THE INTENSIFICATION OF THE INTERNAL AND EXTERNAL DYNAMIC FLUCTUATIONS OF YUNNAN'S CRUST AND THE OCCURRENCES OF STRONG EARTHQUAKES

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I. Introduction

Yunnan Province is one among China's seismically-active areas which are frequently stricken by shallow-focus earthquakes. The whole province is cut by faults which run in crisscross patterns and produce considerably large deformation rates. Since the turn to the century, the energy released in the form of seismic waves has reached 8.5×10^{16} Joules. In the last 2 decades between 1970—1989, the province had been hit by 4 occurrences of strong earthquakes which comprised 6 Ms≥7 events (see Table 1), and distributed extensively over different fault systems. It is thus evident that Yunnan Province can be regarded as a complicated multi-body system with highly-accelerated energy storages and releases, and that the inner part of the province is often at a disequilibrium and weakly-stable situation which is easily modulated and triggered by external forces.

Taking those 4 M7 strong earthquakes as key examples, the author will discuss in detail the ways in which such a complicated system as Yunnan Province has gone through the evolution and reached the catastrophic changes by dissipating the energy coming from the neighboring geologic bodies, the overburden hydrosphere, atmosphere and other neighboring cosmic bodies.

II. The Disequilibrium State in the Regional Crust before Strong Earthquakes

The seismogenic process of a strong earthquake can be regarded as the gradual intensification of the stress field around the focus, yet it is also the outcome of the synthetic actions exerted by all the

