Response of mud volcanoes to earthquakes: role of static strains and frequency-dependence of ground motion

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Distant earthquakes can trigger the eruption of mud volcanoes. We report observations of the response of the Davis-Schrimpf, California, mud volcanoes to 2 earthquakes and non-response to 4 other earthquakes. We find that eruptions are triggered by dynamic stresses and that the mud volcanoes are more sensitive to long period seismic waves than short period waves with the same amplitude. These observations are consistent with models in which fluid mobility is enhanced by dislodging bubbles by the time-varying flows produced by seismic waves.

In the Northern Apennines, Italy, we document responses and non-responses to the May-June 2012 Emilia seismic sequence. Here we find that discharge only increases where dikes under the vents are unclamped by the static stresses produced by the earthquakes.

Mud volcanoes can thus respond to static stress changes (if feeder dikes are unclamped) and dynamic stresses produced by seismic waves (possibly by mobilizing bubbles).

How earthquake-induced static stress change could promote new volcanic eruptions: an example from the Southern Volcanic Zone, Chilean Andes

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The goal of our work is to study the contribution of earthquake-induced static stress changes on a volcanic arc in order to define a possible feedback in promoting new volcanic eruptions. We analyzed the Southern Volcanic Zone of the Andes (SVZ) in Chile, which has been affected by four subduction earthquakes with $M_w \geq 8$ since 1906, occurred in proximity of 60 Holocene volcanoes. We resolved the earthquake-induced static stress change on the magma pathway of each volcano instead of considering the crustal volumetric expansion. Magma pathway geometry and possible chamber depth are based on geological-structural evidence along with petrological and geophysical data. Our analysis includes a total of 16 eruptions following these large earthquakes at 9 different volcanoes. Ten out of 16 eruptions occurred at volcanoes that had no activity in the five years preceding the earthquake. Results indicate that the static stress changes were capable of triggering the observed volcanic phenomena up to a distance of 353 km from the epicenter. Regarding the most recent 2010 M_w 8.8 earthquake, the normal stress change calculated on each magma pathway shows a pattern of stress transfer more complex than crustal dilatation, due to heterogeneity in magma pathway geometries and orientation. N- and NE-striking magma pathways suffered a greater decompression in comparison with E- and NW-striking ones. The fault-slip-induced static normal stress changes on each reconstructed magma pathway have effects as far as about 400 km. The latest earthquake-induced event regards the 22 December 2012 eruption at Copahue volcano. The results of our numerical modelling indicate that the N60°E-striking magma pathway was affected by a normal stress reduction of about 0.236 MPa at a distance of 257 km from the 2010 epicentre. As a consequence, we are suggesting a possible earthquake-induced feedback effect on the crust below the volcanic arc up to at least 3 years after a large subduction earthquake, favoring new eruptions. Our results show that the unclamping of magma pathways plays a fundamental role in dictating unrest at volcanoes that are already in a critical state. These studies contribute to identify those volcanoes that are more prone to seismically-triggered eruptive events.

1P2_2B-O3 Room A3 Date/Time: July 21 17:30-17:45

Remotely triggered seismic activity in Hakone volcano during and after the passage of surface waves from the 2011 M9.0 Tohoku-Oki earthquake

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Immediately after the March 11, 2011, M9.0 Tohoku-Oki earthquake, seismic activity increased remarkably beneath Hakone volcano, central Japan, at an epicentral distance of 450 km. The heightened seismicity was initiated during the passage of the large-amplitude surface waves from the Tohoku-Oki earthquake and continued over the subsequent two months. We obtained hypocenters and focal mechanisms of the seismic sequence, with the aim of clarifying the physical mechanism responsible for the remotely triggered seismicity. We used data from a dense seismic network containing 56 online permanent and offline temporary stations in and around Hakone volcano. We determined the hypocenters of triggered earthquakes by using the double-difference method (Waldhauser and Ellsworth, 2000).

