Possible interaction between mega-earthquake and long term volcanic activity

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The 2011 March 11 Off-Tohoku M9 earthquake caused dramatic change in crustal stress field in North Honshu Arc. Source mechanism of crustal earthquakes changed from reverse fault type to strike slip type in most part (Hasegawa et al., 2011). Even normal fault type earthquake has started after the great earthquake. These lines of evidences indicate that regional stress field changed from horizontal compression to neutral or horizontal extension as a result of the M9 earthquake. It is expected that magma flux from the mantle to volcano system in the crust increased in long term after this big earthquake. To understand the response of volcanoes in subduction zones to the crustal stress drop caused by M9 earthquake is very important.
I proposed that synchronous start of modern volcanic activity of three volcanoes in Hokkido, Komagatake (started 1640AD after dormant period of ~3000 years), Usu (started 1663AD after dormant period of ~5000 years) and Tarumae (started 1667AD after dormant period of ~3000 years) may be explained by a triggered of the M9 earthquake took place in AD1611 (Takahashi, 2012). Change in crustal stress field caused by large earthquake may be plausible to explain the synchronous start of the volcanic activity. If modern activity of Komagatake, Usu, and Tarumae were triggered by the 1611 earthquake in Kuril, then interaction time between the earthquake and the volcanic eruption is 30 to 50 years. This interval between the earthquake and the start of volcanic activity may correspond with the time interval at which half solidified magma reservoir and conduits were heated and increased the degree of partial melting by the injection of hot basalt magma from the upper mantle or lower crust. Petrologic study of 1640AD products of the Hokkaido Komagatake volcano supports this interpretation (Takahashi & Nakagawa, 2005).
In the case of Jogan great earthquake (869 AD, >M8.4), only 871AD eruption of Chokai volcano (basalt lava) was recorded. However, if we allow volcanic eruption 30 to 50 years after the earthquake, the last eruption of Towada volcano (Towada-A) that took place in 915 AD may be counted as a possible eruption triggered by Jogan earthquake. Towada volcano erupted episodically in the last 150000 years. Interval time between Towada-A and Towada-B is about 1700 years. It is plausible that silica-rich magma chamber beneath Towada volcano was activated by injection of large amount of basalt magma from mantle source due to stress drop caused by the Jogan great earthquake.
Only a few volcanoes in Tohoku Japan have erupted lava flow or pyroclastic flow in the last 1000 years. Many volcanoes in Tohoku Japan, however, may start magmatic eruptions within next 10~30 years due to the injection of hot basaltic magma from the upper mantle to the lower crust. If basalt magma penetrate the half solidified conduit system and erupt separately from the silicic magma, basaltic eruption may take place much earlier than 30 years. Basalt eruption in Chokai volcano in 871AD may be an example of this type eruption. In order to make prediction of their future activities, it is most important to clarify the deep structure of active volcanoes in Japan. Methods to monitor the deep magma injection, heating process of the magma reservoir and conduits should be developed.

Keywords: mega earthquake, long term volcanic activity, deep structure of volcano

Simultaneous Eruptions and Earthquakes in the 9^{th} Century, in the East and Central Japan

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Based on geological and archaeological data as well as historic documents, Tsukui et al., 2007 (Japan Geoscience Union 2007 Meeting, abstract), Tsukui et al., 2008 (Bull. Volcanol. Soc. Jpn) reviewed eruptions and earthquakes which have occurred during the 9th century in the East and Central Japan. The results reconfirm vigorous activities at Fuji volcano (800 AD, 838-864 AD, 864 AD), Izu-Oshima (-838 AD < N3, N2, N1 < 886 AD), Niijima (-857 AD and 886 AD), Kozushima (838 AD), and Miyakejima (832 AD? and 850 AD). Beside these eruptive events, a big eruption at Niigata Yakeyama volcano occurred in or around 887 AD. Chokai volcano also erupted in 871 AD, and 810-823 AD. In addition, earthquakes with a magnitude from 7 to 8 took place at Itoigawa-Shizuoka Tectonic Line active fault system (ISTL; in 841 or 762 AD), and at Nagano fault system (887 AD). Along the Eastern Margin of Japan Sea, earthquakes hit Akita plains (830 AD), Shonai plains (850 AD) and Echigo plains (863 AD). Plate-boundary great earthquakes occurred at Off Tohoku (869 AD Jogan Earthquake) and at the Nankai trough (887 AD Ninna earthquake). A linkage of these big eruptions and seismic activities in the 9th century extended over 800km long crossing Japan Arc. Geologically this seems to be a surface expression of East-West compression along eastern margin of the Amurian Plate which was driven by the eastward motionof the plate (2cm/yr to East Japan; Ishibashi, 1995, Chishitsu News).

