The Controls of the Regularity of earthquakes from continual-type repeating earthquakes in Taiwan

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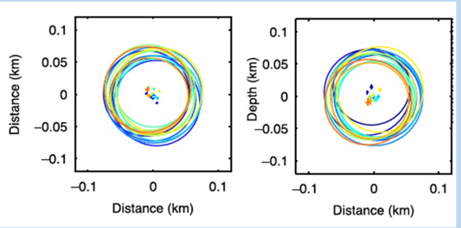
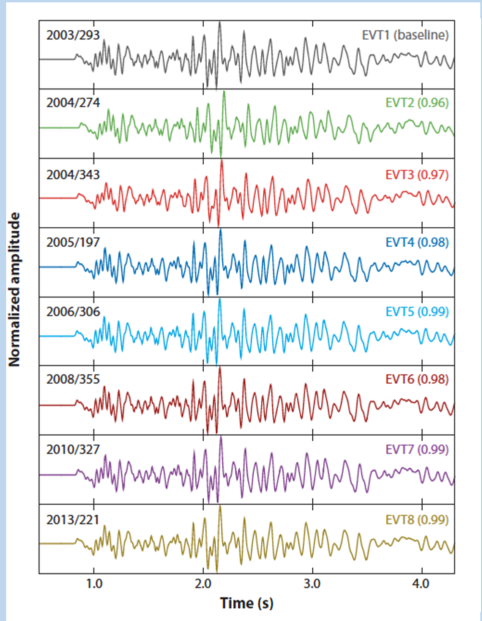
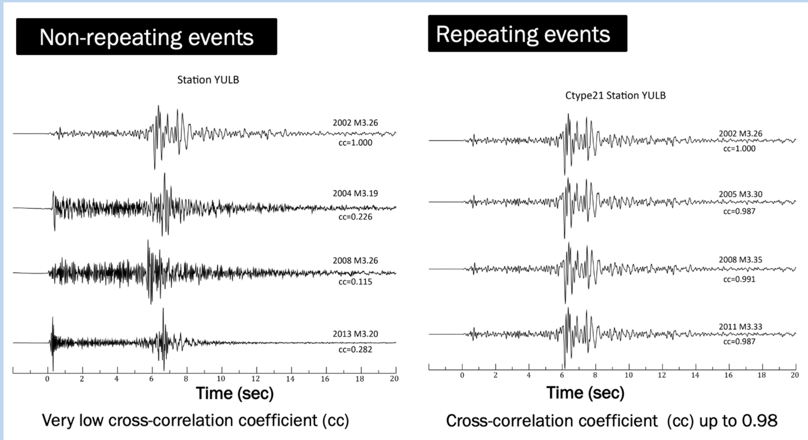
INTRODUCTION

Definition

Repeating earthquakes are a group of earthquakes with highly similar waveforms and locations. The similarity can be defined by cross-correlation coefficient: The higher the coefficient is, the more similar the waveforms are.


Waldhauser and Schaff (2021)


Uchida and Burgmann (2019)

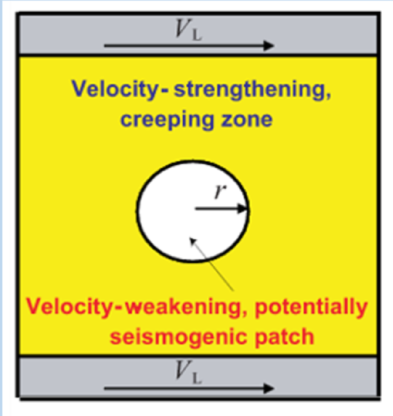


The examples of repeating events and non-repeating events at the same station. The former have nearly the same waveforms with high coefficient, while the latter have very low coefficient. Further more, the former are able to maintain their size and location over time, but the latter are not.

Mechanism

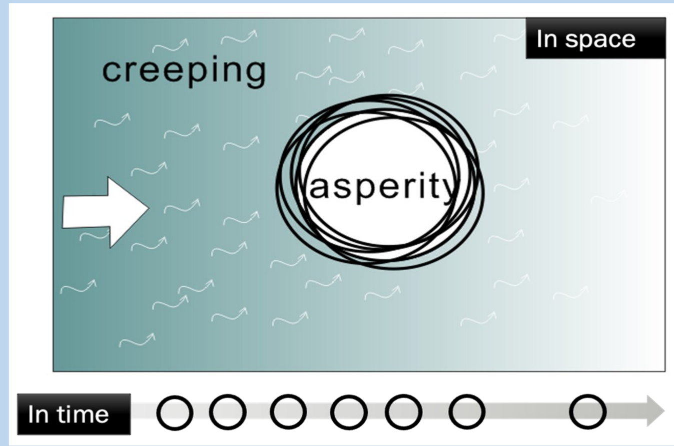
From numerical, analytical, laboratory studies, stable creeping in the surrounding of the repeaters (the white circle) is required to explain the recurrence of earthquakes (the yellow area).