We found that the earthquakes that occurred during the passage of the surface waves are located at the lower depth limit of ordinary seismicity in the caldera and near the high b-value anomaly zones. These earthquakes have larger magnitudes than both the ordinary seismicity prior to the Tohoku-Oki earthquake and the seismicity triggered after the passage of the surface waves. The focal mechanism that we determined is a strike-slip fault type with the P-axis in the NW-SE direction, which is consistent with the focal mechanisms of earthquakes that occurred after the passage of surface waves and the tectonic stress field in the region. We also tried to detect missing events that occurred immediately after the passage of the surface waves, by using a waveform correlation technique (Zhigang and Zhao, 2009). The detected events are distributed near the hypocenters of the earthquakes that occurred during the passage of the surface waves.

The origin times of the first four events after the arrival of surface waves are consistent with the phases of the decrease in normal stress generated by the surface waves. The results suggest that the changes in dynamic stress due to the surface waves from the 2011 Tohoku-Oki earthquake contributed significantly to the initiation of the sequence of triggered seismic activity. Assuming that normal stress changes on the faults did play an important role in the triggering of earthquakes, we propose that fluid flow induced by the oscillation of permeability on the faults is the main mechanism for the initiation of post-Tohoku-Oki earthquakes beneath Hakone volcano.

Volcanic subsidence triggered by the 2011 Mw 9.0 Tohoku earthquake, Japan

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The 2011 Mw 9.0 Tohoku earthquake induced an unprecedented level of seismic activity in eastern Honshu, Japan. How did the volcanoes really respond to the earthquake? Some volcanoes exhibited increased seismic activity, but little is known about the deformation of their edifices.

We performed interferometric synthetic aperture radar (InSAR) analysis using ALOS/PALSAR data acquired before and after the Tohoku earthquake, to investigate the local deformation around volcanoes in the eastern Honshu. The interferograms, after removing the coseismic and early postseismic signals of the Tohoku earthquake, showed subsidence in a few volcanic regions: around Mt. Akitakoma, Mt. Zao, Mt. Kurikoma, Mt. Azuma, and Mt. Nasu. The subsidence reached 5-15 cm and exhibited elliptical shapes with horizontal dimensions of 15-20 x 10-15 km elongated roughly in the direction perpendicular to the axis of maximum coseismic extension. A station of the Global Positioning System (GPS) Earth Observation Network (GEONET) was located within each of the Mt. Zao and Mt. Azuma subsidence areas; the displacement time-series obtained at these sites indicate abrupt surface subsidence whose amount is roughly consistent with the satellite radar observations.

Concentration of Late Cenozoic calderas, high-temperature thermal water, high heat flow data, and borehole sampling of very young and hot granite suggest presence of hot plutonic bodies beneath the subsided regions. We hypothesize that magmatic and surrounding hot rock complexes, having a magma reservoir at the center surrounded by hot pluton and thermally weakened rock, have very small viscosity (effectively no shear strength) as a whole and played a major role in the subsidence. Using a boundary element method, we modeled the weak region as a fluid-filled ellipsoid and investigated how it deforms in response to the stress changes given by the Tohoku earthquake. It was found that such ellipsoids having the longer horizontal axis of 10-20 km and top depth of shallower than a few kilometers can deform to reproduce the observed subsidence signals.

Similar subsidence signals were also observed at several volcanoes in central Chile in association with the 2010 Maule earthquake (Mw 8.8), indicating that such subsidence triggering is ubiquitous for active volcanic chains along subduction zones.

1P2_2B-O5 Room A3 Date/Time: July 21 18:00-18:15

Interactions among the Galapagos volcanoes triggered by earthquakes and eruptions

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The Galapagos basaltic shield volcanoes are among the most active volcanoes in the world. They are known for their dynamic calderas which are inflating and deflating by decimeters to meters between eruptions, which is well resolved by satellite radar interferometry. Here we report on geodetic observations indicating interactions among the volcanoes. During 2006-2007 several seismic swarms occurred that led to inflation at some and deflation at other volcanoes. We report on earthquake-volcano and on volcano-volcano interactions. The 2009 eruption of Fernandina volcano led to a cessation of inflation at Wolf and Alcedo volcanoes. These observations show that the magmatic plumbing systems of the individual volcanoes are interconnected.

