Principle of Earthquake Aroused by Cavity in the Lithosphere

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ABSTRACT

Water displays supercritical state when ground temperature and pressure exceeded critical point (374℃ and 22.1 MPa). Lithosphere would expand resulting in the development of tensional faults because of the high local mantle magma pressure caused by the dive of continental plate to another continental plate. Then mantle magma and hydrothermal fluid can go out to the surface along tensional faults, from which rocks are formed by cooling when mantle pressure decrease. Upwelling supercritical fluid would force the left magma into mantle. Supercritical fluid would convert to a mineral substance and fill up faults in upper crust. The middle-lower crust would be filled with supercritical fluid. Because subducted plate blocks mantle heat flow, the lower crust temperature of overlying lithosphere will go down. Then groundwater can get into middle crust. The tensional fault zones temperature in middle-lower crust would decrease because of groundwater vertical convection, which makes supercritical fluid convert into gas/liquid. Sedimentation occurs in faults in lower crust and the faults in middle crust will be worthy of the name of cavity. When surrounding rocks of the cavity are damaged, rocks would fall into cavities and resulting in earthquake. The scale of the earthquake depends on qualities and decline depths of rocks

KEY WORDS: cavity in the lithosphere, water, supercritical fluid, earth crust

1. WATER EAKAGE OF NORTHERN QIANGTANG BASIN

Tibet covers an area of about 1.2×10^6km^2. Outflow region accounts for 49% of total areas of Tibet. Its total runoff and runoff depth are about 4280×10^8m^3 and 237.6mm respectively. For inflow regions (Qiangtang Basin), according to the evaporation, total runoff and runoff depth are only 202×10^8m^3 and 34mm respectively, equal to about one-twenty-first of that of outflow region. The research has discovered that leakage occurs in some lakes with low TDS in Qiangtang Basin, such as Nam Co and Serling Co. And satellite remote sensing data shows river leakage in Qiangtang Basin (Fig. 1). So the value of runoff calculated from evaporation must be much less than the actual value in Qiangtang Basin. Based on flow statistics of catchments with little precipitation located north of Kunlun and Tanggula Mountain, the average runoff depth of catchments (including mountain and deserts) is about 103mm. If the runoff depth is 103mm, the total runoff would be at least 628×10^8m^3 in Qiangtang Basin. So, seepage amount of Qiangtang Basin would be 426×10^8m^3. The actual seepage amount may be much more than 426×10^8m^3 obtained from catchments with minimum precipitation.

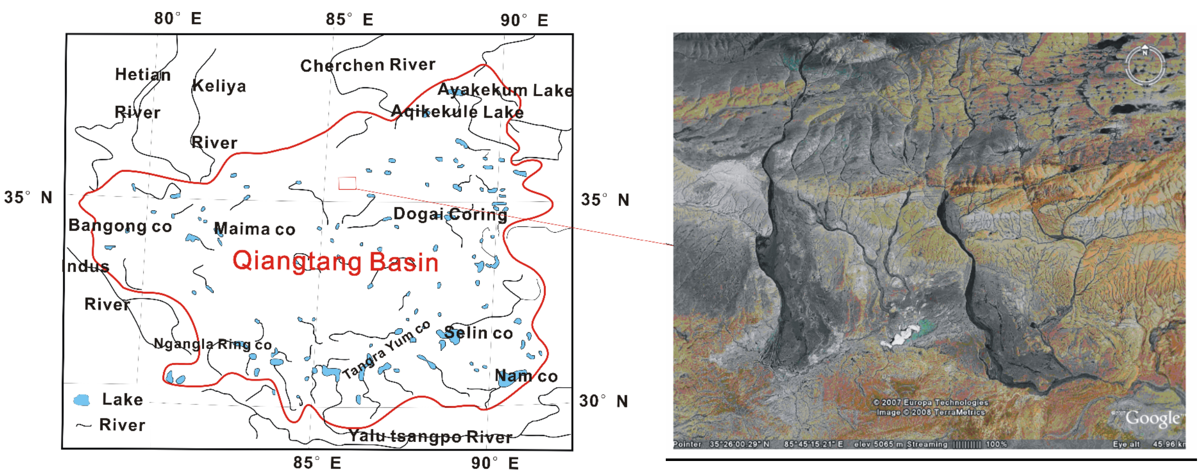

Figure1 (a) Water system distribution of Qiangtang Basin (b) satellite of river leakage (from google maps)