From observation, repeating events are commonly found in the subduction zones and creeping faults. **So it has been widely accepted that the repeaters can be used to detect fault creeping and locations, where the creeping and locked areas abut.**



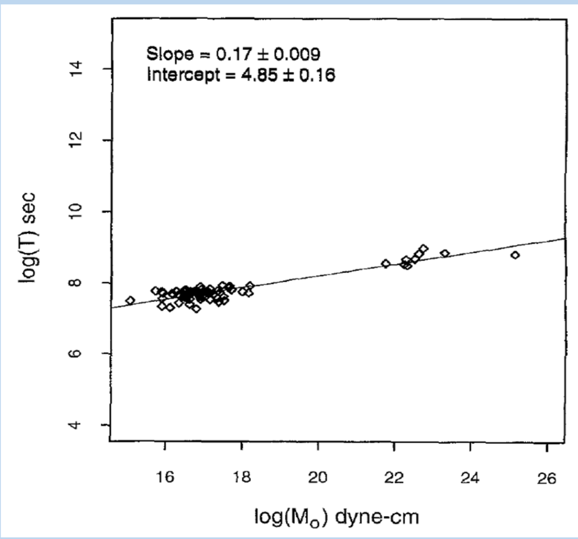
Chen and Lapusta (2009)

The way to use them is based on the idea that repeated ruptures catch up with the creep in the surrounding areas. **Therefore, recurrence behavior changes along with local condition changes.**

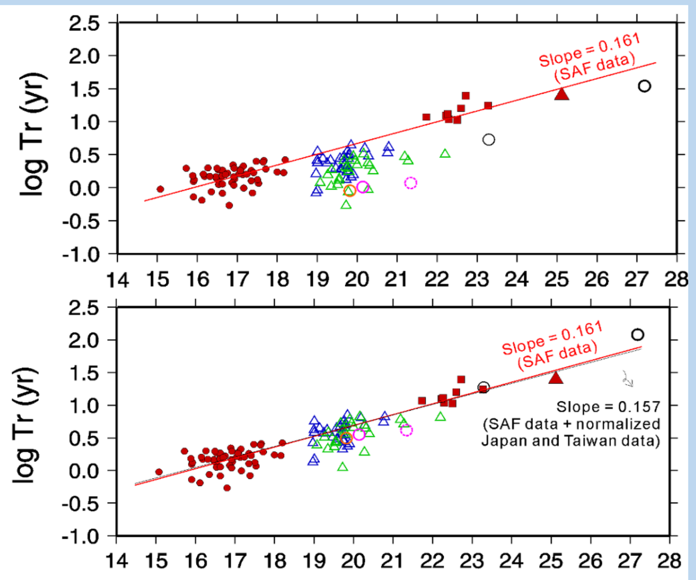


Repeating Factor

From previous studies, it is well-accepted that bigger earthquake has longer return period. As the figure on the figure shows, longer interval is corresponding to bigger magnitude. So, **the magnitude might be one possible factor that controls the recurrence interval**.



But previous study found that the recurrence interval is area dependent. This figure shows the relationship between the magnitude and the recurrence interval in Taiwan, Japan, and California.



Chen et al. (2007)

And for a given magnitude, the repeating sequences in Taiwan (blue and green triangles) have two times shorter intervals than those observed along the central San Andreas Fault (red circles), and Japan (pink circles) are four times shorter than those observed along the central San Andreas Fault.