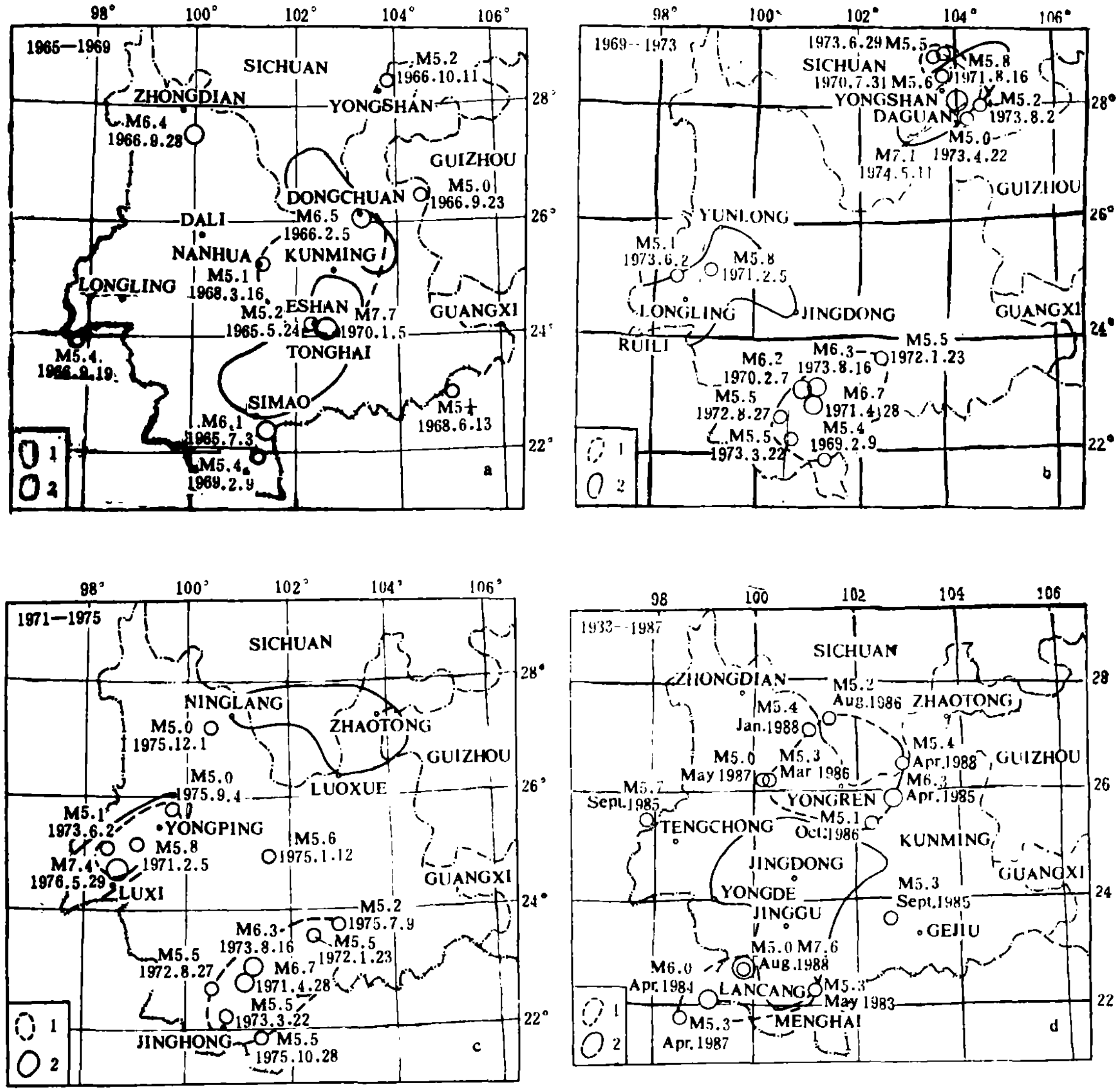

Fig. 1

a. Distribution of Ms≥5 events in 1965-1969 before the Tonghai earthquake (Ms=7.7) in 1970

1. Areas of clustered seismicity of Ms≥5 events
2. Areas of drastic "flood-drought" changes in 1969

b. Distribution of Ms≥5 events in 1969—1973 before the Daguan earthquake (Ms=7.1) in 1974

1. Areas of clustered seismicity of Ms≥5 events
2. Areas of drastic "drought-flood" changes in 1973

c. Distribution of Ms≥5 events in 1971—1975 before the Longling earthquake (Ms=7.4) in 1976

1. Areas of clustered seismisity of Ms≥5 events
2. Areas of drastic "flood-drought" changes in 1975

d. Distribution of Ms≥5 events in 1983—1987 before the Lancang earthquake (Ms=7.6) in 1988

1. Areas of clustered seismisity of Ms≥5 events
2. Areas of drastic "flood-drought" changes in 1988

related structures within the seismogenic system. Therefore, such a seismogenic process is closely related to the adjustments and variations in the neighboring regional stress field as well as the medium environment. Unfortunately, it is beyond our capabitity even to this day to directly trace and observe those vitally-important intra-crust processes. Therefore, we can only use the seismicity changes as a "barometer" to indirectly disclose the status quo of the stress in the local crust and to see whether the local crust is stable.

With the specific conditions of geological structure in Yunnan, we have found the following:

1. Within the 5 years before the occurrence of M7 earthquake, evident intensification of seismicity is found in the areas approximately 2° (longitude) × 2° (latitude) around the forthcoming foci Frequency of M5 and M6 events within the same period is also found to be ⩾3 (see Fig. 1), which is twice or greater the normal seismicity level.

2. In the background of intensified activities of such moderately-large seismic events, the process showing the annual increase of the frequency N of M⩾3.7 moderate and small events occurring in the same area is plotted in Fig. 2. It should be noted that the N-value often shows a non-linear up-stepping in the particular year preceding each of the strong earthquakes, and that such up-stepping has obviously deviated from the basic state in the many years before the strong earthquakes during which on significant fluctuation in seismicity was observed.

Nevertheless, the above-mentioned phenomenon does not necessarily appear before every strong earthquake. Along with the advancement of time, the tectonic stress in the crust, which is mostly horizontal, may also show decrease. If there exist vertical triggering forces above the unstable rock beds, and if such forces are also strong enough, the dynamic equilibrium would be overcome and thus lead to develop towa-

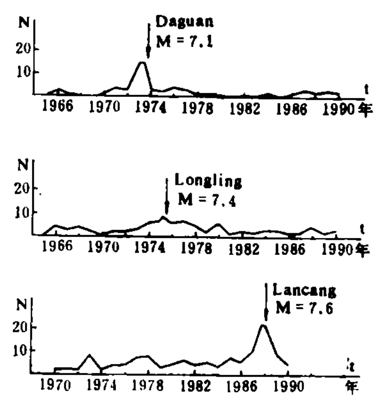

Fig. 2 Increase of annual frequency of M⩾3.7 events surrounding the epicenters of several M7 events in Yunnan Province

rd large-scale disequilibrium. Such vertical triggering forces come mostly from the extra-crust hydrosphere, atmosphere and neighboring cosmic bodies.