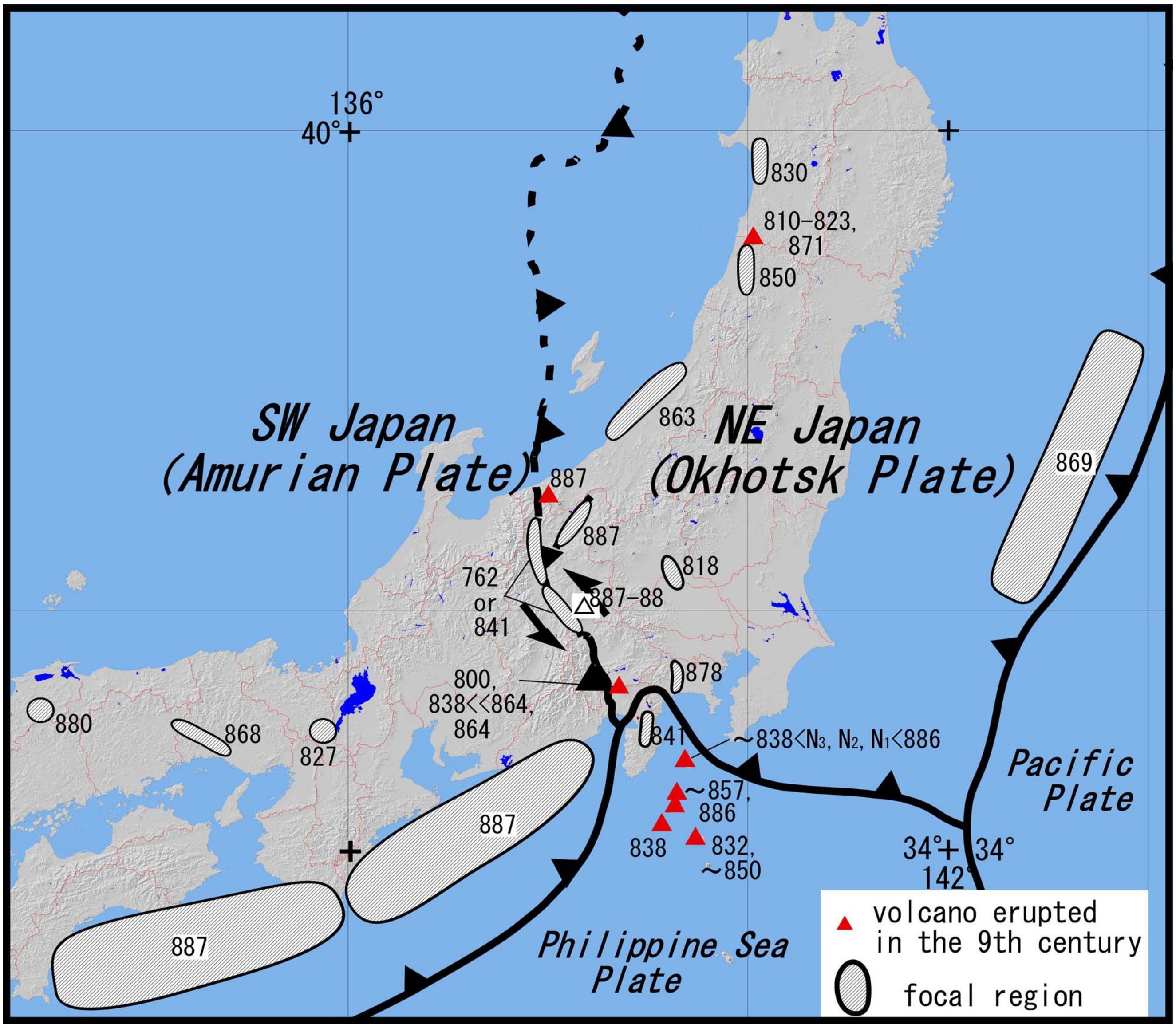
Along the eastern margin of Japan Sea, the Amurian plate subducts beneath the East Japan (Okhotsk plate or North-American Plate). At the northern part of the ISTL, the East Japan thrust over Amurian plate. Along the Nankai trough, the Philippine Sea plate subducts beneath the Amurian plate. The central part of the ISTL acts as left-lateral fault to switch the direction of subuction system.