Studies on electric structures of crust/mantle and characteristics of ruptures in the west edge of the Tibetan Plateau showed that there are 0 to 50km high-resistive zones below the earth's surface. And below the high-resistive, there are tens to hundreds of kilometers thick uninterrupted high conductive zones [1], characterized by low terrestrial heat flow [2], rapid attenuation of Sn wave [3], gravity and magnetic negative anomaly[4]. The author holds that the geophysical explorations datum is related to leakage of more than $426\times10^8 m^3$ surface water. The writer infers that there are larger cavities developing along fault zones. The cavities depth is more than 10km. And the groundwater circulating in the cavities may discharge outside of Tibetan plateau.

In order to identify deduction above, we investigated isotope data of springs and rivers in surrounding areas of Qiangtang Basin. Research shows that the δD, $\delta^{18}O$ values (δD = - 75‰,$\delta^{18}O$ = - 9.75‰）of springs and rivers in Odors Plateau and North China Basin more than 2000km away from the Qiangtang Basin are the same as δD, $\delta^{18}O$ values of precipitation of Qiangtang Basin, but are great different from those of local precipitation (δD = - 50‰, $\delta^{18}O$ = - 6.5‰). The $^3He/^4He$, $^4He/^{20}Ne$ values of springs show that there is helium and neon coming from deep crust. The geothermal gradient has dropped by 40% since Upper Jurassic in Odors Plateau and North China Basin. Almost all rivers in Odors originate from spring relating to the fundamental fault. Water table of basement fault zones is the highest (Fig. 2). The salt and isotope datum confirmed that prelatic water is not recharged by local precipitation. So it can be only from groundwater coming from fundamental fault zone. The author considers that leakage water from Qiangtang Basin recharges the stable rivers of Odors Plateau.

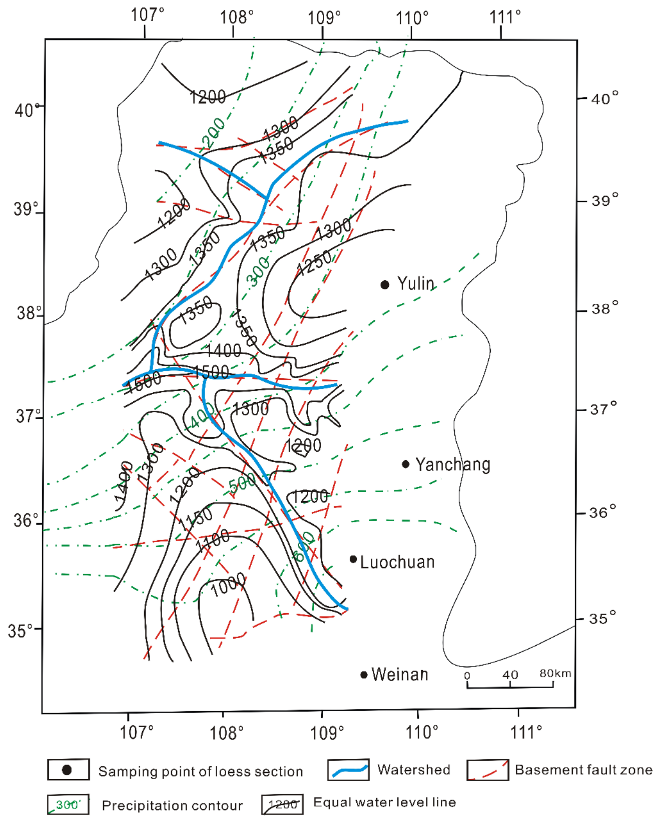

Figure 2 Watershed, basement faults, precipitation contour and water table in Odors Plateau [5][6]

2. SUPERCRITICAL FLUID IN THE LITHOSPHERES

Material in earth interior expands with the increase of temperature caused by the energy accumulation of radioactive material disintegration. The expansion can produce tensional fault zones if swelling pressure is greater than failure strength of the lithosphere. Then, mantle magma would break through the surface along tensional fault zones and volcano rocks form. Some faults without magma will be filled with mantle gas and supercritical fluid. After exceeding critical point of water (Tc = 374.15℃; Pc = 22.1MPa), water is in supercritical states. The critical temperature rises with the increase of salinity. From room temperature to critical temperature, molar volume of water is rising gradually; density is decreasing gradually; dielectric constant and conductivity drop markedly. Supercritical water exhibits an array of unique properties, such as strong fluidity, low viscosity. Many insoluble compounds are easily soluble at supercritical environment. For example, Copper and Gold can be dissolved by supercritical water [7].