Interactions between earthquake and volcano activity (average picture from worldwide catalogues)

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Using worldwide catalogues for M>4.8 earthquakes and VEI index for eruptions, 1973-2010, we resolve a significant, when tested against catalogue randomizations, increase of eruption onsets the day on the earthquake day.

First, we find this increase is stronger for earthquake-eruption pairs that are within ten fault length distance from the trigger earthquake. For these distance ranges these observations suggest the dynamic triggering of volcano activity by earthquakes.

Second, we observe the clustering in time for earthquake-eruption pairs is not bounded to the earthquake/eruption day. The signal remains above noise level up to 100, 10 days after and before the eruption day, respectively.

These later results suggest the earthquakes map a brittle damage process around eruption times. The brittle damage, as mapped by M>4.8 earthquakes before and after eruption time, is localized within 50 km from the volcano. These patterns in space and magnitude are far beyond the regular definition of VT earthquakes as M=3-4 events within 5-10 km from the volcano. These results, all emerging from mean field analysis, are evidence for a mechanical coupling, as pressure and stress build up within the brittle crust, between earthquake and eruption up to 50 km around the ongoing eruption.

Last, the pre-eruption patterns support the faster the increase in the average earthquake rate, i.e. the exponent of the inverse Omori's law, the larger the VEI of the ongoing eruption.

Temporal Relationships between Vertical-CLVD Earthquakes and Volcanic Unrest

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Although most volcanic earthquakes are small, occasionally volcanoes generate earthquakes that can be detected globally. Some of the largest and most unusual volcanic earthquakes are vertical-CLVD events, for which deviatoric moment tensors have large non-double-couple components dominated by vertical extension or compression. Well-studied examples include M_W >5 earthquakes associated with fissure eruptions at Bárdarbunga and Nyiragongo volcanoes, as well as the Tori Shima earthquake, which is associated with a volcanogenic tsunami. To assess the link between the occurrence of these anomalous earthquakes and volcanic unrest, we performed a systematic global search for vertical-CLVD earthquakes located near volcanoes that erupted in the last ~100 years. We identified 101 vertical-CLVD earthquakes with magnitudes $4.3 \geq M_W \geq 5.8$, and found that approximately 70% are associated with documented episodes of volcanic unrest at a nearby volcano. The vertical-CLVD earthquakes in our data set are linked to many different types of eruptive activity including volcanic earthquake swarms at submarine volcanoes, and effusive and explosive eruptions and caldera collapse at subaerial volcanoes. Vertical-CLVD earthquakes are predominantly located in subduction zones, although a small number of events are located in continental rifts and regions of hotspot volcanism. Most source volcanoes have caldera structures and erupt magmas with low silica contents. A source model consisting of dip-slip motion on volcano ring faults can explain the seismic radiation patterns and source durations of vertical-CLVD earthquakes, as well as their relationship to volcanoes in specific geodynamic environments. A particularly important result of our global study is the observation that one type of vertical-CLVD earthquake, those with dominant tension axes, generally precedes volcanic eruptions. These vertical-T earthquakes are likely generated by slip on curved reverse faults triggered by the inflation of shallow magma chambers. Similarly, the other type of vertical-CLVD earthquake, those with dominant pressure axes, generally occurs after the start of eruptive activity at a source volcano. These vertical-P earthquakes are likely generated by slip on curved normal faults triggered by the deflation of shallow magma chambers. Our work clearly indicates that vertical-CLVD earthquakes are causally related to dynamic physical processes occurring inside the edifices and magmatic plumbing systems of active volcanoes, and suggests that the occurrence of these events may be useful for identifying volcanoes that have recently erupted and volcanoes that are likely to erupt in the future.

1W_2B-P1 Date/Time: July 21 Poster

Experimental simulation of the processes at volcano reservoirs triggered by earthquakes

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Evidence is increasing that tectonic earthquakes may trigger volcanic activity. Some volcanoes erupt immediately after an tectonic earthquake occurred. Other volcanoes show merely signs of unrest, but no eruption. Even other volcanoes do not show any response, even though being in a state of a generally high activity.