Judging from the relation between volcanic activities and 869AD Off Tohoku Jogan earthquake, 887AD Nankai trough Ninna earthquake, volcanoes did not necessarily activated by the earthquakes, but often erupt prior to great earthquakes. These examples show that it is difficult apply a simple model to the 9th century episodes that an earthquake release compressional stress and allow magma ascend.

During the recent 60 years, eruptions (Miyakejima (1962 AD, 1983AD, 2000AD), Izu-Oshima (1986 AD), Submarine eruption off Ito (1989 AD)), earthquakes along the Eastern Margin of Japan Sea (1964, 1983, 1993, 2004, 2007 AD), the Great East Japan Earthquake off Tohoku (March 11, 2011, M9.0), North Nagano earthquake (March 12, 2011 M6.7; extension of Nagano Fault System), and Kamishiro Fault Earthquake (2014AD, M6.7; occupying northern part of ISTL Active Fault System) are taking place in areas overlapping with those occurred in the 9th century.

Overflow of magma from the Miyakejima summit crater, dome formation of Niijima and Kozushima of the 9th century imply high magma head or high horizontal stress in Izu Islands. Whereas lateral eruption at Izu-Oshima in 1986 AD and the collapse of summit at Miyakejima in 2000 AD resulted from intrusions of a large amount of magma into neighboring crust indicate lower horizontal stress in recent years. Although many common points are found between 9th century and the present, the stress states are different and it is difficult to find a rule in the order among outbreak of earthquakes and eruptions.

Keywords: 9th century , linkage of eruption and earthquake, east-west compression


136°
40°
SW Japan
(Amurian Plate)
NE Japan
(Okhotsk Plate)
830
810-823,
871
850
863
869
887
887
818
762
or
841
887-88
800,
838<<864,
864
878
880
868
827
841
~838<N3, N2, N1<886
~857,
886
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832,
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887
887
Pacific
Plate
34°
34°
142°
Philippine Sea
Plate
volcano erupted
in the 9th century
focal region

The effect of the 1611 Sanrikuoki earthquake on volcanic activity in Hokkaido, Japan

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After several thousand years dormancy, three active volcanoes in southwestern Hokkaido (SW Hokkaido), Hokkaido-Komagatake, Usu and Tarumai volcanoes, started their eruptive period with large eruptions of VEI=5 during AD 1640 to 1667. It has been discussed that these could be caused by the 1611 Sanriku earthquake (M>8). It has been recently proposed that the source of the earthquake was distributed widely from off the eastern coast of Hokkaido to the Sanriku area. In this research, I compile the eruptive history of active volcanoes in Hokkaido to clarify the regional difference of the eruptive activity around 17th century. In addition, I also compile the structure and eruptive processes of magma plumbing system of these three volcanoes to discuss the relationship between earthquake and volcanic eruption. Relatively large eruptions occurred in Hokkaido during end of Plesitocene to early Holocene. In E Hokkaido belonging to Kuril arc, two large eruptions of Me-Akandake (VEI=5) and Mashu volcanoes (VEI=6) occurred 13 and 7 ka, respectively. Nigorikawa and Tarumai volcanoes in SW Hokkaido belonging to NE Japan arc occurred a large eruption of VEI=5 9 and 7 ka, respectively. Since then, volcanoes in E Hokkaido, such as volcanoes in the Shiretoko peninsula, Masu, Atosanupuri, Me-Akan and O-Akan volcanoes, had been active until ca. 1000 years ago. On the other hand, in SW Hokkaido, although a large eruption of VEI=5 occurred in Tarumai volcano, smaller eruptions of VEI<3 sporadically occurred in other volcanoes. In summary, eruptive activity in SW Hokkaido had been quite lower than that of E Hokkaido since ca. 5000 years ago. In contrast, the eruptive activity of volcanoes in central Hokkaido belonging to the boundary between the two arcs has been relatively low. A large eruption of VEI>4 has not occurred in the region. In 17th century, as mentioned above, three volcanoes in SW Hokkaido started vigorous eruptive activity and has continued their activity until now. Other volcanoes adjacent these three volcanoes have also started their activity since then. In contrast, although two relatively large eruptions occurred in Mashu and Me-Akandake volcanoes ca. 1ka, and Rausu volcano ca. 0.7ka, eruptive activity of volcanoes in E Hokkaido has been quite weak since then. Although small magmatic eruption have sporadically occurred in Tokachidake volcano in central Hokkaido, no magmatic eruptions have occurred in E Hokkaido at least since 17th century. Considering temporal change of eruptive activity of active volcanoes in Hokkaido during Holocene, if 1611 Sanriku earthquake affected the volcanic activity, it should be emphasized that the earthquake had reduced eruptive activity in E Hokkaido, whereas it had caused sequential eruptions in SW Hokkaido. In other word, the earthquake caused distinct influences to southwestern and eastern part of Hokkaido, respectively.