If salinity of formation is 4%, the critical temperature of water will rise to 400℃. Temperature gradient of upper crust is about 3℃/100m, so the temperature of continental lithosphere is 400℃ in depth of 15km. Compared to Conrad surface, normalcy / supercritical interface seems to coincide with Conrad surface. So, the author thinks Conrad surface may be the normalcy / supercritical interface (Fig 3) which is only a physical interface formed when temperature was highest in the geological history. But it doesn't represent the present temperature profile. If Conrad surface is the normalcy / supercritical interface, it will only relate to temperature and salinity of formation, not to depth, which can be used to explain upper, middle and lower crust distribution of marine formation. According to hydrothermal ore-forming theory, supercritical fluid can not convert to a mineral substance. So, sedimentation won't occur in faults of middle-lower crust when mantle hydrothermal fluid is upwelling. And because pressure of mantle hydrothermal fluid is much higher than gravity of overlying rocks, overlying rocks can not subside to cavity to cause earthquakes.

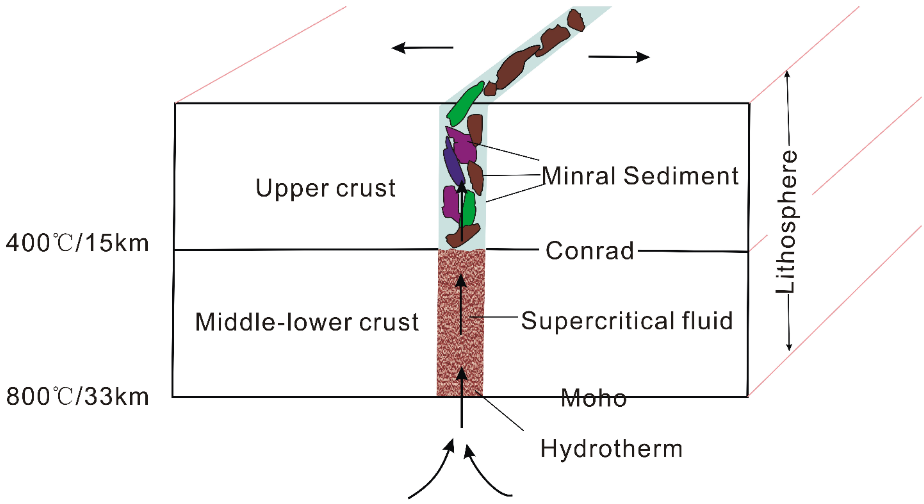

Figure 3 Supercritical fluid of middle-lower crust upwelling at the highest temperature

Hydrothermal fluid in middle-lower crust can arrive in upper crust or the surface responding to pressure of earth mantle (Fig. 3). The shorter the distance from earth surface is, the lower temperature and pressure of hydrothermal fluid are. So, hydrothermal fluid will change from supercritical state to normal state. At the same time, different nonmetallic or metal sediments will be produced to fill tensional fault at different Eh and PH in upper crust. On the other hand, tensional fault can also be filled with SiO_2, $CaCO_3$ sediments. But the cavity can not be filled up in middle and lower crust because sedimentation does not occur in supercritical state. Then high / low interface can be found, called Conrad surface. Distribution of the Conrad surface is caused by the discontinuous distribution of tensional fault.

3. FORMATION PRINCIPLE OF VOLCANO AND SHALLOW EARTHQUAKE IN SEDUCTION ZONE

In middle-lower crust, cavities which are not filled up can not lead to earthquake because pressure of mantle hydrothermal fluid is much higher than the gravity of overlying rocks and overlying rocks can not subside into cavity to cause earthquakes. Collision between two plates will happen because of plate movement which is forced by magma poured out ocean ridge. When the collision ends, an earthquake and volcanic eruption will generally occur in different places. Take collision between Pacific plate and Asia-Europe plate as example, the increase of mantle pressure coming from dive of Pacific plate to Asia-Europe plate can result in tensile expansion of faults in Asia-Europe plate. Then mantle magma derived by high pressure will break through the surface along the faults to form volcanic. On the other hand, Pacific plate separates the Lithosphere and mantle in Asia-Europe plate edge with result that magma can not arrive at faults of the lithosphere edge. And the temperature of middle-lower crust of

Asia-Europe plate will fall because of lower temperature of upper crust of Pacific plate. It is possible for seawater to arrive at cavities of middle-lower crust with a decrease in temperature in shallow sea of continental shelf, which leads to a change for cavities from supercritical high pressure layer to low pressure layer. So, there will be an earthquake because of collapse of surrounding rocks damage of cavities (Fig. 4).