When we assume that the recurrence interval is inversely proportional to the regional loading rate, we can re-calculate the recurrence interval:

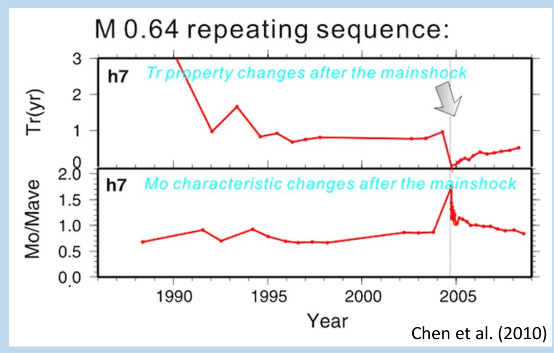
$$T_r \propto 1/V_f \quad \Rightarrow \quad T_r^{nor} = \frac{V_f \times Tr}{V_{parkfield}}$$

average loading rate on the fault plane

Chen et al. (2007) found when the loading rates are adjusted to be the same, all the repeaters' data fits into the same regression line. Therefore they concluded:

Instead of magnitude, loading rate controls the recurrence interval.

Except loading rate, the earthquakes interaction might also play a role. Chen et al. (2010) observed the variation of recurrence interval for individual sequence. They found that large earthquake influenced the repeater's interval significantly.



Chen et al. (2010)

The arrow indicates much shorter interval after the M6 earthquake, which occurred on the same fault.

Types

Based on timespan, repeating earthquakes can be divided into continual type (> 3 years) and burst type (< 3 years).

Also, they can be divided into two types based on regularity: the sequence with regular interevent time called 'quasi-periodic type', and the sequence with irregular interevent time called 'aperiodic type'. Usually, coefficient of variation of interevent time can used to quantify regularity. In general, coefficient of variation > 0.3 could represent as aperiodic type, while others could represent as quasi-periodic type.

In this study, to understand the control factors of recurrence intervals, only the continual-type sequences are considered.

MOTIVATION

From the review paper in 2017, the continental creeping faults have been found around the world. All of them are strike-slip faults, except for the normal fault in Italy and thrust fault in Taiwan. Therefore, thrust creeping faults in Taiwan provides an unique opportunity to study the recurrence behavior of repeating earthquakes.

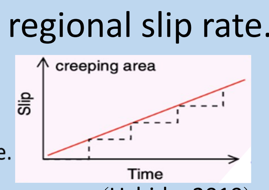
METHOD

First, I study the basic understanding of repeating earthquakes by visual inspection on the waveforms, and learn how to calculate cross correlation. And then, I used the repeating events catalog by Chen et al. (2020) to study: the type of repeating earthquakes sequences, and where they occur, what controls their recurrence interval.

To know if there exists a regional difference between areas, in each area enclosed by the rectangles, the histograms of magnitude for aperiodic and quasi-periodic sequences are plotted below. Also, we determine the slip for each area by using the recurrence interval, seismic moment, and the loading rate on the fault. Then we sum the slips from all repeating events, in order to obtain the regional slip rate.

$$slip = \frac{M_0}{\mu} = \frac{M_0 \dot{\tilde{d}} T_i}{\sum M_0}$$

A: rupture area. $\dot{\tilde{d}}$: fault loading rate.
T_i: sum of recurrence intervals.
M_0: sum of seismic moment in a sequence.



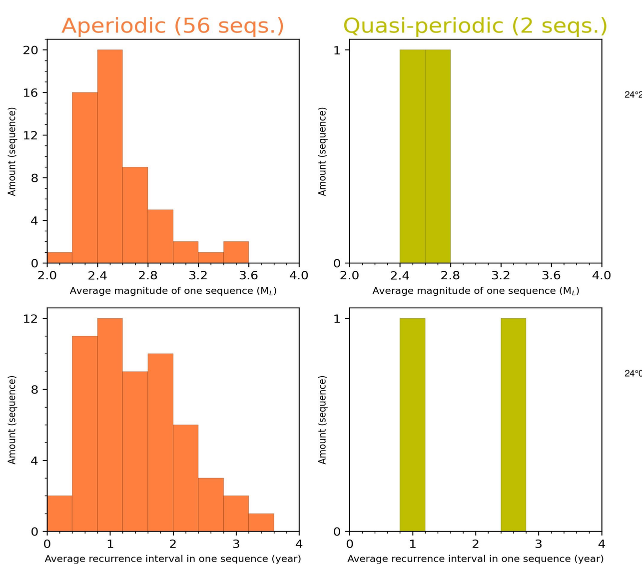
(Uchida, 2019)