Eruptive history, the structure of magma plumibing system and its eruption processes of these three volcanoes in SW Hokkaido are summarized as follows. 1) Each volcano started its eruptive activity after a long dormancy. 2) Although whole-rock chemistry of major eruptive magma is silicic, ranging from dacitic andesite to rhyolite, whereas their melt compositions are similar rhyolite. 3) Each initial eruption had been caused by the injection of mafic magma into the above silicic magma less than several years before eruption. These features suggest that enough volume of silicic magma had been accumulated in each volcano. Thus, a large earthquake could affect the activity of a volcano to cause mafic injection and/or activation of a voluminous silicic magma chamber. However, there existed the interval of 30 years between the earthquake and the initial eruption in AD 1640. This would not be consistent with the 1611 Sanriku explanation that the earthquake caused sequential large eruptions in SW Hokkaido.

Keywords: volcanic eruption, earthquake, Hokkaido, 1611 Sanriku earthquake, magma cahmber

Great earthquakes in Japan and Kuril Trenches and eruption of three volcanoes in Southwest Hokkaido in 17th century

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Great earthquakes with M~8 repeatedly occur with recurrence interval of ~ 70 years along the Kuril Trench off Hokkaido. Studies of tsunami deposits (e.g., Nanayama et al., 2003, Nature) indicate that the size of earthquake and tsunami occurred in the 17th century was much larger. Three volcanoes in southwest Hokkaido also erupted in the 17th century; Komagatake in 1940 and 1694, Usu in 1663 and Tarumai in 1667 and 1739. The tsunami deposits are usually found beneath these volcanic tephra layers, at 20 m altitude on the coast (Hirawaka, 2012, Kagaku) and inland up to several km from the coast.
The mechanism of the 17th century earthquake was studied by tsunami numerical simulations from interplate earthquake models (two different depths down to 50 km and 85 km) and tsunami earthquake model near the trench axis (Satake et al., 2008, EPS). Comparison of computed inundation areas with the distribution of tsunami deposits shows that the best model of the 17th century earthquake is a 300 km long, 100 km wide fault at a depth range of 17 to 51 km, with slip of 10 m off Tokachi and 5 m off Nemuro. This model may represent a simultaneous rupture of Tokachi-oki and Nemuro-oki earthquakes. The maximum coastal tsunami height from this Mw = 8.5 earthquake model was about 10 m. Recently, Ioki and Tanioka (2016, EPSL) modified the above fault model to include near-trench subfault (tsunami earthquake fault with 25 m slip along the trench axis) and showed that the coastal tsunami heights can be more than 20 m and able to explain both tsunami heights and inundation. Moment magnitude of this model is Mw = 8.8.
Tsunami deposits were also found from older earthquakes along the Pacific coast of Hokkaido. Another tsunami layer was found between tephra layers of the 17th century and 10th century. Three or four more tsunami layers were identified between the 10th century tephra and that of 2500 year BP (Nanayama et al., 2003). From the long core samples, Sawaii et al. (2009, JGR) showed that recurrence interval of 15 tsunamis in the last 6000 years varies from 100 to 800 years with an average of 400 years.
The three volcanoes in southwest Hokkaido belong to Honshu arc rather than Kuril arc, hence the earthquake related to these eruptions may be the one along Japan Trench rather than Kuril Trench. Along the northern Japan Trench, an earthquake in 1611 (Keicho earthquake) caused devastating tsunami damage and casualties similar to those of 2011 in Sendai plain and Sanriku coast. However, no damage due to ground shaking was recorded, hence it is considered as a ‘tsunami earthquake’. If it was similar to other ‘tsunami earthquakes’ such as the 1896 Sanriku earthquake, with the fault motion limited near the trench axis, then it is unlikely that such a shallow slip would affect volcanic eruptions. The 1611 Keicho earthquake may be the 17th century earthquake that brought tsunami deposits in Hokkaido. If so, the slip must be three times larger than the above models, in order to reproduce the tsunami heights and inundation areas in Sanriku and Sendai coasts (Okamura and Namegaya, 2011, GSJ). Annual bands of lacustrine deposit in Harutori-ko (Kushiro) suggest that the 17th century earthquake occurred in 1636 (Ishikawa et al., 2012, JpGU meeting). In northern Tohoku such as Morioka and Hirosaki, official daily records of clans should have recorded ground shaking from an earthquake in Kuril Trench (Satake, 2004, Annals Geophysics).
When the relation between the giant earthquakes and volcanic eruption is discussed, it must be considered that near-simultaneous eruptions occurred only in the 17th century during the several thousand years, while the giant earthquakes that leave tsunami deposits have recurred at 500 years

interval.