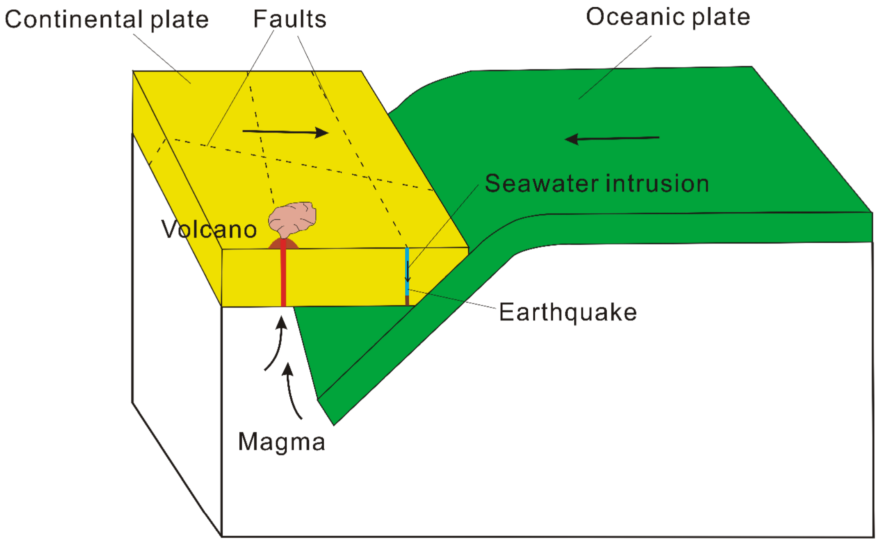

Figure 4 Earthquake and volcano caused by collision between Pacific plate and Asia-Europe plate

Pacific plate underthrusting Asia-Europe plate would be melted because of high temperature of mantle magma. When subducted plate moves at a slow speed, it is impossible to go far because it will be melted continuously. Influence scope of subducted plate is also connected with thickness of plate. The thicker plate is, the greater influence scope is. So, velocity and thickness of subducted plate are the two factors determining influence scope.

4. PRINCIPLE OF INTRAPLATE EARTHQUAKE

China is a country with frequent intraplate earthquakes. Tangshan Earthquake with 7.8 magnitudes or Wenchuan Earthquake with 8.0 magnitudes belongs to intraplate earthquake. The thickness of Pacific plate underthrusting Asia-Europe plate is only 7.5km with a result that influence scope of Pacific plate is not great. But the average thickness of the continental plates is 33km. It must take longer time and more heat energy to melt continental plates. So, continental plates can move a long distance. The collision between the India plate and the Eurasian plate is one kind of such intraplate earthquake (Fig. 5).

