Faulting events at Pallett Creek Trench 5

Fault strand	Youngest layer offset	Oldest layer not offset	Estimated time of faulting (calendar date)	Recurrence interval (in years)
C	ground surface		1857	45
			1812	
			1480	
			1346	
			1100	
			1048	
			pre-529	

Pallett Creek, Trench 10



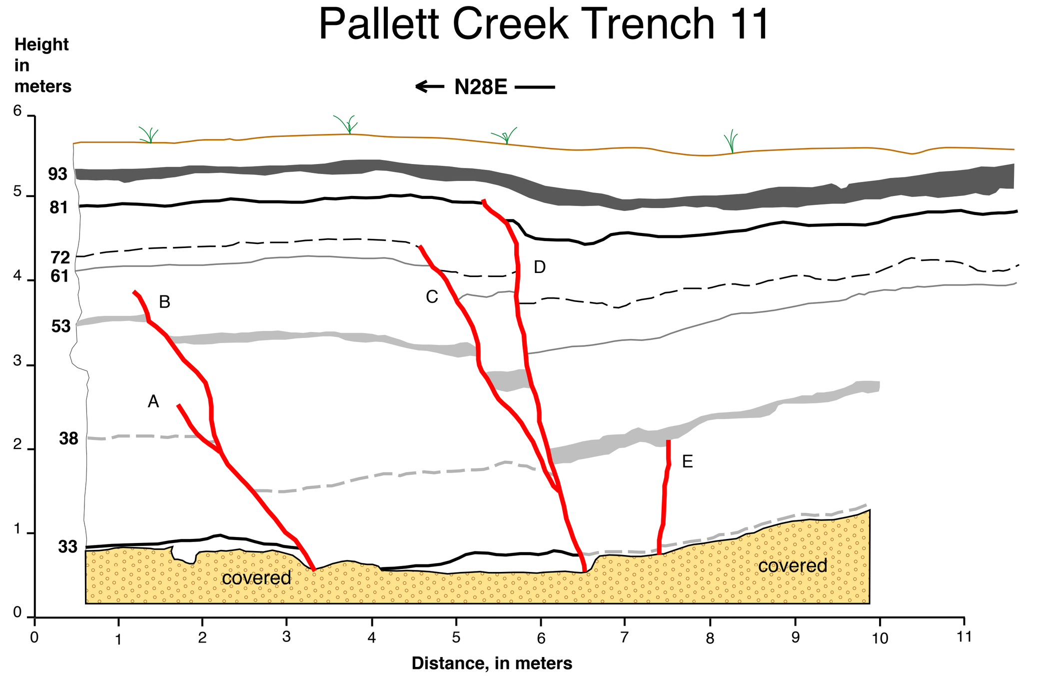
Sedimentary layers are labeled numerically, from oldest to youngest; not all are shown here
Faults are labeled alphabetically, from northeast to southwest

Layer #	Calendar date (A.D.) of deposition
88	1857
81	1812
72	1480
68	1480
61	1235
52	1050
47	955
38	800
33	740

Faulting events at Pallett Creek Trench 10

Fault strand	Youngest layer offset	Oldest layer not offset	Estimated time of faulting (calendar date)	Recurrence interval (in years)
D	81 (1812)	post 1857	1857	
			1346	246
			1100	
			997	
			671	more than 142
			pre-529	