Keywords: great earthquakes, volcanic eruption, Kuril Trench, Japan Trench, tsunami

Conditions for a magma reservoir that is easy to activate: a comparison between Usu and some other volcanoes

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Understandings of magma reservoirs, preeruptive magma processes, and their time scales are being developed [see the review by Tomiya (2016: Bull. Volcanol. Soc. Japan) and references therein]. A magma reservoir is rapidly cooled and solidified, and tends to form a crystal mush with a high (>40-50%) crystal content and virtually immobile state if there is no heat supply. It is necessary to remobilize the mush and to form an eruptible (low-viscosity) magma before an eruption. In this case, there will be a long time lag between an eruption trigger (e.g., an injection of a hot magma) and the eruption. On the other hand, if there is already sufficient eruptible magma, the time lag will be shorter. Thus, we can expect a positive correlation between the repose time since the last eruption and the time lag after the eruption trigger as shown below. This can explain the positive correlation between repose times and run-up times found by Passarelli and Brodsky (2012: Geophys. J. Int.).
An active volcano with a repose time of less than tens of years probably keeps eruptible magma. The historical activity (since 1663 AD) of Usu volcano is such a case. Zoning profiles of phenocrysts in the eruptive products demonstrate that the Usu magma has been in a condition where crystal growth and diffusion are effective (Tomiya and Takahashi, 2005: J.Petrol.). From diffusion analysis for magnetite, the time scale of the preeruptive magma processes for each historical eruption is several days, which is consistent with the duration of the precursory seismicity. Thus, a magma reservoir with an eruptible magma can be triggered in several days.
A volcano with a repose time of hundreds of years probably has little (insufficient) eruptible magma. The 2011 eruption of Shinmoedake, Kirishima volcanic group, is such a case. Petrographic study demonstrates that the main eruptive product is mixed andesite formed by remobilization of the mushy magma reservoir and that the time scale for the remobilization is more than tens of days, probably about one year, corresponding to the duration of the precursory crustal deformation (Tomiya et al., 2013: Bull.Volcanol.).
A volcano with a repose time of thousands of years probably has no eruptible magma. The 1663 eruption of Usu, the 1667 eruption of Tarumai, and the 1640 eruption of Hokkaido-Komagatake are such cases. Crystal size distribution (CSD) analysis demonstrates that the residence time of the Usu magma before the 1663 eruption is 10^2 to 10^3 years (Tomiya and Takahashi, 1995: J.Petrol.), although the error may be an order of magnitude. Thus, at least tens of years was needed to prepare the eruptible magma for the 1663 eruption.
Depth (pressure, water content) of magma reservoir is also an important factor. At a higher pressure with a higher water content, melting of a crystal mush can proceed effectively at a lower temperature, producing much silicic melt (e.g., rhyolite). The high water content also reduces the viscosity of the melt, promoting segregation and accumulation of the interstitial silicic melt. The magma of the 1663 eruption of Usu volcano was nearly aphyric rhyolite, and the reservoir was at ca. 250MPa (10km) and 780°C., according to high-pressure melting experiments (Tomiya et al., 2010: J.Petrol.). The high-pressure, high-water condition probably promoted production, segregation, and accumulation of the rhyolitic melt before the eruption. On the other hand, the magmas of the 1667 eruption of Tarumai and the 1640 eruption of Hokkaido-Komagatake were porphyritic andesite, and the reservoirs were at ca. 100MPa (4-5km) and 900-950°C, according to MELTS calculations. The low-pressure, low-water condition required a high temperature for melting, and also suppressed

segregation of the interstitial melt. This caused the eruption of the porphyritic magma, a mixture of the melt and the crystals from the mush.