The problem in volcano-earthquake interaction research is that the physical processes of the triggering are only poorly understood, however. Some recent studies suggest a combination of (quasi)static and dynamic triggering, associated with the permanent displacement and the short term passing of seismic waves, respectively. However, no consensus exists concerning the type of waveform most effective for the triggering process, or about the time delays often observed between the passage of the seismic waves and unrest occurrence.

In order to better understand the way earthquakes may trigger volcanoes, we first collected empirical data and re-evaluate the empirical database. Second, we design laboratory experiments aiming to simulate selected real scenarios as recorded by geophysical instruments. Our reservoir is simulated on an earthquake simulator, constructed to allow systematic exploration and scenario simulation of empirical observables. For instance, we evaluate how the frequency and amplitude of seismic waves affects a bubbling fluid, leading to fluid mobilization, mixing and ultimately to the increase of a reservoir pressure. The implications of the results are wide, and may apply to volcanoes triggered by earthquakes, as well as other fluid reservoirs containing different fluid and/or gaseous phases.

Effect of seismic oscillation on the bubble detachment from wall of magma chamber

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The bubble detachment or departure from wall of magma chamber is thought to be a candidate as a mechanism of triggering of volcanic eruptions by seismic oscillation, because thereby the advective overpressure or the abrupt vesiculation by convective overturn is expected to bring the rested magma chamber to unstable and overpressurized state. We conducted the laboratory experiments in order to investigate the effects of oscillation frequency, amplitude, and bubble radius on the bubble detachment process. The simple experimental setup consists of an acrylic cylindrical container (diameter 80 mm, height 100 mm) and an underlain oscillator by which we can control the frequency and amplitude of vertical oscillation. Commercially available carbonated water in the container was used as an analogue material to magmas containing bubbles. When the carbonated water (500 ml) is poured in the container, CO2 bubbles form on the wall by heterogeneous nucleation and grow. Even in the oscillation-free state, the bubble detachment occurs when a bubble size exceeds a critical value determined by liquid/gas-, gas/substrate-, and liquid/substrate-interfacial tensions (oscillation-free detachment bubble size). In the case that the oscillation is applied, the critical bubble size of detachment change with the amplitude and frequency of oscillation. In order to understand the relationship among the detachment size of bubble, amplitude and frequency of oscillation, we conducted a series of experiments, bubble detachment experiments and bubble growth experiments. Two video images were taken for a close view and whole view, which were used for the analysis. After the stationary state was achieved in the filled carbonated water, we applied oscillations with frequencies every 10 Hz from 10 to 100 Hz. For a chosen frequency we gradually increase the amplitude until substantial bubble detachment occurred. We measured the minimum radius of detached bubbles as function of the amplitude for the given frequency. As a result we obtained the detachment condition in terms of bubble radius, frequency and amplitude. The minimum amplitude of bubble detachment decreases with increasing bubble radius and with increasing frequency. This relationship can be interpreted by the force balance among the buoyancy force, inertial acceleration and surface tension force, which act on a bubble attaching on the bottom substrate. Applying this relationship to the natural case with seismic frequency, around 1 - 10 Hz, we roughly predict that 1 mm bubbles can detach from the bottom of magma chambers for approximately 0.1 mm displacement by a seismic vibration, suggesting a possible seismic triggering of volcanic eruptions.

Static and Quasistatic stress changes due to Tohoku megathrust earthquake: Effects on Japanese volcanoes

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An enormous crustal deformation due to the Mw9.0 megathurst Tohoku earthquake on Mar. 11, 2011, gave much perturbation on the regional tectonics and we have to pay attention to seismicity and volcanic activity. Volcanic eruption triggered by >M8 earthquakes have been widely reported in the world, and we have to estimate the eruption potential from the view of volcanic hazard mitigation. Shortly after the megathrust earthquake, i.e. within about three months, 20 volcanoes in Japan suggested abnormal seismicity, however, we have no eruptions by January, 2013 (about 22 months).