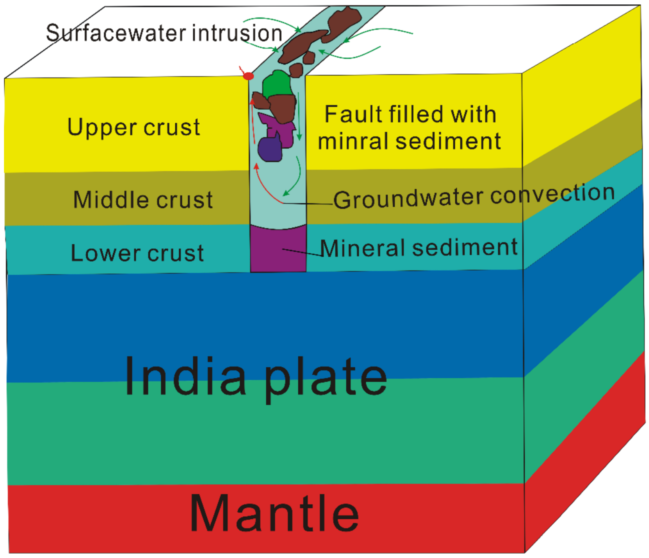

Figure5 The collision between India plate and the Eurasian plate

Principle of intraplate earthquake and shallow earthquake is the same. That is lithosphere expands resulting in the development of tensional faults because of the high local mantle magma pressure caused by the dive of continental plate to another continental plate. Mantle magma and hydrothermal fluid would go out to the surface along tensional faults, from which rocks are formed by cooling when mantle pressure decrease. Upwelling supercritical fluid would force the left magma into mantle. Supercritical fluid would convert to a mineral substance and fill up faults in upper crust. The middle-lower crust would be filled with supercritical fluid. Because subducted plate blocks mantle heat flow, the lower crust temperature of overlying lithosphere will go down. Then groundwater would movement in middle crust. The tensional fault zones temperature in middle-lower crust will decrease because of groundwater vertical convection, which makes supercritical fluid convert into gas/liquid. Sedimentation will occur in faults in lower crust and the faults in middle crust will be worthy of the name of cavity. When surrounding rocks of the cavity are damaged, rocks would fall into cavities and resulting in earthquake. The scale of the earthquake depends on qualities and decline depths of rocks.

In china, collapses once took place in Tarim Basin, Qiadam Basin, Ordos Basin, Sichuan Basin and Junggar basin. The crust cavities were basically filled up because of collapses in the center of basin, which cause the subsidence of the basin surface. So, in these basins, though groundwater is still moving in the interior of the basin, a major earthquake will not happen. Quantity of circulating water and hydraulic gradient increased after rapid uplift of the Qinghai-Tibet Plateau. The scope of groundwater intrusion expanded to Inner Mongolia Plateau, North China plain and Central Plains. Intraplate earthquake will last a long time because there are still cavities that are not filled up in surrounding areas of basins.

5. DISCUSSION

5.1The Relationship between Groundwater Circulation, Ground Temperature and Earthquake

Groundwater Circulation in middle-lower crust shows that there are mis-understandings in geophysical exploration. If the fundamental reason of earthquake is the existence of big cavities in middle crust where groundwater circulates, seismic energy will generate from gravitational potential energy. And geothermal gradient in seismic belt will lower because of bringing off heat of mantle and crust due to groundwater circulation. Hence low velocity and high conduction layer may be the cavities filled with groundwater in crust. Groundwater deep circulation evidence also emerges from marine cold spring. Cold springs were found in South China Sea with sinter area of 430km^2 and Okinawa Trough with cold springs of 2.1km [8], lower the terrestrial heat flow and temperature gradient on the side nearer continent (Fig. 6)[9][10].