III. The Modulating Effect on Strong Earthquakes Exerted by Drastic Variations of Drought and Flood at the Earth's Surface

The atmospheric precipitation is one of the key factors controlling not only the natural aqueous circulation between the ground surface and the underground hydrosphere, but also the loading variations of large artificial reservoirs. The quasi-two-year (actually 2—3 years) atmospheric precipitation fluctuations show obvious modulating effect on the seismicity patterns in Yunnan. In ordinary years, the amplitude of such precipitation fluctuation only reaches limited dimensions, and only when serious drought and flood occur successively can such precipitation fluctuation reach a high-enough level to control the occurrence of strong earthquakes[1]. We have calculated the respective extreme values of such drought and flood fluctuations in Yunnan's history as well as their occurrence years using data collected from 150 meteorological stations located both in Yunnan and her neighboring areas. Further, we made overall statistics to obtain the number n of stations in Yunnan at which the annual precipitation fluctuations have reached the historic extreme values, and the statistical results are shown in Fig. 3.

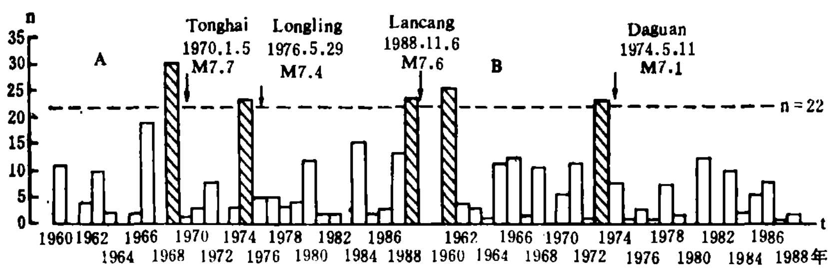

Fig. 3 Number of stations with emergences of extreme values of annual precipitation changes in Yunnan Province since 1960

A. Number of stations with drastic "flood-drought" changes

B. Number of stations with drastic "drought-flood" changes

It is easily seen from Fig. 3 that if n⩾22 is taken as the anomalous index, 5 events of drastic drought-flood (or flood-drought) changes had taken place in the last 30 years respectively ended in 1961, 1969, 1973, 1975 and 1988. Those drastic drought-flood changes showed not only considerably-large spatial sizes (>60,000km²), but also strengths of precipitation fluctuation (level of material losses or gains) with an average value of 500 mm/cm². It should also be noted that 4 among those areas with drastic drought-flood changes happened to overlap the unstable blocks which have been plotted in Fig. 1. The non-linear up-stepping of the occurrence frequency N of M⩾3.7 moderate and small events shown in Fig. 5 also emerged in those times. It can be seen that such exterior giant fluctuations did serve to intensify the fluctuations within those blocks, the result of which turned the seismogenic processes irreversible and led to the occurrences of the M7.7 Tonghai, M7.1 Daguan, M7.4 Longling and M7.6 Lancang earthquakes which respectively occurred between the end of the corresponding year and the beginning of the following year in the overtapping areas.

Apart from those 4 drastic drought-flood (or flood-drought) changes which heralded M7 or larger earthquakes, another drastic drought-flood change had also been observed in Yunnan in 1961 and the previous year. That drastic drought-flood change had produced extreme values at 25 stations which were located atong central Yunnan During the same period and the few preceding years, the seismically-active areas of M5—M6 events, namely the intra-crust areas showing explicit tectonic stress increases, were located in northwestern Yunnan, the ranges affected by the endogenic and exogenic factors did not coincide (Fig. 4). Therefore, on additive multiplication effects were produced, and on M⩾7 earthquakes were generated within the following year of the drastic drought-flood changes. Nevertheless, one M6.2 strong event did occur within that area which showed drastic drougth-flood changes, and that M6.2 event was the strongest in the period 1956—1965.