In this paper, we evaluate static and quasistatic stress change due to the enormous crustal deformation, affected on the magma plumbing system beneath Japanese volcanoes. FEM modeling is applied both for static and quasistatic responses. Both Japanese mainland and target volcanic region are modeled by seismic tomography result, and the topographic effect is also included. For example, static differential stress given to Mount Fuji magma reservoir, which is assumed to be located to be in the hypocentral area of deep long period earthquakes at the depth of 15 km, is estimated to be the order of about 0.001-0.01 and 0.1-1 MPa at the boundary region between magma reservoir and surrounding medium. This pressure change is about 0.2 percent of the lithostatic pressure (367.5 MPa at 15 km depth), but is enough to trigger an eruptions in case the magma is ready to erupt. Quasistatic stress is calculated based on the linear Maxwell model, and for the fault and boundary node, we applied MPC (multi-point-constraint) method instead of Split node method for static stress calculation. Our calculation suggests that the stress field around eastern mainland of Japan reduces to about 78 percent in 100 years, on the other hand, the stress is concentrated at the boundary of magma system and surrounding rock about 7 percent in 100 years. Quantitative estimation of stress changes around magma plumbing system may give information on eruptive potential triggered by earthquakes.

A large-scale block slide over a buried old caldera triggered by the 2011 March 11 M9 earthquake Japan: A case study for understanding of earthquake triggering mechanism of volcano flank collapse

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A flank collapse of a volcano is a rare but extremely devastating hazard that may claim many lives as well as huge sociological and economic damage. Despite keen demand for revelation of the mechanisms for the development of effective mitigation measures, the rareness of the events prevents accumulation of basic data for a detailed analysis. The unique exception of a scientific surveillance opportunity on such mass movement was the 1980 Mt. St. Helens flank collapse which were closely monitored and observed by scientists using the most advanced measurement instruments up to the date. The collapse is believed to be triggered by an M5+ earthquake but the detailed mechanism of the initiation of the sliding remains as a mystery (Voight, 1981). One possible remedy to resolve the lack of essential data is to learn from of similar geodynamic events having common driving mechanism. An example of such events is a large scale block sliding triggered by a big earthquake. The March 11, 2011 earthquake cast strong ground shaking over a large part of the northeastern Japan. A space borne L-band radar interferometry (ALOS/PALSAR) revealed a wide distribution of ground surface instability. Among those a large horizontal block slide found over a buried late Cenozoic caldera (Hanayama caldera; Yoshida et al., 2005) about 50km to the north of Sendai city deserves close attention for a detailed analysis. An interferogram spanning over the quake depicted a clear fringe pattern indicating a horizontal sliding of ground block of 7km size. The estimated slipping distance was larger than several decimeters toward east. Another data revealed that the same block slipped during 2008 Iwate Miyagi Inland earthquake (M7). This repeating tendency suggests the vulnerability prone to the strong ground shaking inherent in a structural background. Strong motion record at a nearby seismic station registered the maximum vertical acceleration as large as 1.9G. The horizontal components were almost of the same order. A permanent displacement derived from the double integration of the acceleration was as large as 4m in EW direction showing a good agreement with GPS results. We assumed that the sliding was initiated when the Amontons-Coulomb friction criterion is exceeded. A simple calculation using the strong motion record showed that during the most turbulent period the shear force driven by the horizontal seismic motion became larger than the friction force. It is conceivable the sliding was initiated the friction status changed from static to kinetic. A large spatial wavelength of the seismic wave is likely to make the coherent triggering of a 7km size block possible. We also infer that boundary between old caldera basement and the overlying pyroclasts of later volcanism acted as a sliding surface. This example demonstrates a possibility that a flank failure may be triggered by an analogous mechanism on a volcano flank, if a geological setting is similar.

Tectonic earthquakes triggering volcanic activity? Preliminar study case: Central American Pacific coast, 2012.