Keywords: eruption trigger, eruptible magma, magma reservoir, Usu volcano, time scale, crystal mush remobilization

Effects of stress change on activity of a volcano with a long-time quiescence

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Stress field including stress change can control the development of magma plumbing system. (1) Horizontal stress change affects on fissure eruption sites in a volcano. For example, a flank eruption site shifts from the previous flank to the opposite one where stress is released after neighborhood earthquake. (2) Vertical stress change can control magma ascent beneath a magma chamber or from it to the surface. (3) This paper introduces several examples on triggering or accelerating process of volcanic activity on dormant volcanoes such as Fuji 1707 eruption and etc. The process to Pinatubo 1991 eruption is compiled after 1990 earthquake. (4) Analog experiments on behavior of liquid-cracks under the stress change are demonstrated.

Keywords: Stress change, earthquake, fissure eruption, Fuji volcano, Pinatubo volcano

Recent Volcanic deformation around Zao and Azumayama Volcanoes

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Mt. Zao is an active volcano located in northeastern Honshu and has histories of phreatic or phreato-magmatic eruptions in the last 2 ka. Unrest of Zao volcano started in January, 2013 with a volcanic tremor (JMA, 2013) followed by activated seismicity mainly in the lower crust and very -long-period seisimic events (VLP) up to today. Since a burst of shallow volcanic earthquakes initiated in April 2015, JMA announced a Volcanic Warning for the area near crater, which was lifted in June because of the quiescence of the seismicity.
Mt. Azumayama is an active volcano located in northeastern Honshu and has repeatedly erupted around the Oana crater within recorded history, and currently a fumarolic area extends across its southern and eastern flanks (JMA, 2013). Recent seismicity between 2001 and 2009 are characterized as repetition of active and quiet periods with intervals of around 2 to 3 years, while it shows steady activity after 2010 (JMA, 2014a). Seismic activity looks gradually increasing since October 2014. A volcanic tremor with a duration of about 35 minutes occurred on December 12, 2014, and the monthly number of volcanic earthquakes in December 2014 counted 576, and a volcanic alert (Level 2) was applied by JMA and is lasting at present.
GNSS data obtained around the two volcanoes are processed using the precise point positioning strategy (Zumberge et al., 1997) of GIPSY-OASIS II ver. 6.2 with IGS08 precise ephemerides and GMF mapping functions (GMF, Boehm et al., 2006). Since the wide area of northeastern Honshu still suffers the long lasting postseismic deformation following the 2011 Tohoku-oki earthquake (M9.0), we extract volcanic deformation related to the unrest of the volcano by fitting an approximation function of time consisting of linear, logarithmic, annual, and semi-annual terms. The coefficients of each term are estimated by the least-squares method.
Resulting displacements around Zao and Azumayama volcanoes show radial expansion and uplifting, and suggest the existence of pressure sources for the periods between January 2015 and May 2015, and October 2014 and May 2015, respectively. These deformations can be modeled with an point pressure source at a depth of around 5 km and 3 km, respectively beneath the summit, and related to raised volcanic activity.

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Keywords: Volcano, deformation, GNSS

Past ca. 800 years magma feeding system beneath Zao volcano

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The Zao volcano is an active stratovolcano in northeast Japan, which has many historical eruption records. After the Great East Japan Earthquake, many precursory phenomena of eruption such as volcanic tremors have been detected. Zao volcano has a long-eruption history of ca. 1 million years, and the activities can be divided into six stages, these can be further divided into several sub-stages. The eruption style and magma compositions are different among stages and sub-stages. Here, we will present eruption history and temporal change of magma feeding system after ca. 800 years ago, when the present crater Okama was formed. By the tephro-stratigraphic research, seven eruption episodes (episode 1 to 7) were recognized during past ca. 800 years. First four were during 13th to 16th century, and the other three were in 17th century, 18th century and AD1894 to 1897. The eruptions started by phreatic eruption and followed by magmatic ones in all episodes but the last one. The last one is unique characterized by lacking obvious magmatic eruption products. Except for the last one, the eruption episode continued for several decades with intermittent short dormancies. Proximal facies of the eruption products during past ca. 800 years are well exposed in the cliff surrounding the crater lake Okama. Five sets (unit 1 to 5) of hydrothermal eruption products to pyroclastic surge deposits with agglutinate layers can be recognized. These would be formed during episode 1 to 5 each. Covering these units, thick hydrothermal eruption layers can be observed. These would be formed by episodes 6 and 7. Using systematically collected bomb samples from the unit 1 to 5, we performed petrologic study to reveal the magma feeding system and its evolution beneath Zao volcano. Rocks are medium-K calc-alkaline series olv bg. cpx opx andesites. Petrographic and mineralogic features show that these were formed by mixing between basaltic (containing olivine and An-rich plagioclase) and andesitic (containing Mg#-poor pyroxenes and An-poor plagioclase) magmas. Infusions of the former magma would activate the shallow chamber filled by the latter magma, and these would mix to erupt. The ranges of silica content are similar (57-59% SiO_2) among units, but some other compositions are slightly different among units, which suggests the slight difference of the end-member magmas among units. In each unit, the whole rock compositions gradually change to mafic towards upper. Such compositional change can be explained by the successively increased percentage of the basaltic magma involved in the mixing. Consequently, each eruption episode would correspond to a series of ascent pulses of mafic magma.