Ⅳ. The Triggering Effect on Earthquakes Exerted by Giant Fluctuations of Atmospheric Pressure

Apart from the effect exerted by the hydrosphere, the circulating current of the atmosphere enwrapping the earth's surface can produce a total energy amounting to 12^{21} Joules. The energy of such circulat-

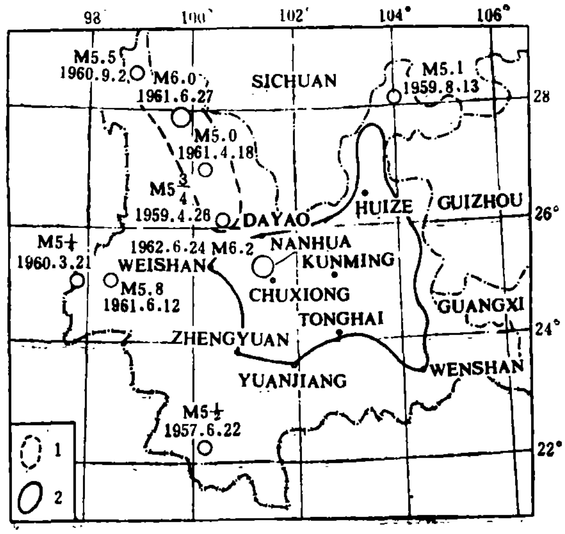

Fig. 4 Distribution of Ms≥5 events in 1957-1961 before the Nanhua earthquake (Ms=6.2) in 1962

1.Area of clustered seismicity of Ms≥5 events

2.Area of drastic "drought-flood" changes in 1961

ing current is featured by its quick variations and large power capacity, and a number of weather systems are capable of creating within a short time pressure changes amounting to 10^1—10^2 hPa/cm² which can reach basically un-attenuated the depth range where shallow earthquakes are generated.[2] Therefore, in areas with available data of the anomalous changes of the solid crust and the hydrosphere, it would be possible to further determine the short-term, impending occurrence times of M7 events by estimating this new energy input coming from the atmosphere.

Fig. 5 illustrates the respective time-dependent fluctuations of the first order difference $\Delta\overline{P}$ of the 10-day average of the atmospheric pressure P in the vicinity of the epicentral area both before and after the M7 events contemporarily occurred in Yunnan Province. The giant fluctuations among the common ones are marked by hatched areas in order to show that the M7 earthquakes were successively triggered off by the abrupt excitations of those giant fluctuations.

In order to show that such pre-shock triggering effect by the atmosphere is non-coincidental, we' have respectively calculated the mean vatues $\Delta\overline{P}$ of the $\Delta\overline{P}$ series for every epicentral area (which are all close to zero and are regarded as the equilibrium state of the atmosphere) and their mean squares σ. In the light of such calculations, we identified the following:

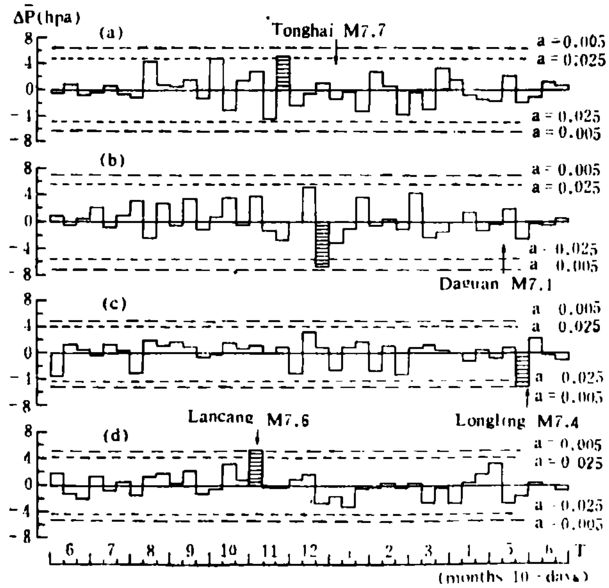

Fig. 5 Fluctuation of the first order difference $\overline{\Delta P}$ of the 10-day mean atmospheric pressure in the epicentral regions both before and after respective strong M7 earthquakes in Yunnan province

a) The $\Delta\overline{P}$ distribution in the epicentral region of the Tonghai earthquake between the first 10-day in June 1969 and the last 10-day in June 1970

b) The $\Delta\overline{P}$ distribution in the epicentral region of the Daguan earthquake between the first 10-day in June 1973 and the last 10-day in June 1974

c) The $\Delta\overline{P}$ distribution in the epicentral region of the Longling earthquake between the first 10-day in June 1975 and the last 10-day in June 1976

d) The $\Delta\overline{P}$ distribution in the epicentral region of the Lancang earthquake between the first 10-day in June 1988 and the last 10-day in June 1989