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Three large earthquakes with Mw>7, occurred in the Central American Pacific coast during a period of only 72 days. On 27 August 2012, the first earthquake Q_1) occurred on the SW coast of El Salvador (Mw=7.3). The second earthquake Q_2) struck 9 days after, on the NW coast of Costa Rica, with Mw= 7.6. On 7 November, a third earthquake Q_3) with Mw=7.4 hit the the NW coast of Guatemala.
With this, the first question of the volcanologist was: could these earthquakes trigger volcanic unrest?
We try to analyze the relationship between these seismic events and the observed volcanic unrest during and after the seismic crisis, by recording: a) the name of the volcano in unrest after the earthquakes; b) the time lapsed in days between and the onset of the volcanic unrest; c) the distance in kilometers between the volcano and the epicenters of the earthquakes; d) the type of change or level of the unrest of the volcano, indexed on 1) an increase in seismic activity, 2) a combination of increased seismic activity, temperature and output rate of degassing and/or the occurrence of small eruptions, 3) large eruptions with ash fall. We observed that 13 volcanoes in Costa Rica, Nicaragua, El Salvador and Guatemala were in a state of volcanic unrest and/or eruptions. Of those, 6 volcanoes only showed changes of type 1, 4 volcanoes with changes of type 2 and 3 volcanoes with changes of type 3. To explain what could have happened in the crust, we simulated the crustal deformation associated with these 3 earthquakes based on the Okada's 1992) formula, and calculated the ΔCFF, strain, horizontal and vertical displacement. We found some apparent correlation between the observed volcanic unrest and the earthquakes, suggesting that tectonic earthquakes are able to change the state of volcanic systems.

Shallow magmatic source inferred from seismic and deformation observation at Galunggung Volcano, West Java

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Galunggung is a strato volcano as part of southern Jawa volcanoes group that consist of several active volcanoes. Latest eruption of Galunggung volcano occurred in 1982-1983. It was explosive magmatic eruption with Plinian to Strombolian type that produced rock fall, mud and pyroclastic flow. Cinder cone formed at the end of the phase. Eruption history of Galunggung volcano noted that it has short repose period of 24 years and the longest period is 72 years.

Changes on volcanic activity of Galunggung volcano observed during the period of May-July 2011 when the seismicity increased significantly followed by the changes of crater lake color. This changes continue till February 2012 along with the increase of crater lake temperature and extend of gas bubble distribution. These brought the upgrade of Galunggung volcano alert level from NORMAL (Level I) into WASPADA (Level II) till the end of May 2012.

This research focused on the recent volcanic activity of Galunggung volcano after it last increases in February-May 2012 and interpreted the source and mechanism of magmatic system beneath it. This research applied seismic, GPS (Global Positioning System), and TLS (Terrestrial Laser Scanner) methods. Seismic method applied to understand type, characteristic and source of earthquakes while GPS and TLS to detect ground deformation. TLS is the new method for volcano monitoring in Indonesia. This research also introduce and asses the contribution of TLS method for volcanic deformation monitoring.

Seismic observation noted domination of volcanic-hybrid and low frequency type that assumed as implication from shallow fluid injection. While GPS and TLS showed minor inflation trend. This result supported by geochemistry analysis that indicate injection of some non magmatic elements.

Preliminary research on mud volcanoes and earthquakes activity in the northern tianshan mountain,xinjiang

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Mud volcano is the phenomenon of fluid geology on the condition of special tectonic and hydrological geology, and it is associated with oil and gas belt, and its eruptive material consists of low-temperature sand rock, underwater and nature gas from several Kilometer underground.

Mud volcano formation has usually the following geologic condition:Having rich clay strata in the deep and high pore fluid pressure; Having the screening zone of Argillaceous strata, which can keep deep sediment being in the high pore fluid pressure state;having the channel of deep mud eruption, which is related with active fault;having the active fault, which is dynamic mechanism triggering the mud volcano activity(Gao Xiaoqi, 2008;Milkov,2000;Zhu tingting,2009).