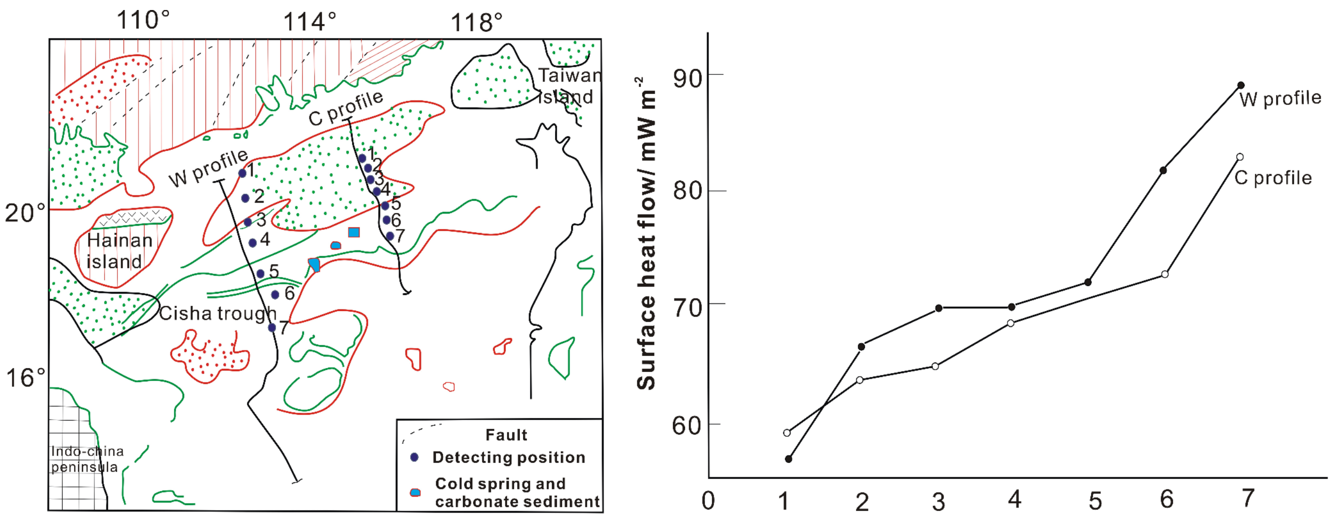

Figure6 Surface heat flow and distribution of cold springs in South China Sea

Groundwater deep circulation can lead to geothermal anomaly. Temperature anomaly was found in many deep wells. But the anomaly was neglected generally for the balance time is short in well. There were 107 of 117 wells affected by groundwater in song-liao basin, and 161 of 196 well in Junggar basin [11][12]. There is deep confined water in regions with temperature anomaly. Low velocity and high conduction layer and lower geothermal gradient can also be found in these regions. For example, the terrestrial heat flow is only 8mW/m^2 in Okinawa Trough [13]. The lower geothermal parameters were processed in method of weighting average hiding existence of faults in some seismic belts.

5.2 Agglomeration Effects and Blowout Resulting from Earthquake

Almost all earthquakes were accompanied with movement of groundwater. For example, about 3 minutes after the Northwest Sumatra Island earthquake occurred in December of 2004, a sudden blowout occurred in an earthquake observation well in Meizhou of Guangzhou. The well is about 800m deep, and the blowout was about 50m high and lasted 12 days [14]. Blowout shows that there are passages between the regions and seismic region. Circulating water in these passages is fresh-water at room temperature.

There are deep confined water in most of northern China regions and coastal areas. Deep confined water head is higher than surface, called artesian basin often belonging to fault basin. Faults develop in these basins. The writer believes that water pressure rising or dropping suddenly caused by collapse will pass very far through fault zones and cause the water table change or blowout. Sudden changes in water pressure can cause series of earthquakes, called agglomeration effect. For example, there were more than a few hundred earthquakes (Ms>3.9) following 8.0 magnitude Wenchuan Earthquake, which can not be explained by elastic or burst energy releasing.

5.3 Energy source of earthquake and Activity of Faults

Earthquake is geological activities with destructiveness. Wenchuan Earthquake of magnitude 8.0 released 6.3×10^{16}J of energy. If the height of cavity is 3.5km, the volume of collapse rock will be 970km^3 defined by the expressions $V=E/((\gamma_{岩}-\gamma_{水})\times g\times h)$. If cracking length of surface is 300km, the cavity width will be more 1km considering the friction term. This is the reason of land subsidence. Space occupied by fragmented rock is much larger than that of dense rock. So, it is impossible that earthquake can be caused by elastic or burst energy releasing, after which the volume of rock will be greater but not less.

Many people think that earthquakes are caused by the fault movement, so the concept of seismic intensity is adopted. The author holds that the basic reason of the earthquake is not the activities of the fault zone which is just a necessary condition of the earthquake, but the existence of cavities in crust. The Triaxial Test confirmed that axial pressure were proportional to confining pressure [15]. So, complete rock can not be destroyed because of the gravity of the overlying rocks. The precondition of cavity collapse is that overlying rocks are destroyed caused by plate movement. For Wenchuan Earthquake, there is a cavity 300km long, 3.5km wide and 1km deep in the Longmenshan fault zone. The overlying rocks of cavity fell into cavity and caused Earthquake of magnitude 8.0. Rocks continue to fall into cavities which are not filled up. Then aftershocks will occur. Energy of aftershocks decreased gradually with decrease in altitude and volume of cavity. Energy of earthquake is decided by quality of collapse rocks and the dip of fault. The greater quality and dip are, the larger magnitude is. The whole cavity can not be filled up in an earthquake, which leads to more earthquakes, called agglomeration effect. In theory, there will not be an earthquake again when cavities are filled up.