1. Giant fluctuations of atmospheric pressure were detected respectively in the first 10-day in November, 1988 (principally between November 1—6) in the seismic area of Lancang and the last 10-day in May, 1976 (principally between May 21—27) in the seismic area of Longling. The 2 giant atmospheric pressure fluctuations had all exceeded the significance level of 0.005, and are thus regarded as rare atmospheric disturbances. The strength of such atmospheric disturbances might have reached the threshold value at which the foci lose stability, and thus quickly triggered off the 2 strong earthquakes.

2. The 2 maximum atmospheric pressure fluctuations in the focal

regions respectively prior to the M7.7 Tonghai, 1970 earthquake and the M7.1 Daguan, 1974 earthquake had only exceeded the significance level of 0.025, yet they also served as important triggerings causing the foci to lose stability, the process of which had paved the way for the forthcoming strong earthquakes which occurred shortly afterwards. Nevertheless, this also suggests that other pre-shock factors also incorporated forces in triggering off the strong shocks.

V. Astronomical Problems involved at the Triggering-off Point of Strong Earthquakes

When the foci of strong earthquakes in Yunnan have been pushed into the impending state by the intra- and extra-crust forces, the specific occurrence time of earthquakes seems to be related to the astronomical conditions among which the relative positions of the sun, the earth and the moon are of vital importance. In this moment, the attraction by the celestial bodies conforming with the dynamic features of the seismogenic structures as well as the rupture mode of the foci may demonstrate the triggering effects.

As shown in Fig 6, and in the light of the 20-plus M≥6.5 events occurred in Yunnan since the beginning of the 20th century (the 4 contemporarily-occurred M7 events inclusive), it would not be hard to sequentially classify the following temporal belts of strong-shock occurrences in the SW-NE orientation in Yunnan Province:

1. The afternoon earthquake-occurring belt
   4 among the 5 strong shocks in this belt occurred between 13:00 and 15:00.
2. The evening earthquake-occurring belt
   11 among the 12 strong shocks in this belt occurred between 20:00 and 23:00.
3. The midnight earthquake-occurring belt
   The 6 strong shocks in this belt occurred exclusively between 23:00—02:00.
4. The predawn earthquake-occurring belt
   The 3 strong shocks in this belt occurred exclusively between 03:00—07:00.

Despite that we still do not know much about the astronomical dynamic mechanism causing the formationing of such overall regular patterns with the only exception of Lushui region which had been hit by earthquake swarms, yet the orientation of the temporal belts of

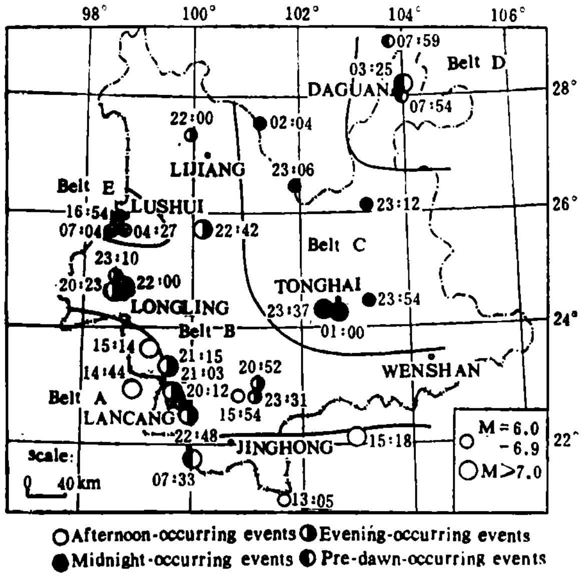

Fig. 6　The belt-shape distribution of originate times of Ms≥6.5 events in Yunnan province since the beginning of the 20th century