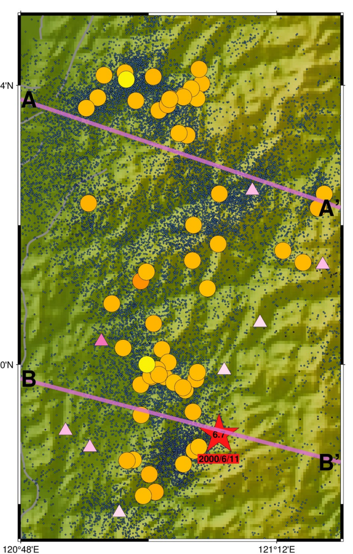
Chichi source area

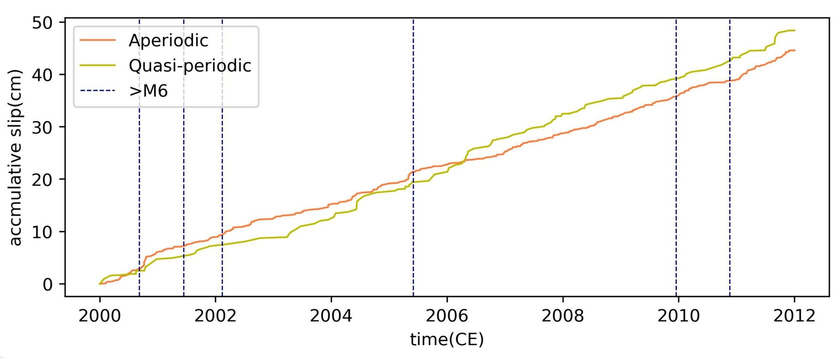
Most of the seismicity occurred above the depth of 30 km as a result of Chi-Chi source area and Sanyi-Puli seismic zone. There are sequences with similar magnitude range from 2.0 to 3.4, and recurrence intervals range mainly in 1 to 2 years.

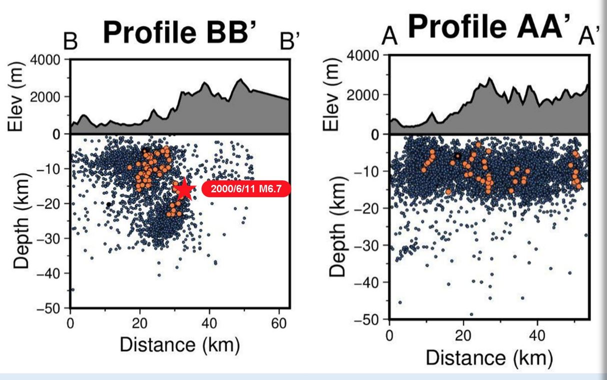
To profile AA', the sequences didn't seem to follow a main structure but were sparsely distributed; to profile BB', the seismicity extended deeper to 40 km, and that is likely associated with M6.7 Nantou earthquake in 2000. The sequences tend to concentrated in two cloud-like clusters.

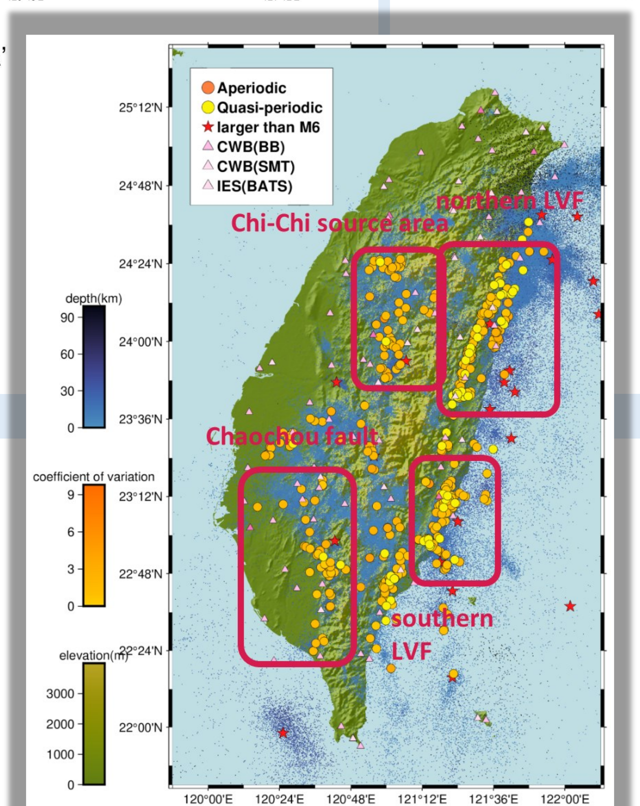
The slip rate from aperiodic type is stable through the study period, about 4 cm/yr. The earthquake of magnitude greater than 6 in this area happened in the middle of 2000 didn't influence the regional slip rate.