Pallett Creek Trench 11

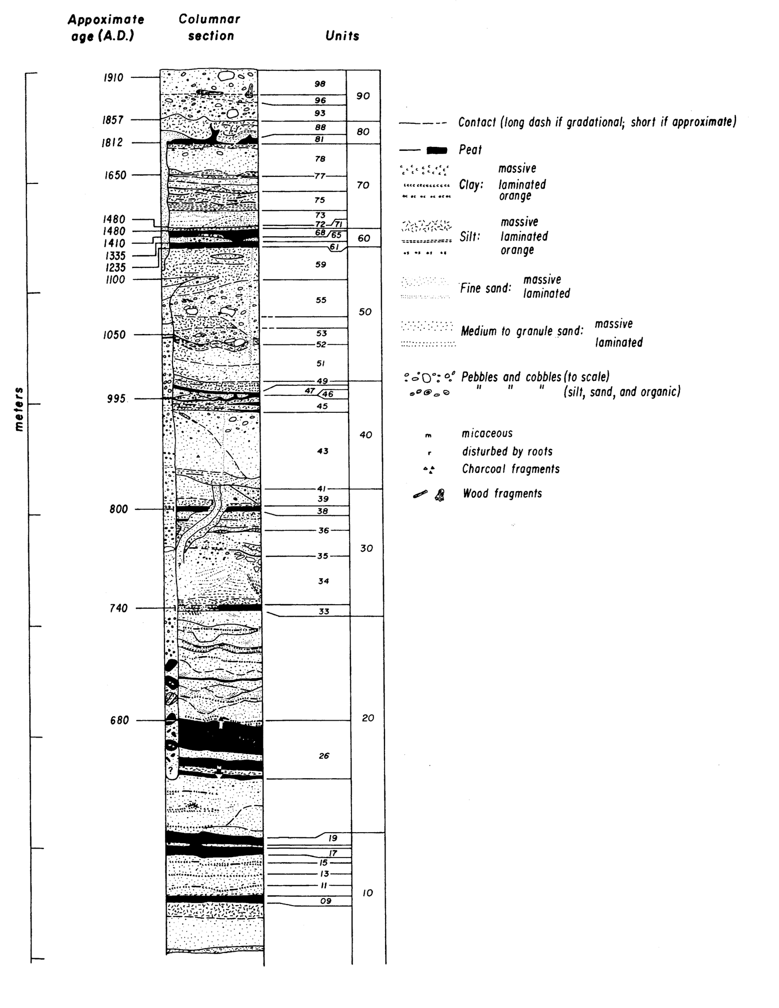


Sedimentary layers are labeled numerically, from oldest to youngest; not all are shown here
Faults are labeled alphabetically, from northeast to southwest

Layer #	Calendar date (A.D.) of deposition
93	post 1857
81	1812
72	1480
61	1235
53	1050
38	800
33	740

Faulting events at Pallett Creek Trench 11

Fault strand	Youngest layer offset	Oldest layer not offset	Estimated time of faulting (calendar date)	Recurrence interval (in years)
D			1857	
			1812	
			1346	
			797	
			734	
			671	more than 142
			pre-529	



Composite columnar section for Pallett Creek trenches (from Sieh, et al., 1989)

Teaching tips

Students have settled into this assignment much more readily when I have shown a few photographs in class of trenches -- and how they are logged -- before handing out the assignment. If the students have no previous experience with relative dating, I go through an example of how to determine the age of a fault, or have them start the homework exercise in class.

Most students, at all levels, are initially frustrated by their inability to determine *exactly* when each fault moved. We have added a few undated horizons to the trench logs where this would reduce ambiguity about relative ages of faults that cut the same dated layers. When discussing student questions about exact timing, we point out that geologists who initially did the work here had the same questions about precise age control.

In the past, we have asked students to make their own data tables as part of this assignment. With introductory-level non-science majors, however, there were so many questions about making the table, we were concerned that the students were focusing on that and losing sight of the main point of the exercise. We have since gone to the tables shown here, but recommend that more advanced students or geology majors be required to design their own data table.

In the past, we have tried giving students the original age data (see Sieh and others, 1989), with plus-and-minus values for each date. Again, this has resulted in enough confusion in the target audience that it seemed like the main point of the exercise was not getting through. Original age data could be used by more advanced students, and would probably provoke some good discussions.

References Cited

Sieh, K. E., 1978, Prehistoric large earthquakes produced by slip on the San Andreas Fault at Pallett Creek, California: Journal of Geophysical Research, A, Space Physics, v. 83, n. B8, p. 3907-3939.

Sieh, K., Stuiver, M., Brillinger, D., 1989, A more precise chronology of earthquakes produced by the San Andreas Fault in Southern California: Journal of Geophysical Research, B, Solid Earth and Planets, v. 94, n. 1, p. 603-623.