(A) Belt of afternoon-occurring events (4/5 of the events at 13:00—15:00)

(B) Belt of evening-occurring events (11/12 of the events at 20:00—23:00)

(C) Belt of midnight-occurring events (6/6 of the events at 23:00—02:00)

(D) Belt of pre-dawn-occurring events (3/3 of the events at 03:00—07:00)

(E) Belt of irregularly-occurring events

strong-shock occurrences roughly runs parallel with the NW-SE striking abyssal Red River fault which marks the major boundary of crustal structures in Yunnan, and cuts at large angles with the orientation of the NNE compressional force caused by the squeezing of the Indian plate against Yunnan's crust. Therefore, there might exist some crustal units which are structurally, physically or mechanically undergoing gradual changes. When the seismogenesis is maturing, those crustal units might be sensitive respectively to the triggering by the joint tidal effects exerted by the celestial bodies such as the sun, the moon, etc. which are at their specific time intervals.

Ⅵ. Conclusion

We have up to now preliminarily identified that the seismogenic system in Yunnan is an open one which is closely linked up with the exterior ambiance, and that the dynamic fluctuations have led to its

Table.1 The processes showing the giant interior and exterior fluctuations before respective M7 earthquakes contemporarily occurred in Yunnan

Classification of pre-shock episodes	Mode of intra- and extra-crust fluctuations surrounding the epicenters	1.M7.7 Tonghai earthquake occurred 01:00 Jan. 5, 1971	2. M7.1 Daguan earthquake occurred 03:00 May, 11, 1974	3. M7.4 Longling earthquake occurred 20:00 May 29, 1976	4. M7.6 Lancang earthquake occurred 21:00 Nov. 6, 1988
		Emergence time of pre-shock fluctuations			
Long-term	Years of M5.6 event concentration (i.e. years in which frequency of M 3.7 events up-step)	1965—1968 (No data)	1970—1975 (Starting 1973)	1971—1975 (Starting 1974)	1983—1987 (Starting 1987)
Mid-term	Years of drought-flood of flood-drought drastic changes	1968—1969	1972—1973	1973—1975	1986—1988
Short-term	Period of atmospheric giant fluctuations	Nov. 21—30, 1969	Jan. 1—10, 1974	May21—28, 1976	Nov. 1—6, 1988
Impending	Earthquake-prone astronomical times	23:00—02:00	03:00—07:00	20:00—23:00	20:00—23:00

macroscopic order. We have also outlined from different levels and episodes the additive process on the seismogenesis and triggering effects by factors such as the locally-unstable crust, the fluctuation of the overburden hydrosphere and atmosphere and even by the motions of the celestial bodies (Table 1).

Despite that the above-discussed results can not, for the time being, form a complete method to be used in earthquake prediction practices, yet they are after all a kind of understanding on the overall features of the evolution of strong earthquakes, and such understanding is extracted from the most realistic laboratory--the Nature. Therefore, our findings deserve to be further studied theoretically in a more deep-going way as well as tested repeatedly in our future scientific practices.

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云南地壳内、外动力涨落加剧与强烈地震的爆发*

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摘 要

自1970年以来，云南已先后发生了4次Ms≥7级强烈地震(1970年1月5日通海—峨山7.7级、1974年5月11日永善—大关7.1级、1976年5月29日龙陵—潞西7.4级、1988年11月6日澜沧—耿马7.6级)，说明云南地区的地壳可能经常处于非稳态，易因内、外涨落加剧而产生状态突变。

为此，本文专门做了系统的资料分析，初步勾画出了云南强震前一再重复出现的如下基本物理图象：

1.强震前5年，其周围二百余公里范围内5—6级地震明显活化；

2.震前1—3年，震中区降水剧变，出现罕见的旱涝振荡；

3.进而，M≥3.7级地震频次呈非线性增长，不久，气压出现短临性巨涨落；

4.强震总在一定的天文时刻爆发。

研究上述的地壳内、外巨涨落过程，不仅有助于云南强震的实际预报，亦有助于孕震动力模型的研究。

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