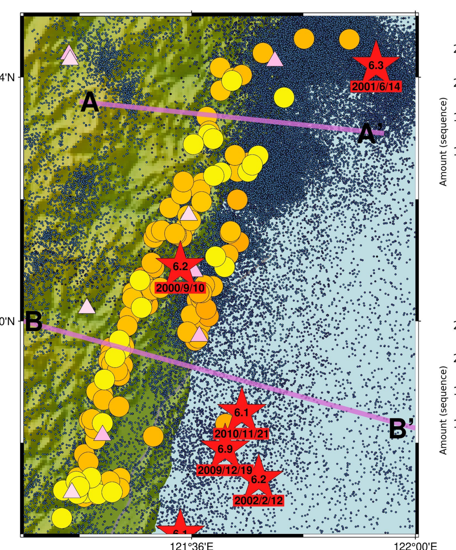


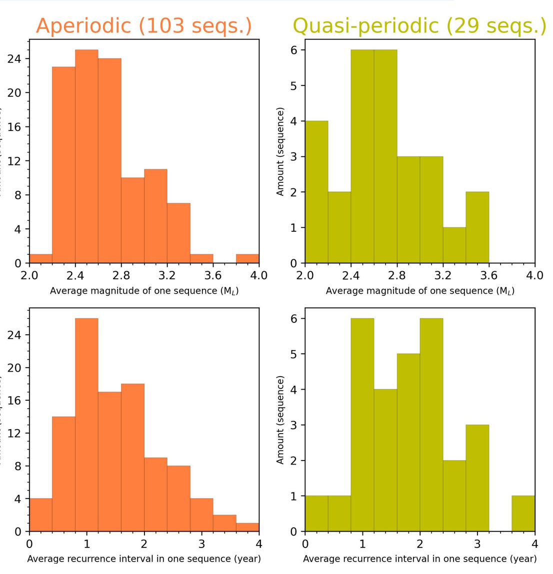






Northern Longitudinal Valley Fault

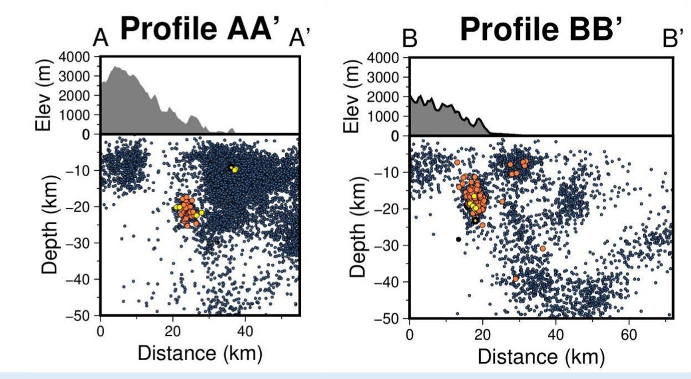


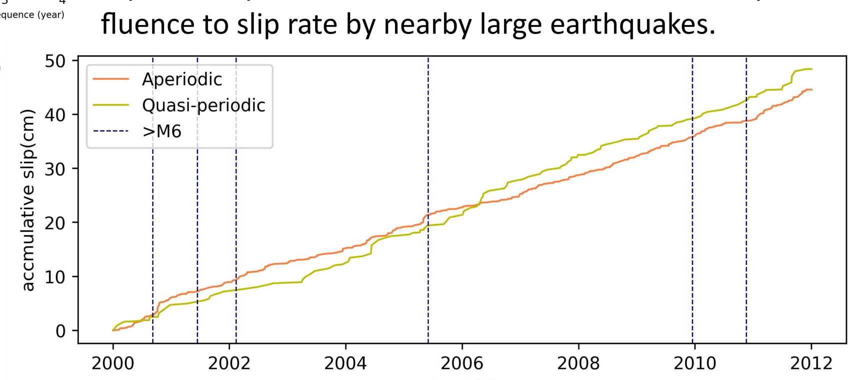


The termination of Ryukyu subduction zone leads to a large number of earthquakes. There are sequences with similar magnitude range of 2.0 to 3.8, and the averaged interval of aperiodic type is concentrated near 1 year, while of quasi-periodic type are evenly distributed from 1 to 3 years.