5.4 The prevention and prediction of earthquakes

Generally, earthquakes occurred on the fault zone, almost all in fault basin, such as North China Basin. For large basins, earthquakes occurred chiefly in the edge zone of basins, such as Tarim Basin. Arid and water shortage towns located at the areas with the rich groundwater in northern China, such as Beijing. Cyclic confined water from middle crust provides abundant water for the development of towns, which may cause earthquake in the future. Therefore, geophysical exploration should be done in detail in towns with dense population and the rich groundwater. The most important is to check concealed fault zone with a steep dip. Maybe there would be a serious earthquake after crushing failure of rocks if concealed fault zone is in active stage. For the edge zone of artesian basin, the relocation of industrial and inhabited areas with dense population is necessary in the regions with less than 2℃/km in geothermal degree, where there is low velocity and high conduction layer and a relatively large-scale fundamental fault with a steep dip. As a general rule, there will not be an earthquake in the regions with hot springs , heavy saline groundwater, larger than 3℃/km in geothermal degree, in which there was a volcanic explosion in Mesozoic.

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REFERENCE

[1] JIN Sheng, YE Gao-feng, WEI Wen-bo,DENG Ming, JING Jian-en. (2007). The Electrical Structure and Fault Feature of Crust and Mantle of Western Tibet Plateau: Based on Results of Magnetotelluric Survey along Profile Zhada-Quanshuihu. Earth Science(Journal of China University of Geosciences) **32:4**, 474-480.
[2] SHEN Xian-jie, ZHANG Wen-ren, ZHANG Ju-ming, YANG Shu-zhen. (1991). Terrestrial Heat Flow on the Qing-zang Plateau and the Modeling of the Tectno-thermal Evolution of Terranes in ITS Southern Part . Chinese Science Bulletin **8,** 611-613.
[3] Barazangi M, Ni J. (1982). Velocities and Propagation Characteristics of Pn and Sn Beneath the Himalayan Arc and Tibetan Plateau: Possible Evidence for Underthrusting of the Indian Oontinental Lithosphere Beneath Tibet. Geology **10**, 179-185.
[4] LI Ting-dong. (1995). the Uplifting Process and Mechanism of the Qinhai-Tibet Plateau . ACTA GEOSICIENTIA SINICA **1**, 1-9.

[5] WANG Wei, LIU Zu-qi, LI Ying. (2004). Characteristics of groundwater resources and Protection and development reasonable in the Cretaceous Groundwater Basin of the Ordos . the Shanxi Technology and Science press.

[6] HONG Guang-cai, ZHANG Mao-sheng. (2004). Sustainable utilization of groundwater resource in Odors Basin . the Shanxi Technology and Science press.

[7] XIE Hong-sen, HOU Wei, ZHOU Wen-ge, ZHENG Hai-fei, SU Gen-li, ZHU Wei-guo, GUO Jie. (2000). Material Science of the Earth's Interior . EARTH SCIENCE FRONTIERS **7:1**, 217-228.
[8] LUAN Xi-wu, QIN Yun-shan. (2005). Discovery of Gas Seepage in Majicosima Western in Okinawa Trough . Chinese Science Bulletin **50:8,** 802-810.
[9] CHEN Zhong, CHEN Mu-hong, WANG Shu-hong, LU Jun, XIAO Shang-bin. (2006). Discovery of seep authigenic carbonate nodules on northern continental slope of South China Sea: New evidence of marine gas vent. Chinese Science Bulletin **51:9,** 1065-1072.

[10] ZHANG Jian , WANG Ji-yang. (2000). Deep Geothermal Characteristics on Northern Continental Margin of South China Sea . Chinese Science Bulletin **45:10,** 1095-1100.

[11] WANG Yong-xin, FENG Dian-sheng, WANG Ji-yang, WU Tie-sheng. (2003). Present-day Geothermal Field and Thermal History of Eastern Subdepression . LIAOHE BASIN Chinese Journal of Geophysics **46:2,** 97-202.
[12] WANG Sheng-jiao, HU Sheng-biao, WANG Ji-yang. (2000). The Characteristics of Heat Flow and Geothermal Fields in Junggar Basin . Chinese Journal of Geophysics **43:6,** 771-779.
[13] LUAN Xi-wu, ZHANG Xun-hua. (2003). Heat flow measurement and distribution of East China Sea and Ryukyu Trench Arc Back-Arc system . Progress In Geophysics **18:4,** 670-678.
[14] WAN Yong-fang, YE Dong-hua, YANG Xiang-dong. (2006). Analysis of the Coseismic Effect of the Dec.26,2004 M8.7 Indonesia Earthquake upon Guangdong Region. South China Journal of Seismology **26:4,** 67-73.
[15] ZHU Rui-geng, WU Mian-ba. (1984). Failure Criterion of Granite at Different Loading Rates . Rock and Soil Mechanics **5:1,** 37-46.