Keywords: Zao Volcano, Magma Feeding System, Magma Evolution, Volcanic Eruption, Large Earthquake

Deep seismic structure beneath volcanic arcs

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The subduction zone system on the Earth is over 40,000 km long. The active processes –brittle deformation, metamorphism, convection and volcanism– beneath volcanic arcs are all linked with slab-derived fluids. Here I review seismological observations in subduction zones and show that a low-velocity zone is observed in the mantle wedge beneath all volcanic arcs. Interestingly, geometries of the low-velocity zone, however, vary depending on the dip and age of the subducting slab. I also present deep crustal structure in NE Japan and discuss how the crustal structure changes along the volcanic front, providing a clue to understand deep origins of arc magmas and ongoing processes beneath volcanic arcs.

Keywords: volcano, Tohoku, upwelling flow

Toward an examination of magmatic activation from viscosity-perspective

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Magma viscosity is one of the most important factors controlling activation of volcanic activity, because the timescale of magma motion is essentially controlled by the balance between the viscous resistance and the driving forces inside or outside the magmas. The present study reviews viscosity estimate for erupted magmas and modeling studies on magmatic activation from viscosity-perspective. Finally, some future studies on the evidence-based relationship between preeruptive magma viscosity and magmatic activation are proposed.
The basaltic to rhyolitic magmas have preeruptive viscosities over the range 10^1 to 10^8 Pa s (Scaillet et al., 1998, JGR; Takeuchi, 2011, JGR; Andújar and Scaillet, 2012, Lithos). Here, preeruptive magma viscosity means viscosity of phenocryst-bearing magmas in the preeruptive magma reservoirs. The preeruptive magma viscosity can be estimated from petrological data by using melt viscosity models (e.g. Giordano et al., 2008, EPSL) and rheological models of multiphase magmas (e.g. Marsh, 1981, CMP). Increasing bulk SiO2 content, preeruptive magma viscosities roughly increase from 10^1 to 10^5 Pa s. Some andesitic to dacitic magmas are estimated to be up to ca. 10^8 Pa s (Takeuchi, 2011, JGR) due to a large amount of phenocryst content of ca. 50 vol %. The high viscosities arise from high undeformable phenocyrst concentration in magmatic suspension and shifting melt SiO2 content to high silica rhyolitic composition. Andesitic to dacitic magmas, which are most common in arc volcanism, have wide range of preeruptive viscosities from 10^3 to 10^8 Pa s. This wide range of preeruptive viscosity may influence timescale for magmatic activation.
There are several modelling studies on activation of magmatic activity from viscosity-perspective. Models of remobilization and convective overturn in crystal mush magmas heated by injecting high temperature magmas (e.g. Burgisser and Bergantz, 2011, Nature) suggest that as a heated magma has higher viscosity, the timescale of convective overturn becomes longer. Models of dike propagation from preeruptive magma chambers at initial stage of eruption (e.g. Rubin, 1995, JGR) suggest that as a magma has higher viscosity, excess pressure required for the dike propagation from the chamber becomes larger.
Several future studies on magmatic activation from viscosity-perspective are proposed; relationship between eruptive history and temporal variation of preeruptive magma viscosity in a volcano (e.g. Gardner et al., 1995, Geology; White et al., 2006, G3); relationship between timescale of magma mixing (e.g. Tomiya et al., 2013, BV) and preeruptive magma viscosity; relationship between geophysically-detected eruption precursor and preeruptive magma viscosity (e.g. Passarelli and Brodsky, 2012, GJI). A melt viscosity scale for preeruptive magmas (Takeuchi, 2015, BV) is useful to easily estimate preeruptive magma viscosity.