To profile AA', the seismicity are mostly within 20 km depth, while the sequences are strongly localized as a cluster; to profile BB', the background seismicity is relatively diffuse. The sequences also concentrate underneath Central Range and located at the depth from 10 to 20 km.

Same as Chi-Chi source area, the slip rate from aperiodic and quasi-periodic type are stable through the study period, about 4 cm/yr. Compared between the M6 events and the repeater slip as the function of time, it seems nearly no influence to slip rate by nearby large earthquakes.

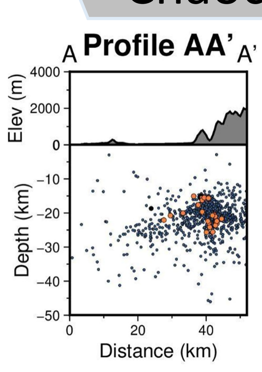


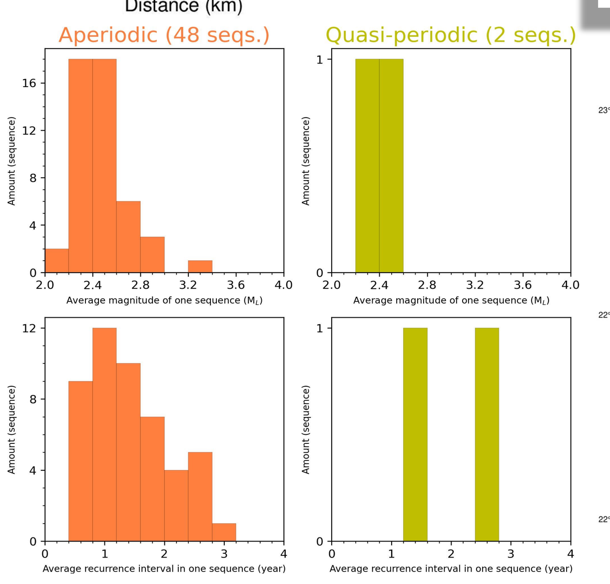


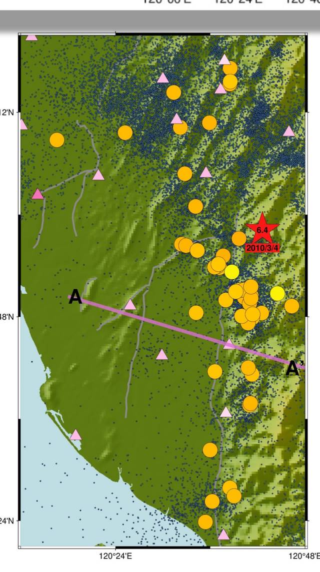
Chaochou Fault

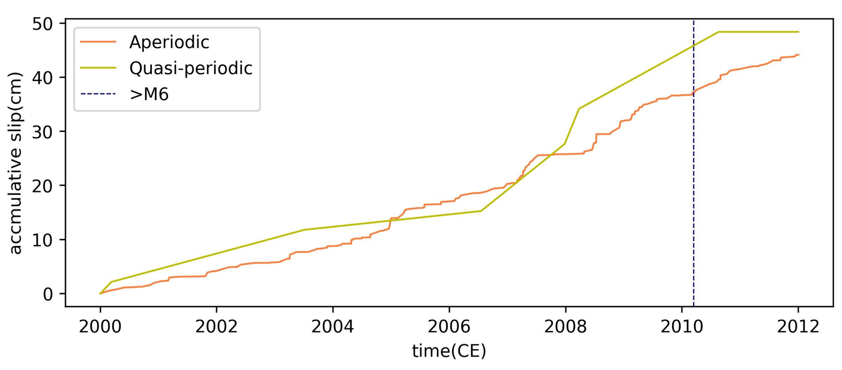
There are sequences with a smaller magnitude range comparing with three other areas, from 2.1 to 3.2. and the averaged interval for aperiodic type concentrated near 1.2 year. The seismicity is not very active comparing with other areas, while the majority of sequences are located beneath the Chachou fault.

Since there are only two Quasi-periodic sequences, the slip versus time curve of it is not reliable; the slip rate from aperiodic sequences is about 3.7 cm/yr. And it seems that the regional slip rate wasn't influenced by nearby 2010 M6.7 event.