There are many mud volcanoes in the northern Tianshan mountains, Xinjiang, and mud volcanoes in the Dushanzi, Khorgos, Shihezi and Usu are typical(Wang Dao,2000). These mud volcanoes locate in Anticline axis of the piedmont depression belt of the northern Tianshan mountains, where most outcropping strata are sand rocks. These rocks are rich in multi-layer groundwater, which is characteristic of high pressure, high salinity and rich gas or oil. Under the action of regional principal compressive stress in the NS direction, the rocks in the region appear deformation and rupture, and pore stress is abnormal.

Earthquake and mud volcano are both the reflection of the modern crustal motion, mud volcano and earthquake activity have some genetic relation. When regional tectonic stress increasing continuously, rock pore stress in closed construction gradually strengthens, which causes mud volcano eruption, as same that earthquake preparation and occurrence result from increasing the regional tectonic stress. Earthquake activity may accompany mud volcano acidity, and large-scale mud volcano activity could trigger small earthquakes.

Shihezi to Usu region in the northern Tianshan mountains is not only the concentrated area of mud volcano activity, but also mid-strong earthquakes in the region are active. Khorgos mud volcano erupted a great deal of muddy water with hydrocarbon gases and high mineralized water when Zaisang M7.3 earthquake on Jun.14, 1990, KAZAKSTAN, occurred , which is 450km from M7.3 earthquake. Tuositai mud volcano erupted much mud and sand before and after Usu M5.2 earthquake on Oct.25, 1990, which is 40km from M5.2 earthquake. The 24-hour observation record shows that Usu mud volcano spewed mud before Nilka M6.0 earthquake on Nov.1, 2011 and Xinyuan M6.6 earthquake on Jun.30, 2012.

If mud volcano locates near source region of mid-strong earthquake activity, mud volcano eruption activity may be taken as short-impending precursor of strong earthquake. By monitoring mud volcano activity, it is possible to trace dynamic change of regional stress, and provide one new idea for short-impending prediction.

Study of Seismic Activity at Ceboruco Volcano, Mexico

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Many societies and their economies endure the disastrous consequences of destructive volcanic eruptions. The Ceboruco stratovolcano (2,280 m.a.s.l.) is located in Nayarit, Mexico, at the west of the Mexican volcanic belt and towards the Sierra de San Pedro southeast, which is a key communication point for coast of Jalisco and Nayarit and the northwest of Mexico. Its last eruptive activity was in 1875, and during the following five years it presents superficial activity such as vapor emissions, ash falls, and riodacitic composition lava flows along the southeast side. Although surface activity has been restricted to fumaroles near the summit, Ceboruco exhibits regular seismic unrest characterized by both low frequency seismic events and volcano-tectonic earthquakes. The seismicity at Ceboruco is currently monitored with a three-component short-period seismograph station, located in the south flank and within 2 km from the summit. We use data recorded from March 2003 to July 2008 at the CEBN triaxial short period digital station. We classified them according waveform characteristics of the east-west horizontal component. We obtained four groups: impulsive arrivals, extended coda, bobbin form, and wave package amplitude modulation earthquakes. The extended coda is the group with more earthquakes and present durations of 50 seconds. Using the moving particle technique, we read the P and S wave arrival times and estimate azimuth arrivals. A P-wave velocity of 3.0 km/s was used to locate the earthquakes, most of the hypocenters are below the volcanic edifice within a circular perimeter of 5 km of radius and its depths are calculated relative to the CEBN elevation as follows. The impulsive arrivals earthquakes present hypocenters between 0 and 1 km while the other groups between 0 and 4 km. The epicenters show similar directions as the tectonic structures of the area (Tepic-Zacoalco Graben and regional faults). Results suggest fluid activity inside the volcanic building that could be related to fumes on the volcano. We conclude that the Ceboruco volcano is active. Therefore, it should be continuously monitored due to the risk that represent to the surrounding communities and economic activities. Since March 2012 we installed four seismic stations, each includes a digital acquisition system TAURUS of Nanometrix and a Lennartz 3D lite (1Hz) seismometer. Batteries are change and data collected monthly. We use the data to establish the average seismic activity rate; we also aim to corroborate previous studies that showed four families of seismic events; and to localize and make preliminary evaluations of the events.