Keywords: preeruptive magma viscosity, melt viscosity scale, magmatic activation

Sloshing of a bubbly magma reservoir as a mechanism of triggered eruptions

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Large earthquakes sometimes activate volcanoes both in the near field as well as in the far field. One possible explanation is that shaking may increase the mobility of the volcanic gases stored in magma reservoirs and conduits. Here experimentally and theoretically we investigate how sloshing, the oscillatory motion of fluids contained in a shaking tank, may affect the presence and stability of bubbles and foams, with important implications for magma conduits and reservoirs. We adopt this concept from engineering: severe earthquakes are known to induce sloshing and damage petroleum tanks. Sloshing occurs in a partially filled tank or a fully filled tank with density-stratified fluids. These conditions are met at open summit conduits or at sealed magma reservoirs where a bubbly magma layer overlays a newly injected denser magma layer. We conducted sloshing experiments by shaking a rectangular tank partially filled with liquids, bubbly fluids (foams) and fully filled with density-stratified fluids; i.e., a foam layer overlying a liquid layer. In experiments with foams, we found that foam collapse occurs for oscillations near the resonance frequency of the fluid layer. Low viscosity and large bubble size favor foam collapse during sloshing. In the layered case, the collapsed foam mixes with the underlying liquid layer. Based on scaling considerations, we constrained the conditions for the occurrence of foam collapse in natural magma reservoirs. We find that seismic waves with lower frequencies < 1 Hz, usually excited by large earthquakes, can resonate with larger magma reservoirs whose width is > 0.5 m. Strong ground motion > 0.1 m/s can excite sloshing with sufficient amplitude to collapse a magma foam in an open conduit or a foam overlying basaltic magma in a closed magma reservoir. The gas released from the collapsed foam may in filtrate the rock or diffuse through pores, enhancing heat transfer, or may generate a gas slug to cause a magmatic eruption. The overturn in the magma reservoir provides new nucleation sites which may help to prepare a following/delayed eruption. Mt. Fuji erupted 49 days after the large Hoei earthquake (1707) both dacitic and basaltic magmas. The eruption might have been triggered by magma mixing through sloshing.

Keywords: Large earthquake, Foam collapse, Magma mixing

Basic fluid dynamical processes in rejuvenation of magma chamber

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Large earthquakes are expected to activate magma chamber to induce eruptions. Up to now only phenomenological correlation between occurrence of earthquake and the timing of eruption has been suggested and the linking physical process is still unknown. When we evaluate probable long-term effects of the Great Tohoku Earthquake on the volcanic activity the lack of models for the linkage is crucial. From the lessons from historical eruption cases time scale up to 50 years is suggested for the linkage(Takahashi 2012), which indicates involvements of lower crustal processes because of the long term nature. We strongly need for conceptual models which link between the large earthquake and eruptions in the lower crustal situations. The models should be presented in a testable,observable style. Material scientific investigations on various eruption cases have revealed injection of fluidic magma into crystal-rich mushy magma chamber could be a direct trigger for the eruptions. In this presentation we summarize basic fluid dynamical processes associated with this injection process to induce rejuvenation of magma chamber.
In the pioneering works on the modeling (Burgisser and Bergantz,2011,Huber et al 2011) importance of fluidization has been addressed. Both works are an approach from numerical simulation. Since the process is essentially dynamical two-phase system and the relevant rheology is complicated experimental supports are necessary further on the simple numerical simulations. Here we report three cases of fluidization from experimental approaches:1) fluidization of packed beds, 2) switching permeable/gross flows in deformable gel system, and 3)shear-induced fluidization of yield-stress fluid system. When fluid is injected to the aggregate of particles and liquid fluid usually flows through the space between particles as a permeable flow. Above the critical injection flux both the particles and the fluid begin to flow together. This is fluidization process, which could be a kind of phase transition. As an example of 1) we demonstrate the initiation process of fluidization in a conventional experimental setup of fluidizing beds(Kon & Kurita 2016). The initial state is the packed bed formed by homogenous sized particles of sodalime glass,polystyrene and acryl. Injection of water induces disintegration of the particles. The propagation velocity of fluidized zone is controlled by free-fall velocity of the particles and the injected fluid velocity. This basically controls the time scale of fluidization. When the particles become soft and irregular shaped the system begins to behave as a yield stress fluid and peculiar cyclic behavior switching permeable flow and gross flow appears(example 2, Kumagai et al 2010). This suggests pressure oscillation phenomena in rejuvenation process. As an example of 3) we show fluidization process induced by shear in terms of development of shear-banding(Kurokawa et al 2015). Curious stress fluctuation phenomena found in this experimental study is suggested for the origin of low frequency earthquakes.

Keywords: volcanic eruption, fluidization, solid-liquid two-phase system