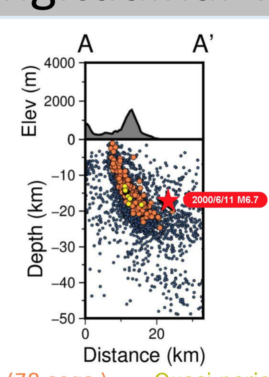






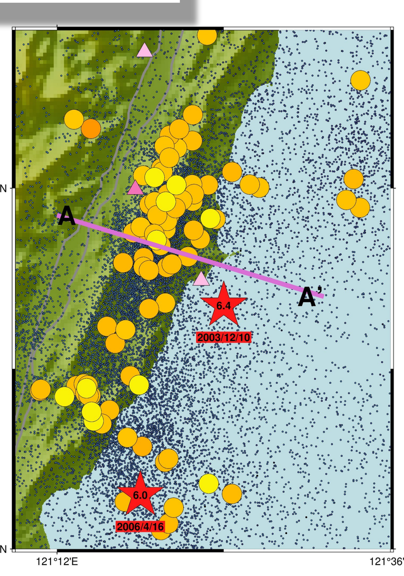


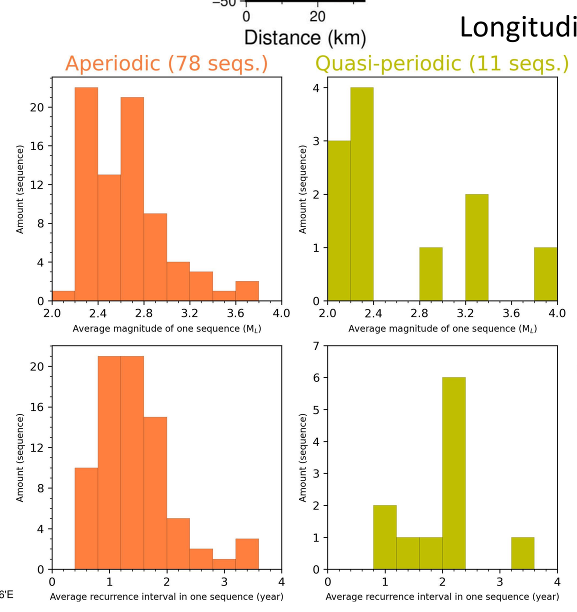
Southern Longitudinal Valley Fault



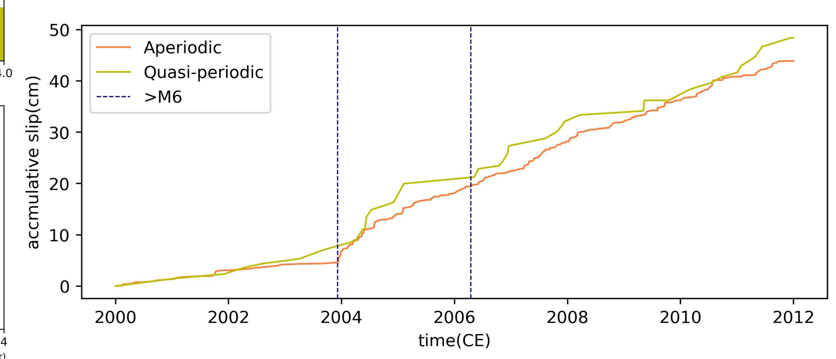
There are sequences with the similar magnitude range of 2.1 to 3.9. The averaged interval for aperiodic type is concentrated near 1.2 year, while the quasi-periodic type shows a peak around 2 years.

This is the area where the creeping Chishang fault is located. Note that the sequences on the southern Longitudinal Valley Fault is distributed along the east-dipping Chishang fault, unlike those in northern Longitudinal Valley Fault.





Both aperiodic and quasi-periodic sequences are strongly influenced by the 2003 M6.4 Chengkung earthquake, after which the slip rate were elevated, suggesting a strong influence of large event in the same fault.



SUMMARY

In this study we have learned the basic information for continual type repeating earthquake sequences in Taiwan, which can be divided into four groups:

In the Chichi source area and Chaochou fault area, the sequences are mostly aperiodic, and they are sparsely distributed without strong association with active faults.

In the northern Longitudinal Valley Fault, we believe that the sequences are concentrated along the Central Range fault, which is less influenced by nearby large earthquakes that occurred at different fault zone.

In the southern Longitudinal Valley Fault, the sequences are distributed along the Chishang fault. The regional slip rate is largely influenced by the M6 event on the same fault.

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